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CAN GEOGRAPHICAL FACTORS LOCK A SOCIETY IN STAGNATION?

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Can geographical factors lock a society in stagnation?

Nguyen Thang DAO[1] and Julio DÁVILA[2]

Abstract

We extend the model in Galor and Weil (2000), considering geographical factors, to show that, under some initial condition, an economy may be locked in Malthusian stagnation and it never takes off. Specifically, we show how the interplay of "land", its "accessibility", and technology prevents an economy from escaping stagnation.

Keywords: Geographical factors, depreciation of technology, human capital.

JEL Classification: O11, O33.

1. Introduction

Galor and Weil (2000), hereafter GW(2000), advanced a unified growth model to interpret the historical evolution and interaction between population, technology, and output. The authors show that the transition from stagnation to modern sustained growth is an *inevitable* outcome of the development process when the driving forces for technological progress are the level of education and the population size. Technological progress is assumed to appear nonetheless even when education is zero and population is small. So, eventually, the Malthusian stagnation vanishes endogenously, leaving the arena to modern growth forces and permitting the economy to take off and converge to a modern steady state growth. Their seminal paper explains well the evolution of population, technology, and output for societies in Western Europe and many other societies in the world. In this paper, we build on GW(2000), introducing geographical factors to show that under specific initial conditions, an economy will be locked in stagnation, with a low population size, a basic technological level, and zero-education. In our model, we consider too the depreciation of technology, which (when the education level of society is zero) allows for technological progress if and only if the population size is large enough. Thus, societies whose geographical factors prevent from reaching such a sufficiently large population never escape the stagnation.

In the widely popular book "*Guns, Germs, and Steel: The Fates of Human Societies*", Jared Diamond (1997) provides evidence that some societies show no sign of escaping the stagnation on their own due to the losses of technology and culture, in particular small and isolated societies. The most extreme losses of technology took place on the Tasmania island. Aborigines in Tasmania were separated from mainland Australians due to rising sea

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level around 10.000 years ago. With the stable population of 4.000, Tasmanians had the simplest material culture and technology of any people in the modern world. Like mainland Aborigines, they were hunter-gatherers but they lacked many technologies and artifacts widespread on the mainland. Some technologies were brought to Tasmania when it was still a part of the Australian mainland, and were subsequently lost in Tasmania's cultural isolation. For example, the disappearance of fishing, and of awls, needles, and other bone tools, around 1500 BC (Diamond 1997, p312-13). Diamond argues that a small population of 4.000 was able to survive for 10.000 years, but was not enough to prevent it from significant losses of technology, culture and from significant failures to invent new technology, leaving it with a uniquely simplified material culture. This paper therefore makes stand out clearly the importance of the roles played by the depreciation of technology and geographical factors to avoid a stagnation trap. The rest of the paper is organized as follows. Section 2 introduces the model. Section 3 characterizes its equilibria. Geographical factors under which an economy is unable to escape stagnation are studied in section 4. Section 5 makes a summary and concludes the paper.

2. The model

2.1. Geographical factors

We refer by "land" to the entire geographical resources and environmental condition supporting the living. Obviously, our lives depend on how suitable the ecosystem around us is. Due to technological constraints, people may not make the most of the available land, e.g. they may just occupy the part of their geographical territory that is most suitable for their lives. This part of land is called "productive land", whose size depends on the technological level and land "accessibility". The accessibility of land captures its intrinsic suitability for people to live in the ecosystem as a whole such as temperature, humidity, river density, bio-diversity, etc. The size of the productive land of the economy in period t, X_t, is

$$X_t = \chi(\theta, A_t)X \tag{1}$$

where $\chi(\theta, A_t) \in [0, 1)$, $0 \leq \theta$ is an accessibility parameter; A_t is the technological level at time t; $X > 0$ is total land (i.e. the entire resources and environment of the economy). Moreover, $\chi(0, 0) = 0$, $\chi_\theta(\theta, A_t) > 0$, $\chi_A(\theta, A_t) > 0$, $\chi_{AA}(\theta, A_t) < 0$, and $\lim_{\theta\to+\infty}\chi(\theta, A_t) = \lim_{A_t\to+\infty}\chi(\theta, A_t) = 1$, $\lim_{A_t\to+\infty}\chi_\theta(\theta, A_t) = \lim_{A_t\to+\infty}\chi_A(\theta, A_t) = \lim_{A_t\to+\infty}\chi_{AA}(\theta, A_t) = 0$.

