Natural Limits to Economic Development: Endogenous Growth or *Panacea*?*

Simone D'Alessandro♣ and Francesco Drago♠

Ph.D. Students, Department of Economics,
University of Siena, Siena, Italy

Very preliminary draft
5-01-2003
Comments are welcome

Abstract

The relevance of environmental problems (e.g. scarcity of water and desertification) calls for a fully comprehensive analysis of the connections between economic growth and natural resources. In this paper, we analyse in an historical perspective how natural resources bound the possibility for an economy to grow indefinitely. We compare the Classical approach to growth and the recent Neoclassical Endogenous Growth Theory (EGT). We point out how the assumptions that in the EGT are taken into account to overtake the boundary of resources can be traced back to the von Neumann model. With a simple model, we provide evidence that the presence in the wage goods basket of commodities produced with scarce resources is crucial for the overcoming of natural limits to growth. The reference to the Classical approach is useful to compare EGT models with the von Neumann model in order to understand which assumptions allow to grow without any limits. We argue that the von Neumann model shows already how strong must be the hypotheses to have endogenous growth without limits. Finally, we emphasize that, differently from the Classical economics, the inadequacy of von Neumann model and the EGT to treat environmental problems are related to their historical, axiomatic and reductionism features.

Keywords: Endogenous Growth Theory, von Neumann Model, Classical Economics, Natural Limits.

---

* We would like to thank Martina Pignatti Morano for their generous comments on previous versions of this paper.

♣ e-mail: dalessandro2@unisi.it, simonedalessandro@hotmail.com
♠ e-mail: drago@econ-pol.unisi.it, francescodrago@hotmail.com

Introduction

The scarcity of natural resources in the last centuries, although the severity of the effects varied, has constrained economic activity. Before the industrial revolution, because of lack of technology and limitation of forests, shortage of fuel was serious. Since the eighteenth century, English agriculture experienced the limitedness of the best quality land and, after the industrial revolution, the scarcity of mines was also recognized by Adam Smith and John Stuart Mill.

Absolute scarcity is still severe, in modern economies, e.g. concerning oil reserves. Optimist and pessimist perspectives on the availability of oil say that the extraction peak will be reached in the first half of this century, and their estimates differ just for a period of thirty years (cf. Rifkin 2002, p. 34) [1].

The increase in the size of population and in the needs clashes with the insurmountable problem of the finitude of nature. As ecological economists argue, the conceptualization of lung run growth and of future patterns of development calls for a full investigation of these problems. Theories of economic growth should take into account that resources are limited in quantity and indispensable for *any* system of production.

In this paper, we analyse in an historical perspective how natural resources bound the possibility for an economy to grow indefinitely. In order to understand how theories of economic growth take in account the problem of natural resources we compare the Classical approach of Ricardo to growth and development, the recent models of Endogenous Growth Theory (EGT) and the von Neumann growth model.

The connections between economic growth and scarcity of natural resources have been analysed by different economists starting from Adam Smith until the recent theorists of endogenous growth. When economic growth is analysed it is natural to deal also with the way elements constrain growth. Such elements are factors of production available in given quantity and non-reproducible. Economists recognized very early that one of the main important factors that constrain economic growth is the limitation of nature, evident in the scarcity of natural resources. We shall call this kind of limits more generally *natural limits to growth*. Obviously, the presence of long run growth is related to the presence of environmental constraints in such a way that we can maintain that natural limits are escaped whenever in an economic model there is long run growth.

In addition to the general issue of growth, economists dealt with the eventual overcoming of environmental constraints. Adam Smith for example asserted that increasing returns generated by the division of labor were able to generate long run growth. Contrarily Ricardo was convinced that no elements generated by economic activities could escape

[1] It is interesting to notice that these data have been derived by the major oil companies to support future investment strategies. K.F. Deffeyes (2001), ex responsible of oil exploration in Shell Oil Research of Houston (Texas), presents an enquiry on the impending world of oil shortage.

the tendency to the stationary state. More recently in the EGT models the presence of a "core of cumulative capital goods" as human capital or knowledge escapes natural limits to growth.

