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18 August 2012

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Abstract

This paper incorporates the Bhaduri-Marglin accumulation function in Goodwin's growth cycle model. It seems that, a priori, nothing unambiguous can be said about the dynamic behaviour of that extended system, since it depends crucially on two separate factors: (i) the form of the accumulation function; and (ii) the degree of capital heterogeneity.

Key words: Bhaduri-Marglin accumulation function, capital heterogeneity, Goodwin's growth cycle model, Sraffian theory
JEL classification: B51, C62, C67, E32

1. Introduction

Many scholars have stressed that Goodwin's (1967) growth cycle model neglects altogether any effective demand issues, and this has been generally recognized as a fundamental weakness of the model (see, however, the subsequent contributions by Goodwin, 1986, and Goodwin and Punzo, 1987, ch. 4, which also allow for heterogeneous capital commodities).[1] More recently, Marglin and Bhaduri (1988) have shown, by means of a static post-Keynesian model, that income redistribution (between profits and wages) has ambiguous effects on the equilibrium rates of capacity utilization, profits and accumulation (see also Bhaduri and Marglin, 1990, and Kurz, 1990). Within that model, (i) there is an independent Kaleckian investment (or accumulation) function (for a recent, critical investigation, both theoretical and empirical, of the Kaleckian accumulation function(s), see Skott, 2012); (ii) commodity market is in equilibrium (see also Bhaduri, 2007); and (iii) the share of profits (or, equivalently, the real wage rate) is treated as exogenous variable. However, as it has also been remarked, the context of Bhaduri and Marglin "remains

* This paper draws heavily on Mariolis (2006a, pp. 202-214). Earlier versions were presented at Workshops of the 'Study Group on Sraffian Economics' at the Panteion University, in May 2008 and September 2011: I am indebted to Eleftheria Rodousaki, George Soklis and, in particular, Nikolaos Rodousakis for very helpful discussions, comments and suggestions. Furthermore, I am grateful to Lefteris Tsoulfidis for suggestions and encouragement. The usual disclaimer applies.

[1] As it has been argued, the absence of 'structural stability' in Goodwin's model (for a survey of this issue, see, e.g. Sportelli, 1995, pp. 36-40) is not sufficient to reject it a priori (see Vercelli, 1984, and Veneziani and Mohun, 2006).

the short run of Keynes and Kalecki. It may be objected at the outset that an exogenous short-run determination of the real wage is somewhat implausible. The approach is, nevertheless, worth pursuing particularly if it is understood as clearing the ground for more comprehensive dynamic analysis in which some aspect of the short-run outcome (say the rate of unemployment) feeds back into the wage rate (perhaps via a real Phillips curve)." (Mainwaring, 1991, p. 632).

The only purpose of this paper is to incorporate the Bhaduri-Marglin accumulation function in Goodwin's model (or, 'conversely', to close the Bhaduri-Marglin model by means of Goodwin's endogenous determination of distribution) and to explore the dynamics of that extended system.[2]

The remainder of the paper is structured as follows. Section 2 constructs and explores the model, and tries to trace the implications of capital heterogeneity for the system's dynamic behaviour. Section 3 concludes.

2. The Model

Consider a closed capitalist economy, with constant returns to scale and excess capacity of capital, producing only one commodity which can be used for consumption and investment purposes. Homogeneous labour is the only primary input, capital stock does not depreciate, and competitive conditions are taken to be close to free competition.[3] There are only two classes, workers, employed in proportion to the level of production (i.e. there is no supplementary or 'overhead' labour) and capitalists, and two kinds of income, wages and profits. Wages are paid at the end of the production period and there are no savings out of this income, whilst a given and constant fraction of profits, s $(0 < s \leq 1)$, is saved.[4] The degree of capacity utilization, u $(0 < u \leq 1)$, is given by the relation between actual output and potential output, where the latter is taken to be proportional to the capital stock in existence. The desired rate of capital accumulation is a strictly increasing function of both the

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[2] For this line of research, see, e.g. Skott (1989), Dutt (1992) and Sordi (2003), who do not use the Bhaduri-Marglin accumulation function, and Canry (2005), Barbosa-Filho and Taylor (2006), Flaschel and Luchtenberg (2012, ch. 4), and Nikiforos and Foley (2012), who use, explicitly or otherwise, the said function.

