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New Open Economy Policy Perspectives: Modified Golden Rule and Hybrid Welfare

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Summary: This paper raises several new issues in the context of a modified growth model and the golden rule, respectively. Key issues solved here include the role of long-run monetary policy – to some extent also fiscal policy – where the golden rule is considered as a serious point of reference for economic policymakers; this includes aspects of the Transatlantic Banking crisis. Also the role of negative external effects from $C0_2$ production is considered here in a straightforward manner. Finally, a new approach for a consistent transition between the Keynesian approach and the long-run neoclassical world is proposed.

Zusammenfassung: Dieser Beitrag greift eine Reihe neuer Aspekte und Fragen im Kontext eines modifizierten Wachstumsmodells bzw. der Goldenen Regel zum Wachstumsmodell auf. Hauptfragen, die hier gelöst werden, betreffen die Rolle langfristiger Geldpolitik – und zu einem gewissen Ausmaß auch die der Fiskalpolitik-, wobei die Goldene Regel als sinnvoller Bezugspunkt der Wirtschaftspolitik betrachtet wird. Die Überlegungen beinhalten auch Aspekte der Transatlantischen Bankenkrise. Hinzu kommt, dass negative externe Effekte der CO2-Produktion in einem einfachen Ansatz betrachtet werden. Schließlich wird ein neuer Ansatz für eine konsistente Verbindung von keynesianischem Ansatz und langfristigem neoklassischem Wachstumsmodell vorgeschlagen.

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1. Introduction

Economics is facing serious challenges after the Transatlantic Banking Crisis, which has almost brought the capitalist system to a financial meltdown in the wake of the Lehman Brothers crisis. Why did so few economists from the US or Europe anticipate this crisis – some notable exceptions were RAJAN (2005) and ARTUS/VIRARD (2005) whose warning against excessive required rate of return on equity of banks was published in French in the book "The Current Self-Destruction of Capitalism" – went unheard? The sharp global recession of 2009 caused by the Transatlantic Banking Crisis was followed by a strong recovery in 2010 on the one hand, on the other hand the massive recapitalization expenditures of several governments of OECD countries for ailing banks and the massive cyclical deficits occurring in the context of expansionary fiscal policies brought a confidence crisis among the sovereign debt market, with Greece being the first victim – partly due to the fact that the outgoing conservative Greek government had produced fake statistics for deficit-GDP ratios in 2009 and in earlier years, therefore the confidence crisis shaking the government bonds markets brought Greece to the brink of bankruptcy. I would like to add that in my book Transatlantic Banking Crisis published in early 2009 – the German manuscript was finished in 2008 – the section of conclusions clearly mentioned the likely scenario of a Greek debt crisis and the Euro crisis, respectively. Mailing the file and later also the book to the German Chancellor's chief economist obviously did not ring a bell in the economic advisor team and so the German government stumbled in the Greek and Euro crisis in early 2010 without any preparations and this has certainly raised costs for the German and European taxpayer, respectively.

The Transatlantic Banking Crisis is shocking to the extent that the enormous advances in economic modeling since the 1960s lets one expect that the Economics profession – at least a broader subgroup – should have been able to send out analytical warning signals in the late 1990s or a bit later since there were so many strange developments in the US and partly also in the EU financial markets. Moreover, the Transatlantic Banking Crisis was not the only big surprise for economists and international organizations, respectively. It is indeed noteworthy that the IMF has delivered considerable analytical insights during the Transatlantic Banking Crisis, but it also is remarkable that the October 2008 forecast (in the World Economic Outlook) did not anticipate the economic recession of the Euro zone in 2009 when output strongly fell in real terms. This poor forecasting from the IMF might not be considered as a problem since so many other forecasters came up with modest results in their forecasting exercises. However, the IMF stood for its own policy blunder in the early 1990s when its poor advice to Russia, namely to adopt fixed exchange rates, indirectly contributed to the Russian crisis which partly emerged as an echo effect to the Asian crisis. As a personal note I may mention that I had been invited to a high level IMF workshop on Russia in 1998 and Mr. Stanley Fischer kindly welcomed the group of about 30 economists as the leading experts on Russia. In my own introductory statement I expressed my gratitude for the invitation but I pointed out that at the table no leading experts on Russia were present since nobody from BOFIT had been invited – the Finnish Central Bank's research institute renowned for timely and excellent analysis on Russia (including a paper on Non-Sustainability of Russian public finances which had been written in late 1997). One may take these events, pitfalls and problems to raise a few key questions on the role of modern Economics at the turn of the century. What went wrong? What is the problem with modern Economics? These questions are very difficult to answer, but rather than ignoring the analytical challenge, the following reflections try to give some answers on the basis of certain key questions and facts.

One of the facts that has to be critically considered with respect to the Transatlantic Banking Crisis is related to the finding that European economists seem to be catching up with the so-far leading US academic community, which is, however still dominant in the leading Economics journals (CARDOSO/GUIMARAES/ZIMMERMANN, 2010). This suggests that in a transatlantic perspective there is increasing competition but there is also – according to CORDOSE/GUIAMARAES/ZIMMERMANN - increasing cooperation in writing scholarly articles in Europe... European and certainly also Asian economists are trying to meet the US standards in Economics and there has been some success in this respect. The troubling question however is, whether or not Europeans and other researchers aspire to meet the right benchmark? And are we focusing on relevant issues, do we have a realistic perception of the US economy and the EU, respectively? If a community of economists and the paradigms represented by their large majority are so outstanding why did so few researchers anticipate the historical shocks of the US banking crisis and the Transatlantic Banking Crisis? It is clear that there is intensive discussion among US economists as well as among European economists, but given the emphasis on the robustness of paradigms which has been emphasized by Thomas Kuhn in his book ***The Logic of Scientific Revolutions***, it is not obvious whether a new convincing paradigm will emerge from the US – but one may hope that the discussion will develop momentum in North America and elsewhere. There is a need for a new paradigm which one may dubb Double Sustainability: There is a need for environmental sustainability on the one hand, on the other hand investment and innovation should be sustainable – the accumulation dynamics should lead to a long run equilibrium (read: steady state) and ideally indeed to a situation with an optimum economic welfare, namely a maximum per capita consumption. Or is anybody really interested in roughly quadrupling asset prices and equity prices within 12 years – the case of Ireland 1995-2007 – and then losing this increase in wealth and suffering a sharp recession, a massive drop of consumption per capita? Something is wrong with the modern market economy and the market dynamics which generate doubtful risk premia and enormous price bubbles which under restrictive assumptions are dubbed rational.

Developments in Economics

Modern Economics has certainly been characterized by several different elements of progress as perceived by the community of Economists:

Economics has become more tuned towards Mathematical Economics: This suggests that there is scope for better modeling, improved analytical tools and better forecasting. To some extent this is indeed what we have seen in some fields, including Business Cycle Analysis and including Auction Rules for frequency auctions in mobile telephony and for new regulatory approaches in telecommunications. In Business Cycle Analysis DSGE models have played a prominent role and they have been useful to some extent – more in explaining certain dynamics, less in short-term forecasting. An approach that might bring some fresh ideas to analysis is agent-based modeling, which is, however, even more complex than DSGE models. This Schumpeterian approach to economic dynamics might, however, contribute with some very useful insights since this approach allows to combine principles of economic analysis, learning theory and some principles of bounded rationality that seem to be acceptable to a broader group of economists.

Economics has become more specialized as is visible e.g. in the splitting up of the American Economic Review into several specialized reviews. This raises the question: which group of economists – if at all – should work as system integrators, that is pull together key insights from a specialized group of economists. Specialized chairs in Economic Policy seem to be the natural way for such an analytical integration that is highly relevant for economic policymakers.