It is interesting to note that in all the examples mentioned above the overcoming of natural limits to growth has its origins in the (voluntary or involuntary) behaviour of individuals; and that economic growth is conceived as endogenous. If one considers that the engine of growth is the accumulation of physical (or human) capital, which pace is regulated by the rate of profit, consequently, also the source of the eventual overcoming of natural limits must be endogenous. Differently in models of exogenous growth, the source of the overcoming of natural limits to growth consists in unexplained and exogenous elements as the exogenous rate of technological progress or the exogenous rate of growth of labor force. In the following sections, we focalise our attention on endogenous theories of Ricardo, von Neumann and EGT models.

The underlying ideas on how the economic system overcomes natural limits are implicitly or explicitly translated in models of economic endogenous growth through assumptions. For example in the EGT models the idea that the accumulation of human capital drives growth is modelled in such a way that decreasing returns are not involved in the accumulation process. In this case, human capital, the reproducible and cumulative factor of production, is always abundant relatively to non-reproducible factors of production given in fixed quantity, as natural resources. In the following sections the focus will be in the full and critical understanding of the assumptions which allow for long run growth and on the underlying ideas involved by these assumptions.

Surveying the three approaches, our attempt is to show which assumption in EGT models allows to overcome the environmental constraints to growth. Moreover, we show how the hypothesis on the primary factors of production in EGT and Classical approach can be traced back to the von Neumann model.

We analyse the von Neumann model, the Classical approach and EGT models mainly for the following reason: they are the three main approaches that theoretically conceive growth as an endogenous mechanism. We are convinced that this brief survey can clarify some aspects with regard to growth and natural limits to economic development. Regarding these limits, we chose to focus on the following elements: the rule of free goods, the related concept of relative scarcity and the assumptions on primary factors of production.

The paper is divided as follows, in the second section, we compare the Classical approach of Ricardo, EGT models and von Neumann model concerning the assumptions on primary factors and on their scarcity. In the third section, we provide evidence with a simple model about the assumptions that allow the economy to growth indefinitely. In the fourth section, we point out differences and analogies between EGT and the Classical approach with the von Neumann model regarding absolute scarcity of primary factors of production. In the final section, we draw some conclusions.

1. Von Neumann model, EGT models and the Classical approach: how environment constrains endogenous growth?

1.1. The von Neumann growth model

The von Neumann growth model reaches a solution through a system of equations that describes an expanding economy. It is assumed that: "Goods are produced not only from "natural factors of production", but in the first place from each other. These processes may be circular […]"[2]. Moreover, it is assumed that there are constant returns to scale in the production of final good G_j and that "natural factors of production, including labor, can be expanded in unlimited quantity"[3].

Following the exposition of Dore (1989), we summarize the fundamental inequalities of the growth model:

$$\alpha Ax \leq Bx\,, \tag{1}$$

$$\beta pA \geq pA\,, \tag{2}$$

where x is the vector of the activity levels, p is the vector of prices, A is the matrix of input coefficients, B is the matrix of the output coefficient, β and α are respectively the interest rate and the expansion factor. It is assumed that 'if there is excess of production of G_j, G_j becomes a free good and its price $[p_j]=0$". The process that incurs in extra costs will not be operated and x and p are semipositive. It follows that:

$$x^t(B-\alpha A)p = 0\,, \tag{3}$$

$$x^t(B-\beta A)p = 0\,, \tag{4}$$

$$x \geq 0, p \geq 0\,, \tag{5}$$

where equation (3) is the rule of free goods, and equation (4) implies that the loss-making process is abandoned.

[2] Von Neumann (1937).
[3] Ibidem.

Von Neumann using a generalization of the Brouwer's Fix Point Theorem determines the processes operated, the prices of the commodities produced, the rate of expansion and the interest rate. In his analysis he shows that a solution exists and that necessarily $\beta=\alpha$.

