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TEMPORARY MIGRATION AND FOREIGN DIRECT INVESTMENT*

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Abstract

The question of complementarity or substitutability of FDI and international labour mobility has not yet been answered. The substitutability assumption does not take into consideration the technological spillover of FDI in the host countries. Moreover, migration flows reveal cultural characteristics and labour force properties of their native country which may stimulate bilateral business networks, strengthening the complementarity assumption between capital and labour flows. In this paper we build a continuous time dynamic model where these offsetting forces are at work. We analyze whether, and to what extent, the increase of labour mobility might affect FDI outflows. A numerical simulation is performed showing

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that to a higher labour mobility corresponds a higher income growth rate. Some policy implications and further research direction are suggested.

Keywords: Temporary Migrations; Migrant Network; FDI; Dynamic Model; European Union; CEECs. - JEL: J61, F21, F22 .

1 Introduction

Migration theory generally predicts a negative impact of migration on the source country. Particularly, depending on the educational level of emigrants, the term "brain drain" has been widely used (Lowell et al, 2004; Docquier and Marfouk, 2005; Dumont and Lemaitre, 2005). The mobility of the highly skilled has been growing rapidly in volume and complexity. The 1990s saw a surge in the number of highly skilled migrants entering the United State, Western Europe, Canada, etc. According to United Nations data the total amount of migrants is about 3% of the world's population (about 180 million people), and it is expected to increase. This has triggered particular interest in politicians as well as social scientists and international organizations. As regard the educational contents of migrants, high skilled workers mobility has been growing, reaching 34% of the stock of migrants in 2000 in the OECD countries. Low and middle income countries are the mostly hit by this phenomenon. The skilled migration rate increased from 6.6 to 7.2 % in non-OECD countries while it decreased from 4.1 to 4.0% in the OECD. As noted by Mountford and Rapoport (2006), the rise in the brain drain has been caused by two simultaneous aspects: an increasingly selective immigration policy implemented by receiving countries on the demand side, and a positive self-selection by migrants on the supply side. At the same time as more skilled migrants settle permanently in host countries, another part of them increasingly come back to the origin countries. The role of temporary migration on the native country is not usually emphasized in the standard migration literature. However, in the real world not all of those who migrate

never come back or stay abroad for long periods: "They may return bringing with them experience and entrepreneurship...They come and go several times following a dynamic process of brain circulation" (International Organization for Migration, 2006: pag.12). Empirical research shows that return migration has been a constitutive part of international migration flows. Particularly, in Western Europe the return of expatriates from Central and Eastern Europe steeply increased during the '90s

Moreover, standard trade models argue that international capital flows and migration are substitutes as well as are factor mobility and trade (Faini et al., 1999; Hazari and Sgro, 2001). Empirical evidence shows instead that there may be a dynamic complementarity relation. As noted by Kugler and Rapoport (2005), while acquiring skills in the host country, migrants release information on the source economy stimulating foreign investors interest for FDI: "...their integration into the host country labour market acts as a revelator of the characteristics of the workforce in their home country and may therefore reduce uncertainty and possibly remove any concern potential investors could have in this respect. Hence, migration of both skilled and unskilled workers can facilitate in the long run the outflow of FDI from the destination to the origin country" (pag. 3). Also, migrants whilst in the host country, thanks to the contacts and knowledge of the business rules and customs in their native country, may activate a network. They can either act as intermediaries between potential investors in the host country and the business community in their origin country, starting new production activities or facilitating partnership, or acting

themselves as local partners for FDI from their origin country. Migration has other positive aspects like the opportunity to acquire new skills that positively affect labour productivity once workers return to their origin country .Simply, diasporas may improve access to capital, knowledge and new technology and play an important role for social development, growth opportunities, and connection between markets and countries. (IOM, 2006) Ivleves (2006), establishes in a Heckscher-Ohlin framework, a complementarity relation between migration, trade and international capital flows.

The important role of diasporas within FDI and Trade has also been demonstrated. For example, it has been estimated that between 50 and 70% of FDI in China originated in the Chinese diaspora (IOM, 2006). Similarly, from a study on Germany, Buch, Kleiner and Toubal (2003), show that German FDI outflows and migration inflows are strongly complementary. Finally, preliminary results from a World Bank study show that outflows of U.S. FDI from a specific sector to a specific country are triggered by the existing share of workers in that sector from that country (World Bank, 2005)

Our paper adds to the existing literature demonstrating that the relation that links FDI and migration can be positive and complementary. Both contribute to the economic growth of the interested countries.