With the increasing role of international organizations after 1995, – such as the IMF, the Bank of International Settlements, the World Trade Organization and the World Bank or in a European context the European Commission and the European Bank for Reconstruction and Development – the role of economists in such organizations has also become more important. While few of them show up at national or regional meetings, there is no doubt that they are quite influential. Did international organizations stand up to the challenges? Often yes, but there were very notable exceptions such as the IMF in the Asian Crisis and in the Russian Crisis of 1998.

There is a key problem with the increasing role of mathematical modeling and the rising role of economists in key international organizations. The traditional link in part of the Economics community with legal experts and faculties of law has become much weaker. It is quite obvious that this is a problem for economic policymaking in the sense that institutions and rules shape incentives for firms and banks, for regulators and other bureaucrats, for investors and innovators. While modern economists have picked up some key issues in the joint realm of Economics and Law, it is fair to say that this area is of declining importance in Economics. The increasing emphasis on mathematical modeling makes cooperation between economists and legal experts often quite cumbersome. The fact that the Transatlantic Banking Crisis has partly been caused by very obviously doubtful financial innovations – which were easy to recognize (such as the multi-stage opaque repackaging of loans through Collateralized Debt Obligations or opaque over the counter-trading of Credit Default Swaps) – is a good example to recognize the limited ability of mathematical modeling to contribute to understanding straightforward pitfalls in the banking sector and the financial community. It is plausible to assume that a better cooperation of economists and legal experts could have identified some of the key problems of CDOs and CDS early on. One may point out that indeed it was the US DEPARTMENT OF DEFENCE (2006) whose report on the over-indebtedness of army officers alarmed at least part of the US political establishment. At the same time the US practice of state prosecutors to not take most of the doubtful banks to court but rather to hammer out an out-of-court settlement has weakened the economic system in the US and the credibility of institutions and rules.

Economists face a serious analytical problem which has been unsolved for decades, namely to reconcile short-term Keynesian analysis with long-run growth modeling. Worse, while open economy macroeconomics has looked into short- and medium-term models, there has hardly been a serious body of research on open economy growth analysis in an explicit two-country model with trade and foreign direct investment. This is strange since this is exactly the real world in which economic actors have been active since the 1970s. While there has been progress in the understanding of economic globalization, it is unclear to what extent the Economic profession has a broader understanding of long-run economic dynamics.

An important approach to long run economic analysis is neoclassical growth theory. In the growth theory of the 1960s the neoclassical Solow growth model was developed, from which several economists derived the golden rule (Phelps and von Weizsäcker), which indicates the condition under which the steady state – characterized by a constant long-run capital intensity – goes along with a maximum per capita consumption C/L (C is consumption, L is population). The neoclassical full-employment growth model was subsequently modified as the role of human capital was analyzed (e.g. LUCAS, 1988). Growth modeling has remained largely an analysis which puts the focus on the real economy, and only few economists have looked into monetary growth modeling (e.g. TOBIN, 1965). Another refinement was to consider open economies and the role of foreign direct investment have also been analyzed (e.g. WELFENS, 2008).

Certainly modeling became more complex in endogenous growth models that explained technological progress – e.g. through the share of the workforce employed in the R&D sector. The golden rule aspects were dropped in the growth modeling after the 1960s and 1970s although it is not just a fable for economists but stands for a very important aspect when we take a broader welfare perspective into account. Such a broader perspective is adopted subsequently, including environmental aspects and global warming, respectively.

2. From the Traditional Model Towards a New Approach

Let us briefly recall the basic neoclassical growth model before we consider several crucial modifications, which in the end bring new insights with respect to monetary and fiscal policy as well as innovation policy. In a nutshell, the neoclassical growth model (SOLOW, 1956) consists – with Y, K, L, A denoting output, capital, labor and labor-augmenting knowledge - of a neoclassical production function Y(K,L,A), a simple savings function S=sY and an equilibrium condition for the goods markets, namely sY = dK/dt +δK (δ is the capital depreciation rate). As the subsequent new theoretical and political considerations will refer to a setup with the Cobb-Douglas production function $Y=K^{ß}(AL)^{1-ß}$, the neoclassical standard model can be characterized for the case of such a production function as follows:

In a setup with an exogenous population growth rate n and labor-augmenting progress rate a and a given capital depreciation rate δ, the standard assumption of a savings function S=sY (with Y standing for output; s denoting a positive parameter in the range between 0 and 1) the steady state solution k'#:= K/(AL) – with AL denoting labor in efficiency units (A is knowledge, L is labor, K is the capital stock) – can be written for the case of the above Cobb-Douglas production function as follows: $k'\# = [s/(a+n+\delta)]^{1/(1-ß)}$; hence the level of the growth path in the steady state (denoted by #) is given by y'#:= Y/(AL)

$=[s/(a+n+\delta)]^{ß/(1-ß)}$; the growth rate of per capita income y:=Y/L in the steady state is equal to the progress rate a. The long-run growth rate of output is a+n, the growth rate of per capita income in the steady state is equal to a. The golden rule requires the marginal product of capital, namely $ßk'^{ß-1} = a + n + \delta$; this implies that the net marginal product of capital is $ßk'^{ß-1} - \delta = a+n$: the net marginal product of capital is equal to the growth rate of output. We will return to this case of technological progress subsequently.

In the case that the exogenous growth rate of the population is n, while A=1 and there is no technological progress, the differential equation for capital accumulation is $dk/dt = sk^{ß} - (\delta+n)k$, where k:=K/L and dk/dt= (dK/dt)/L – nk has been used. Thus the equilibrium capital intensity in the steady state (with dk/dt=0) is given by $k\# = [s/(n+\delta)]^{1/(1-ß)}$ and per capita output is $y\#=k\#^{ß}$. In this setup, the golden rule requires that the marginal product of capital is equal to (δ+n), that is $ßk^{ß-1}= (n+\delta)$ and this in turn implies $k= [ß/(n+\delta)]^{1/1-ß}$; considering k# the implication is that government should manipulate the savings rate in such a way that s=ß... This might be interpreted as the case of a classical economy in the sense that the share of capital income – assuming competition in goods markets and factor markets – is ß and if all profits are saved and workers do not save, we have ß=s.

Politico-economic Aspects of the Golden Rule

One politico-economic extension is appropriate here which already points to a problem: If workers have savings rate s” and capitalists have savings rate s’ we still can get an equivalent result of S = s’ßY + s”(1-ß)Y = [s” + ß(s’-s”)]Y; one may assume s’>s”. Hence the golden rule now requires ß= s” + ß(s’-s”), which implies the condition: ß(1+s”-s’) = s” and after taking logs this gives the condition (as an approximation where we use the rule ln(1+x)≈x) lnß ≈ lns” + (s’-s”). Thus governments would have to manipulate the savings rate of the workers or the capitalists accordingly. If it is assumed that k# is below $k\#^{gold}$ initially, governments would have to raise the overall savings rate, which is s” + ß(s’-s”). A conservative government might have a preference for raising s’ if it is assumed that owners of capital have conservative voting preferences. A left government, however, is rather likely to raise s” since this would imply that workers – largely voting for the left government – will own a larger share of the capital stock than if s’ is raised. Such a perspective implicitly assumes that owning capital generates specific utility, not just consumption as is assumed in the standard literature. If k# is above $k\#^{gold}$ the government would have to discourage savings. In an international context this would also affect the current account, namely to the extent that the current account-GDP ratio reflects the difference between the average savings ratio and the domestic investment ratio. Discouraging savings implies that the current account will worsen. If, however, the country considered has already reached a critically high foreign debt-GDP level, there will be international pressure to raise the savings rate and this in turn implies a loss of economic welfare in a setup in which only consumption per capita is considered as relevant in the utility function.