The assumptions above allow the economy to grow indefinitely at a constant rate equal to the interest rate. It follows that the von Neumann model is the first model of endogenous growth in which the growth rate is determined *inside* the model.

For our objectives, it is interesting to note the presence of the rule of free goods. As Dore (1989) argues, von Neumann was the first to determine endogenously whether a resource is scarce or not[4]. In this context the price paid for the use of land is equal to zero since land is assumed to be unlimited. In the economic system when natural resources given in quantity are assumed to be inputs in the production of final or intermediate goods, it is not absolute scarcity that per se constrains economic growth but it is relative scarcity that *may* constrain economic activity[5].

With regard to labor, it does not appear in input matrix A. The worker's "consumption basket" figures in matrix A in the place of labor and this implies that workers consume the entire income available. This implies from one hand that technology "produces" the labor force (in this sense the supply of labor force is not exogenous), and from the other hand that labor can be produced without any limits since land is unlimited and workers consume also commodities produced with land.

1.2. The Classical approach

When we refer to the Classical approach we mean the Ricardian theory of differential rent. Ricardo, similarly to von Neumann, applies the rule of free goods to natural resources. As he claims, "no rent could be paid for such land [land that is not scarce], for the reason stated why nothing is given for the use of air and water, or for any of the gifts of nature which exist in boundless quantity"[6]. The existence of a positive rent on land depends on the demanded quantity of commodities to be produced with land, once we know as data: the quantity of resources available which can be utilized in place of land, and the available technology to produce the commodities with land or with other natural resources. Hence if a natural resource is (relative) scarce it depends from the data of economic system.

---

[4] More precisely, von Neumann was the first to introduce formally the slackness condition. Nevertheless, as Kurz and Salvadori (1993) point out the idea of the rule of free goods (at least for natural resources) is already present in the Classical approach.
In this growth model the rule of free goods is applied to primary factors of production excluded labor (cf. Kurz and Salvadori (1993)).

[5] A natural resource is relatively scarce when the demand for its use exceeds the quantity available in the market so that it is fully employed.

[6] Ricardo, *Works I*, p.69.

With regard to the other primary factor of production, i.e. labor, according to the Classics the economic system "produces" the amount of labor demanded for production of commodities. The wage is entirely consumed and it consists of commodities produced with land. Indeed, it is a subsistence wage, seen as "feed for cattle" or "oil for machine", given by social and political conditions. As a consequence, with the increase of population, the presence of diminishing returns on capital and labor - due to the limitedness of land - pushes down the rate of profit and the economy tends to the stationary state.

What emerges is that, unlike the von Neumann model, not all the primary factors of production are expandable indefinitely: land is considered as an inexhaustible resource given in quantity; labor, although in principle reproducible without any limit, is constrained by the fact that labourers consume corn and land is given. Moreover, once land is relatively scarce, there is no element such as technological progress which is able to escape from the progressive attainment of stationary state in the long run.

1.3. EGT models

The recent literature on the New Growth Theory, namely endogenous growth theory, started in the late eighties with the contributions of Romer (1986), Lucas (1988) and Rebelo (1991). One of the main points of the EGT models is the focus on primary factors of production as human capital or knowledge. They are reproducible and cumulative factors of production. Human capital is embodied in labourers, knowledge is considered as a stock and it can be produced by means of knowledge, human capital and physical capital. As Kurz and Salvadori (1998) pointed out, In EGT models human capital and knowledge play the same role of labor in the Classical approach. It is assumed that the production of these inputs responds to economic incentives. We can maintain that the pace of the accumulation of human capital is endogenous, as determined by economic variables.

