Endogenous Discounting via Wealth, Twin-Peaks and the Role of Technology

I. Schumacher

Discussion Paper 2006-59

Département des Sciences Économiques
de l'Université catholique de Louvain

UCL

CORE DISCUSSION PAPER

2006/104

ENDOGENEOUS DISCOUNTING VIA WEALTH, TWIN-PEAKS AND THE ROLE OF TECHNOLOGY

Ingmar SCHUMACHER[1]

11/2006

Abstract

The article gives new answers to the two following questions: One, what can be a potential source of the twin-peaks of economic growth? Two, why were some of the countries that were believed to belong to the group of low steady state countries (like Taiwan, South Korea, Japan, etc.) able to reach a convergence path which led them to a high steady state?

We endogenize the time preference rate via a broad measure of wealth and provide empirical evidence that wealth affects the discount rate negatively. We provide sufficient conditions for multiplicity of equilibria and demonstrate how endogenous discounting via wealth leads to the twin-peaks of economic growth. We prove that improvements in technology can help avoid the Twin-Peaks.

JEL classification: D90, C61, O41.

Keywords: endogenous time preference, recursive utility, twin-peaks of economic growth.

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[1]Center for Operations Research and Econometrics (CORE), Université catholique de Louvain, Belgium. E-mail: schumacher@core.ucl.ac.be.
The author is grateful for helpful comments by Raouf Boucekkine. Financial support from the Chaire Lhoist Berghmans in Environmental Economics is kindly acknowledged. Obviously, any errors lie with the author.

1 Introduction

We are becoming more and more aware that convergence between country's income levels is far from obvious. Empirical observation has forcefully shown that rich countries are becoming richer, while poor ones are not able to catch up. For example, Jones [23] finds that the world income distribution changed from a somewhat normal distribution shape towards a twin-peak shape. Even more disturbing, the key results from the recent empirical evidence suggest that the distribution of country's income diverges into rich and poor, whereas the group of middle-income countries vanishes (Azariadis [1], [2], Quah [34], [35], Barro and Sala-i-Martin [6]). We then provide new answers to the following two questions: One, what can be a potential source of these twin-peaks? Two, why were some of the countries that were believed to belong to the group of low steady state countries (like Taiwan, South Korea, Japan, etc.) able to reach a convergence path which led them to a high steady state?

Theoretical models have attempted to draw some conclusions on the possible sources of these twin-peaks of economic growth. These models have either built on non-convexities in technologies to arrive at multiple steady states (Azariadis and Drazen [3]) or on incomplete markets (Durlauf [14], Galor and Zeira [21], Quah [34]). A review of the models and sources of twin-peaks can be found in Azariadis [2].

In this article we propose endogenous discounting as another potential source of the twin-peaks of economic growth. Specifically, we argue that wealth affects the discount rate by proposing that this is a shortcut for suggesting that wealthier countries have better health standards (Case et al. [8], Pritchett [33]) and better insurance markets (Caroll [9], Banerjee and Newman [4]), all of which generally affects the agent's discount rate negatively (Frederick et al. [20]). We thus propose that wealth is assumed to affect the level of the discount rate negatively. This leads to a departure from the time-additive framework of Koopmans [26] to the recursive framework poineered by Uzawa [39].

There exist now an increasing number of endogenous discounting models, which however (nearly exclusively) have consumption as the source of endogenity (e.g. Becker and Mulligan [7], Epstein and Hynes [15], Obstfeld [30], Das [10], Drugeon [13]). Two articles which investigates a decreasing discount rate endogenized via consumption are Drugeon [13] and Das [10]. They suggest the possibility of multiple steady states without deriving conditions and without further analysis. As far as the author is aware, the endogenous discounting literature has therefore not yet dealt with the existence and implications of multiple steady states thoroughly enough.

We derive the sufficient condition for the existence of multiple steady states and show that, given the conditions are satisfied, three steady states can exist, two of which are stable. One of these will be a low-wealth, and the other a high-wealth steady state. Furthermore, we are also able to show that the group of middle-wealth countries is at an instable steady state and will therefore vanish and converge to either of the two high- or low-wealth steady states. Hence, discounting endogenized via wealth can provide another explanation for the development of the twin-peaks of economic growth.

We answer our second question by demonstrating how improvements in technology can help avoid the twin-peaks. This result ought to be particularly interesting for the case of developing countries.