Profit maximization which is often considered to be a natural element of neoclassical analysis raises awkward questions: In the setup with technological progress the golden rule in combination with profit maximization, namely $ßk'^{ß-1} - \delta = r = a+n$. The capital intensity in the steady state is then $k'\#=[ß/(a+n+\delta)]^{1/1-ß}$. By implication, it may be argued that profit maximization is consistent with the golden rule.

In terms of economic welfare considering profit maximization makes sense if it is assumed that households interested in maximizing per capita consumption are not identical to the group of households owning the capital stock. In a small open economy it might be assumed that profit maximization is imposed through the pressure of free capital flows and profit maximization abroad – in a dominant foreign economy.

If the money market equilibrium (M is the nominal stock of money, P the price level of newly produced goods, r is the real interest rate and ε is a positive parameter) is also to be considered, it can be defined by the equation:

$$(M/P)/(AL) = (Y/AL)/(\varepsilon r)$$

The real interest rate thus implies an endogenous monetary policy since we have zero expected inflation in this setup– and denoting (M/P)/(AL) as m' – it will hold:

$$m'\#= [ß/(a+n+\delta)]^{ß/(1-ß)}/[(a+n)\varepsilon].$$

Here we have taken into account that r= a+n. The equation presented stands implicitly for the optimum money supply, however, in the setup presented here money has no direct role for production.

For the special case of ß=0.5 and δ=0, the result in the steady state (starting with t=t') is:

$$[M/P](t') = \{0.5/[\varepsilon(a+n)^2]\}A_oL_oe'^{(a+n)t}$$

The level of the optimum money supply is a negative function of the growth rate and the interest elasticity, but it also is a positive function of ß (here ß was set equal to 0.5). An increase of the growth requires reducing the real money supply.

A somewhat different setup makes more sense in economic terms, namely if an economy is considered in which the holding of money by households generates positive external effects on output so that money enters the production function, which now reads:

$$y' = m'^{ß'}k^{ß}$$

The marginal product of capital is now influenced through the stock of money; the MPC is given by:

$$\partial y'/\partial k' = ßm'^{ß'}k^{ß-1}$$

The marginal product of capital is raised through the stock of real money balances relative to labor in efficiency units (AL). The golden rule in the case of an economy with technological progress and population growth thus becomes:

$$ß\, m'^{ß'}k^{ß-1} = (a+n+\delta);$$

Hence we have:

$$k^{gold} = [ßm'^{ß'}/(a+n+\delta)]^{1/1-ß}$$

The golden capital intensity is higher than in a non-monetary economy if $m'^{ß'}$ exceeds unity; this also implies that per capita consumption in the golden state in a monetary economy exceeds that of a non-monetary economy if $m'^{ß'}$ exceeds unity. While in OECD countries, (M/P)/(AL) may be assumed to exceed unity, it is unclear how big ß' really is. The implication of the golden rule here is that s=ß. This follows from the steady state condition $dk'/dt = 0 = sm'^{ß'} k'^{ß} - (a+n+\delta)k'$ and thus $k\# = [sm'^{ß'}/(a+n+\delta)]^{1/(1-ß)}$; note that it has been assumed that m' is a policy variable which the central bank can control so that m' may be assumed to be constant.

As $C/(AL) = (1-s)k'\#^{ß}$ per capita consumption in a monetary economy could be higher – compared to a nonmonetary economy – for two reasons in the golden state: The savings could be higher, and the capital intensity exceeds that of a non-monetary economy (with respect to the role of the capital intensity, the alternative Tobin-approach may also be considered for the case of a monetary economy).

The goal of government and the central bank in the long run could be to implement the golden rule – with zero inflation. The zero inflation condition or the condition that nominal interest i (the opportunity costs of holding money balances) equals to the real interest rate r is not automatically an obvious choice, but in a broader context it may be argued that zero inflation implies an optimum working of markets so that transaction costs in financial markets and goods markets are minimized. This could be covered by considering a savings function $S=s(1-\theta\pi)Y(1-\tau)$ where θ is a positive parameter and π is the inflation rate and τ is the income tax rate. The political system thus wants to maximize C/L under the side constraint that π is zero, where the central bank is responsible for zero inflation and the government has to choose the tax rate τ that brings about the golden rule.

3. Endogenous Population Growth

Let us consider poor countries in which the population growth rate n is a positive function of C/L; for the sake of simplicity the level of knowledge is assumed to be given. Hence the relevant differential equation for k in a society with zero technological progress is given by:

(1) $dk/dt = sk^{ß} - [n(C/L) + \delta]k$

In low-income countries the growth rate of the population may be assumed to be a positive function of C/L, beyond a critical level of C/L – and a certain level of education – one may assume that the growth rate of the population is a negative function of C/L.

In advanced societies with high per capita income we may assume that n is a negative function of C/L; defining a positive parameter n" the follow may be specified:

(2) $n = n' - n''/[C/L]$

and as we assume C/L=cy, we can write $n = n' - n''/(ck^{ß})$ and inserting this in the above equation gives:

(3) $dk/dt = sk^{ß} - [n' + \delta]k + [n''/c]k^{1-ß}$

We can easily solve the equation for the special case of ß= 0.5 for which we get (using c:= 1-s):

(4) $k\# = \{[s + n''/(1-s)]/[n'+\delta]\}^2$

(5) $y\# = \{[s + n''/(1-s)]/[n'+\delta]\}$

The insight from this equation is: In a society with an endogenously shrinking population growth – linked to per capita consumption – it is all the more important to achieve a high savings rate as can be seen from the nominator expression in the above equation; if we set n" to zero, the steady state would be characterized by a stationary population.

4. Economic Welfare, Golden Rule and C02 Emissions in the Context of a Modified Growth Model

Economic welfare has traditionally been measured through the Systems of National Accounts and gross national income (GNI); GNI is defined as gross domestic product plus net factor income from abroad and per capita income is a standard measure of international economic comparisons. One key problem with GNI per capita is that international comparisons will have to rely on corrected data in the sense that international differences in nontradables prices – such prices are relatively low in poor countries compared to rich countries – have to be taken into account: This standard correction brings GNI per capita at purchasing power parity.

A traditional critique of GNI as a welfare measure points out that depreciations on capital have to be considered if one is interested in a long-term perspective – capital depreciations or equivalently reinvestment is necessary to maintain the existing stock of capital and the capital intensity (K/L), respectively (K is capital, L is labor); if population L is growing at rate n, the necessary per capita investment to maintain capital intensity is $nk + \delta k$, where δ is the rate of capital depreciation. The standard economic approach here is the neoclassical growth model. Hence in a traditional model approach net national income is a useful concept to measure economic welfare.

However, microeconomic approaches always emphasize that economic agents maximize utility and utility is a function of (per capita) consumption – and possibly also of leisure. The neoclassical growth model emphasizes the role of maximum per capita consumption in the context of the so-called golden rule, which is defined by capital intensity that maximizes long-run per capita consumption. As regards depreciations, a more refined approach – e.g. partly adopted by the WORLD BANK – has not only to take into account physical capital depreciations but should also consider depreciations of non-renewable natural resources and human capital as well as the role of negative external effects: The World Bank has coined this broad approach in a genuine savings rate. This concept in turn has been used as one of the pillars for the EIIW-vita Global Sustainability Indicator (GSI), which takes a closer look at two other pillars, namely revealed comparative advantage in environmental-friendly products –the relative export position of a country in the field of green products in world markets – and the share of renewable energy in total energy (WELFENS/PERRET/ERDEM, 2010).

