CAN THE WORLD FEED ITSELF? SOME INSIGHTS FROM GROWTH THEORY

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This paper develops a two-sector growth model incorporating the essential distinguishing features of agriculture, including the reliance of production on a natural resource base as well as on industrially produced inputs, the low income elasticity of demand for food and the life-sustaining function of food consumption. In this framework, the ability of an economy to supply an adequate supply of food to a growing population can be related to the existence of a steady state. This property is used to define a simple analytical criterion upon which to assess the long-term food situation of a closed economy. This sustainability condition relates all the dynamic parameters of the economy: rates of technological change in the two sectors, rate of population growth and rate of land degradation. The condition is used to highlight the technological characteristics in agriculture conducive to sustainability and to assess empirically the food situation of a number of countries. Although no global food crisis appears to be looming ahead, the data suggest that sub-Saharan Africa is likely to increase its food dependence in the future.

1. INTRODUCTION

Concerns over the ability of the world to feed a growing population are hardly new. Already in year AD 200, Tertullianus expressed the view that an increasing population pressure imposed on land could only result in famines and wars[1]. Later, in the 18th and 19th centuries, agriculture and its ability to generate an adequate supply of food for an increasingly large population would still lie at the heart of the theories developed by the most prominent classical economists. Hence, David Ricardo identified the diminishing returns to agricultural land as the ultimate cause of economic stagnation (Kindleberger, 1977) while Thomas Malthus, in his celebrated essay "On population" (1798), envisioned even gloomier prospects for humanity that would remain associated with his name forever.

Today the debate over the world food situation persists, justifying the publication of related books and the organisation of food summits on a regular basis. The current concerns arise from a number of simple observations: first, world hunger remains widely spread, with a food insecure population in the range of one billion[2]. Second, although the rate of world

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population growth appears to be diminishing (Shane et al; 1997), the absolute size of the forecasted increment in population over the next 50 years is unprecedented and daunting: from an existing level of approximately six billion, the world population will most likely reach 9 billion around 2020 and 12 billion around 2050, with virtually all of the increase taking place in low or middle-income countries. Finally, there is mounting evidence that the agricultural resource base of several countries might be eroding (Wiebe, 1997).

In response to those concerns, various approaches have been followed to assess the world food situation, including the development of large econometric models or the computation of technical indicators such as the population carrying capacity of the planet[3]. This paper explores a new route, which builds on the theory of growth because, at the outset, it is believed that this theory presents a number of appealing characteristics to model the food-population nexus: its fully dynamic nature seems adequate to study a relationship that takes place over a long period of time while the general equilibrium structure, both intra and inter-temporally, captures the responsiveness of the economic system to the changing relative scarcity of goods and factors over time.

However, in the past, growth theory has completely ignored the characteristics of the agricultural sector, making it of little relevance to the analysis of problems in low-income and still predominantly agrarian economies (Ruttan, 1998). This paper is intended to address this shortcoming by introducing explicitly a farm sector into a Ramsey model of growth. In this simplified framework, the question as to whether a country will manage to feed its population in the future can be related to the existence of a steady state.

The next section develops the analytical framework and insists on the special characteristics of the model. Section three identifies necessary conditions for the existence of a steady state, shows that they essentially capture the ability of an economy to feed its population and highlights the technological characteristics, both in agriculture and in the rest of the economy, that are conducive to sustainability. The fourth section investigates empirically whether that condition is met in a number of countries and the last section concludes the paper.

2. AGRICULTURE AND LAND IN A TWO-SECTOR MODEL OF GROWTH

Consider a stylised economy composed of two sectors, manufacturing and agriculture, that produce two homogenous goods. Both technologies are Cobb-Douglas with constant returns to scale, with each employing two economy-wide factors, capital K and labour L, which can be reallocated freely and costlessly between sectors. In addition, land T is sector-specific, i.e. land can be rented in (out) among producers in agriculture but it is not a factor of production in the rest of the economy. It is further assumed that land degradation takes place at a constant rate ε. Referring to manufacturing and agriculture with a and m subscripts, the sectorial production functions are written as:

$$Y_m = A_m B_m K_m^{\alpha} L_m^{1-\alpha} \tag{1}$$

$$Y_a = A_a B_a K_a^{\beta_1} L_a^{\beta_2} T^{1-\beta_1-\beta_2} \tag{2}$$

Technological progress takes place exogenously in the two sectors at different rates μ_a and μ_m[4]. Notice that the formulation of production in the model is kept as general as possible, with no restrictions imposed on the relative intensity of factor use or on the speed of productivity gains in each sector.