Focusing on the environmental problem, as in the standard neoclassical theory, in EGT models the rule of free goods is applied to all commodities and to all primary factors of production, included natural resources. Differently from the Classical approach, in EGT models the relative scarcity of natural resource does not involve the attainment of stationary state in the long run, for example in Romer (1986) and in Rebelo (1991). The inexistence of natural limits to growth is based on some assumptions on the production of the cumulative "core of capital goods", which imply that there exists a sector capable of producing indefinitely primary factors of production. The difference with the Classical approach is clear: in Ricardo, the production of labor was constrained; in EGT models, the production of human capital or knowledge is possible without any limit.

1.4. Analogies: relative scarcity, labor and endogenous growth

What emerges from the simple comparison treated above is that the general mechanism that generates economic growth is very similar in the different approaches: firstly, it is endogenous; secondly, there is the same view on the way labor is "produced" among the Classics, von Neumann and EGT models (for the latter the production concerns the human capital input); finally, the presence of natural resource relative scarce is not sufficient in order to obtain natural limits to growth (if in the Classical approach it is sufficient, in EGT models it is not).

Once we have recognized these points we can understand which assumptions allow for continuous growth in the von Neumann model and in EGT models. In the first approach, the economy grows assuming that all primary factors of production are unlimited in quantity so that environmental constraints are explicitly excluded by hypothesis. In the second, as we will see in the next section, it is crucial to assume that the production of the "core of capital goods" does not involve directly, neither indirectly, natural resources.

2. A simple model

2.1. AK models

The Rebelo's article (1991) originated a long sequence of models named AK. The main characteristic of these models is that an optimal path of balanced growth is possible in a framework of convex technology. Therefore, endogenous growth is not a result of increasing returns of scale. For this reason, this kind of models is fit for a comparison with linear models (von Neumann model) and with the Classical framework (cf. Pasinetti 1960).

In the basic model, Rebelo considers two sectors; one produces a cumulative good and the other the consumption good. The former represents a general omni comprehensive capital good or, to be precise, a mix of physical capital and human capital, where human capital entirely substitutes labor. This good is produced only by means of itself. The consumption good is the only variable that enters in the instantaneous utility function and is produced using land and capital. The problem of this model is to maximize the actual value of future utilities under the boundaries given by the production functions. The features of the solution are very easy to obtain. Subsequently the two parts of the wide concept of capital are explicitly considered and Rebelo proves that growth is possible not only with linear production functions (à la von Neumann) but also with functions that are linearly homogeneous.

Which are the necessary conditions to have endogenous growth in this framework? How Rebelo himself emphasizes,

> *…growth is endogenous despite the absence of increasing returns because there is a "core" of capital goods that can be produced without the direct or indirect contribution of factors that cannot be accumulated, such as land.*[7]

To comment exhaustively on the role of this necessary condition, we want to point out some results through a simple model that brings the economy towards a "classic" stationary state.

2.2. The model

The economy is described by two sectors of production:

$$I_t = A(\phi_t Z_t)^{\alpha} C_t^{1-\alpha}, \tag{6}$$

$$C_t = B[(1-\phi_t)Z_t]^{\beta} T^{1-\beta}, \tag{7}$$

where I_t is the quantity of investment good produced at time t, C_t is the quantity of consumption good produced at time t. The two production functions are two linearly homogeneous Cobb Douglas, therefore the two exponents are such that $0<\alpha<1$, $0<\beta<1$. T is a composite good which summarizes the fixed amount of non-reproducible factors. Finally Z_t summarizes the quantity of all reproducible factors considered as a composite of human and physical capital, therefore labor does not explicitly appear but is included in this variable. The only difference with the Rebelo model is the presence of the consumption good in the production of the investment good. This hypothesis of considering consumption as necessary in the production of human capital, and hence in the production of composite capital (cf. equations (7) and (8)) seems correct, and is at the base of the different result of the model. Its justification lies in the fact that workers need consumption in the wage goods basket in order to accumulate human capital.