The novelty of our paper is twofold: to our knowledge it is the first dynamic continuous time model that analyzes the aforementioned complementarity relation; in addition we introduce a variable, a "revelator effect", that represents the stock of information about the more or less favorable environment for FDI.

In this context, international migration can be a significant source of insights about the opportunities and risks for investments in their native country.

The paper is structured as follows: in the next section the theoretical model is presented. In the third section, the transitional dynamics of the system are examined and the stability analysis is carried out. The partial equilibrium path is presented in the fourth section together with a comparative dynamics analysis. In the final section, we draw some policy suggestions. Direction of further research are also proposed.

2 The theoretical model

We consider a small open economy that represents the originating country of migrants. Due to the structural change in the economic system, the country experiences a lack of productive capital and skilled labour force[1]. The key assumptions of the model are the following:

- Migration is only temporary. Differently from the common assumption made in the related literature, in real life migration is not always permanent. Quite often migrants return to the origin country. Also recent works on the subject (i.e. Dustman, 2001; IOM, 2006) stress the relevance of temporary migration.

- In each period return migrant flow equals in size migrant outflow[2].

[1] This reflects one of the most outstanding features of transition economies, like those involved in European Eastern enlargement.

[2] This hypothesis is supported by the literature on demographic impact of migration. In particular, in that strand of the literature that analyzes the spatial structure of migration (see Newbold and Peterson, 2001).

- Investment is only due to FDI inflows coming from emigrants host countries. Since we are primarily interested in the role of foreign capital flows, we neglect for the time being domestic investment.

These assumptions are motivated by two main reasons: to simplify the mathematics without loss of generality and to concentrate our attention on the role of return migration. For the same reasons, at this stage we neglect the positive interaction of FDI and migration with trade. In addition, we do not consider the role of remittances given that the evidence of their effect on long term economic growth is not yet unequivocal (World Bank, 2006).

2.1 The equations

In the model all the variables adjust to their partial equilibrium levels with a certain mean time lag, $\frac{1}{\eta_i}$, according to the dynamic disequilibrium approach in continuous time[3].

For clarity we first present the model in a table and then discuss each equation.

$$Y(t) = AK(t)^{1-\beta} [\Psi(t) L(t)]^{\beta} \tag{1}$$

$$D \log K(t) = \eta_1 \log \left(\frac{\widehat{K}(t)}{K(t)} \right) \tag{2}$$

[3] See Gandolfo, 1996.

$$\widehat{K}(t) = Be^{\alpha_1 i(t)} \Psi(t)^{\alpha_2} \Pi(t)^{\alpha_3} \tag{3}$$

$$\Pi(t) = \Gamma(t) H^{\alpha_4} \tag{4}$$

$$L(t) = N(t) - \Gamma(t) + \Upsilon(t) \tag{5}$$

$$\Upsilon(t) = -\Gamma(t) \tag{6}$$

$$D \log \Psi(t) = \eta_2 \log \left(\frac{\widehat{\Psi}(t)}{\Psi(t)} \right) \tag{7}$$

$$\widehat{\Psi}(t) = C\Gamma(t)^{\alpha_5} K(t)^{\alpha_6} \tag{8}$$

$$D \log \Gamma(t) = \eta_3 \log \left(\frac{\widehat{\Gamma}(t)}{\Gamma(t)} \right) \tag{9}$$

$$\widehat{\Gamma}(t) = \left(\frac{W(t)}{W^* e^{\lambda t}} \right)^{-\alpha_7} \tag{10}$$

$$W(t) = A\beta K(t)^{1-\beta} [\Psi(t) N(t)]^{\beta-1} N(t) \tag{11}$$

$$N(t) = N_0 e^{nt} \tag{12}$$

$$E\left[\frac{\mathrm{d}s}{\mathrm{d}t}\right] = i\left(t\right) - i^{*} \tag{13}$$

where $\alpha_i > 0, i = 1, ...7$.