The demand side of the economy is modelled by a representative household maximising a discounted flow of instantaneous utility over an infinite horizon:

$$\underset{c_{mt}, c_{at}}{Max} \int_0^{+\infty} \frac{u(c_{mt}, c_{at})^{1-\theta}}{1-\theta} e^{-(\rho-n)t} dt \tag{3}$$

where c_{mt} and c_{at} denote the per capita consumption of manufactures and food at time t. The intertemporal utility function is the familiar CES $f(u)=u^{1-\theta}/(1-\theta)$, where the instantaneous utility u or felicity is assumed to take the Stone-Geary form:

$$u(c_m, c_a) = Bc_m^{\lambda}(c_a - \gamma)^{1-\lambda} \tag{4}$$

The consumer's willingness to smooth consumption over time is given by the elasticity of inter-temporal substitution $1/\theta$ and ρ denotes the discount rate. The household's size, L, grows at the exogenous rate n while the scale parameter B is set equal to $\lambda^{-\lambda}(1-\lambda)^{\lambda-1}$ to simplify the expression of the expenditure function.

The non-homotheticity of the Stone-Geary preference system has the desirable property of being able to reproduce Engel's law, known to play a major role in the process of structural transformation of an economy[5]. Furthermore, in the context of a poor economy, parameter γ can easily be interpreted as a subsistence level, i.e. an absolute level of food intake below which life cannot be sustained.

The flow budget constraint for the household can be written as a function of capital stock per capita, k, land per capita τ and the relative price of food in terms of manufactures p[6]:

$$\dot{k}_t = w_t + (r_t - n - \delta)k_t + s_t\tau_t - c_{mt} - p_t c_{at} \tag{5}$$

This equation states that the household derives income from the sale of labour services at wage rate w, from the sale of capital services at rate r and from the sale of land services at rate s. Income is then allocated to consumption of both goods and savings[7].

Before analysing the competitive equilibrium of this stylised economy, it is worth highlighting the asymmetries between the two sectors that confer its originality to the model and that play a crucial role in explaining the contribution of agriculture to the growth process. First, agricultural production relies on a fixed and degrading resource base so that the model incorporates explicitly the Ricardian intensive margin. This element is necessary for the model to capture the decreasing returns to accumulable factors in agriculture that lie at the core of virtually all Malthusian theories, old and new. Second, the farm sector uses industrially produced capital goods, which introduces a backward linkage between agriculture and industry. This feature appears essential to capture the sort of complementarity among sectors in the process of growth and development that is suggested by the success of the green revolution. Third, while the agricultural sector produces a pure consumption good, manufacturing output can be either consumed or invested in physical capital. Fourth, the growth rates of total factor productivity as well as the relative intensities of factor use can differ in the two sectors. Fifth, the income elasticity for food is strictly less than one while it is greater than one for manufactures, in concordance with Engel's law. Finally, a minimum consumption requirement is only imposed on food to reflect the life-sustaining aspect of food consumption.

3. MALTHUSIAN OUTCOME OR SUSTAINED GROWTH? ANALYSIS OF THE STEADY STATE PROPERTIES

Steady state characterisation: The competitive equilibrium of the economy specified above is now characterised. Note that since there are no externalities and markets are assumed perfect, the fundamental welfare theorems apply and solving for a socially optimal plan would be equivalent. The advantage of solving for a competitive equilibrium lies in the fact that not only equilibrium quantities but also equilibrium prices can be computed.

A competitive equilibrium consists of a sequence of prices and quantities such that:

- The household maximises its inter-temporal utility (3) subject to its dynamic budget constraint (5)
- The two firms treat prices parametrically and maximise profit subject to the technological constraints (1) and (2)
- All markets clear

Combining the zero-profit conditions in each sector, the market-clearing conditions for production factors and food, and the solution to the household's inter-temporal problem, the model can be reduced to a set of three static equations, two differential equations, one initial condition k_0 and one transversality condition[8].