Modeling of economic growth has at first ignored the problem of the use of energy and the associated emissions that stand for negative external effects – e.g. in the context of global warming. There are, however, several authors who have considered the role of energy in growth and growth simulations (e.g. GRIES, 2011)**...** Assuming that CO_2 emissions are proportionate to real gross domestic product, the golden rule of traditional growth theory can be modified in an important way.

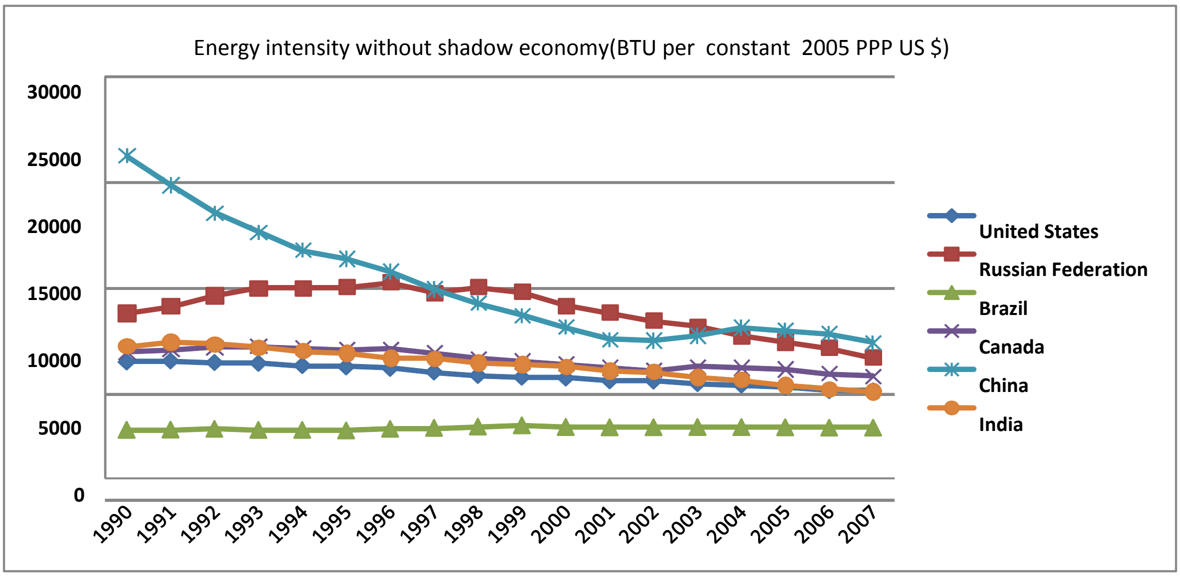
The Traditional Growth Model

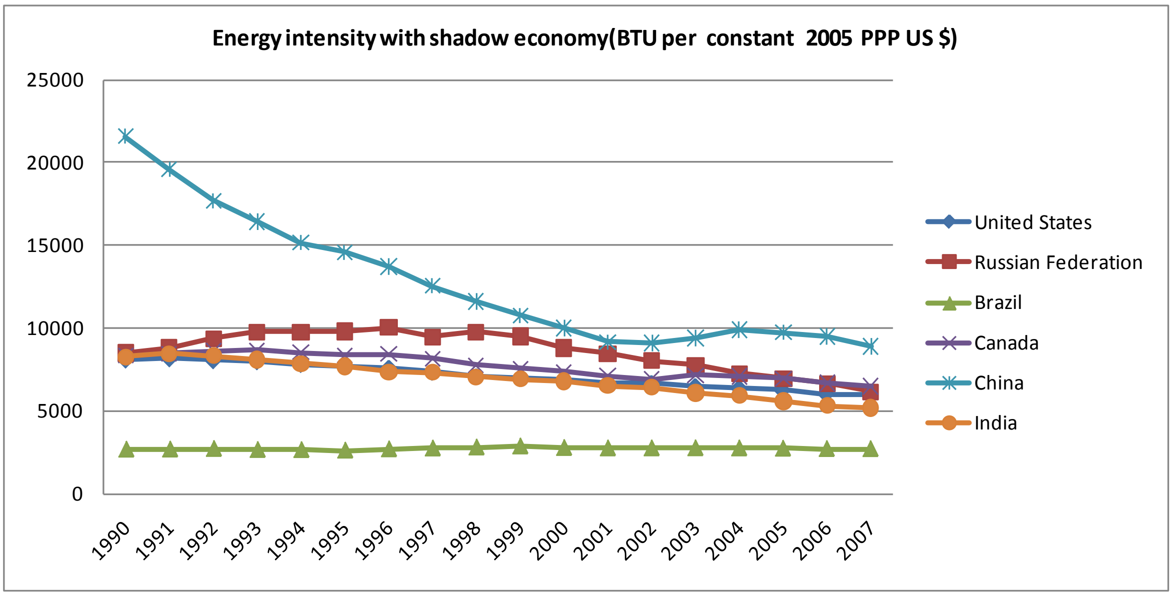
Assume that the aggregate savings function is S=sY (with 0<s<1; Y is GDP) and that the production function is a well-behaved neoclassical function with positive marginal products of the respective input factors – the second derivative is negative; a standard function with these properties is the Cobb-Douglas production function $Y= K^{ß}(AL)^{1-ß}$, where A is labor-augmenting knowledge; hence $Y/(AL)= k'^{ß}$ where k':= K/(AL). It will be assumed that the population growth at rate n and that the growth rate of knowledge is given by dlnA/dt=a (t is the time index). Moreover, we impose the condition that goods market equilibrium holds, namely S= I= dK/dt +δK (t is the time index); dK/dt + δK is gross investment where δK stands for reinvestment. If capital per unit of labor is defined in efficiency units, namely K/(AL):=k', the accumulation dynamics of k' can be expressed by the differential equation $dk'/dt = sk'^{ß} – (a + n + δ)k'$. This leads to the steady state solution for $k'\#=[s/(a+n+δ)]^{1/(1-ß)}$; # denotes the steady state and the long-run equilibrium, respectively. Hence $y'\# :=Y/(AL)= [s/(a+n+δ)]^{ß/(1-ß)}$ and per capita income – with e' denoting the Euler number and recalling that $A(t)=A_0e'^{at}$ - in the steady state is $y\#= \{A_0[s/(a+n+δ)]^{ß/(1-ß)}\}e'^{at}$ so that the growth rate is given by the progress rate a, while the level of the growth path is determined by the expression $A_0[s/(a+ n+δ)]^{ß/(1-ß)}$. To the extent that production is associated with CO_2 emissions, there are specific challenges since such emissions contribute to global warming and climate problems. The standard golden rule according to which the marginal product of capital is equal to (a + n + δ) is not valid any more, rather a modified condition will have to be derived.

New Data on CO_2-GDP Ratios

In the following table the effective CO_2-GDP ratios are indicated where for the first time the impact of the shadow economy is considered. The figures for the shadow economy are taken from the research group of FRIEDRICH SCHNEIDER (2010) and it is obvious that ignoring the shadow economy, which is not recorded in the System of National Accounts, means ignoring a considerable part of the effective value-added in most countries.

Figure 1: Energy Intensity of selected countries with/without shadow





Hybrid Economic Welfare Maximization

A pragmatic way to consider the maximization task in the context of a golden rule approach is to assign Y and Y/L, respectively, a negative imputed utility linked to emissions – the relevant positive parameter is Ω. Thus – in a setup with a given level of technology - we still want to maximize C/L but the constraint and the relevant equation, respectively, look somewhat different than in the standard model:

(6) $C/L = y(1-\Omega) - (\delta+n)k$

Maximization of C/L requires a necessary condition:

(7) $d(C/L)/dk = (1-\Omega)ßk^{ß-1} - (\delta+n) = 0$

(8) $(1-\Omega)ß\, k^{ß-1} = (\delta+n)$

(9) $k^{gold} = [(1-\Omega)ß /(\delta+n)]^{1/1-ß}$

The golden capital intensity that maximizes per capita consumption in an economy with CO_2-emissions causing negative external effects is, therefore, lower than in an economy without CO_2 emissions.