2.2. Production and technology

The productivity of each unit of time of a household in period t is given by its human capital, h_t, and the technological level, A_t. Each period is normalized to be one unit of time. The output produced per unit of time in period t and per household is

$$y_t = f(A_t)h_t$$

where $f(A_t) > 0\ \forall A_t \geq 0$, $f'(A_t) > 0$, and $f''(A_t) < 0$.[3]

[3] In order to make stand out clearly the importance of the interplay between population, education and environment, we abstract from land as an input of the production function. In fact, introducing land in the production function does not change the qualitative analysis.

The technological level in period $t+1$ is

$$A_{t+1} = (1-\lambda)[1+g_t]A_t \tag{2}$$

where $\lambda \in (0,1)$ is the depreciation rate, g_t is technological progress in t, and $(1-\lambda)[1+g_t]$ is technological growth rate between periods $t+1$ and t. As in GW(2000), we assume that g_t depends on the average education, e_t, and the size L_t of the working generation in period t, i.e.

$$g_t = g(e_t, L_t) \tag{3}$$

in which, for any period t, $\forall e_t \geq 0$, $\forall L_t > 0$, we have $g(0, L_t) > 0$, $\lim_{L_t \to 0^+} g(0, L_t) = 0$, $g_e(e_t, L_t) > g_L(e_t, L_t) > 0$, $g_{LL}(e_t, L_t) < 0$.

From equations (2) and (3) we know that if the education of the working generation t is zero, then the economy has positive technological growth if and only if the size of population is large enough, i.e.

$$(1-\lambda)[1+g(0,L_t)] > 1 \quad \Leftrightarrow \quad g(0,L_t) > \frac{\lambda}{1-\lambda}$$

which implies that for positive technological growth to exist it must hold $L_t > \underline{L}$, where $\underline{L}$ satisfies

$$g(0, \underline{L}) = \frac{\lambda}{1-\lambda} \tag{4}$$

2.3. Households

In each period t, a generation consists of L_t identical working households. Each household lives for two periods. In the first period (say childhood), $t-1$, it uses up a fraction of its parent's time. In the second period (say parental), t, it is endowed with one unit of time which it allocates between child-rearing and production. The preferences of the household born in period $t-1$ are defined over the number and quality of its children, n_t and h_{t+1} respectively, as well as from its consumption in period t, c_t, as follows

$$u_t = \gamma \ln(n_t h_{t+1}) + (1-\gamma)\ln c_t \tag{5}$$

Each household chooses a number of children and their quality under the constraint of the unit of time they can use to child-rearing and production. The only input required to produce both child quantity and quality is time. We assume that the time to raise children physically, regardless education investment, is decreasing in per household resources X_t/L_t.[4] For simplicity, we assume that the cost in time for raising n_t children physically is $(\frac{L_t}{X_t})^{\beta} n_t$, where $\beta \in (0,1)$. We define $\frac{L_t}{X_t}$ as the "effective population density". So the opportunity cost that households devote to raise n_t children with education e_{t+1} for each child is $y_t n_t[(\frac{L_t}{X_t})^{\beta} + e_{t+1}]$. Hence, the agent born at date $t-1$ maximizes at date t its utility (5) under the following budget constraint

[4] This idea is introduced in Goodsell (1937) and Thompson (1938), recently cited by de la Croix and Gosseries (2012) to take into account that when households have small dwellings, child production is more costly and households have fewer children.

$$y_t n_t[(\frac{L_t}{X_t})^\beta + e_{t+1}] + c_t \leq y_t \tag{6}$$

GW(2000) assume that human capital formation of children born at date t, h_{t+1}, depends positively on education investment, e_{t+1}, and negatively on the growth rate of technological progress from period t to period $t+1$, g_t. They argue that education lessens the obsolescence of human capital in a changing technology. And, hence, households have incentives to invest in education when technological progress appears regardless the level of technology. From our viewpoint, however, the incentives in educating their offspring depend on the level of technology, A_{t+1}, rather than the growth rate of technological progress, g_t. In effect, for an economy with a high enough level of technology, even if there is no technological progress, agents have incentives to educate their offspring in order to able them to make use of the technology. Hence, we assume that

$$h_{t+1} = h(e_{t+1}, A_{t+1}) \tag{7}$$

where $h(e, A) > 0$, $h_A(e, A) < 0$, $h_{AA}(e, A) > 0$, $h_{eA}(e, A) > 0$ $\forall(e, A) \geq (0, 0)$; $h_e(e, A) > 0$, $h_{ee}(e, A) < 0$, $\forall(e, A) \neq (0, 0)$, $h_e(0, 0) = 0$, $\lim_{A \to +\infty} h(e, A) > 0$ $\forall e > 0$ and $\lim_{A \to +\infty} h(0, A) = 0$, and $\lim_{A \to +\infty} h_e(e, A) > 0$ $\forall e \geq 0$.