The path of accumulation can be summarized through the variation in time of composite capital ($\dot{Z}_t$):

$$\dot{Z}_t = I_t - \delta Z_t = A(\phi_t Z_t)^{\alpha} C_t^{1-\alpha} - \delta Z_t, \tag{8}$$

[7] Rebelo (1991) p. 501.

where δ is the rate of depreciation of capital.

The economy driven by the preferences of consumers must find the optimal path that allocates a quote ϕ_t of the capital good to the sector of investment, through the maximization of the actual value of future instantaneous utility:

$$U = \int_0^{\infty} e^{-\rho t} \frac{C_t^{1-\sigma} - 1}{1-\sigma} dt \,. \tag{9}$$

The result of this equation is well known in the endogenous growth theory, and is capable of optimising the choice between saving and consumption, that is

$$g_c = \frac{r_t - \rho}{\sigma}, \tag{10}$$

where g_c is the rate of growth of consumption, r_t the rate of interest at time t, ρ the discount rate of preferences and $\frac{1}{\sigma}$ the intertemporal rate of substitution between present and future consumption.

With this model, we want to prove that if the consumption good enters in the production of composite capital, there exists no path of equilibrium with constant rate of growth, and the rate of growth of the balanced growth path is decreasing.

It is quite easy to find the solution of balanced growth; that is when ϕ_t is constant in time. The equilibrium in the long run is characterized by two conditions.

Firstly, in each efficient allocation the marginal product of composite capital measured in terms of units of consumption good has to be equated in the two sectors, therefore

$$p \;\alpha A(\phi_t Z_t)^{\alpha-1} C_t^{1-\alpha} = \beta B[(1-\phi_t)Z_t]^{\beta-1} T^{1-\beta}, \tag{11}$$

where p_t is the price of composite capital in terms of the consumption good. If we are interested only in the balanced solutions, we can write the relation among the rates of growth:

$$g_p + (\alpha - 1)g_z + (1 - \alpha)g_c = (\beta - 1)g_z, \tag{12}$$

where g_p is the rate of growth of the price of capital good in terms of the consumption good, while g_z and g_c are respectively the rate of growth of composite capital and of consumption.

The second condition is a standard arbitrage condition: according to it the net marginal product must be equal in each sector. In this case

$$r_t = r_t^c = r_t^z + g_p = \alpha A(\phi_t Z_t)^{\alpha-1} C_t^{1-\alpha} - \delta + g_p, \tag{13}$$

where r_t^c and r_t^z are the net marginal revenues respectively of the sector of consumption and of the composite capital. From equation (7) it follows that

$$g_c = \beta g_z. \tag{14}$$

Finally from equations (9), (12), (13) and (14), through some algebra, we obtain an expression of the rate of growth of composite capital:

$$g_z = G Z_t^{(1-\beta)(\alpha-1)} - \frac{\delta + \rho}{\sigma\beta - \alpha\beta + \alpha}, \tag{15}$$

In this expression $G = \dfrac{\alpha A \phi^{\alpha-1}(1-\phi)^{\beta(1-\alpha)} T^{(1-\beta)(1-\alpha)}}{\sigma\beta - \alpha\beta + \alpha}$ is always positive. By calculating the variation of the rate of growth of composite capital in time, we obtain that

$$\dot{g}_z = G(1-\beta)(\alpha-1) Z_t^{(1-\beta)(\alpha-1)-1} \dot{Z}_t. \tag{16}$$

This means that the rate of accumulation is always negative because $(1-\beta)(\alpha-1) < 0$, at least when there is accumulation, therefore when $\dot{Z}_t > 0$. Instead, when $\dot{Z}_t = 0$ the rate of growth is zero, namely we reach the "classical" stationary state.

How we pointed out above, the results concerning the rate of growth are opposite to those of the EGT models. The crucial difference lies in the assumption that, in the production function of the composite capital good, the consumption good is a necessary input.