In every period, in the considered economy, a composite good is produced according to a Cobb-Douglas technology function, as shown by equation (1). Labour is divided into two components: the number of employees $L\left(t\right)$, and the average efficiency of workers, $\Psi\left(t\right)$. The number of employees is equal to the working-age population $L\left(t\right)$, minus the migrants outflow $\Gamma\left(t\right)$, plus the return migrants $\Upsilon(t)$. As it appears from (6) the two flows equals.

According to equation (2) the stock of capital adjusts to its partial equilibrium level, $\widehat{K}\left(t\right)$, with adjustment speed equal to η_1. We assume that new capital comes totally from abroad and is positively influenced by the rate of return of capital with elasticity α_1, by labour efficiency with elasticity α_2 and by a "revelator effect", $\Pi\left(t\right)$ with elasticity α_3.

Equation (4) specifies the behavior of $\Pi\left(t\right)$, the "revelator effect" variable. It is a key variable in our model. It can be considered to be an indicator of the more or less favorable environment attracting FDI. $\Pi\left(t\right)$ is positively influenced by migration flows, with elasticity equal to α_4. The economic intuition behind this hypothesis is that emigrants release information on the origin country characteristics[4] and by so doing it reduces the investment risk. Moreover, the intensity of migration may reinforce the interest of foreign investors for

[4] Information about the political situation, the esistence of more or less good infrastructures, consumer tastes, autocton workers skills, and so on.

cross-border FDIs.

Equation (7) specifies the labour efficiency dynamic. As shown in equation (8), the partial equilibrium level labour productivity depends on migration flows $\Gamma(t)$. The way migrants acquire knowledge is not explicitly formalized: it increases because of the positive "learning by doing" externality in the host country which is technologically more advanced. As Bhagwati (1988) remarks "*...it would be foolish to assume that learning automatically follows from doing, rather learning is a function of doing within an appropriate environment*". Once back home these workers increase total labour productivity of their native economy. Their skill absorption capacity, is higher the higher is their education level[5].

Equations (9), (10) and (11) describe the dynamics of migration flows.

Since the seminal papers of Todaro (1969) and Harris and Todaro (1970), in the economic literature migration is primarily believed to be motivated by wage differentials between the origin and the foreign country. Differently from the most relevant literature on this subject, in our model the wage differential is affected by the change in the native worker's productivity. Feenstra and Hanson (2003) argue that almost the same pattern of wage changes occured in Mexico and Usa.

The institutional aspects that regulate legal migration are taken into account by hypotheses on the value of η_3. A low value of η_3 reflects relatively high restrictions, the transition to a regime of free international labour flows, is

[5] As shown by the empirical and theoretical literature, the propensity to emigrate increases with skills (Doquier and Marfouk, 2005).

equivalent to an increase in η_3[6].

The foreign country's wage follows an exogenous growth path, $W^* e^{\lambda(t)}$. Population growth rate is assumed to be constant over time (equation 12). Finally, according to the hypothesis of international perfect capital mobility, uncovered interest parity condition holds (equation 13). Assuming static expectations, $E\left[\frac{\mathrm{d}s}{\mathrm{d}t}\right] = 0$ we have $i(t) = i^*$.[7]

3 Transitional dynamics

After substitutions, we obtain the following system of three simultaneous differential equations, where lower case letter indicates the logarithm of the variable.

$$\dot{k} = \eta_1 \left[b + \alpha_1 i^* + \alpha_2 \psi + \alpha_3 \left(h + \alpha_4 \gamma\right) - k\right] \tag{14}$$

$$\dot{\psi} = \eta_2 \left[c + \alpha_5 \gamma + \alpha_6 k - \psi\right] \tag{15}$$

$$\dot{\gamma} = \eta_3 \left\{-\alpha_7 \left[a + \log\beta - (1-\beta)\left(\psi - k + n_0 + nt\right) + n_0 + nt - w^* - \lambda t\right] - \gamma\right\} \tag{16}$$

3.1 Stability analysis

By solving the homogenous part of the system eqs. (14-16)[8], we obtain the dynamic path of the endogenous variables $k(t)$,$\psi(t)$ and $\gamma(t)$.

[6] While the barriers to capital movement have been quickly removed by mutual agreement, the progress towards free movement of labour is extremely slow particularly referring to the recent enlargement of EU.

[7] In this context, without loss of generality, we simply assume that $i(t) = i^* = 0$.

[8] See Appendix A.