[3] "This allows us to interpret the underutilization of productive capacity as caused essentially by an insufficient effective demand" (Kurz, 1995, pp. 96-97; see also Kurz, 1994, Sections 3 and 6).

[4] Matrices (and vectors) are delineated in boldface letters. The symbols '> 0', '≥ 0' denote strict positivity and semi-positivity, respectively. Finally, a 'dot' ('hat') above a variable denotes time derivative (logarithmic derivative with respect to time).

degree of capacity utilization and the share of profits in total income, h $(0 \le h \le 1)$. Finally, technological change,[5] fiscal and monetary considerations are ignored.

On the basis of these assumptions, we can write the following system of relations (for a thorough investigation, see Bhaduri and Marglin, 1990, and Kurz, 1990):

$$g^{\mathrm{S}} = sr \tag{1}$$

$$g^{\mathrm{I}} = F(u,h),\ F(\mathbf{0}) \ge 0,\ F_x \equiv (\partial F / \partial x) > 0,\ x = u,\ h \tag{2}$$

$$r = \pi_K hu \tag{3}$$

$$w = \pi_L (1-h) \tag{4}$$

$$g^{\mathrm{I}} = g^{\mathrm{S}} \tag{5}$$

$$s\pi_K h > F_u \tag{6}$$

where g^{S} denotes the actual rate of capital accumulation, determined by the amount of savings, g^{I} the desired rate of capital accumulation, $F(\bullet)$ a continuous function, r the profit rate, π_K the technologically fixed capacity-capital ratio or capital productivity, w the real wage rate, and π_L the technologically fixed labour productivity. Equation (2) defines an accumulation function. Equation (5) defines the commodity market equilibrium. Finally, relation (6) gives the short-run Keynesian stability condition for the $g^{\mathrm{I}} - g^{\mathrm{S}}$ equilibria (i.e. savings must increase by more than investment demand when u rises).

Equations (3) and (4) define a linear '$\rho - w$ curve', i.e. $\rho \equiv ru^{-1} = \pi_K (1 - \pi_L^{-1} w)$, the absolute value of the elasticity, e_1, of which equals the wage-profit ratio, i.e.

$$e_1 \equiv d \log \rho / d \log w = -\pi_L^{-1} w (1 - \pi_L^{-1} w)^{-1} = -(1-h)h^{-1} \tag{7}$$

Equations (1), (2), (3) and (5) define a relationship between profit share and degree of capacity utilization, $u = f(h)$, or 'IS – curve' (non-Hicksian), i.e.

$$F(u,h) = s\pi_K hu$$

[5] As Kurz (1990, pp. 232-233) stresses, "within the framework of the present model the choice of technique problem cannot generally be considered to be decided in terms of the technical conditions of production alone: the degree of capacity utilization matters too. The latter, however, reflects a multiplicity of influences, such as the state of income distribution and savings and investment behavior […]. In particular, there is the possibility that, assessed in terms of the degree of utilization associated with the existing technique, a new technique proves superior, while in terms of its own characteristic steady-state degree of utilization it turns out to be inferior.".

the elasticity, e_2, of which is given by

$$e_2 = (F_h - s\pi_K u)(s\pi_K h - F_u)^{-1} hu^{-1} \quad (8)$$

Since the term $(sh\pi_K - F_u)^{-1}$ is positive (see condition (6)), $F_h > s\pi_K u$ (i.e. savings respond more strongly than investment with respect to changes in h) implies that $e_2 > 0$, and vice versa. Finally, differentiation of $r = \pi_K hf(h)$ with respect to h gives

$$dr/dh = (1+e_2)\pi_K f(h) \quad (9)$$

from which it follows that an elastic, negatively sloped *IS* – curve necessarily implies that $dr/dh < 0$.[6]

Now, following Goodwin (1967), assume that (i) the labour force, N, grows at the steady rate n, i.e.

$$\hat{N} = n \ (< s\pi_K f(h)) \quad (10)$$

and (ii) the real wage rate rises in the neighbourhood of full employment ('real wage Phillips curve'), i.e.

$$\hat{w} = \gamma E - \delta, \ \delta\gamma^{-1} < 1 \quad (11)$$

where $E \equiv LN^{-1}$ denotes the employment rate, L the volume of employment, and γ, δ are positive constants.