The article is structured as follows. Section 2 provides some empirical evidence for an effect of wealth on the discount rate. Section 3 introduces the model. In Section 4 we solve the model and give the sufficient condition for multiple steady states. We also derive the stability conditions. Section 5 assesses the effect of improvements in technology on the twin-peaks and Section 6 concludes.

2 Wealth as a source of endogenous discounting?

Our treatment of wealth here will be based upon a broad view of wealth by taking a combination of physical capital and human capital (see e.g. Mankiw [27], Barro and Sala-i-Martin [6]). This allows for a wider applicability of the model.[1] As the empirical evidence is rather extensive, we shall only present a selection here. For a more thorough review of empirical evidence on the wealth channel the reader is referred to Schumacher [37].

[1] For an endogenous discounting model which separates human capital from physical capital see Fall and Schumacher [17].

Fielding and Torres [19] estimate the relationship between wealth, health and education for 41 developing countries. Their measure of wealth is particularly useful here, as it is based upon a wider measure of wealth than prior empirical analysis that only refers to income. They build an index of wealth including variables like electricity supply, number of radios, TVs or cars, access to flush toilet, etc. They use this to estimate that improvements in physical and human wealth lead to lower mortality rates. Their results are robust even across countries, pointing at a uniform effect of the variables in question.

This finding seems now widely accepted in the literature. Grossman and Kaestner [22] as well as Grossman [2003] review the literature on the relationship between human wealth and health. Basically, the variable which has the highest correlation with health is human wealth. Elias [16] estimates the magnitude of this effect by relating the death rates to the educational attainments for the USA for white males. From the 45 to 64 years old with less than 12 years of schooling, the death per 100,000 inhabitants were 1,304 in comparison to 510 deaths for the ones with more than 13 years of schooling. Those findings seem robust over time. Kitagwa and Hauser [25] utilize data from the 1960 Census Records for the USA and even after controlling for income, they find that human wealth has a strong negative relationship with mortality rates. These results are confirmed by Feldman et al. [18], Pappas et al. [31], Preston and Elo [32], Richard and Barry [36].

Wealth as a source of endogenous discounting has also been proposed by Becker and Mulligan [7] as well as Deaton and Paxson [12], who, respectively, show that financial assets and human capital inequality grow as cohorts age, interpreted as a sign that either affects preferences. This also helps to shed light on the empirical observation that households with similar lifetime incomes hold very different amounts of wealth at retirement. These results are interpreted by Becker and Mulligan [7] as a potential consequence of endogenous time preference.

Overall it seems that there are consistent reasons for wealth as a source of endogenous discounting, where wealth affects the discount rate negatively. We shall now turn to the model to assess the implication of this empirically-based extension.

3 The Model

The model is based on an infinitely-lived agent approach where the agent obtains utility from consumption. In addition, his wealth affects the discount rate negatively. Then, wealth can be accumulated by investing but is reduced by consumption and constant depreciation. The infinitely-lived agent then attempts to solve the following problem.

$$\max_{\{c(t)\}} \int_{t=0}^{\infty} u(c(t))e^{-\theta(t)}dt \quad \text{s.t.} \begin{cases} \dot{k}(t) = f(k(t)) - c(t) - \delta k(t), & \forall t \\ \dot{\theta}(t) = \rho(k(t)), & \forall t \\ k(t) \geq 0,\ c(t) \geq 0, & \forall t, \\ \text{with } k(0) \text{ given.} \end{cases} \tag{1}$$

We make use of the following assumptions.

(A1) We impose that the production function $f : \mathbb{R}_+ \to \mathbb{R}_+$ follows standard assumptions of concavity, such that $f(k) \geq 0$, $f(0) = 0$, $f'(k) > 0$, $f''(k) < 0$, with $\lim_{k\to 0} f'(k) = \infty$, and $\lim_{k\to\infty} f'(k) = 0$. We also assume that the function is invertible, such that f^{-1} exists. We define $\bar{k}$ as the level of k which solves $f(k) = \delta k$, and $\tilde{k}$ as the level of k that solves $f'(k) = \delta$.

(A2) The utility function $u : \mathbb{R}_+ \to \mathbb{R}_+$ is at least twice continuously differentiable with $u'(c) > 0$, $u''(c) < 0$, $\forall c$, and $\lim_{c\to 0} u'(c) = \infty$. The constant relative risk aversion (CRRA) utility function has the functional form of $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, with $\sigma \geq 0$.

