Many hands make hard work, or why agriculture is not a puzzle

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The Neolithic Revolution from a price-theoretical perspective

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Abstract

The adoption of agriculture, some 10,000 years ago, triggered the first demographic explosion in human history. When fertility fell back to its original level, early farmers found themselves worse fed than the previous hunter-gatherers, and worked longer hours to make ends meet. I develop a price-theoretical model with endogenous fertility that rationalizes these events. The results are driven by the reduction in the cost of children that followed the adoption of agriculture.

1 Introduction

The shift from hunting and gathering to agriculture, or Neolithic Revolution (10,000 to 5,000 B.P.), was followed by a sharp increase in fertility (Bocquet-Appel, 2002). In the course of few centuries, typical communities grew from about 30 individuals to 300 or more, and population densities increased from less than one hunter-gatherer per square mile, to 20 or more farmers on the same surface (Johnson and Earle, 2000, pp. 43, 125, 246).

This demographic explosion has been attributed to two causes. First, food was available to early farmers in unprecedented quantities (Price and Gebauer, 1995). Second, children were much cheaper for early farmers than for hunter-gatherers: caring for children interfered with hunting-and-gathering, but not with farming, and the children of early farmers contributed to food production (Kramer and Boone 2002).

Although farmers produced food in large quantities, their nutrition was poorer than the nutrition of hunter-gatherers (Armelagos et al., 1991; Cohen and Armelagos, 1984). To make matters worse, working time increased as a result of the adoption of agriculture: ethnographical studies indicate that hunter-gatherers worked less that six hours per day, whereas primitive horticulturists worked seven hours on average, and intensive agriculturalists worked nine (Sackett 1996, pp. 338–42).

I develop a price-theoretical model with endogenous fertility that rationalizes these events. In my model, a tribe of hunter-gatherers discovers agriculture and adopts it because doing so increases the return to labor and reduces the price of children. When population restabilizes, the later generations consume less food and work longer hours than their hunter-gatherer predecessors. Still, they choose to remain farmers because reverting to hunting and gathering would make them even worse off.

These results are driven by the fall in the price of children. Enhancements in the food production technology have only one effect in the long-run: increasing population.

2 Related literature

Previous explanations to the loss of welfare that followed the Neolithic Revolution include the following.

In Weisdorf's (2004) model, early farmers give away leisure in exchange for goods produced by an emerging class of specialists (e.g., craftsmen and bureaucrats). Marceau and Myers (2006) model the fall in consumption and leisure as a tragedy of the commons. Both Weisdorf, and Marceau and Myers assume a constant population during the transition to agriculture.

Weisdorf (2007) and Robson (2008) incorporate demographics to their models. Weisdorf combines Malthusian population principles with the evolution of human metabolic rates. In his model, agriculture favored the evolution of humans better suited for longer hours of work. Robson develops a model with two goods: children and their health. Infectious diseases become more prevalent as population increases. This makes the health of children more expensive, so farmers choose to invest less on it.

3 A model of agriculture adoption

3.1 Model setup

A tribe has $N > 0$ identical adult members or tribesmen. Each tribesman chooses food consumption $c > 0$, leisure $r > 0$, and quantity of children $n > 0$ in order to maximize utility. His is subject to the following budget constraint:

$$w\,(T - r + \alpha n) \geq c + \kappa n$$

Variable $w > 0$ is the return to labor in units of food, $T > 0$ is the tribesman's disposable time, and $T - r > 0$ is his labor supply. Parameter $\alpha \geq 0$ represents child productivity measured in man-hours. The children of hunter-gatherers don't contribute to production: $\alpha = 0$. When agriculture is adopted, α rises to a positive amount. Parameter $\kappa > 0$ measures the food requirements of a child.

The budget constraint can be rewritten as follows

$$I \geq c + p^r r + p^n n, \tag{1}$$

where $I = wT$ is total income, $p^r = w$ is the price of leisure, and $p^n = \kappa - \alpha w > 0$ is the price of children.

The return to labor w is a function of a technology parameter A and of population N. As usual, w is increasing in A. Following Malthus, assume w falls with N. Using subscripts to denote partial derivatives: $w_A > 0$ and $w_N < 0$.

Population dynamics is governed by the following equation:

$$N' = \frac{nN}{\overline{n}},$$

where N' is next period's adult population, and parameter $\overline{n} > 0$ represents the replacement fertility rate.

In the short-run, population N is fixed, while in the long-run, diminishing returns to labor operate as a Malthusian check: as population grows, the return to labor declines, until the tribesman's optimal decision is to bear just enough children to keep population constant ($n = \overline{n}$).