3. The role of primary factors

3.1. Behind human capital: the marginalization of natural world

Human capital constitutes a primary factor of production, which is reproducible, cumulative and inherently embodied in workers. It can be cumulated through voluntary (i.e. education) or involuntary (i.e. learning by doing) behaviour, or both. Since it is supported by labor, the human capital input is the labor input in the production process, adjusted for quality in terms of skills rewarded in the job market. Therefore, the human capital input cannot be interpreted as being totally immaterial if the labor input is not separately specified. In this sense, the production of human capital inputs needs also material inputs, because, in the wage goods basket, there are commodities produced with non-reproducible resources.

Instead, in EGT models, the sectors making up the process of accumulation are directly and indirectly separated by sectors involving natural resources. In this way, the sector (or the sectors) producing the consumption good(s) becomes non-necessary to growth, and hence, in a "classical" sense, this good has only the role of a luxury good. In the light of what we said above, by comparing these models of EGT with the mathematical representation of the Ricardian system done by Pasinetti (1960), it is easy to understand how much the two descriptions of the economy are similar. From one side the difference between the results is given by the hypotheses on the consumption good (how we showed above), on the other side if workers of the Ricardian system consume the cumulative good, namely gold, the result of the model are exactly the same of the models of EGT[8].

Indeed, these models hide the resurgence of the accumulation of labor behind the introduction of human capital. Nevertheless, the assumption is exactly the same of "feed for cattle" or "oil for machine" in the classic framework. The attempt to consider labor as endogenous must take into account this classic vision of workers. It is not possible to delete complitely the materiality of work with the employment of a generic human capital.

After we have made clear the concept of human capital, the role left to natural resources in EGT seems clearer. If all the non-reproducible factors are completely involved in the

[8] D'Alessandro and Salvadori (2002).

production of luxury goods, the (absolute or relative) scarcity of these factors cannot stop the unlimited growth. This configuration implies that land, other natural resources and any other non-reproducible factor are either useless or unlimited.

These assumptions are very strong, and are exactly the same at the basis of the von Neumann model. Hence, the Endogenous Growth Theory generalizes the linear von Neumann model in the case of linearly homogeneous production, and introduced a new autonomous sector that produces a luxury good. However, the role of all natural resources is marginal because their full introduction would change the result toward the stationary state.

3.2. Endogenous Growth and Environment

The connections between endogenous growth and environment are apparently quite simple. Obviously, in all the approaches at least one primary factor of production has to be produced indefinitely in order to obtain long run growth. Only in this way this factor can be relatively abundant with respect to the eventual factor that cannot be accumulated, so that its productivity is not decreasing. In the Classical approach, the labor input cannot be produced indefinitely because land is in limited quantity and it imposes diminishing returns to capital and labor, while in EGT models the human capital input substitutes labor. Differently by labor, the human capital input is accumulable and it is not produced directly neither indirectly by means of natural resources, so it can be expanded indefinitely. This implies that relative scarcity of natural resources does not impose natural limits to growth. Relative scarcity involves natural limits to growth only if natural resources incise on the production of the factors driving growth. Moreover, the recourse to human capital inputs substituting labor solves the problem of cumulativity. Indeed, if a labor efficiency unit was assumed in place of human capital, an exogenous rate of growth of labor force has to be assumed in order to expand labor indefinitely. This is the case of exogenous growth models à la Solow in which the exogenous technological progress is labor augmenting.

In the von Neumann model, natural limits to growth are excluded by hypothesis, disregarding non-reproducible factors available in given quantity. As Champernowne (1945) pointed out in his note on the von Neumann's article: 'in a world where the scarcity of non-augmentable resources exerts a major influence on the productive system, von Neumann's model ceases to be interesting"[9]. We want to ask to which extent the assumption on the primary factors of production in the von Neumann model really differs from the underlying ideas of EGT models; in other words if the Champernowne's comment is equally applicable to EGT models. The answer does not depend on the

[9] Champernowne (1945).

presence of natural limits but rather on the soundness of the treatment of the means to overcome the limitedness of nature.