Equations (4), (7) and (11) imply that

$$\dot{h} = (\delta - \gamma E)(1-h) = e_1(\gamma E - \delta)h \quad (12)$$

Since $L = \pi_{\mathrm{L}}^{-1}\pi_K uK$, where K denotes the capital stock in existence, and $g^{\mathrm{S}} \equiv \hat{K}$, it follows that $\hat{L} = \hat{u} + g^{\mathrm{S}}$ or, recalling equations (1), (3) and (8),

$$\hat{L} = e_2\hat{h} + s\pi_K hf(h) \quad (13)$$

or, recalling equation (12),

$$\hat{L} = e_2 e_1(\gamma E - \delta) + s\pi_K hf(h) \quad (14)$$

Substituting equations (10) and (14) in $\hat{E} = \hat{L} - \hat{N}$ yields

$$\dot{E} = [e_2 e_1(\gamma E - \delta) + s\pi_K hf(h) - n]E \quad (15)$$

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[6] It is easily checked that a linear accumulation function, $g^{\mathrm{I}} = a_0 + a_1 u + a_2 h$, where a_0 (≥ 0) represents the level of Keynesian "animal spirits", necessarily implies that $e_2 < 0$ (this is not necessarily true for an open economy; see Blecker, 1989, p. 400; Mariolis, 2006b, pp. 55-56) and may imply a non-monotonic relationship between r and h (since $dr/dh = 0$ at $h = [a_1 a_2 \pm \sqrt{a_1 a_2 (a_1 a_2 + a_0 s\pi_K)}](a_2 s\pi_K)^{-1}$).

Consequently, the model reduces to the non-linear system of equations (12) and (15), which has two equilibria with $\dot{h} = \dot{E} = 0$, namely

$$h^* = 1,\ E^* = 0 \tag{16}$$

and

$$h^{**} = (s\pi_K f(h^{**}))^{-1} n,\ E^{**} = \delta\gamma^{-1} \tag{16a}$$

To the latter there corresponds a unique value for g^S $(=n)$ and may correspond, when $e_2^{**} < 0$, more than one economically significant value for h (and, therefore, for u and w).

The Jacobian matrix, $\mathbf{J} \equiv [J_{ij}]$, of equations (12) and (15) is (take into account equation (9))

$$J_{11} \equiv \partial\dot{h} / \partial h = (\gamma E - \delta) \tag{17a}$$

$$J_{12} \equiv \partial\dot{h} / \partial E = -\gamma(1-h) \tag{17b}$$

$$J_{21} \equiv \partial\dot{E} / \partial h = \{[(de_2 / dh)e_1 + e_2 h^{-2}](\gamma E - \delta) + s\pi_K (1+e_2) f(h)\}E \tag{17c}$$

$$J_{22} \equiv \partial\dot{E} / \partial E = e_2 e_1 (2\gamma E - \delta) + s\pi_K h f(h) - n \tag{17d}$$

Since $\partial(\dot{E}E^{-1}) / \partial(1-h) < 0$ does not necessarily hold true (see equation (17c)), this system does <u>not</u> correspond to Kolmogorov's 'predator $(1-h)$ – prey (E) model' (see, e.g. May, 1972, p. 901. If $\partial(\dot{E}E^{-1}) / \partial(1-h) > 0$, the "two species are in symbiosis"; see Hirsch and Smale, 1974, p. 273). At the trivial fixed point, (h^*, E^*), $e_1^* = 0$ and $\mathbf{J}^*$ is diagonal, with $J_{11}^* < 0$ and $J_{22}^* > 0$; therefore, it is a saddle point, precisely like in Goodwin's model. Next consider the non-trivial fixed point(s), (h^{**}, E^{**}). Then $J_{11}^{**} = 0$, $J_{12}^{**} < 0$, and there are the following cases:

(i). When $e_2^{**} > 0$, it follows that $\text{Tr}\,\mathbf{J}^{**} < 0$ and $\text{Det}\,\mathbf{J}^{**} > 0$: stable.