Proposition 1 *: Given the stability conditions of a simultaneous system of three differential equations*[9]*, if the following inequalities:*

$$(1-\alpha_2\alpha_6)-(1-\beta)\,\alpha_7\,(\alpha_5+\alpha_3\alpha_4\alpha_6) \;>\; 0 \tag{17}$$

$$\eta_3\,(1-\beta)\,\alpha_7\,[\eta_1\eta_2\alpha_5\,(\alpha_2-2)+\eta_2+\eta_3] \;<\; Z, \tag{18}$$

where

$$Z=\eta_1\eta_2\eta_3\,(1-\alpha_2\alpha_6)+(\eta_1+\eta_2+\eta_3)\,[\eta_1\eta_2\,(1-\alpha_2\alpha_6)]+\eta_1\alpha_3\alpha_4\,[\eta_1+\eta_3+\eta_2\,(2-\alpha_6)]$$

are satisfied, then all the roots of the characteristic polynomial have negative real part. (Proof: see Appendix A).

4 Equilibrium solution and comparative dynamics

The particular solution of the system eqs. 14-16 is a polynomial function of the following form[10]:

$$\overline{\mathbf{y}}=\boldsymbol{\mu}+\boldsymbol{\sigma}\mathbf{t}.$$

$$\boldsymbol{\sigma}=[\sigma_1,\sigma_2,\sigma_3]$$

[9] Gandolfo (1997), pag. 221.
[10] See Appendix B

where:

$$\begin{aligned}\sigma_1 &= \varkappa(\alpha_2\alpha_5 + \alpha_3\alpha_4)\\ \sigma_2 &= \varkappa(\alpha_3\alpha_6\alpha_4 + \alpha_5)\\ \sigma_3 &= \varkappa(1 - \alpha_2\alpha_6)\end{aligned}$$

and

$$\varkappa = \frac{\alpha_7\,(\lambda + n\beta)}{1 - \alpha_2\alpha_6 - \ \alpha_7\ (1-\beta)\,[\alpha_3\,\alpha_4\,(1-\alpha_6) - (1-\alpha_2)\,\alpha_5]}$$

By substituting the solutions for the endogenous variables into the income function (equation 1) we obtain the partial equilibrium path of the considered economy:

$$Y\,(t) = A\widetilde{K}^{\beta}(N\,(t)\,\widetilde{\Psi}\,(t))^{1-\beta}$$

where $\widetilde{K}$ and $\widetilde{\Psi}$ are the equilibrium values of the variables.

In order to get some insights on the functioning of the system, we perform the comparative dynamic exercise with respect to some key parameters.

First, we evaluate the derivative of σ_i with respect to the elasticity of foreign investment to labour efficiency, obtaining

$$\frac{\partial\sigma_i}{\partial\alpha_2} > 0,\ i = 1,2 \quad \text{while} \ \frac{\partial\sigma_i}{\partial\alpha_2} < 0,\ i = 3.$$

The more sensitive are foreign investors to workers' efficiency the higher will be the growth rate of FDI inflows[11]. This will increase labour efficiency even more thus reducing the wage gap and so the migration pressure.

Differentiating σ_i with respect to the elasticity of foreign capital flows to the revelator effect (α_3), we obtain:

$$\frac{\partial \sigma_i}{\partial \alpha_3} > 0,\ i = 1, 2 \quad while\ \frac{\partial \sigma_i}{\partial \alpha_3} < 0,\ i = 3.$$

The results can be interpreted as follows: if the elasticity of FDI with respect to the revelator effect increases, for each value of this last variable the capital stock increases faster, so does labour productivity. That implies a reduction in the wage gap, consequently reducing the emigration rate.

The derivative of σ_i with respect to α_4 gives:

$$\frac{\partial \sigma_i}{\partial \alpha_4} > 0,\ i = 1, 2 \quad while\ \frac{\partial \sigma_i}{\partial \alpha_4} < 0,\ i = 3.$$

Increasing the information contents relaxed by emigrants on their origin country to the potential investors from the foreign country, the effect is an higher inflow of capital, higher increase in labour productivity and again a reduction in the wage gap. As a consequence migration is reduced.