As $k\# = [s/(\delta+n)]^{1/1-ß}$, we have the implication that we should have:

(10) $s = (1-\Omega)ß$

Thus the savings rate should be lower than in a CO_2-free world. Moreover, if there is technological progress that allows the reduction of specific CO_2 emissions – hence Ω falls – the optimal savings rate (leading to the golden capital intensity) will increase. From this perspective it is obvious that it is useful to also consider a world with technological progress.

Next let us consider an economy with an exogenous "embodied" progress rate a, but we want to take the vintage effects into account, which are associated with capita-embodied technological progress; as STOLERU (1978) has shown, the case of the Cobb-Douglas production function with embodied technological progress means that the depreciation rate is a positive function of the progress rate a (one may dub this the Stoleru effect). Thus the steady state equilibrium for k':= K/(AL) is given by:

(11) $k'\# = [s(1-\Omega)/(a + n + \delta(a))]1/1-ß$

(12) $y'\# = [s(1-\Omega)/(a + n + \delta(a))]ß/1-ß$

A rise in the progress rate will cause a larger fall in the level of the growth path than without considering the vintage effect. Moreover, if Ω is assumed to be a negative function of progress rate a, we have the following steady-state condition for y':

(13) $y'\# = [s(1-\Omega(a))/(a + n + \delta(a))]^{ß/1-ß}$

Now the progress rate has an ambiguous role in the level of the growth path:

A rise in the progress rate reduces Ω and therefore the nominator will increase

At the same time a rise in the progress rate raises the size of the denominator.

We can state for the impact of a change in the progress rate on y'#:

(14) $dy'/da = [ß/(1-ß)][-s\Omega_a)/(a + n + \delta(a))] + s(1-\Omega(a))/(a + n + \delta(a))^2(1+\delta_a);$

If technological progress has a strong green bias in the sense that Ω_a

is strongly falling, the sign of dy'/da could be positive.

The golden rule condition in this setup with the Stoleru effect reads:

(15) $ß = (a + n + \delta(a))$

Thus the modified golden steady state capital intensity requires:

(16) ß = s(1-Ω(a))

If government imposes an income tax rate the condition of the golden rule is modified, namely ß= s(1-τ) provided that the $C0_2$ emissions are ignored. The following figure shows that the steady state realized is not necessarily in line with the golden rule which requires that the marginal product of capital is equal to the depreciation rate of capital (assuming that the population growth rate n=0 and that the rate of progress a is zero); the tax rate has to be τ_1 if the golden rule is to be realized. If one takes into account the $C0_2$ emissions the condition for the golden rule has to be modified accordingly.

Figure 2: Growth Model: Golden Rule

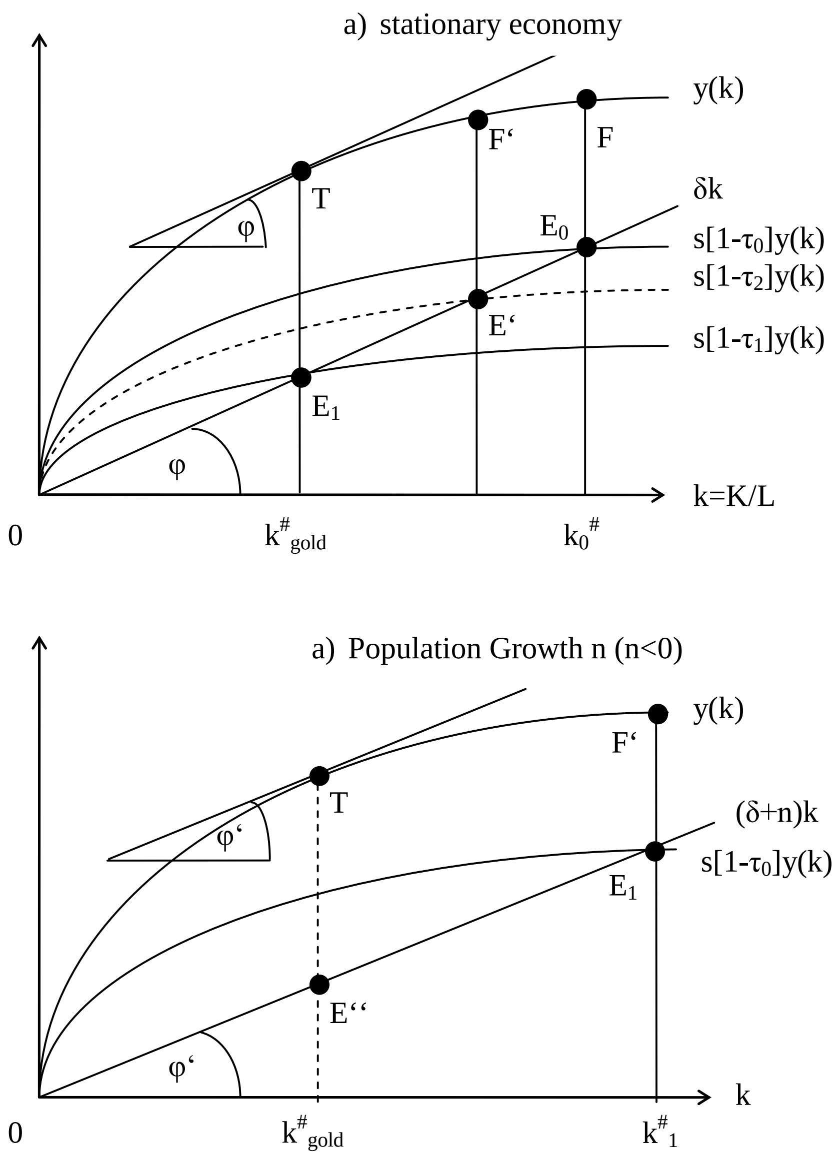
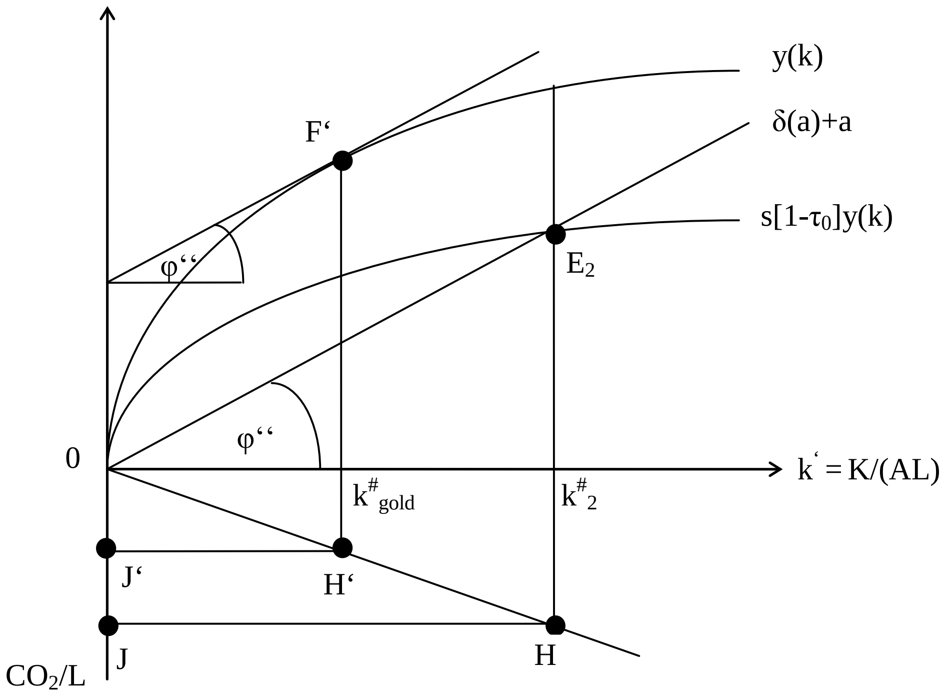