The assumption $u'(0) = \infty$ allows to concentrate on interior solutions only. It corresponds to the assumption that at least a minimum amount of consumption is required for the continuation of the generations. The requirement of a positive domain for felicity is necessary for intuitive results, as shown in Schumacher [37]. The basic reasoning is that a policy maker who can choose the level of the discount rate will always wish to increase it in case felicity is negative, as this then improves overall utility. To avoid this counterintuitive situation we impose positive felicity throughout.

(A3) We take $\rho(k) : \mathbb{R}_+ \to \mathbb{R}_+$ and C^1 with $\rho'(k) < 0$ and $\rho''(k) > 0$, where we impose $\lim_{k\to\infty} \rho(k) >$

0.[2]

The assumptions underlying the behaviour of the discount rate have been motivated in the previous section. Defining the optimization problem by introducing the discount factor as another constraint allows the Hamiltonian to be independent of time which greatly simplifies the analysis.

4 Solving the Model

The Hamilton of the above system writes

$$\mathcal{H} = u(c(t))e^{-\theta(t)} + \lambda(t)[f(k(t)) - c(t) - \delta k(t)] - \mu(t)\rho(k(t)). \tag{2}$$

The Pontryagin necessary conditions for optimality are

$$\begin{aligned} u'(c(t))e^{-\theta(t)} &= \lambda(t), & (3)\\ \lambda(t)[f'(k(t)) - \delta] - \mu(t)\rho'(k(t)) &= -\dot{\lambda}(t), & (4)\\ -u(c(t))e^{-\theta(t)} &= \dot{\mu}(t), & (5)\\ \lim_{t\to\infty} \mathcal{H}(t) &= 0, & (6) \end{aligned}$$

where equation (6) gives the transversality condition of the system.[3] As the Hamiltonian is autonomous we know that $\frac{\partial \mathcal{H}}{\partial t} = 0$. Given the transversality condition $\lim_{t\to\infty} \mathcal{H}(t) = 0$, this gives us that the *optimized* $\mathcal{H}^*(t) = 0$, $\forall t$. Transforming the Pontryagin necessary conditions from (3) till (5) and disregaring time subscripts for convenience, plus making use of $\mathcal{H}^*(t) = 0$, $\forall t$, we can derive the following

[2]Specific functional form could be $\rho(k) = \bar{\rho}e^{-\beta k}$ or $\bar{\rho}/(1 + \beta k)$, where $\beta > 0$, $\rho > 0$.

[3]For this kind of transversality condition, see Michel [29].

dynamical system

$$\dot{c} = -\frac{u'(c)}{u''(c)}\left[f'(k) - \delta - \rho(k) - \frac{\rho'(k)}{\rho(k)}\left(\frac{u(c)}{u'(c)} + \dot{k}\right)\right], \tag{7}$$

$$\dot{k} = f(k) - c - \delta k. \tag{8}$$

With respect to steady states it is simple to show that a steady state always exists for interior paths. We now provide a sufficient condition for the existence of multiple states.[4] We define $m(k) = \frac{\rho''(k)\rho(k)-\rho'(k)^2}{\rho(k)^2}$ with $m(k) \gtrless 0$, and $n(k) = \frac{u'(c)^2-u''(c)u(c)}{u'(c)^2} > 0$.

Proposition 1 *Sufficient conditions for the existence of multiple steady states are given by $\exists k < \tilde{k}$ such that $f''(k) > \rho'(k) + m(k)\frac{u(c)}{u'(c)} + [f'(k) - \delta]\frac{\rho'(k)}{\rho(k)}n(k)$ AND $f'(k) - \delta < \rho(k) + \frac{\rho'(k)}{\rho(k)}\frac{u(f(k)-\delta k)}{u'(f(k)-\delta k)}$, as well as $-\frac{\rho(\tilde{k})^2}{\rho'(\tilde{k})} > \frac{u(f(k)-\delta k)}{u'(f(k)-\delta k)}$.*

Proof 1 *See Appendix.*■

The first part of the sufficient condition is a requirement on the slope of the production function and a necessary condition for a low steady state. The second part is a sufficient condition for a high steady state. In combination, both conditions are sufficient for the existence of the three steady states. We denote the steady states as $0 < k^l < k^m (< \tilde{k}) < k^h (< \bar{k})$. In effect, our conditions for multiple equilibria are quite strong, as they restrict the k^m steady state to be to the left of $\tilde{k}$. It is possible to provide a set of sufficiency conditions which are less restrictive, but at the cost of tractability without changing the main results of the model.