Household's optimization

Each household t chooses the quantity n_t and quality h_{t+1} of its offspring, and consumption c_t so as to maximize its utility. From (5), (6), and (7), the optimization problem is

$$\max_{n_t > 0, e_{t+1} \geq 0} \gamma \ln [n_t h(e_{t+1}, A_{t+1})] + (1 - \gamma) \ln \left[(1 - n_t[(\frac{L_t}{X_t})^\beta + e_{t+1}]) y_t \right]$$

The first-order condition with respect to n_t gives us

$$n_t = \frac{\gamma}{(\frac{L_t}{X_t})^\beta + e_{t+1}} \tag{8}$$

And the first-order condition with respect to e_{t+1} requires the following relationship between e_{t+1} and A_{t+1}, $\frac{L_t}{X_t}$ to hold:

$$G\left(e_{t+1}, A_{t+1}, \frac{L_t}{X_t}\right) = h_e(e_{t+1}, A_{t+1})[(\frac{L_t}{X_t})^\beta + e_{t+1}] - h(e_{t+1}, A_{t+1}) \begin{cases} = 0 \text{ if } e_{t+1} > 0 \\ \leq 0 \text{ if } e_{t+1} = 0 \end{cases} \tag{9}$$

Proposition 1: *In the economy set up above, there exists a threshold of technological level in any period t, $\hat{A}_{t+1} = \hat{A}\left(\frac{L_t}{X_t}\right) > 0$, such that households educate their offspring if, and only if, the level of technology exceeds this threshold, i.e.*

$$e_{t+1} = e\left(A_{t+1}, \frac{L_t}{X_t}\right) \begin{cases} = 0 \; if \; A_{t+1} \leq \hat{A}\left(\frac{L_t}{X_t}\right) \\ > 0 \; if \; A_{t+1} > \hat{A}\left(\frac{L_t}{X_t}\right) \end{cases}$$

Moreover, $\hat{A}'\left(\frac{L_t}{X_t}\right) < 0$.

Proof: We prove that, for all $\frac{L_t}{X_t}$ there exists unique $\hat{A}_{t+1}$ such that $G(0, \hat{A}_{t+1}, \frac{L_t}{X_t}) = 0$. From the assumptions of $h(e_{t+1}, A_{t+1})$ and the equation (9), we find that $G(0, A_{t+1}, \frac{L_t}{X_t})$ is monotonically increasing in A_{t+1},

$$\frac{\partial G(0, A_{t+1}, \frac{L_t}{X_t})}{\partial A_{t+1}} = h_{eA}(0, A_{t+1})(\frac{L_t}{X_t})^{\beta} - h_A(0, A_{t+1}) > 0$$

Furthermore, $\forall X_t, L_t > 0$, $\lim_{A_{t+1} \to +\infty} G(0, A_{t+1}, \frac{L_t}{X_t}) > 0$, whereas from (7) $h_e(0,0) = 0$ and $h(0,0) > 0$ indicate that $G(0, 0, \frac{L_t}{X_t}) < 0$. So there exists a unique $\hat{A}_{t+1} > 0$ such that $G(0, \hat{A}_{t+1}, \frac{L_t}{X_t}) = 0$, and therefore, as follows from (9), $e_{t+1} = 0$ for $A_{t+1} \leq \hat{A}_{t+1}$.

Applying the implicit function theorem to $G(0, \hat{A}_{t+1}, \frac{L_t}{X_t}) = 0$, we get $\hat{A}_{t+1} = \hat{A}(\frac{L_t}{X_t})$, and

$$\hat{A}'(\frac{L_t}{X_t}) = \frac{-\beta h_e(0, A_{t+1})(\frac{L_t}{X_t})^{\beta-1}}{h_{eA}(0, \hat{A}_{t+1})(\frac{L_t}{X_t})^{\beta} - h_A(0, \hat{A}_{t+1})} < 0$$

Q.E.D.