Figure 3: Golden Rule in a Growth Model with Technological Progress and the Stoleru Effect



5. Open Economy and Economic Growth

In an open economy economic growth models have to be modified in an adequate way. Basically, five key aspects have to be considered:

The production function: If knowledge from abroad (country II) and the foreign progress rate affects the progress rate in country I (a country with an income and technology gap vis-à-vis country II) the production function needs to be specified adequately. One possible way to express the fact that the exports x – while assuming that X=xY* - contribute to GDP in the home country (country I) through specialization is to specify $Y=K^{ß}(xY^*)^{\eta}(AL)^{1-ß}$; by implication that the growth rate of GDP, namely g_Y, is determined according to $g_Y= ßg_K +(1-ß)(a+n) + \eta g_{Y^*}$ (* denotes foreign variables, η is a positive parameter in the interval [0,1], g denotes growth rates; note that it has been assumed that x is constant). Hence trade brings an international growth bonus which is expressed here by ηg_{Y^*}. If there is international symmetry, the foreign production function – with j denoting the foreign export ratio and assuming that exports X*=jY - can be written as $Y^* = K^{*ß^*}(jY)^{\eta^*}(A^*L^*)^{1-ß^*}$ and therefore we can restate the production function for country I as $Y= K^{ß}[x\, K^{*ß^*}(jY)^{\eta^*}(A^*L^*)^{1-ß^*}]^{\eta}(AL)^{1-ß}$ and – defining ß'=ß/(1-η*η), ß'*=ß*/(1-η*η), η'=η/(1- η*η), η'*=η/(1-η*η) - therefore $Y= K^{ß'}x^{\eta'}j^{\eta'^*}K^{*ß'^*}(A^*L^*)^{(1-ß^*)/(1-\eta^*\eta)}(AL)^{(1-ß)/(1-\eta^*\eta)}$. Thus foreign capital accumulation and foreign knowledge and labor input effectively contribute to domestic output – read: output in country I.

The impact of the foreign progress rate (a* in country II) on the progress rate of the poor country (country I) also needs to be considered. There will be some international technology spillover – partly related to trade and also to foreign direct investment inflows and outflows.

If there is foreign direct investment (FDI), the impact of inward and outward FDI needs to be considered. From an analytical perspective, it also needs to be taken into account that cumulated FDI inflows imply that part of the domestic capital stock– say in country I which has attracted FDI inflows – is owned by foreign investors; hence the difference between gross domestic product and national income needs to be considered. If only international dividend payments are considered and it is assumed that production factors – in the traditional production function $Y=K^{ß}(AL)^{1-ß}$ in country I and $Y^* = K^{*ß^*}(A^*L^*)^{1-ß^*}$ in country II – are rewarded in accordance with the marginal product rule, we can state (with α* denoting the share of capital K owned by foreign investors) that national income in country I (Z) is equal to Z=Y(1-α*ß), since ßY is the share of GDP accruing to the owners of capital. In this simple case we have assumed asymmetric foreign direct investment, namely investors from country II invest in country I, but there are no FDI flows from country I to country II; in this setup, the foreign national income Z*= Y* + αßY/q*, where q*:=eP*/P (e is the nominal exchange rate, P is the price level, * stands for foreign variable). The case of two-way FDI flows can, of course, also be considered, where α denotes the share of K* owned by investors from country I. As long as no specialization gains from trade are considered in the production function, the respective function in country II is given by the expression $Y^*=K^{*ß}(AL)^{1-ß}$.

One may want to consider maximization of global economic welfare, namely in the simple sense that consumption per capita should be maximized in both countries: That is the conditions for the golden rule can be identified in both countries.

Transition and adjustment dynamics could also be considered, including those that occur if the steady state capital intensity differs from the capital intensity in line with the golden rule (k'^{gold}): We have to focus on three different cases: (i) $k'\#>k^{gold}$ and $k\#^*>k^{*gold}$ so that both countries will want to reduce the savings rate; this implies a deterioration of the current account balance for the country that proceeds quickly and strongly with a policy that reduces the savings rate – and most likely there will be international conflicts over adjustment policies. (ii) $k'\#>k'^{gold}$ and $k\#^*<k^{*gold}$... Country I will want to reduce its savings rate – this implies a transitory deterioration of the current account position - and country II will want to raise its savings rate – this implies a transitory improvement of the current account position, which in principle is compatible with the desired adjustment dynamics of country I. (iii) $k'\#<k'^{gold}$ and $k\#^*<k^{*gold}$: Both countries will want to raise the savings rate, but this could again imply conflicts over inconsistent desired current account dynamics in both countries.

Let us first consider the simple case of no effect of trade on the production function, while there is asymmetric foreign direct investment in the sense that country I faces cumulated FDI inflows – but there are no FDI outflows from country I towards country II; the share of the capital stock owned by foreigners is α, which is in the range (0,1). It is adequate, of course, to consider that savings is proportionate to gross national product so that S= sZ and hence the savings function in country I (with technological progress rate (a) and a constant growth rate of the population (n)) reads:

(17) $S= s(1-\alpha^*ß)Y$

Hence the steady state solution for y' is given by:

(18) $y' = [s(1-\alpha^*ß)/(a+n+\delta)]^{ß/(1-ß)}$

An interesting question concerns the issue to what extent progress rate a is a positive function of α: If a(α*), an increase in α* will go along with a fall in the level of the growth path and a rise in progress rate a; a stronger presence of foreign subsidiaries thus raises the progress rate, which is plausible to the extent that multinational companies are characterized by ownership specific advantages, namely technology advantages. Whether or not the government is eager to promote FDI inflows depends on the political time horizon and discount rate applied in the political process. This is due to the fact that y' will fall in the short run but will be higher in the presence of FDI in the long run.

If there are two-way FDI flows, for Z (with q* denoting the real exchange rate and α being the share of foreign) we have to write:

(19) $Z = Y(1- \alpha^*ß) + q^*\alpha ß^* Y^*$; (and $Z^* = Y^*(1- \alpha ß^*) + \alpha^* ß Y/q^*$)

Here αß*Y* stands for country I's profits accrued from abroad and multiplying the term with the real exchange rate q* translates such profits into domestic goods units of country I. In such a setup it is not easy to state the equation that governs the accumulation of k'... Let us consider the current account equilibrium which states that the sum of exports plus profits accruing from abroad must be equal to imports plus profits of foreign subsidiaries accruing to parent companies abroad (we denote the export-GDP share by x and the import-GDP share by j):

(20) $xY^* + q^*\alpha ß^* Y^* = q^* jY + \alpha^* ß Y$

(21) $[x+ q^*\alpha ß^*]Y^* = [q^* j + \alpha^* ß]Y$

Hence we have:

(22) $Y^* = \{[q^* j + \alpha^* ß]/[x+ q^*\alpha ß^*]\}Y$

Thus national income in country II can be expressed as follows:

(23) $Z= Y(1- \alpha^* ß) + q^*\alpha ß^*\{[q^* j + \alpha^* ß]/[x+ q^*\alpha ß^*]\}Y$

Hence a setup with savings S=sZ can be written as:

(24) $S= s\{(1- \alpha^* ß) + q^*\alpha ß^*\{[q^* j + \alpha^* ß]/[x+ q^* \alpha ß^*]\}\}Y$

Thus the steady state for k' becomes:

(25) $k'\# =\{s\{(1-\alpha^* ß[1-[x+ q^*\alpha ß^*]^{-1}] +q^*\alpha ß^* q^* j/[x+q^*\alpha ß^*]\}/(a+n+\delta)\}^{1/(1-ß)}$

In principle the right-hand side term can be larger or smaller than in a closed economy with the solution $k'\#= [s/(a+n+\delta)]^{1/(1-ß)}$... Thus, the empirical aspects will have to be looked at carefully. The situation looks even more complicated if we include trade-related effects in a monetary economy.