Finally, taking the derivative of σ_i with respect to the elasticity of labour

[11] Let us recall that σ_i are rates of growth, being the variables defined in logarithmic form:

$$k = \log K = \mu_1 + \sigma_1 t.$$

Thus

$$K = e^{\mu_1 + \sigma_1 t} = K_0 e^{\sigma_1 t}.$$

efficiency to emigration, the results are:

$$\frac{\partial \sigma_i}{\partial \alpha_5} > 0,\ i = 1, 2 \quad while\ \frac{\partial \sigma_i}{\partial \alpha_5} < 0,\ i = 3.$$

A higher elasticity of labour productivity with respect to migration can be interpreted as an higher emigrant's capacity of acquiring new skills. That implies an higher contribution to the increase in labour efficiency once back home and more capital from abroad is attracted. Wage differential decreases and so does emigration.

5 Numerical simulation

In order to better understand the functioning of this economy we perform a numerical simulation exercise. The base set of the parameter's values is given by Table 1:

Parameter	**Values**
$\eta_1 = 0.4$	$\alpha_1 = 1.3$
$\eta_2 = 0.25$	$\alpha_2 = 1$
$\eta_3 = 0.1$	$\alpha_3 = 2.9$
$\lambda = 0.001$	$\alpha_4 = 0.01$
$\beta = 0.3$	$\alpha_5 = 1.1$
$n = 0.002$	$\alpha_6 = 0.4$
	$\alpha_7 = 0.08$

(Table 1)

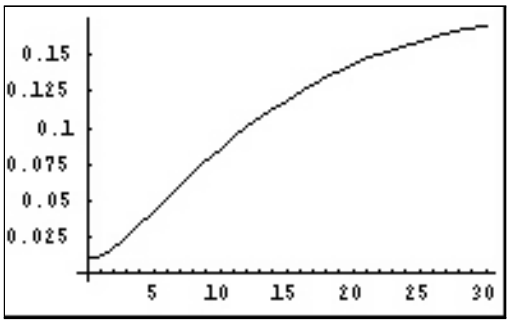
The parameter values have been chosen in order to depict a small open economy characterized by temporary migration and FDI. Our aim is to understand if the positive linkages of FDI and migration flows foster economic growth of the emigrant native country. Here we are assuming the foreign investors pay sufficient attention to any increase in labour efficiency ($\alpha_2 = 1$) but they are particularly affected by the informations flows and network externalities (thus the relatively high value of α_3). Referring to migrants, we assume that their skill absorption capacity is quite high ($\alpha_5 = 1.1$), so that the labour efficiency has a great beneficial effect from migration.

As a starting point for our numerical investigation of the model, a low adjustment speed for migration ($\eta_3 = 0.1$)[12] is chosen thus reflecting institutional features as barriers to international labour movement. Recognizing the asymme-

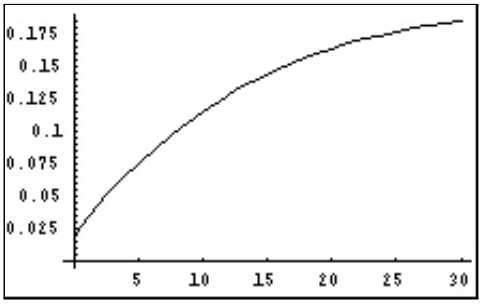
[12] The transition to a regime with higher labour mobility is equivalent to an increase in η_1 or, which is the same, a decrease in the mean time lag.

tries between labour and capital flows adjustment speed, $\eta_1$has been attributed a value of 0.4.

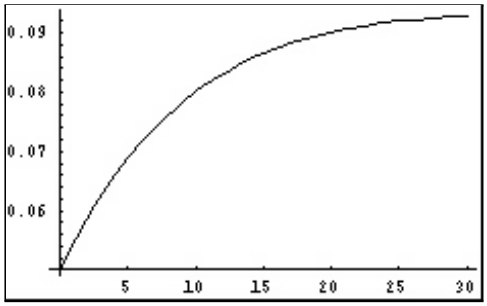
Figures 1-3 show the resulting paths of the endogenous variables when the model is run using the aforementioned set of parameter's values.