Finally, let the tribesman choices be summarized by his Marshallian demands:

$$\begin{aligned} c &= c^{\mathrm{m}}(p^r, p^n, I), \\ r &= r^{\mathrm{m}}(p^r, p^n, I), \\ n &= n^{\mathrm{m}}(p^r, p^n, I). \end{aligned}$$

3.2 Comparative statics

The effects of an increase in children productivity

Totally differentiating w and the Marshallian demands we obtain a linear system for the effects of a rise in α:

$$\mathrm{w}_\alpha = w_N \mathrm{N}_\alpha, \tag{2}$$

$$\mathrm{c}_\alpha = c^{\mathrm{m}}_{p^r}\ \mathrm{w}_\alpha + c^{\mathrm{m}}_{p^n}\,(-w - \alpha \mathrm{w}_\alpha) + c^{\mathrm{m}}_I\ \mathrm{w}_\alpha T, \tag{3}$$

$$\mathrm{r}_\alpha = r^{\mathrm{m}}_{p^r}\ \mathrm{w}_\alpha + r^{\mathrm{m}}_{p^n}\,(-w - \alpha \mathrm{w}_\alpha) + r^{\mathrm{m}}_I\ \mathrm{w}_\alpha T, \tag{4}$$

$$\mathrm{n}_\alpha = n^{\mathrm{m}}_{p^r}\underbrace{\mathrm{w}_\alpha}_{\frac{\mathrm{d}p^r}{\mathrm{d}\alpha}} + n^{\mathrm{m}}_{p^n}\underbrace{(-w - \alpha \mathrm{w}_\alpha)}_{\frac{\mathrm{d}p^n}{\mathrm{d}\alpha}} + n^{\mathrm{m}}_I\underbrace{\mathrm{w}_\alpha T}_{\frac{\mathrm{d}I}{\mathrm{d}\alpha}}, \tag{5}$$

where w_α, c_α, r_α, n_α, and N_α are unknowns; and subscripted, roman letters denote total derivatives. The system is closed with $\mathrm{N}^{\mathrm{SR}}_\alpha = 0$ for the short-run, and with $\mathrm{n}^{\mathrm{LR}}_\alpha = 0$ for the long-run, where superscripts SR and LR distinguish short-run and long-run solutions. We search for conditions that suffice to reproduce the stylized facts of the Neolithic revolution: a short-run fertility rise, long-run falls in food consumption and leisure, and a long-run increase in population.

Initially, the tribesman hunts an gathers, so $\alpha = 0$. Replacing $\alpha = 0$ in equations (3)–(5), we get:

$$\begin{aligned} \mathrm{c}_\alpha &= (c^{\mathrm{m}}_{p^r} + c^{\mathrm{m}}_I T)\mathrm{w}_\alpha - w c^m_{p^n}, & (6)\\ \mathrm{r}_\alpha &= (r^{\mathrm{m}}_{p^r} + r^{\mathrm{m}}_I T)\mathrm{w}_\alpha - w r^m_{p^n}, & (7)\\ \mathrm{n}_\alpha &= (n^{\mathrm{m}}_{p^r} + n^{\mathrm{m}}_I T)\mathrm{w}_\alpha - w n^m_{p^n}. & (8) \end{aligned}$$

From equations (2) and (6)–(8), plus condition $\mathrm{N}^{\mathrm{SR}}_\alpha = 0$ we obtain:

$$\begin{aligned} \mathrm{c}^{\mathrm{SR}}_\alpha &= -w c^m_{p^n}, & (9)\\ \mathrm{r}^{\mathrm{SR}}_\alpha &= -w r^m_{p^n}, & (10)\\ \mathrm{n}^{\mathrm{SR}}_\alpha &= -w n^m_{p^n}, & (11) \end{aligned}$$

Equation (11) tells us that fertility will increase in the short-run when α increases if the demand for children is negatively sloping: $n^m_{p^n} < 0$. Equations (9) and (10) imply consumption and leisure will fall if they are gross substitutes of children: $c^m_{p^n}, r^m_{p^n} > 0$.

Should the tribesman adopt agriculture? Yes. Adopting agriculture increases α, which brings p^n down, hence pushing the tribesman's budget constrain outwards and unambiguously increasing his utility.