$$\frac{\alpha w - rk(1-\alpha)}{\alpha\beta_2 - \beta_1(1-\alpha)} = (1-\lambda)cp^{1-\lambda} + \gamma p \tag{7}$$

$$\frac{\dot{k}}{k} = \left[\frac{r\beta_2}{\alpha\beta_2 - \beta_1(1-\alpha)} - n - \delta\right] - \frac{\beta_1 w/k}{\alpha\beta_2 - \beta_1(1-\alpha)} - \lambda\frac{cp^{1-\lambda}}{k} \tag{8}$$

$$\frac{\dot{c}}{c} = \frac{1}{\theta}[r - (1-\lambda)\frac{\dot{p}}{p} - \delta - \rho] \tag{9}$$

$$p = \frac{r^{\beta_1}w^{\beta_2}}{A_a}\left[\frac{1-\beta_1-\beta_2}{\alpha\beta_2 - \beta_1(1-\alpha)}\frac{\alpha w - rk(1-\alpha)}{\tau}\right]^{1-\beta_1-\beta_2} \tag{10}$$

$$w = A_m^{\frac{1}{1-\alpha}} r^{\frac{-\alpha}{1-\alpha}} \tag{11}$$

$$\lim_{t \to +\infty} k_t e^{-\int_0^t (r_v - n)\,dv} = 0 \qquad (12)$$

where

$c = u(c_m, c_a)$ is defined as aggregate consumption[9].

The first equation (7) derives from the market clearing condition for food, where the left hand-side corresponds to supply and the right hand-side to the Hicksian demand, both expressed in value terms. Equation (8) corresponds to a restatement of the budget constraint while the Euler equation (9) characterises the optimal consumption path of the household. It guarantees that the benefits from increased consumption are equal to the benefits from foregone consumption at each instant. Note, however, that relative price changes p/p impact real returns to savings and therefore affect the consumer's optimal decision. Equations (10) and (11) are restatements of the zero-profit conditions in the two sectors, and the transversality condition (12) guarantees that the household's utility is finite.

It can be shown analytically that a steady state with sustained growth exists only under certain configurations of parameters. The results are summarised in the following proposition:

Proposition 1: *A necessary condition for the existence of a steady state with sustained growth is:*

$$\beta_1 \frac{\mu_m}{1-\alpha} + \mu_a \geq (1-\beta_1-\beta_2)(n+\varepsilon) \qquad (13)$$

If this condition is met, the steady state is unique and the growth rates of all endogenous variables are then defined in Table 1.

Proof. Close inspection of system (7-12) allows us to identify a unique set of growth rates necessary for the existence of a steady state. By definition of a steady state, γ_k[11] must be constant which has three implications through equation (8): r, w/k and $cp^{1-\lambda}/k$ must also be constant in steady state, or in terms of growth rates $\gamma_r=0$, $\gamma_k=\gamma_w$ and $\gamma_c+(1-\lambda)\gamma_p=\gamma_k$. Using these conditions, by log-differentiation of (11) we obtain the steady state growth rates for k and w shown in Table 1. The growth rate γ_p follows from log-differentiation of (10) so that γ_c can then be computed. All the other conditions result from log-differentiation of static equilibrium conditions.

Table 1: Steady state growth rates

Variable[10]	Steady state growth rate
k: aggregate K/L ratio	$\mu_m/(1-\alpha)$
GDP per capita	$\mu_m/(1-\alpha)$
k_m: K/L ratio in manufacturing	$\mu_m/(1-\alpha)$
k_a: K/L ratio in agriculture	$\mu_m/(1-\alpha)$
l_m: L share in manufacturing	0
l_a: L share in agriculture	0
c: aggregate consumption per capita	$\frac{\mu_m}{1-\alpha}[1-(1-\lambda)(1-\beta_1)]+(1-\lambda)\mu_a-(1-\lambda)(1-\beta_1-\beta_2)(n+\varepsilon)$
c_m: consumption of manufactures	$\mu_m/(1-\alpha)$
c_a: consumption of food	$\beta_1\frac{\mu_m}{1-\alpha}+\mu_a-(1-\beta_1-\beta_2)(n+\varepsilon)$
y_m: production of manufactures	$\mu_m/(1-\alpha)$
y_a: production of food	$\beta_1\frac{\mu_m}{1-\alpha}+\mu_a-(1-\beta_1-\beta_2)(n+\varepsilon)$
p: relative price of food	$(1-\beta_1)\frac{\mu_m}{1-\alpha}-\mu_a+(1-\beta_1-\beta_2)(n+\varepsilon)$
r: interest rate	0
w: wage rate	$\mu_m/(1-\alpha)$
s: land rental rate	$\mu_m/(1-\alpha)+n+\varepsilon$
p^T: price of land	$\mu_m/(1-\alpha)+n+\varepsilon$

The sustainability condition arises from the observation that equation (7) can only hold if $\gamma_p \leq \gamma_k$[12].