(ii). When $e_2^{**} = 0$, it follows that $\text{Tr}\,\mathbf{J}^{**} = 0$ and $\text{Det}\,\mathbf{J}^{**} > 0$: the system behaves locally like Goodwin's one.

(iii). When $-1 < e_2^{**} < 0$, it follows that $\text{Tr}\,\mathbf{J}^{**} > 0$ and $\text{Det}\,\mathbf{J}^{**} > 0$: unstable.

(iv). When $e_2^{**} = -1$, it follows that $\text{Tr}\,\mathbf{J}^{**} > 0$ and $\text{Det}\,\mathbf{J}^{**} = 0$: unstable.

(v). When $e_2^{**} < -1$, it follows that $\text{Tr}\,\mathbf{J}^{**} > 0$ and $\text{Det}\,\mathbf{J}^{**} < 0$: saddle point.[7]

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[7] Cases (i), (iii) and (v) correspond to alternative sets of steady-state equilibria or growth regimes, i.e. "Keynesian, overaccumulation and underconsumption regimes", respectively (according to Kurz's,

Thus, it can be concluded that, depending on the local elasticity of the IS – curve, which depends, in its turn, on the form of the accumulation function, the system can generate complex dynamic behaviours.

Finally, consider an identical system that produces, however, many 'basic commodities' (in the sense of Sraffa, 1960, pp. 7-8) by linear processes of single production, and assume that: (i) the production period is uniform across sectors; (ii) the degree of capacity utilization is uniform both within and across sectors; (iii) the desired rate of accumulation is a strictly increasing function of both the degree of capacity utilization and the aggregate profit share; (iv) workers and capitalists have identical rigid consumption patterns; and (v) the consumption vector is adopted as the numeraire.[8] Now, as is well-known, (i) the negatively sloped $\rho - w$ curve is not necessarily linear; and (ii) the aggregate productivities of labour and capital are not given independently of, and prior to, prices, income distribution and growth (unless the labour input vector or the consumption vector is the Perron-Frobenius eigenvector of the capital coefficients matrix), and, in fact, can change in a complicated way as distribution changes (see Sraffa, 1960, chs 3-6, and, for example, Marglin, 1984, pp. 233-244).[9] Consequently, equations (8) and (9) should be replaced by

$$e_2 = [F_h - (1+e_3)(s\pi_K u)](s\pi_K h - F_u)^{-1} h u^{-1}$$

and

$$dr / dh = (1 + e_3 + e_2)\pi_K f(h)$$

where e_3 denotes the elasticity of π_K with respect to h, and consists of a price effect and a quantity effect (for a detailed examination, see Mariolis, 2007, pp. 366-368). It is noted, moreover, that h continuous to be a strictly increasing function of ρ (see

1990, pp. 222-226, terminology). Some numerical examples are given in the Appendix: It is shown (see Example 3) that a 'U-shaped' IS – curve (see also Marglin and Bhaduri, 1988, pp. 22-23, and Bhaduri and Marglin, 1990, pp. 392-393) may generate a Hopf bifurcation of periodic solutions (for an introduction to the Hopf bifurcation theorem, see, e.g. Medio, 1992, pp. 59-69).

[8] It need hardly be emphasized that assumptions (ii) and (iii) are rather crude. However, more realistic assumptions lead to great complications. Assumptions (iv) and (v) imply that the money wage rate equals the real wage rate.

[9] Consider the eigenvalues of the capital coefficients matrix: As it has recently been argued, when the ratios of the moduli of the first non-dominant eigenvalues to the dominant one fall 'quite rapidly', and the rest constellate in much lower values forming a 'long tail', the $\rho - w$ curve is almost linear irrespective of the numeraire chosen, and the price – ρ (and quantity – $s\rho$) curves tend to be monotonic (see Schefold, 2008, Mariolis and Tsoulfidis, 2011, and Iliadi et al., 2012). Consequently, (i) the deviations between the directions of the labour input and consumption vectors and the relevant Perron-Frobenius eigenvectors; and (ii) the speed of fall of the eigenvalue ratios could be considered as measures of the degree of capital heterogeneity.