3. Equilibria

We focus on an economy with geographical factors not supporting to escape stagnation. We prove later that, under specific initial conditions, the technological level stays always below the threshold of technology, implying the optimal education investment for children is always zero. So hereafter, we set $e_t = 0 \, \forall t$. The competitive equilibrium of this economy is characterized by the following system of equations (10)-(13), given θ,α, β, γ, X, L_t, and A_t.

$$n_t = \gamma \left(\frac{X_t}{L_t} \right)^{\beta} \tag{10}$$

$$L_{t+1} = n_t L_t \tag{11}$$

$$A_{t+1} = (1 - \lambda)[1 + g(0, L_t)]A_t \tag{12}$$

$$X_t = \chi(\theta, A_t)X \tag{13}$$

The competitive equilibrium can be fully characterized by the following reduced system describing the equilibrium dynamics of the population L_{t+1} and technology A_{t+1}

$$L_{t+1} = \gamma \left(\chi(\theta, A_t)X \right)^{\beta} L_t^{1-\beta} \tag{14}$$

$$A_{t+1} = (1 - \lambda)[1 + g(0, L_t)]A_t \tag{15}$$

for a given initial conditions L_0, A_0, and $e_0 = 0$.

4. Stagnation trap

This section studies the conditions on geographical factors (X, θ) under which an economy starting from specific initial conditions never escapes stagnation. Specifically we characterize a set of geographical factors that does not allow an economy to reach the critical population size $\underline{L}$ guaranteeing technological growth. As a consequence, the technological level will remain lower than the take-off threshold, locking the economy at zero-education. Zero-education associated with small population cannot guarantee a technological progress able to offset depreciation, so that the economy can not expand its productive land to enhance fertility and reach a bigger population. This negative feedback loop prevents the economy from escaping stagnation.

Proposition 2: *An economy with*

$$(X,\theta) \in S = \left\{ (X,\theta) \in \mathbb{R}^2_+ : \frac{\chi(\theta, \hat{A}(\underline{L}/X))X}{\underline{L}} \leq \gamma^{-1/\beta} \right\}$$

and initial condition $L_0 < \underline{L}$, $e_0 = 0$, and $A_0 \leq \underline{A}$, where $\underline{A}$ solves $A = \hat{A}\left(\frac{\underline{L}}{\chi(\theta,A)X}\right)$,[5] *will be locked in a stable steady state with small population and zero level of technology, specifically*

$$\tilde{L} = \gamma^{1/\beta}\chi(\theta, 0)X < \underline{L} \qquad \tilde{A} = 0$$

Proof: We first prove Lemma 1 below

Lemma 1: $\rho\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right) < \hat{A}\left(\frac{L_t}{\chi(\theta,\rho A_t)X}\right) \quad \forall \rho \in (0,1) \quad \forall A_t > 0$

Proof: For any given θ, X, and L_t, we consider the following function

$$\Lambda(A_t) = \rho\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right) - \hat{A}\left(\frac{L_t}{\chi(\theta,\rho A_t)X}\right)$$

$$\Lambda'(A_t) = \rho\frac{\mathrm{d}\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right)}{\mathrm{d}A_t} - \rho\frac{\mathrm{d}\hat{A}\left(\frac{L_t}{\chi(\theta,\rho A_t)X}\right)}{\mathrm{d}(\rho A_t)} = \rho\left[\frac{\mathrm{d}\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right)}{\mathrm{d}A_t} - \frac{\mathrm{d}\hat{A}\left(\frac{L_t}{\chi(\theta,\rho A_t)X}\right)}{\mathrm{d}(\rho A_t)}\right] < 0$$

since $\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right)$ is increasing and strictly concave in A_t.

$$\Rightarrow \Lambda(A_t) < \Lambda(0) = (\rho - 1)\hat{A}\left(\frac{L_t}{\chi(\theta,0)X}\right) < 0 \quad \text{i.e.} \quad \rho\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right) < \hat{A}\left(\frac{L_t}{\chi(\theta,\rho A_t)X}\right) \quad \blacksquare$$