To verify that a steady state actually exists, it is necessary to normalise the variables by dividing them by an appropriate combination of exogenous variables so that the resulting variables are constant in steady state. The normalisations used are:

$$\hat{k} = k / A_m^{1/(1-\alpha)},\ \hat{w} = w / A_m^{1/(1-\alpha)},\ \hat{p} = pA_a\tau^{1-\beta_1-\beta_2} / A_m^{(1-\beta_1)/(1-\alpha)},$$
$$\hat{c} = c/(A_m^{[1-(1-\lambda)(1-\beta_1)]/(1-\alpha)} A_a^{1-\lambda}\tau^{(1-\lambda)(1-\beta_1-\beta_2)}).$$

If the sustainability condition holds with a strict inequality, analytical expressions of the steady state values of the normalised variables can be computed from the transformed system (7-12). From the transversality condition, these values can be shown to be always positive, therefore establishing the existence of a unique steady state in that case. If (12) holds with equality, the steady state can only be defined implicitly from the transformed system (7-12) but it can still be shown that the steady state exists and is unique[13]!

Interpretation and implications: Proposition 1 can be understood by decomposing the growth in agricultural output. First, express the production function in the agricultural sector in intensive form[14]

$$y_a = A_a B_a k_a^{\beta_1} l_a^{\beta_1+\beta_2} \tau^{1-\beta_1-\beta_2} \tag{14}$$

where

$y_a=Y_a/L$ is per capita production of food, k_a is the capital-labour ratio in agriculture and l_a the share of labour force employed in agriculture. By log differentiating this expression we obtain:

$$\frac{\dot{y}_a}{y_a} = \frac{\dot{A}_a}{A_a} + \beta_1 \frac{\dot{k}_a}{k_a} + \beta_2 \frac{\dot{l}_a}{l_a} + (1-\beta_1-\beta_2)\frac{\dot{\tau}}{\tau} \tag{15}$$

In the long run, the proportion of labour force allocated to agriculture l_a can be expected to converge to a constant so that $\dot{l}_a = 0$. Equation (15) therefore shows that the growth in per capita food production has only three components in the long run. The first one, μ_a corresponds to the contribution of technological progress in agriculture to the growth in food production and is always positive. The second one,

$$(1-\beta_1-\beta_2)\,\dot{\tau}/\tau,$$

reflects the decrease in agricultural output per capita resulting from the decline in the land-labour ratio. This decline has itself two origins, the growth in population occurring at rate n as well as land degradation at rate ε, so that this term, which is negative and captures the Malthusian component of the model, can also be written as

$$-(1-\beta_1-\beta_2)(n+\varepsilon).$$

Finally, the last term

$$\beta_2\, \dot{k}_a / k_a$$

represents the positive contribution that capital deepening in agriculture makes to the growth in per capita food production. It can be shown that, due to diminishing returns with respect to the accumulable factor in manufacturing, the capital-labour ratio in agriculture k_a can not grow continuously at a rate greater than $\mu_m/(1-\alpha)$. Therefore, in the long run, if condition (13) does not hold, the sum of these three contributions is strictly negative and per capita production of food decreases continuously. Consequently, condition (13) reflects the ability of a country to generate enough food to satisfy the basic needs of its population, which justifies its interpretation in terms of sustainability. Notice also from Table 1 that the sustainability condition guarantees a non-negative steady state growth rate of food consumption.

What happens if the sustainability condition is not satisfied? The model reaches its limits at this level because of the exogeneity of all the dynamic parameters (rate of population growth, rate of technological progress in each sector and speed of land degradation). However, it is natural to postulate that a Malthusian adjustment would take place with the rate of population growth dropping to a level n' implicitly defined by:

$$\beta_1 \frac{\mu_m}{1-\alpha} + \mu_a = (1-\beta_1-\beta_2)(n'+\varepsilon) \tag{16}$$

This decline in the rate of net population growth could conceivably originate from either an increase in mortality rate or from a decline in the birth rate.