Franke, 1999, pp. 46-49 where $u = 1$ holds by assumption) and, therefore, $h = \pi_K^{-1}\rho$ implies that $1 + e_3 > 0$. Furthermore, equation (13) should be replaced by

$$\hat{L} = (e_3 - e_4 + e_2)\hat{h} + s\pi_K hf(h) \tag{18}$$

where e_4 denotes the elasticity of π_L with respect to h (and $e_4 - e_3$ equals the elasticity of capital-intensity with respect to h). Thus, equations (10), (11) and (18) imply that the model reduces to the following non-linear system:

$$\dot{h} = e_1(1+e_3)^{-1}(\gamma E - \delta)h$$

$$\dot{E} = [(e_3 - e_4 + e_2)e_1(1+e_3)^{-1}(\gamma E - \delta) + s\pi_K hf(h) - n]E$$

which includes the system of equations (12) and (15) as a special case (i.e. $e_1 + (1-h)h^{-1} = e_3 = e_4 = 0$). It then follows that, in a heterogeneous-capital world, the system is very complex, even if the accumulation function is supposed to be linear. Moreover, after Rodousakis's (2012) contribution, it seems that the study of its dynamic behaviour cannot be simplified significantly by using Goodwin's (1976, 1977, 1984) method of diagonalization of the production system into 'eigensectors'.

3. Concluding Remarks

It has been shown that the incorporation of the Bhaduri-Marglin accumulation function in Goodwin's growth cycle model leads to rather complicated interactions between distribution, capacity utilization, accumulation and labour employment. More specifically, the degree of complexity depends crucially on two separate factors: (i) the form of the accumulation function; and (ii) the degree of capital heterogeneity. Thus, it seems that, a priori, nothing unambiguous can be said about the dynamics of the system.

Future work could allow for commodity market disequilibrium, concretize the analytical framework (primarily by including the presence of depreciation, 'overhead' labour, technological change, monetary factors, and disaggregated accumulation functions) and, finally, test empirically that more realistic model(s).

Appendix: Numerical Examples

Example 1

Consider a linear accumulation function, $g^{\mathrm{I}} = a_0 + a_1 u + a_2 h$, and assume that $a_0 = 0.01$, $a_1 = 0.03$, $a_2 = 0.05$ and $s\pi_K = 1$. It is obtained that (see equations (8) and (9))

$$u = (0.01 + 0.05h)(h - 0.03)^{-1}$$

$$e_2 = -0.23h[(0.17 + h)h - 0.006]^{-1}$$

$\{u > 0,\ e_2 < 0\}$ for $h > 0.03$, $u = 1$ at $h \cong 0.042$, and $e_2 = -1$ at $h \cong 0.113$. Now, assume that $\gamma = 0.004$, $\delta = 0.003$ and $n = 0.03$. Thus, it is obtained that (see equations (16a)) $h_{1,2}^{**} = 0.2 \pm \sqrt{5550^{-1}}$ and $E^{**} = 0.75$. At $h_1^{**} \cong 0.348$ we get $e_2^{**} \cong -0.459$, $\mathrm{Tr}\,\mathbf{J}^{**} \cong 0.003$, $\mathrm{Det}\,\mathbf{J}^{**} \cong 0.001$ and that the discriminant, $\Delta^{**} \equiv (\mathrm{Tr}\,\mathbf{J}^{**})^2 - 4(\mathrm{Det}\,\mathbf{J}^{**})$, is negative: the fixed point is an unstable focus. At $h_2^{**} \cong 0.052$ we get $e_2^{**} \cong -2.157$: the fixed point is a saddle point.