It is believed that the accumulation of human capital is such a strong process for the determination of growth that for the sake of simplicity natural resources are excluded from the inputs of human capital. Instead, we showed that this is not the case; therefore, it is possible to justify the exclusion of natural resources only by sustaining that in the real world natural limits to growth are not important enough to tackle the limitedness of nature.

4. Concluding Remarks

Among the different models of endogenous growth we can distinguish between models that explicitly take into account the presence of limitedness of natural resources and models in which these problems are not treated. As we pointed out above, in all the growth models it is possible to identify the eventual presence of a natural limit to growth and to recognize which ideas allow to overcome these problems. In this paper, we tried to establish some analogies and some connections between the analysed models, concerning the endogenous mechanism whereby the economy grows.

The von Neumann model shares with EGT models the inexistence of natural limits to growth. Nevertheless, while in the von Neumann model the purpose is explicitly the description of an expanding economy in which there is no problem of scarcity of non-reproducible factors, in EGT models the recourse to human capital inputs is a trick to solve the problem of absolute scarcity of natural resources. However, in EGT models natural resource are marginalized (cf. paragraph 4.2) and they are not involved in the sectors driving growth. Therefore, in order to interpret EGT models also in a normative sense, we have to consider that natural resources are necessary in any system of production. Unlimited growth is possible just because there exist ad hoc assumptions on the production of human capital and knowledge inputs.

We think that investigation of the connections between endogenous growth and endogenous formation of human capital with regard natural limits to growth is a fruitful field of research.

References

Champernowne, D.G. (1945). 'A note on J. v. Neumann's article on 'A Model od Economic Equilibrium'', *Review of Economic Studie,* 13, pp. 10-18.

D'Alessandro, S., Salvadori, N. (2002), ' Pasinetti versus Rebelo: two different models or just one?' ,http://www-dse.ec.unipi.it/salvadori/pdf/PasinettiRebelo.pdf).

Deffeyes, K. S. (2001). *Hubbert's Peak. The Impending World of Oil Shortage*, Princeton (NJ): Princeton University Press.

Dore, M. (1989). ' The Legacy of von Neumann' in, Dore, Chakravarty and Goodwin (1989), pp. 89-99

Lucas, R.E. (1988). 'On the mechanism of economic development', *Journal of Monetary Economics,* 22(1), pp. 3-42

Neumann, J. von (1937). 'Uber ein Okonomisches Gleichungssystem und eine Verallbemeinerung des Brouwerschen Fixpuntktsatzes' , *Ergbenisse eines Mathematischen Kolloquim*, **8**, pp. 85-104. Tradotto in inglese (1945). 'A Model of Generale Economic Equilibrium,' *Review of Economic Studies*, **13**, pp.1-9.

Kurz, H. D. and Salvadori, N. (1993). ' Von Neumann's growth model and the 'Classical' Tradition ', *The European Journal of the History of Economic Thought,* 1, pp. 95-123.

Kurz, H. D. and Salvadori, N. (1998) ''Classical' vs. 'Neoclassical' Theories of Value and Distribution and the Long-period Method' ,F. H. Hahn and F. Petri, eds., *General Equilibrium: Problems and Prospects*, London: Routledge.

Pasinetti, L.L. (1960), ' A mathematical formulation of the Ricardian system' *Review of Economic Studies*, 27(2), 78-98.

Rebelo, S. (1991). 'Long run policy analysis and long run growth', *Journal of Political Economy,* 99. pp. 500-521

Ricardo, D. (1951–73). *The Works and Correspondence of David Ricardo*, edited by Piero Sraffa with the collaboration of Maurice H. Dobb, 11 vols, Cambridge: Cambridge University Press.

Rifkin, J. (2002), *The Hydrogen Economy: The Creation of the World-Wide Energy Web and the Redistribution of Power on Earth*, New York: Jeremy P. Tarcher/Putnam.

Romer, P. M. (1986). 'Increasing returns and long run growth', *Journal of Political Economy,* 94(5), pp. 1002-1037