Given the conditions for multiple equilibria are fulfilled we are able to characterize the dynamic behaviour of the curves in a Phase-Diagram, where we take the case of complex dynamics for the k^m steady state. This situation is depicted in Figure 1.

We are now going to derive the arrows for the Phase-Diagram, making use of equations (7) - (8). If (c, k) is above the $\dot{k} = 0$ line, then $f(k) - \delta k - c < 0$ and hence $\dot{k} < 0$, for (c, k) below the $\dot{k} = 0$ we have

[4] The case of unique steady state has been treated in Schumacher [37].

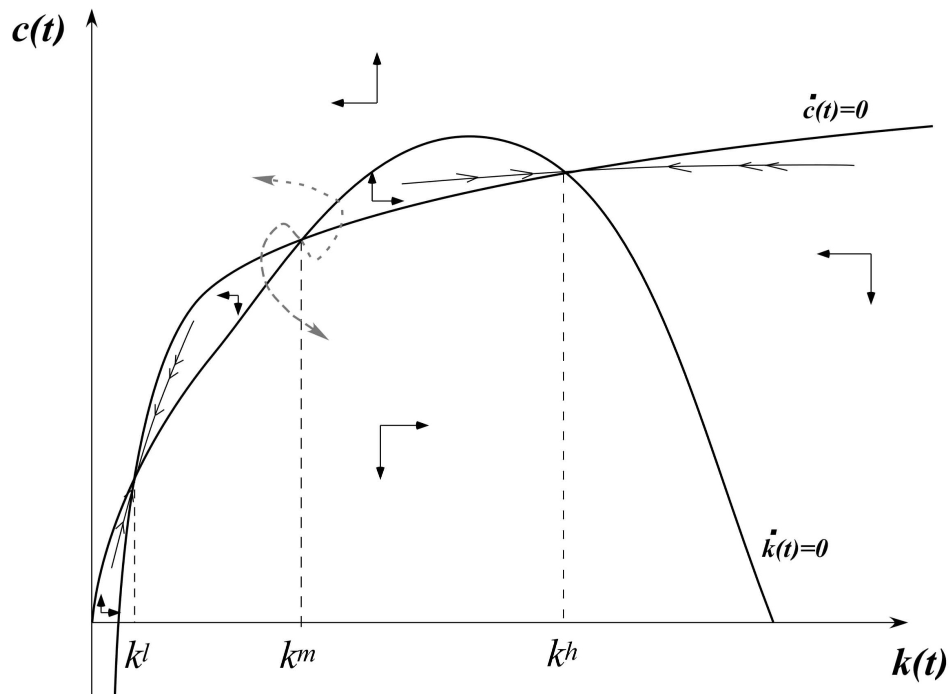

Figure 1: Saddle path dynamics

$\dot{k} > 0$. For (c, k) under the $\dot{c} = 0$ line, we have $\dot{c} < (>)0$ if $f''(k) - \rho'(k) < (>)m(k)\frac{u(c)}{u'(c)} + [f'(k) - \delta]\frac{\rho'(k)}{\rho(k)}n(k)$. When we look at the conditions for multiple equilibria, we exactly notice that $\dot{c} < 0$ for the low and high steady states, but $\dot{c} > 0$ for the middle steady state. Hence we can draw the arrows as in Figure 1 and notice that the low and the high steady state are stable, whereas the middle one is instable. Furthermore, from the subsequent analysis we will obtain that for some conditions, the middle steady state will have complex dynamics.

In addition, conditions for the dynamics can be derived locally, from linearizing the system around the steady states. When one linearizes the dynamical system around the non-trivial steady states, $\{c^l, k^l\}$, $\{c^m, k^m\}$ and $\{c^h, k^h\}$, one gets the following differential system:

$$J = \begin{bmatrix} \rho(k) + \delta - f'(k) & -\frac{u'(c)}{u''(c)}\left(f''(k) - \rho'(k) - m(k)\frac{u(c)}{u'(c)} - (f'(k) - \delta)\frac{\rho'(k)}{\rho(k)}\right) \\ -1 & f'(k) - \delta \end{bmatrix}. \tag{9}$$

As is well-known, the system is saddle path stable if there exists one positive and one negative eigenvalue, denoted by $\lambda_{1,2}$. As the trace is $\text{Tr}(J) = \lambda_1 + \lambda_2$, and the determinant is $\text{Det}(J) = \lambda_1\lambda_2$, it suffices to show that the trace is positive and the determinant is negative. We can thus show that the trace of this matrix is given by $\text{Tr}(J) = \rho(k) > 0$, while the determinant is negative if

$$f''(k) < \rho'(k) + m(k)\frac{u(c)}{u'(c)} + \frac{\rho'(k)}{\rho(k)}(f'(k) - \delta)n(k). \tag{10}$$