If the savings function is S/L=s(1-τ)Y/L – with τ denoting the income tax rate – the government has a simple tool, namely the tax rate, to manipulate the effective savings rate s(1-τ). In the case of a constant population size – with a savings rate s(1-τ_0) – we initially have equilibrium point E_0, while the distance E_0F stands for per capita consumption C/L in the steady state. The golden rule requires that the slope of the production function – the marginal product of capital – be equal to the capital depreciation rate: Hence point T on the production function is relevant and point E_1 is the desired optimal intersection point of the curve δk and the savings function. In this case it would be adequate to raise the income tax rate and the maximum per capita consumption – equivalent to the distance TE1 – obtained. A fall in the effective savings rate and hence a rise in the income tax rate was adequate here since the initial steady state capital intensity exceeds that of the golden rule capital intensity ($k\#^{gold}$). In an open economy, country I could have FDI outflows equivalent to the distance $k\#_0$ – $k\#g^{gold}$ without any welfare loss; on the contrary, there would be an increase in national income and hence national economic welfare. It is, however, an issue whether country II will benefit from such outflows; if country II's capital intensity is below the golden rule capital intensity, FDI inflows will be welcome. The basic problem setting is not changing much if we consider (as in the next diagram) a situation with positive or negative population growth – for many OECD countries declining population growth rates might be characteristic in the future.

In the case of a model with technological progress and the Stoleru Effects, an interesting situation is shown in the subsequent diagram, which refers to an economy with CO_2 emissions. The steady state capital intensity exceeds the golden rule capital intensity. If the government can reduce the effective savings rate, the economy will move to the golden rule situation; at the same time there will also be an increase in welfare from the reduction of CO_2 per capita emissions.

Reconciling the Short-term Keynesian Model and the Long-Run Growth Model

In qualitative terms, one can move from the core result of the Keynesian model to the neoclassical growth model through a sign-switching function sΨ(t), where Ψ(t) has the characteristic to switch from s in t_0 to 1/s for t approaching infinity. From mathematical signaling theory we can plug in an appropriate sign-switching function. There is, however, a theoretical challenge, namely to explain exactly why such a sign-changing function is generated through the economic system, namely in the sense that dY/ds>0 in the short run, while dY#/ds>0 in the very long run. Logically the existence of such a sign-switching function may be postulated; moreover, the multipliers for various policy instruments, including monetary policy and fiscal policy might also change over time and we might indeed find a good new way of understanding the short-run, medium-term and long-run economic dynamics on the basis of such a sign-changing function. The proposed way is useful for achieving a more consistent macroeconomic modeling approach. Moreover, one has a new starting point for considering both short-term stabilization gains from economic policy and long-term effects on the level of the growth path (and the trend growth rate if a model with progress is considered). There is more research to be conducted, but we have indeed found a new avenue for analytical progress.

In an analytical perspective the short- and medium-run approach of New Keynesian Macroeconomics could be a starting point for the short-run/long-run link, namely in the following way: A typical element is a technology shock which implies – in an initial situation with constant relative prices – that the mark-up will increase and the unemployment rate will rise; in the long-run, relative prices are flexible, including the relative price of nontradables whose development is not only important for the sectors (nontradables, tradables) but also for current account equilibrium and full employment. However, it is not clear to what extent this changes the role of the savings rate in a qualitative way. One option to link the short run and the long run in a consistent way is to define an operator FLEX, which is the frequency of price adjustments per period, where we assume that the price adjustment frequency is increasing when approaching the market equilibrium. In a two-sector economy with constant knowledge, the divergence k# - k(t) = λ'FLEX p_i/P, where p_i is the price of investment goods and P is the general price level so that p_i/P is a relative price indicator; λ' is a positive parameter.

Here we face a formidable challenge in Economics. It is quite unsatisfactory that so far there is no consistent analytical link between the short-run (New) Keynesian macroeconomic equilibrium and the long-run equilibrium as established in the neoclassical growth model. One proposal suggested here is the hybrid Keynes-Solow approach presented.

6. A Broader View on the Golden Rule and Innovation in Open Economies

Let us assume that savings S is composed of a domestic component and a foreign component related to profits made in country I. The setup is asymmetric in the sense that country I has net FDI inflows, but there are no FDI outflows from country I. The savings function (with s'* for the savings rate of foreign subsidiaries in country I) is:

(26) $S= sY(1-\tau)(1-\alpha^*ß) + s'^*\alpha^*ßY(1- \tau) = [s(1-\alpha^*ß) + s'^*\alpha^*ß](1-\tau)Y$

Hence overall savings consist of domestic savings (in a narrow sense) and of savings from subsidiaries from abroad $[(s'^*\alpha^*ß)(1-\tau)Y]$.

Moreover, it is assumed that there is an exogenous element of technological progress a0, as well as a foreign element, which is related to share α that foreign investors hold in the overall capital stock. Thus the following progress function is used (assuming that a* is constant and using a positive parameter α"):

(27) $a= a_0 + \alpha''\alpha^*a^*$

Thus the steady state in an economy with population growth rate n (n can be positive or negative) and a Stoleru effect based on a positive link between the depreciation rate and a*, a_0 and α (the presence of cumulated foreign investment and spillovers contributes to vintage effects):

(28) $k'\# = \{[(s(1-\alpha^*ß) + s'^*\alpha^*ß)(1-\tau)]/(a_0 + \alpha''\alpha^*a^* + n + \delta(\alpha^*a^*)\}^{1/1-ß}$

Taking a look at the golden rule issue we now have to consider that:

(29) $C/L = c(1-\alpha^*ß)(1-\tau)y$

In an open economy with foreign direct investment and net income transferred abroad, the income use side reads (in the case of income taxation and with $s'\alpha ßY(1-\tau)$ denoting the savings of foreign subsidiaries):

(30) $Y= C + S + T + \alpha^*ßY = cY(1-\tau) + sY(1-\alpha^*ß)(1-\tau) + s'^*\alpha^*ßY(1-\tau) + \tau Y + \alpha ßY$

Alternatively we can write:

(31) $Y[(1-\alpha^*ß) – c(1-\tau) -\tau] = [s(1-\alpha^*ß)+s'^*\alpha^*ß](1-\tau)Y$

The task of maximizing C/L now has to take into account that the distance between the (1-a*ß) line and the investment line (a+ n +δ)k' has to be maximized. Hence we must have

(32) $(1-\alpha^*ß)ßk'^{ß-1} = a_0 + \alpha''\alpha^*a^* + n + \delta(\alpha^*a^*)$

Taking the steady state condition for k'# into account, we get:

(33) $(1-\alpha^*ß)ß = [s(1-\alpha^*ß) + s'^*\alpha^*ß](1-\tau)$

In this setup it is obvious that the level of maximum consumption per capita is affected through the presence of foreign investors: The required income tax rate that brings about the maximum consumption per capita can be derived as follows (after division of the above equation by s(1-α*ß) and after taking logarithms while using the approximation ln(1+x) ≈x):

(34) $\tau \approx s'^*\alpha^*ß/s(1-\alpha^*ß) – \ln(ß/s)$

A special case of parameter sets brings the result that τ=0.