More optimistic scenarios could also be envisioned to restore the sustainability of growth when equation (13) does not hold. In particular, following the induced innovation hypothesis defended by Hayami and Ruttan (1991) as well as Boserup (1965), it could be argued that the increasing population pressure would result in faster technological change in agriculture (larger μ_a), an adjustment that would restore the equality between the left and right hand-sides of the sustainability condition (13).

Another result of the model is worth pointing out. By combining the sustainability condition to the steady state growth rate for the relative price of food presented in Table 1, it is straightforward to establish that the rate of growth of the relative price of food can never exceed a constant equal to $\mu_m/(1-\alpha)$. Therefore the model confirms the conventional wisdom in the development literature that the process of growth and development can be jeopardised by domestic terms of trade turning too much in favour of the agricultural sector.

Factors conducive to economic sustainability: Close examination of condition (13) establishes the characteristics of the economy that, ceteris paribus, makes it more likely for economic growth to be sustainable in the long run. Those characteristics are summarised in Table 2.

The table reaffirms that fast technological change in agriculture (large μ_a) drives the economy towards sustainability through its direct and positive effect on agricultural output. However, several other characteristics of the economy are important in reinforcing this effect: first, technological progress in manufacturing (parameter μ_m) speeds the accumulation of capital and thus benefits the agricultural sector and accelerates its growth. This effect will be stronger if capital plays a bigger role in the production process of food, i.e. if capital share β_1 is large. In other words, the model shows that technological progress in manufacturing spills over to agriculture, with the extent of the spill-over depending on the capital elasticity of output in agriculture. In a similar fashion, a larger capital share in the production of manufactures guarantees faster capital accumulation and agricultural growth in steady state.

Table 2: Effect of an increase in parameter value on likelihood of sustainable growth

Parameter definition	Effect
μ_a: rate of TC in agriculture	+
μ_m: rate of TC in manufacturing	+
α: K share in manufacturing	+
β_1: K share in agriculture	+
β_2: L share in agriculture	+
$1-\beta_1-\beta_2$: land share in agriculture	-
n: rate of population growth	-
ε: speed of land degradation	-

Fast population growth or intense land degradation have similar adverse effects on sustainability through their negative effect on the land-labour ratio. However, this effect will vary according to the reliance of agricultural production on land input as measured by the output elasticity with respect to land ($1-\beta_1-\beta_2$): the larger this elasticity, the more important the Malthusian forces driving the economy away from sustained growth.

4. EMPIRICAL APPLICATION

The analytical framework developed in the previous section can be used to combine growth theory and the results of growth accounting to determine whether a number of countries will face a food crisis in the future. In practice, we compute the difference between the right hand-side and the left hand-side of (13) (what we now call the sustainability equation). A positive value suggests that the country lies on a sustainable path of growth and development.

The TFP growth rates are derived from Martin & Mitra (1999) and the rates of population growth from the World Bank Development Indicators (1999) for the 1965-1997 period. Considerable uncertainty remains regarding the importance of land degradation at a country level (Ruttan, 1999) so that three annual rates are considered: 0, 1 and 3%. While the capital share in manufacturing is set to a conventional value of 0.4, three sets of parameters defining the agricultural technology are used when estimating the sustainability condition: (β_1 =0.2, β_2 =0.55), (β_1 =0.1, β_2 =0.5), (β_1 =0.1, β_2 =0.4). Estimates of the sustainability equation are presented in Table 3.[15]