From the sufficient conditions for the multiple equilibria we know that this condition does not hold for the middle steady state, which is thus instable. But we know that it holds for the low and high steady states, which thus implies that they are saddle path stable. Complex dynamics arise if $\text{Tr}(J)^2 < 4\text{Det}(J)$. As $\text{Det}(J) < 0$ for the low and high steady state, this excludes the possibility of complex dynamics for these steady states. However, for the medium steady state complex dynamics occur if $\rho(k)^2 < -4\frac{u'(c)}{u''(c)}\left(f''(k) - \rho'(k) - m(k)\frac{u(c)}{u'(c)} - n(k)\frac{\rho'(k)}{\rho(k)}(f'(k) - \delta)\right)$.
From Schumacher [37] we know that following the saddle path leads to an optimal decision.[5]

The multiplicity of steady states occurs because when an economy is very poor then, firstly, increases in consumption are necessary for survival ($u'(0) = \infty$), and secondly the agents are so impatient that the preferences are nearly exclusively directed towards today, implying that most wealth will be directly consumed. For $k > k^m$ however, this implies that overall wealth has already been built up sufficiently in order to incorporate far-sighted goals, such that the discount rate is relatively low. For example, with a low enough mortality rate agents will need to plan ahead carefully to the distant future, whereas a high mortality rate (due to the various feedbacks in section 2 implies that agents don't expect to become old and thus do not plan ahead.

[5]This is despite the fact that the objective function is not concave in both its arguments. We did not impose the standard Mangasarian requirement of negative utility, $u(c) < 0$, as in Obstfeld [30] and others, because it leads to counter-intuitive implications. See Schumacher [37] for a discussion.

5 The effect of improvements in technology

As the Phase-Diagramm in Figure 1 shows, if the conditions for multiple equilibria are satisfied then there exist three equilibria. One of these starts with a low level of capital, is stable and ends up with a low level of wealth (k^l), another starts with a medium level of capital, is instable and diverges (k^m). The last one is a stable steady state with high wealth (k^h). This corresponds to the recent twin-peaks of economic growth hypothesis raised by researchers like Quah [34], Jones [23] and Azariadis [1]. We can provide more foundation to our analysis with some comparative statics. If there is an exogenous increase in total factor productivity (TFP) A, where we define $f(k) \equiv Ag(k)$, then the steady state curve of capital stock shifts upwards, whereas the one of consumption shifts down (see Figure 2). We take the total derivative of the steady state version of equations (7)-(8) with respect to k and A to get

$$\frac{dk}{dA} = \frac{g'(k) - \frac{\rho'(k)}{\rho(k)} g(k) n(k)}{-Ag''(k) + \rho'(k) + \frac{\rho''(k)\rho(k) - \rho'(k)^2}{\rho(k)^2} \frac{Ag(k) - \delta k}{1-\sigma} + \frac{\rho'(k)}{\rho(k)} \frac{Ag'(k) - \delta}{1-\sigma}}. \tag{11}$$

The nominator of this equation is always positive. If the low and high steady states are saddle path stable then we know that the denominator is positive, wherefore improvements in total factor productivity will increase wealth, whereas for the medium steady state the denominator is negative, which necessarily implies that the wealth of the medium steady state is reduced. The intuition is that if wealth is more productive, then it is more efficient to increase the level of wealth and thus to reduce the discount rate. An exogenous increase of the marginal effect of wealth on the discount rate also shifts the steady state consumption curve down and right, because it is then more efficient to increase wealth to reduce the discount rate than to increase consumption.

This result points at the potential of technology to overcome the twin-peaks and help convergence towards the high steady state. Clearly, in recent years, some of the countries that were believed to belong to the group of low steady state countries (South Korea, Taiwan, etc.) were able to reach a convergence path which led them to a high steady state. It seems evident that this is due to improvements in technology.