Remember that the steady state capital intensity is simply determined by the ratio

(35) $k\# =\{[(s(1-\alpha^*ß) + s'^*\alpha^*ß)(1-\tau)]/(a_0 + \alpha''\alpha^*a^* + n + \delta(\alpha^*a^*)\}^{1/1-ß}$:

Hence if s'* sufficiently exceeds s, the negative impact of foreign subsidiaries on the denominator term, the level of the growth path is increased; as the presence of foreign investors has increased the progress rate – according to our assumptions (which imply sustained competition in all sectors of the host economy) –the case considered here unambiguously implies that foreign investment inflows raises long-run consumption per capita: As C/(AL) is constant in the steady state $C/L = [(C/L)_0 A_0]e'^{at}$. However, if s'* is sufficiently smaller than s, the level of the growth path will fall as a consequence of cumulated foreign direct investment inflows; it should also be pointed out that foreign investors are likely to pay lower effective income tax rates so that savings S= s(1-α*ß)(1-τ) + s'*α*ß(1-τ'), where τ' is the effective income tax rate applied to foreign investors. Such a change in the average income tax rate might raise long-run debt-GDP ratios and will hence bring about a real depreciation in the currency, which in a world of imperfect capital markets according to FROOT/STEIN (1991) implies higher FDI inflows relative to GDP. If the presence of foreign subsidiaries reduces the level of the growth path, the effect of cumulated foreign investment on the progress rate still has to be considered: As the growth rate a is increasing, it is only a question of time until the progress effect will dominate the level effect. However, it is unclear whether policymakers' – or voters' – time horizon is long enough to open up the economy adequately for foreign investors. Moreover, the presence of foreign investors in the model setup presented here implies less policy autonomy since governments can only directly influence part of the savings rate, namely the domestic component; the foreign component s'*αß might also be influenced through adequate tax policies or other incentives, but a small open economy might not find it easy to affect this part of the savings ratio. A big economy – with considerable political and economic leverage (e.g. China) – will find it easier to have an impact here.

Innovation, R&D Sector and Semi-endogenous Growth in Open Economies

The R&D sector has to be considered more explicitly and to do so we first take a look at the simple closed economy setting before we switch to the open economy. Innovation takes place in an R&D sector, where a fraction of GDP is spent on research and development so that capital accumulation in a closed economy is given by:

(36) $dK/dt + \delta K + \varphi Y = sY$

Hence with a Cobb-Douglas production function $Y = K^{ß}(AL)^{1-ß}$ and a constant growth rate of labor and a progress rate $a = \varphi'\varphi$ (φ' is a positive parameter; assumption $\varphi < s$), we get the steady state solution:

(37) $k'\# = [(s-\varphi)/(\varphi'\varphi + n + \delta)]^{1/1-ß}$

Thus per capita output in the steady state is determined by:

(38) $y = A_0[(s-\varphi)/(\varphi'\varphi + n + \delta)]^{ß/(1-ß)}\, e'^{\varphi'\varphi t}$

Therefore, we see it more clearly than in a standard model with exogenous R&D that a rise in the output share of the R&D sector will reduce the level of the growth path.

In an open economy with cumulated FDI inflows and income taxation and a savings function $S = s(1-\tau)(1-\alpha^*ß) + s'^*(1-\tau)\alpha^*ß$, we have – also considering the vintage effect of the progress rate - the solution:

(39) $k'\#\{[(s(1-\alpha^*ß) + s'^*\alpha^*ß)(1-\tau)]/(a_0 + \varphi'\varphi + \alpha''\alpha^*a^* + n + \delta(\alpha^*a^*, a_0 + \varphi'\varphi\,)\}^{1/1-ß}$

Thus it has been assumed that $a = a_0 + \varphi'\varphi + \alpha''\alpha^*a^*$, therefore beside autonomous technological progress, the size of the R&D sectors matters as well as international spillovers. Denoting the export-GDP ratio by x and the import-GDP ratio by j, one may consider to add the term $\lambda a^* + \lambda' x + \lambda'' j a^*$ in the progress function where λ, λ' and λ" are positive parameters: λ is truly exogenous international technology spillovers, λ' indicates how demanding foreign markets are in terms of (induced) technological sophistication and λ" indicates how strong the embodied innovation dynamics in trading partner countries is from which the country is importing goods and services. Looking at the progress function

(40) $a = a_0 + \varphi''\varphi + \alpha''\alpha^*a^* + \lambda a^* + \lambda' x + \lambda'' j a^*$

we see that the long-run growth rate of per capita output depends both on the size of the R&D sector, technological progress abroad and the intensity of trade relations. The parameter φ is basically chosen by firms and industry. The only task for governments is to internalize external effects and if they do so, there will be an optimum progress rate, which may be indicated by a parameter φ" (instead of φ'). In this case, per capita GDP in the steady state – with a= a0 + φ"φ + α"α*a* + λa* + λ'x + λ"ja* - is given by:

(41) $y\# =\{[(s(1-\alpha*ß)+s'*\alpha*ß)(1-\tau)]/(a_0+\varphi''\varphi+\alpha''\alpha*a*+\lambda a*+\lambda'x+\lambda''ja*+ n +\delta(a)\}^{ß/1-ß} e'^{at}$

One further potentially useful modification should be noted with respect to savings function: "Foreign savings" from subsidiaries might not be given by s'*α*ßY but rather by s'*α*ßY + s"*ß*Y*q*, where s"* indicates the willingness of the parent company to devote part of its profits in country II (the headquarter country) to investment projects in country I. Moreover, the case might have to be considered that φ positively depends on the share of the capital stock owned by foreign companies – the higher the share owned by foreign subsidiaries, the higher the share of GDP in the host country, which is devoted to R&D; however, in principle we cannot rule out the perverse effect that φ negatively depends on the presence of foreign investors (e.g. a leading biotechnology from Denmark took over a privatized Brazilian biotechnology company at the beginning of the 21st century – and closed down the R&D activities in Brazil as the key interest was simply to get a hold of the Brazilian company's biotechnology patents; moreover, foreign investors might accelerate the consolidation of certain sectors and indeed weaken actual and potential competition in certain sectors in the long run).

In the above setup the golden rule requires that:

(42) $(1-\alpha ß)ßk^{ß-1} = a_0 + \varphi''\varphi + \alpha''\alpha*a* + \lambda a* + \lambda'x + \lambda''ja* + n + \delta(a)$

The size of the golden capital intensity is a negative function of ß and a negative function of α, however, it must not be overlooked that the progress rate and hence the long-run growth rate of per capita consumption is a positive function of α*.

R&D and Outward Foreign Direct Investment

Let us consider the following asymmetric case of an open economy: Country I has invested abroad but there is no inward foreign direct investment. Hence national income is given by:

(43) $Z = Y+ \alpha ß*q*Y*$

(44) $S= s(Y+ \alpha ß*q*Y*)$

The size of the domestic R&D sector in GDP is φ and hence we can write the accumulation dynamics of k' as follows:

(45) $dk'/dt = s[y+ \alpha ß*q*y*(A*L*)/(AL)] – (n+a+\delta)k'$

(46) $y* = [s*(1-\alpha ß*)/(n*+a*+\delta*)]^{ß*/1-ß*}$

(47) $dk'/dt = s\{y+ \alpha ß*q*(A*L*)/(AL)[s*(1-\alpha ß*)/(n*+a*+\delta*)]^{ß*/1-ß*}\} – (n+a+\delta)k'$

This shows that there is international economic interdependence in the long run, namely based on growth interdependency.

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