Table 3: Empirical assessment of the sustainability condition

			β_1	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1
			β_2	0.55	0.5	0.4	0.55	0.5	0.4	0.55	0.5	0.4
			ε	0	0	0	1	1	1	3	3	3
Countries	μ_m	μ_a	n	Sustainability Equation								
Egypt	2.63	1.23	2.2	1.56	0.79	0.57	1.31	0.39	0.07	0.81	-0.41	-0.93
Honduras	0.22	1.60	3.1	0.90	0.40	0.09	0.65	0.00	-0.41	0.15	-0.80	-1.41
India	-0.33	1.52	2.1	0.89	0.63	0.42	0.64	0.23	-0.09	0.14	-0.58	-1.09
Kenya	0.68	1.69	3.4	1.07	0.44	0.10	0.82	0.04	-0.40	0.32	-0.76	-1.40
Sri Lanka	-2.00	1.94	1.6	0.87	0.97	0.81	0.62	0.57	0.31	0.12	-0.23	-0.69
Madagascar	0.22	-0.18	2.6	-0.76	-1.18	-1.44	-1.01	-1.58	-1.94	-1.51	-2.38	-2.94
Malawi	0.22	0.30	3	-0.38	-0.86	-1.16	-0.63	-1.26	-1.66	-1.13	-2.06	-2.66
Pakistan	1.40	1.70	2.8	1.47	0.81	0.53	1.22	0.41	0.03	0.72	-0.39	-0.97
Tanzania	0.22	5.22	3.1	4.52	4.02	3.71	4.27	3.62	3.21	3.77	2.82	2.21
Zimbabwe	-1.04	-0.67	2.9	-1.74	-2.00	-2.29	-1.99	-2.40	-2.79	-2.49	-3.20	-3.79
Low income av.	0.22	1.44	2.7	0.84	0.40	0.13	0.59	0.00	-0.37	0.09	-0.80	-1.37
Middle income av.	0.76	1.90	1.7	1.73	1.35	1.18	1.48	0.95	0.68	0.98	0.15	-0.32
Developing country av.	0.62	1.76	2	1.47	1.06	0.86	1.22	0.66	0.36	0.72	-0.14	-0.64
Developed country av.	1.91	3.35	0.8	3.79	3.35	3.27	3.54	2.95	2.77	3.04	2.15	1.77
Overall average	1.13	2.31	1.8	2.24	1.78	1.60	1.99	1.38	1.10	1.49	0.58	0.10

Sources: *μ_m and μ_a, Martin and Mitra (1999); n, World Bank (1999).*

The situation of developed countries is first discussed because the results are unambiguous for this set of countries: for all the technologies considered, and even assuming that soil losses occur at a rate of 3% a year, economic growth in developed countries appears sustainable. This is explained primarily by high rates of TFP growth in agriculture for this set of countries, with an average of more than 3% a year. Moreover, developed countries have for the most part completed their demographic transitions, which is reflected by relatively low rates of population growth. The conclusion that developed countries are currently on a sustainable growth path should have been expected and any other one would have cast serious doubt on the validity of the model. Important limits to growth might exist in industrialised countries, in particular in connection with environmental degradations, but they are certainly unrelated to the Malthusian forces captured by the model. If the developed world eventually slows down, it will not be because of an inability to supply food.

The analysis of the results with respect to developing countries brings more insights into the debate over the world food situation. For the subset of middle income countries, presented only by average values in Table 3, the sustainability condition is verified in all cases except in the improbable scenario where the agricultural technology features a very high land share (0.5) and where land degradation takes place at the fast speed of 3% a year. Although the growth rates of population remain relatively high in these countries, with an average of 1.7% a year, productivity gains in agriculture as estimated by Martin and Mitra have been sustained and, if persistent in the future, will prove sufficient to avoid a reversal (or slow down) of the industrialisation process caused by an adverse evolution of the domestic terms of trade. Many regions, including Latin and Central America, the Middle East, North Africa and South and East Asia are represented in the set of middle-income countries.

The results concerning low-income countries are more heterogeneous and we choose to present them individually in Table 3. For the set of benchmark parameter values (β_1 =0.2, β_2 =0.55, ε=0), the sustainability equation is not satisfied in the case of three countries (Madagascar, Malawi and Zimbabwe) out of a total of ten; naturally, the sustainability equation appears more negative for relatively more land intensive technologies or if strictly positive rates of land degradation are assumed. Notice also that these three countries belong to the same geographical region, namely sub-Saharan Africa, which is therefore identified by our analysis as the region of the world facing the most serious challenges in terms of sustainability. This conclusion appears consistent with the literature on food security which invariably singles out

Sub-Saharan Africa as a "hot spot". Hence, Pinstrup-Andersen et al. (1997), in their assessment of the world food situation reflecting IFPRI's position, write (p.22):

If Malthus is to be proven wrong in Sub-Saharan Africa, a much greater effort must be made to ensure that farmers have access to appropriate production technology[....]. Besides new initiatives and expanded support for agricultural development, more must also be done to reduce population growth.

