What Determines the Direction of Technological Progress?

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Abstract

What determines the direction of technological progress is one of the central questions that economics needs to answer. The current paper tries to answer this question by introducing a small but fundamental generalization of Acemolgu (2002). The extended model argues that although changing relative factor prices (as suggested by Hicks 1932) and the relative market size (as argued by Acemoglu 2002) indeed affect the direction of technological progress in the short run, in the long run that direction depends only on the relative supply elasticities of primary factors with respect to their prices. Moreover, it is biased towards enhancing the effectiveness of the factor with the relatively smaller elasticity. The troubling property of the neoclassical growth model discovered by Uzawa (1961), whereby balanced growth is reconcilable only with purely labor augmenting technological progress, is due solely to an implicit assumption that the capital supply elasticity is infinite.

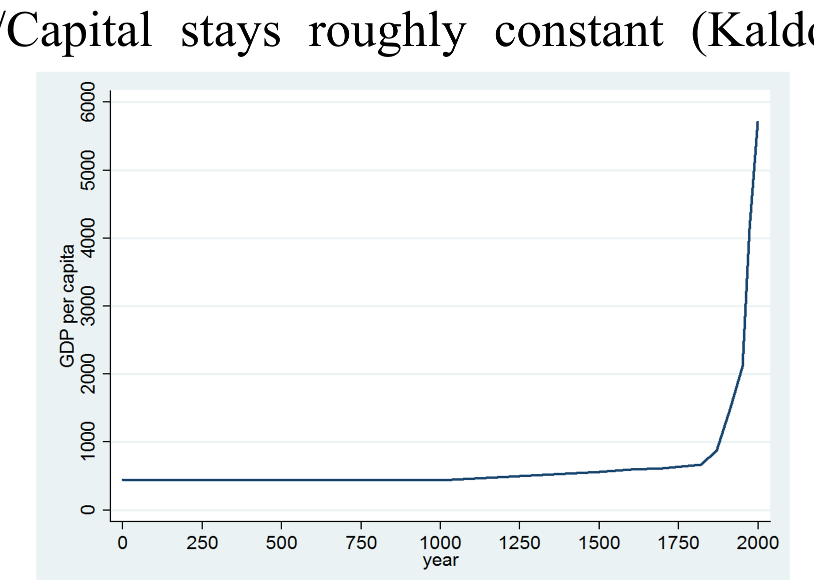
Introduction

Stylized facts in the long run history:

1.Technological progress has generated population growth and higher density, but not higher per-capita income(Ashraf and Galor,2011,AER);

2.Technological progress has caused per-capita output to continually grow at a roughly constant rate but Output/Capital stays roughly constant (Kaldor (1961)'s facts).

Figure 1: The Income per capita of world from A.D. 0 to 2000



Source: Maddison, Angus (2001) The World Economy: A Millennial Perspective. Paris: Development Centre.

Question: Why has technological change hardly increase labor productivity during the preindustrial era but was focused on labor improvement afterwards? What determines that change?

The Benchmark model

The economic environment is an extension of Acemoglu (2002,2003). The economy consists of three kinds of material factors (K,L,S), three sectors of production (a final goods sector, an intermediate goods sector, a research and development (R&D) sector).

Preferences of represent household:

$$U = \int_0^\infty \frac{C(t)^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt$$

The production function of final output:

$$Y = \left[\gamma Y_L{}^{(\varepsilon-1)/\varepsilon} + (1-\gamma) Y_K{}^{(\varepsilon-1)/\varepsilon}\right]^{\varepsilon/(\varepsilon-1)} \quad ,0 \le \varepsilon < \infty$$

where $Y_L = \left[\int_0^N X(i)^\beta di\right]^{1/\beta}$ *and* $Y_K = \left[\int_0^M Z(j)^\beta dj\right]^{1/\beta}, 0 < \beta < 1$

The innovation possibilities frontier functions:

$$\begin{cases} \dot{N} = d_N N S_N - \delta N \\ \dot{M} = d_M M S_M - \delta M \end{cases} ,S_N + S_M = \mathrm{S}$$

where "S" is the amount scientists that is given exogenously.