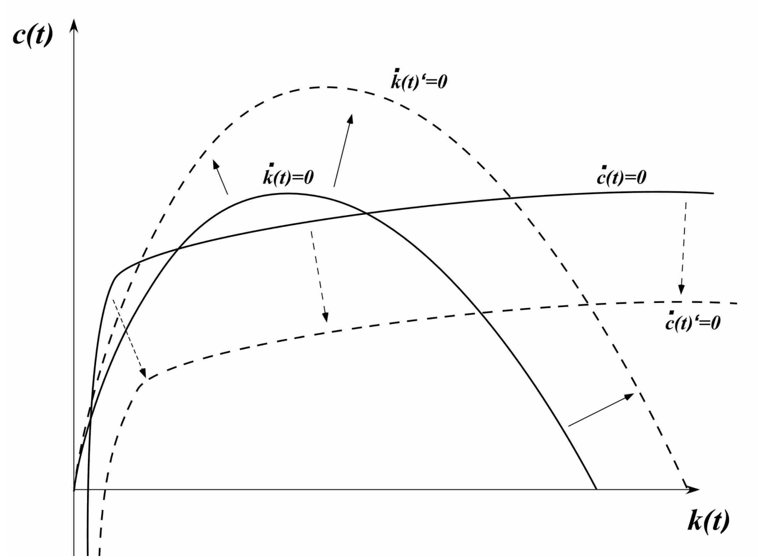

Figure 2: An exogenous shift in TFP

6 Conclusion

In this article we suggest that the discount rate should not be treated exogenously, but instead should be able to vary. Specifically, we provide empirical evidence which suggests that the discount rate is a negative function of a broad measure of wealth, encompassing physical as well as human wealth.

We then show that wealth as a source of endogenous discounting can be another explanation for the twin-peaks of economic growth hypothesis. The twin-peaks of economic growth hypothesis (see Quah [35]) suggests that rich countries become richer while poor ones stay poor, thus producing a twin-peaks distribution of income.

We derive the sufficient conditions for multiple equilibria and show that there will exist three equilibria, two stable ones and one instable one. The two stable ones are the low-wealth and high-wealth equilibria, whereas the instable equilibrium belongs to the middle-income group. We notice that this conforms to recent empirical results from Quah [35] and Azariadis [2]. Whereas the current literature on twin-peaks requires some non-concavity assumption in the production function, we are able to characterize endogenous discounting via wealth as another potential source of the twin-peaks.

We show that improvements in technology can help avoid the twin-peaks. This should provide some new perspective for policy makers with respect to the debate on the development of nations.

7 Appendix: Sufficient condition for multiple Steady States

We use the steady state equations

$$\begin{aligned} f'(k) - \delta - \rho(k) &= \frac{\rho'(k)}{\rho(k)} \frac{u(c)}{u'(c)}, \\ f(k) - \delta k &= c. \end{aligned}$$

We define $G(k) = A(k) - B(k)$, where $A(k) = f'(k) - \delta - \rho(k)$ and $B(k) = \frac{\rho'(k)}{\rho(k)} \frac{u(f(k)-\delta k)}{u'(f(k)-\delta k)}$. Then $G'(k) = f''(k) - \rho'(k) - m(k)\frac{u(c)}{u'(c)} - [f'(k) - \delta]\frac{\rho'(k)}{\rho(k)} n(k)$, where $c = f(k) - \delta k$. We know that $\lim_{k\to 0} G(k) = \infty$ and $\lim_{k\to\bar{k}} G(k) = z$, where z is a negative but finite number. Hence, the curve $G(k)$ starts from positive infinity to negative finite for $k = \bar{k}$. As each argument of $G(k)$ is continuous, we know that $G(k)$ is continuous. A sufficient condition for a low steady state is then that $\exists k < \tilde{k}$ such that $G'(k) > 0$ with $G(k) < 0$. A sufficient condition for a high steady state is $G(\tilde{k}) > 0$. These conditions hold imply that $\exists k < \tilde{k}$ such that $f''(k) > \rho'(k) + m(k)\frac{u(c)}{u'(c)} + [f'(k) - \delta]\frac{\rho'(k)}{\rho(k)} n(k)$ AND $f'(k) - \delta < \rho(k) + \frac{\rho'(k)}{\rho(k)} \frac{u(f(k)-\delta k)}{u'(f(k)-\delta k)}$, as well as $-\frac{\rho(\tilde{k})^2}{\rho'(\tilde{k})} > \frac{u(f(k)-\delta k)}{u'(f(k)-\delta k)}$. $\blacksquare$ We thus know that $0 < k^l < k^m < \tilde{k} < k^h < \bar{k}$.

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Département des Sciences Économiques
de l'Université catholique de Louvain
Institut de Recherches Économiques et Sociales

Place Montesquieu, 3
1348 Louvain-la-Neuve, Belgique

ISSN 1379-244X D/2006/3082/059