Example 2

Consider a 'power' accumulation function, $g^{\mathrm{I}} = a_0 u^{a_1} h^{a_2}$, and assume that $a_0 = 1$, $a_1 = 0.8$, $a_2 = 1.3$, $s\pi_K = 1$, $\gamma = 0.004$, $\delta = 0.003$ and $n = 0.03$. It is obtained that $u = h^{e_2}$, $e_2 = (a_2 - 1)(1 - a_1)^{-1} = 1.5$, $h^{**} = n^{0.4} \cong 0.246$, $E^{**} = 0.75$, $\mathrm{Tr}\,\mathbf{J}^{**} \cong -0.014$, $\mathrm{Det}\,\mathbf{J}^{**} \cong 0.001$ and $\Delta^{**} < 0$: the fixed point is a stable focus. Finally, by letting n vary parametrically, we get

$$\Delta^{**}(n) = 0.003(1 - n^{0.4})n^{-0.8}[0.00675(1 - n^{0.4}) - 10n^{1.4}]$$

from which it follows that $\Delta^{**}(n) \geq 0$, i.e. the fixed point is a stable node, for $n \leq 0.005$ (approximately).

Example 3

Consider the accumulation function $g^{\mathrm{I}} = u^{1/6}\phi(h)$, where $\phi(h) \equiv a_0 + a_1 h - h^2 + h^3$, $d\phi / dh > 0$ for $a_1 > 3^{-1}$, and $a_0 > 0$, and assume that $a_0 = 0.005$, $a_1 = 0.35$ and $s\pi_K = 2$. It is obtained that

$$u = [0.5(0.005h^{-1} + 0.35 - h + h^2)]^{6/5}$$

$$e_2 = [1.2h(-0.005h^{-2} - 1 + 2h)](0.005h^{-1} + 0.35 - h + h^2)^{-1}$$

$u = 1$ at $h \cong 0.00302$, $u \cong 0.12561$ at $h = 1$, $e_2 = 0$ at $h = \tilde{h} \cong 0.50963$ and $e_2 = -1$ at $h \cong 0.00291$ or 0.27045 or 0.37370 (see also Figure A1). Now, assume that $\gamma = 0.004$, $\delta = 0.003$ and $n = \tilde{n} \cong 0.0313517$. Thus, it is obtained that $h^{**} = \tilde{h}$, $E^{**} = 0.75$, $e_2^{**} = 0$, i.e. the system behaves locally like Goodwin's one, and $d(\mathrm{Re}\,\lambda(a_0))/da_0 > 0$ at $a_0 = 0.005$, where $\mathrm{Re}\,\lambda(a_0)$ denotes the real part of the eigenvalues of $\mathbf{J}^{**}(a_0)$, since, as it is easily checked, $\partial e_2 / \partial a_0 < 0$. We can therefore conclude that the system undergoes a Hopf bifurcation at $a_0 = 0.005$.

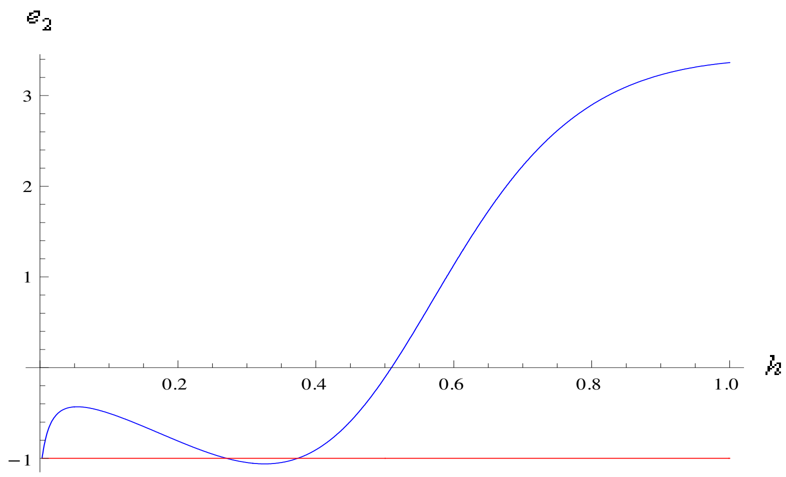

Figure A1. *The elasticity of the IS – curve as a function of the profit share (for* $h > 0.00302$ *).*

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