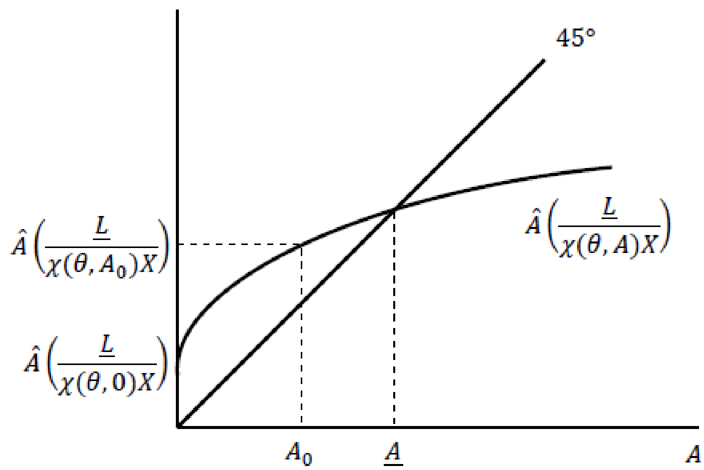
[5] It is straightforward that $\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right)$ is increasing in A_t and it is also concave in A_t, In effect,

$$\frac{\mathrm{d}^2\hat{A}\left(\frac{L_t}{X_t}\right)}{\mathrm{d}A_t^2} = \frac{\partial^2\hat{A}\left(\frac{L_t}{X_t}\right)}{\partial X_t^2}\left(\frac{\mathrm{d}X_t}{\mathrm{d}A_t}\right)^2 + \frac{\partial\hat{A}\left(\frac{L_t}{X_t}\right)}{\partial X_t}\frac{\mathrm{d}^2X_t}{\mathrm{d}A_t^2}, \text{ where } \frac{\partial^2\hat{A}\left(\frac{L_t}{X_t}\right)}{\partial X_t^2} = \frac{-h_{eA}(0,\hat{A}_{t+1})(\frac{L_t}{X_t})^\beta + (1+\beta)h_A(0,\hat{A}_{t+1})}{\left[h_{eA}(0,\hat{A}_{t+1})(\frac{L_t}{X_t})^\beta - h_A(0,\hat{A}_{t+1})\right]^2} < 0$$

$\Rightarrow \frac{\mathrm{d}^2\hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right)}{\mathrm{d}A_t^2} < 0$. So $\hat{A}\left(\frac{L}{\chi(\theta,A)X}\right)$ is increasing and strictly concave in A. Moreover, it is bounded from above by $\hat{A}\left(\frac{L}{X}\right)$, and $\hat{A}\left(\frac{L}{\chi(\theta,0)X}\right) > 0$. Then there exists a unique $\underline{A}$ solving $A = \hat{A}\left(\frac{\underline{L}}{\chi(\theta,A)X}\right)$.

It is straightforward from the increasing concavity of $\hat{A}\left(\frac{\underline{L}}{\chi(\theta,A)X}\right)$ with respect to A that

$$A_0 \leq \underline{A} = \hat{A}\left(\frac{\underline{L}}{\chi(\theta,\underline{A})X}\right) \Leftrightarrow A_0 \leq \hat{A}\left(\frac{\underline{L}}{\chi(\theta,A_0)X}\right)$$



We argue for this economy technological level converges monotonically to zero. Indeed

$$A_0 \leq \hat{A}\left(\frac{\underline{L}}{\chi(\theta,A_0)X}\right) < \hat{A}(\underline{L}/X) \quad \Rightarrow \quad A_0 < \hat{A}\left(\frac{\underline{L}}{\chi(\theta,\hat{A}(\underline{L}/X))X}\right)$$

and $L_0 < \underline{L}$, $\hat{A}' < 0$, hence

$$A_1 = (1-\lambda)[1+g(0,L_0)]A_0 < A_0 < \hat{A}\left(\frac{\underline{L}}{\chi(\theta,A_0)X}\right) < \hat{A}\left(\frac{L_0}{\chi(\theta,A_0)X}\right)$$

$$\Rightarrow e_1 = 0 \quad \text{and} \quad L_1 = \gamma\left(\frac{\chi(\theta,A_0)X}{L_0}\right)^{\beta} L_0 < \gamma\left(\frac{\chi(\theta,\hat{A}(\underline{L}/X))X}{\underline{L}}\right)^{\beta} \underline{L} \leq \underline{L}$$