All sub-Saharan African countries represented in Table 3 are characterised by very high growth rates of population in the range of 3% a year. Estimates of TFP growth rates in Zimbabwe and Madagascar are not only small but negative showing that these countries will probably become more and more food insecure in the near future. Similarly, in Malawi, TFP growth in agriculture as well as in manufacturing has been sluggish and unable to overcome the tendency for decreasing returns in the farm sector. Notice, however, that some Sub-Saharan African countries, namely Kenya and Tanzania, have been successful in achieving fast productivity gains in agriculture that put them on a sustainable growth path.

How sensitive are these results to the choice of agricultural technology and the speed of land degradation? Table 3 shows that if we consider an output elasticity with respect to land of 0.5, combined with an annual rate of soil erosion of 1% a year[16], or an output elasticity with respect to land of 0.4 combined with an annual rate of soil erosion of 3%[17], the conclusions drawn from our analysis are deeply affected. For these two sets of parameters, the average of the sustainability equation takes a strictly negative value over the whole sample of low-income countries, with not only Kenya but also non-African countries no longer appearing on a sustainable growth path. The model therefore suggests in that case that in countries such as Honduras or India, the domestic supply of food might be unable to keep pace with demand in the future.

5. CONCLUSION

This paper presents a neoclassical model of growth with Malthusian features that provides an analytical framework within which to analyse the world food situation. The two-sector model pays particular attention to the representation of the agricultural sector: on the demand side, the necessary aspects of food consumption as well as its low-income elasticity are recognised. On the supply side, the production process relies on a natural resource base, land, as well as on industrially produced inputs.

The contribution of the paper is three-fold: first, it provides a rationalisation of the classical argument in the development literature that neglecting the agricultural sector puts the whole process of growth and development at risk (Schiff & Valdez, 1992). Second, it highlights the technological characteristics, in particular in agriculture, that tend to drive the economy towards sustained growth. Hence, it is established that a large output elasticity with respect to industrially-produced inputs in agriculture facilitates the spill-over of technological progress from manufacturing to agriculture. And finally, the paper provides a simple analytical criterion upon which to assess the long-term food situation of a closed economy.

Although parsimonious, the model appears to produce sensible results. The empirical application concludes that no global food crisis appears to be looming on the horizon but that a number of countries in the developing world, and in particular in sub-Saharan Africa, will most likely become more food dependent in the future.

NOTES

1 *See Holland (1993).*

2 *See Shane et al. (1997).*

3 *See for instance Srinivasan (1985) for a review of the different methods that have not fundamentally changed since that article was written.*

4 *That is,* $\dot{A}_m / A_m = \mu_m$ *and* $\dot{A}_a / A_a = \mu_a$. *The scaling parameters are chosen to simplify the cost functions:* $B_m = \alpha^{-\alpha}(1-\alpha)^{\alpha-1}$ *and* $B_a = \beta_1^{-\beta_1}\beta_2^{-\beta_2}(1-\beta_1-\beta_2)^{-(1-\beta_1-\beta_2)}$.

5 *It is straightforward to check that for* $\gamma > 0$, *the income elasticity for food is strictly less than one and the income elasticity for manufactures strictly greater than 1.*

6 *Parameter* δ *denotes the rate of depreciation of physical capital.*

7 *Time subscripts are dropped in the rest of the paper.*

8 *The special case where* $\alpha\beta_2-\beta_1(1-\alpha)=0$ *is ruled out for simplicity. Note that there are effectively five variables (w, r, k , c, p) in this system, which therefore presents a square structure.*

9 *To derive the Hicksian demand functions, we first compute the expenditure function corresponding to the Stone-Geary preference system* $e(c,p)=cp^{1-\lambda}+\gamma p$.

10 *All physical quantities are expressed in per capita terms.*

11 *In what follows,* γ_x *denotes the growth rate of variable x.*

12 *Another necessary condition comes from the transversality condition (12) which can be simplified to:* $\rho>n+(1-\theta)[(1-(1-\lambda)(1-\beta_1))\mu_m/(1-\alpha)+(1-\lambda)\mu_a]-(1-\lambda)(1-\theta)(1-\beta_1-\beta_2)(n+\varepsilon)$.

13 *This part of the proof is lengthy and is available from the authors upon request.*

14 *In other words, in terms of per capita output.*

15 *For some countries, Martin and Mitra did not report estimates of* μ_m. *The average value for the corresponding group of countries was then used to compute the sustainability equation.*

16 *This corresponds to the tenth column of the table.*

[17] *Column 12 of the table.*

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