The **crucial assumption** of the paper which are different from Acemoglu(2002, 2003) :

$$\begin{cases} \dot{K} = b_K I_K^{\alpha_K} - \delta_K K, \; b_K > 0, \; 0 \le \alpha_K \le 1, \delta_K > 0 \\ \dot{L} = b_L I_L^{\alpha_L} - \delta_L L, \; b_L > 0, \; 0 \le \alpha_L \le 1, \delta_L > 0 \end{cases}$$

Unlike the standard capital accumulation function $\dot{K} = I_K - \delta_K K$, it allows α_K to be any number between 0 and 1. This paper proves that the two parameters, α_K and α_L, which have been ignored by existing growth models, are the only determinants of the direction of technical progress in the steady-state equilibrium.

Results

Proposition 1: Along a steady-state equilibrium path (hereafter SSEP) the direction of technological progress is determined solely by the relative size of α_K and α_L :

$$DT = \frac{1-\alpha_K}{1-\alpha_L}$$

Where $DT \equiv \frac{\dot{B}/B}{\dot{A}/A}$ represents the direction of technological progress, $\dot{B}/B$ and $\dot{A}/A$ represent labor- and capital-augmenting technological progress, respectively.

Proposition 2: Along an SSEP the direction of technological progress is determined solely by the relative primary factor supply elasticities and is biased towards the one with the relatively smaller elasticity:

$$DT = \frac{1+\varepsilon_{L,w}}{1+\varepsilon_{K,r}}$$

Where $\varepsilon_{L,w}$ and $\varepsilon_{K,r}$ are the supply elasticities of K and L in the SSEP, determined by

$$\begin{cases} \varepsilon_{K,r} = \alpha_K/(1-\alpha_K) \\ \varepsilon_{L,w} = \alpha_L/(1-\alpha_L) \end{cases}$$

Remark: It is NOT the relative price (Hicks 1932) or the relative market size (Acemoglu 2002) that determine the direction of technological progress!

Corollary:

(1) If $\varepsilon_{L,w} \to \infty (\alpha_L = 1)$, the technological progress is purely capital augmenting which is consistent with the situation prior to the Industrial Revolution;

(2) If $\varepsilon_{K,r} \to \infty (\alpha_K = 1)$, then technological progress is purely labor augmenting which is consistent with the situation after the Industrial Revolution.

Discussion

Beside the primary factors accumulation functions, other assumptions can be extended.

1.innovation functions can be replaced by Lab equipment specification：

$$\begin{cases} \dot{M} = b_M I_M^{\alpha_M} - \delta_M M, \; b_M > 0, \; 0 \le \alpha_M \le \frac{\beta}{1-\beta}, \delta_M > 0 \\ \dot{N} = b_N I_N^{\alpha_N} - \delta_N N, \; b_N > 0, \; 0 \le \alpha_N \le \frac{\beta}{1-\beta}, \delta_N > 0 \end{cases}$$

This specification also requires knife-edge conditions for a SSEP to exist:

$$\begin{cases} \alpha_K + [(1-\beta)/\beta]\alpha_M = 1 \\ \alpha_L + [(1-\beta)/\beta]\alpha_N = 1 \end{cases}$$

2.The production functions of the inputs Y_L and Y_K can be replaced by following specification,

$$Y_L = \frac{1}{1-\beta}\left[\int_0^N X(i)^{1-\beta} di\right] L^\beta \text{ and} Y_K = \frac{1}{1-\beta}\left[\int_0^M Z(i)^{1-\beta} di\right] K^\beta$$

The core results hold.

Conclusions

By a fundamental extension of Acemoglu(2002,2003)'s framework, this paper makes the following substantive contribution to the literature:

First, it *identifies the determinants* of the direction of technological progress which are totally ignored by existing growth models.

Second, it *provides a reasonable answer* for the problem why technological progress was purely land-augmenting in the preindustrial era and purely labor-augmenting after the industrial revolution.

Third, it *resolves the puzzle of Uzawa's theorem* in an endogenous growth model as the steady state path of our model is compatible with any type of technical change(including any labor- and capital-augmenting) NOT JUST for a C-D production function.

Fourth, it *provides a uniform growth model* which nests several famous growth models as special cases. For example, $\alpha_K = \alpha_L = 0$ amounts to Acemoglu (2002), $\alpha_K = 1$ and $\alpha_L = 0$ amounts to Acemoglu (2003) and the neoclassical growth model, $\alpha_L = 1$ may be interpreted as a Malthusian environment with "K" being interpreted as "land".

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