$$\Rightarrow A_2 = (1-\lambda)[1+g(0,L_1)]A_1 < A_1 < (1-\lambda)[1+g(0,L_0)]\hat{A}\left(\frac{\underline{L}}{\chi(\theta,A_0)X}\right)$$

$$< \hat{A}\left(\frac{\underline{L}}{\chi(\theta,(1-\lambda)[1+g(0,L_0)]A_0)X}\right) = \hat{A}\left(\frac{\underline{L}}{\chi(\theta,A_1)X}\right) \quad \text{(under Lemma 1)}$$

$$\Rightarrow A_2 < \hat{A}\left(\frac{L_1}{\chi(\theta,A_1)X}\right)$$

$$\Rightarrow e_2 = 0 \quad \text{and} \quad L_2 = \gamma\left(\frac{\chi(\theta,A_1)X}{L_1}\right)^{\beta} L_1 < \gamma\left(\frac{\chi(\theta,\hat{A}(\underline{L}/X))X}{\underline{L}}\right)^{\beta} \underline{L} \leq \underline{L}$$

$$\vdots$$

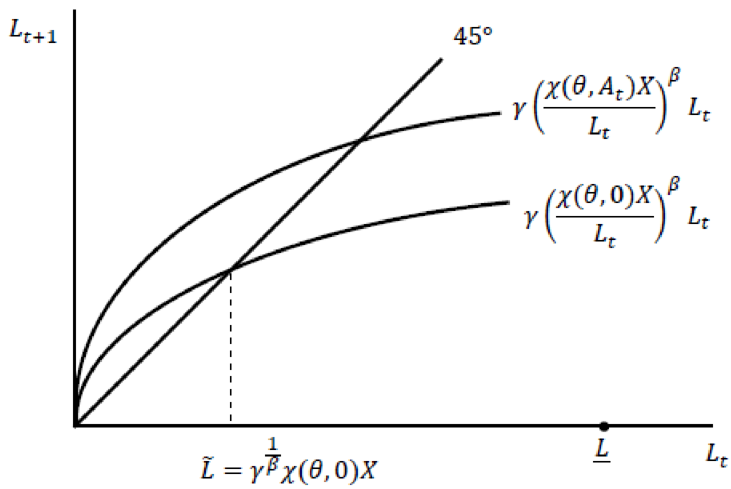
and so on, $\forall t\ A_{t+1} < \hat{A}\left(\frac{L_t}{\chi(\theta,A_t)X}\right),\ e_{t+1}=0,\ L_{t+1}=\gamma\left(\frac{\chi(\theta,A_t)X}{L_t}\right)^{\beta} L_t < \underline{L}$.

And

$$A_{t+1} = A_0(1-\lambda)^{t+1}\prod_{i=0}^{t}[1+g(0,L_i)]$$

Since $L_t < \underline{L}\ \forall t$ then $(1-\lambda)[1+g(0,L_t)] < 1\ \forall t$, the technological level converges monotonically to $A_{+\infty} = 0$. The existence of a steady state for the system (14)-(15) is the existence of a solution $\tilde{L}$ to

$$\gamma\left(\frac{\chi(\theta,0)X}{L}\right)^{\beta} = 1 \quad \Rightarrow \quad \tilde{L} = \gamma^{1/\beta}\chi(\theta,0)X$$



The stable steady state of the system (14)-(15) is

$$(\tilde{L},\tilde{A}) = \left(\gamma^{1/\beta}\chi(\theta,0)X,\ 0\right)$$

Q.E.D.

5. Summary and Conclusion

Consider an economy in an early stage of development with a small population and a sufficiently low technological level that households have no incentive to educate their children (as stated in Proposition 1). For the geographical factors $(\theta, X) \in S$ not allowing for a sufficiently large population (i.e. $L < \underline{L}$), there will be no technological growth in the long run, as well as as no education to enhance technological progress. Consequently, the economy will be locked in stagnation (as stated in Proposition 2). If the geographical factors allow for a sufficiently large population, then the mechanism for the economy to take off is similar to the one in GW(2000). When population large enough, the technological growth appears.

Accumulation of technology over time requires households to educate their children. Education, in turn, enhances technological progress, consequently forcing the economy to take off.

This paper, by examining the evolution of societies with geographical factors not supporting a sufficiently large population, (and hence locked in stagnation, i.e. low population, a basic technology, and zero education), makes stand out clearly the importance of geographical factors and environmental conditions for the development process.

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