From equations (2) and (6)–(8), plus condition $\mathrm{n}^{\mathrm{LR}}_\alpha = 0$ we get the long run comparative statics:

$$\begin{aligned} \mathrm{w}^{\mathrm{LR}}_\alpha &= \frac{w n^{\mathrm{m}}_{p^n}}{n^{\mathrm{m}}_{p^r} + n^{\mathrm{m}}_I T}, & (12)\\ \mathrm{c}^{\mathrm{LR}}_\alpha &= \frac{c^{\mathrm{m}}_{p^r} + c^{\mathrm{m}}_I T}{n^{\mathrm{m}}_{p^r} + n^{\mathrm{m}}_I T} w n^{\mathrm{m}}_{p^n} - w c^m_{p^n}, & (13)\\ \mathrm{r}^{\mathrm{LR}}_\alpha &= \frac{r^{\mathrm{m}}_{p^r} + r^{\mathrm{m}}_I T}{n^{\mathrm{m}}_{p^r} + n^{\mathrm{m}}_I T} w n^{\mathrm{m}}_{p^n} - w r^{\mathrm{m}}_{p^n}, & (14)\\ \mathrm{N}^{\mathrm{LR}}_\alpha &= \frac{w n^{\mathrm{m}}_{p^n}}{w_N(n^{\mathrm{m}}_{p^r} + n^{\mathrm{m}}_I T)} & (15) \end{aligned}$$

Finally, from equations (9)–(11) and (12)–(15) we derive a set of sufficient conditions for $\mathrm{n}^{\mathrm{SR}}_\alpha > 0$; $\mathrm{c}^{\mathrm{SR}}_\alpha, \mathrm{r}^{\mathrm{SR}}_\alpha, \mathrm{c}^{\mathrm{LR}}_\alpha, \mathrm{r}^{\mathrm{LR}}_\alpha < 0$, and $\mathrm{N}^{\mathrm{LR}}_\alpha > 0$:

1. The return to labor is decreasing in the population: $w_N < 0$.
2. The Marshallian demand for children is negatively sloping: $n^m_{p^n} < 0$.
3. The demand for children is increasing in the return to labor: $\mathrm{n}_w = n^{\mathrm{m}}_{p^r} + T n^{\mathrm{m}}_I > 0$.
4. Consumption is a normal good and a gross complement of leisure and children: $c^{\mathrm{m}}_I > 0$, $c^{\mathrm{m}}_{p^r}, c^{\mathrm{m}}_{p^n} > 0$.

5. Leisure is a gross complement of children: $r^m_{p^n} > 0$.
6. Leisure is decreasing in the return to labor: $\mathrm{r}_w = r^{\mathrm{m}}_{p^r} + r^{\mathrm{m}}_I T < 0$.
7. Leisure is more sensitive to changes in the return to labor than to changes in the price if children: $|r^{\mathrm{m}}_{p^r} + r^{\mathrm{m}}_I T| > r^{\mathrm{m}}_{p^n}$.
8. Fertility is more sensitive to changes in the price of children than to changes in the return to labor: $n^{\mathrm{m}}_{p^r} + n^{\mathrm{m}}_I T < |n^{\mathrm{m}}_{p^n}|$.

Latter generations of farmers will not abandon agriculture, because that would increase the price of children, reducing their welfare in the short run.

The effects of enhancements in the food production technology

Totally differentiating w and the Marshallian demands with respect to A, and imposing $\alpha = 0$, we obtain:

$$\begin{aligned}
\mathrm{w}_A &= w_A + w_N \mathrm{N}_A, \\
\mathrm{c}_A &= c^m_{p^r}\,\mathrm{w}_A + c^m_I\,\mathrm{w}_A T, \\
\mathrm{r}_A &= r^m_{p^r}\,\mathrm{w}_A + r^m_I\,\mathrm{w}_A T, \\
\mathrm{n}_A &= n^m_{p^r}\mathrm{w}_A + n^m_I \mathrm{w}_A T
\end{aligned}$$

where w_A, c_A, r_A, N_A, and n_A are unknowns. The system is closed with $\mathrm{N}_A = 0$ for the short-run, and with $\mathrm{n}_A = 0$ and $n = \overline{n}$ for the long-run. Under the conditions stated in the previous section, the solutions to this system are:

$$\begin{aligned}
\mathrm{c}^{\mathrm{SR}}_A &= c^m_{p^r}\,w_A + c^m_I\,w_A T > 0, & \mathrm{c}^{\mathrm{LR}}_A &= 0 \\
\mathrm{r}^{\mathrm{SR}}_A &= r^m_{p^r}\,w_A + r^m_I\,w_A T < 0, & \mathrm{r}^{\mathrm{LR}}_A &= 0 \\
\mathrm{n}^{\mathrm{SR}}_A &= n^m_{p^r} w_A + n^m_I w_A T > 0, & \mathrm{N}^{\mathrm{LR}}_A &= -\frac{w_A}{w_N} > 0.
\end{aligned}$$

It follows that fertility and consumption rise in the short-run, leisure falls in the short-run, and the only long-run effect of a larger A is an increase in population.

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