Capital dynamics

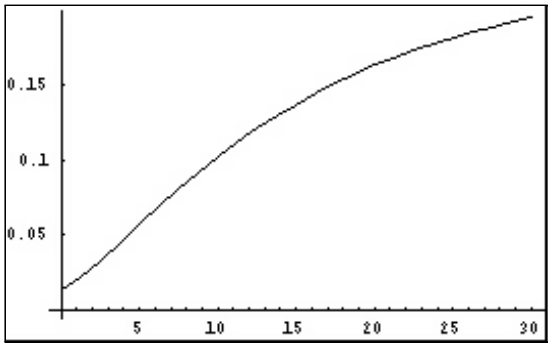


Labour efficiency dynamics



Migration dynamics

From figure 1 we can see that FDI inflows grow strongly at the beginning of the period when the migration grows as well (figure 3). This is in line with our hypothesis that migration, by acting as an "information revelator" represents an incentive for FDI. The increasing of both the accumulation of capital and return migration, positively influences labour productivity (figure 2). After a period of about 20 years all the variables stabilize around their partial equilibrium path. Finally, the income path is depicted in figure 4.



Income dynamics

We also considered the effect of a much higher adjustment speed for migra-

tion to take into account the possible removal of migration restrictions. Accordingly, results suggest a significant impact on migration flows in the very short term, leading to a faster reduction of both labour efficiency and wage gap. Also, the capital accumulation increases faster and has a positive impact on income growth rate.

Our results contribute to the new strand of migration research in which the traditional negative effects of the brain drain stressed in old literature is often reversed by possible positive effects of return migration, business networks and other positive externalities

6 Conclusions and policy suggestions

In this paper, we model the complementarity relation between migration and FDI inflows. We build a continuous time dynamic model in which the positive role of migration for the origin country is stressed. By acting as an "information revelator", migrant workers stimulate FDI inflows in their origin country. Moreover, by acquiring skills during their stay abroad, returning migrants contribute to the adoption of new production processes and to the spread of technological progress in their home country.

The model shows a convergence of the economy towards its partial equilibrium growth path. A numerical simulation has been performed, which confirms the predicted linkages among the variables as we expected and give us the opportunity to draw some policy suggestions.

These findings show that the "brain drain" assumption associated with migration does not always apply. Skilled as well as unskilled emigrants can actually be a "growth factor" for their origin country, even more so if the migration choice is only a temporary one. To improve the positive impact of migration, skill acquisition of migrants whilst in host country should be encouraged. In this context policies directed towards increasing the education level of the population might have a twofold effect: a more educated workforce is more productive and acts as an attractor for FDI inflows. Moreover, it increases the skill absorption capacity of those workers that decide to spend part of their worklife abroad. The next step will thus consider the role of education policy on migration decision as well as on the impact of migration on domestic labour productivity.

The international laws and agreements that limit labour mobility can have negative impacts on transition or developing countries. For example, the "Transitory norms" that delay the application of the Schengen Treaty to new EU member countries can actually reduce the "catching up" speed of those economies.

A further development of the research has to take into consideration the role of remittances in the capital accumulation process. Recent studies by international organizations, show that the share of saving of families with at least one relative working abroad, is very high on the total of domestic savings of migrants' origin country.

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APPENDIX

APPENDIX A

Given the simultaneous differential equation system in the text (eqs. 14 - 16), the characteristic polynomial is the following

$$\lambda^3 + A\lambda^2 + B\lambda + C = 0 \tag{20}$$

where

$$\begin{aligned} A &= (\eta_1 + \eta_2 + \eta_3) \\ B &= \eta_1\eta_3 \left[1 + (1-\beta)\,\alpha_3\alpha_4\alpha_7\right] + \eta_1\eta_2\,(1 - \alpha_2\alpha_6) + \eta_3\eta_2\left[1 - \alpha_5\alpha_7\,(1-\beta)\right] \\ C &= \eta_1\eta_2\eta_3\left\{\alpha_7\,(1-\beta)\left[\alpha_3\alpha_4\,(1-\alpha_6) - \alpha_5(1-\alpha_2)\right] + 1 - \alpha_2\alpha_6\right\} \end{aligned}$$

For a dynamic system to be convergent to a local stable equilibrium, the roots of the characteristic polynomial must have negative real part..A set of necessary and sufficient conditions for all the roots of eq. 20 to have negative real parts is

$$\begin{aligned} A &> 0 \\ B &> 0 \\ C &> 0 \\ AB - C &> 0 \end{aligned}$$

It is possible to observe that the first two conditions are immediately satisfied. For the last two conditions to be verified, it is necessary that the following two conditions are satisfied:

$$1 - \alpha_2\alpha_6 > (1-\beta)\,\alpha_7\,(\alpha_5 + \alpha_3\alpha_4\alpha_6)$$

and

$$\eta_1\eta_2\eta_3\left(1-\alpha_2\alpha_6\right)+\left(\eta_1+\eta_2+\eta_3\right)\left[\eta_1\eta_2\left(1-\alpha_2\alpha_6\right)\right]+$$
$$+\eta_3\left(1-\beta\right)\alpha_7\left[\eta_1\eta_2\alpha_5\left(\alpha_2-2\right)+\eta_2+\eta_3\right]+$$
$$+\eta_1\alpha_3\alpha_4\left[\eta_1+\eta_3+\eta_2\left(2-\alpha_6\right)\right]>0$$

Let us analyse the four elements of the last condition separately.

The first one is certainly greater than zero given the economic assumptions discussed in the text. So are the second and the fourth element. Their sum thus will be positive. Let indicate that sum with Z

$$Z=\eta_1\eta_2\eta_3\left(1-\alpha_2\alpha_6\right)+\left(\eta_1+\eta_2+\eta_3\right)\left[\eta_1\eta_2\left(1-\alpha_2\alpha_6\right)\right]+\eta_1\alpha_3\alpha_4\left[\eta_1+\eta_3+\eta_2\left(2-\alpha_6\right)\right]>0$$

Hence, for the second condition to be verified is sufficient that

$$\eta_3\left(1-\beta\right)\alpha_7\left[\eta_1\eta_2\alpha_5\left(\alpha_2-2\right)+\eta_2+\eta_3\right]<Z$$

APPENDIX B

In order to find the particular solution of the model (eqs. 14 - 16), we apply the rule of undetermined coefficients[13].

Given

$$\dot{\mathbf{y}}+\mathbf{y}B=\mathbf{g}(t)\quad\text{ with }\quad\mathbf{g}(t)=\mathbf{C}_0+\mathbf{C}_1t$$

where

[13] See Gandolfo, 1997, page 159 and 264.

$$\dot{\mathbf{y}} = \begin{vmatrix} \dot{k} \\ \dot{\psi} \\ \dot{\gamma} \end{vmatrix}, \ \mathbf{y} = \begin{vmatrix} k \\ \psi \\ \gamma \end{vmatrix}, \quad \mathbf{B} = \begin{vmatrix} -\eta_1 & \eta_1\alpha_2 & \eta_1\alpha_3\alpha_4 \\ \eta_2\alpha_6 & -\eta_2 & \eta_2\alpha_5 \\ -\eta_3(1-\beta)\alpha_7 & \eta_3(1-\beta)\alpha_7 & -\eta_3 \end{vmatrix},$$

$$\mathbf{C}_0 = \begin{vmatrix} \eta_1(b+\alpha_3 h) \\ \eta_2 c \\ \eta_3[\omega - \alpha_7(a+\log\beta+w^*)] \end{vmatrix}, \quad \mathbf{C}_1 = \begin{vmatrix} 0 \\ 0 \\ \eta_3\alpha_7(\beta n+\theta) \end{vmatrix},$$

we try as a particular solution of the system

$$\overline{\mathbf{y}} = \boldsymbol{\mu} + \boldsymbol{\sigma} t$$

where $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ are vectors of coefficients to be determined. We thus obtain

$$\boldsymbol{\sigma} + \mathbf{B}(\boldsymbol{\mu} + \boldsymbol{\sigma} t) = \mathbf{C}_0 + \mathbf{C}_1 t$$

from which

$$(\mathbf{B}\boldsymbol{\sigma} - \mathbf{C}_1)t + (\mathbf{B}\boldsymbol{\mu} + \boldsymbol{\sigma} - \mathbf{C}_0) = \mathbf{0}$$

The equation will hold for each value of t if, and only if, it is simultaneously verified

$$\begin{aligned} (\mathbf{B}\boldsymbol{\sigma} - \mathbf{C}_1) &= \mathbf{0} \\ (\mathbf{B}\boldsymbol{\mu} + \boldsymbol{\sigma} - \mathbf{C}_0) &= \mathbf{0} \end{aligned}$$

By solving this system, we find the values of μ_i and σ_i shown in the text.