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LABOUR SUPPLIES SHOCKS AND NEOCLASSICAL THEORY

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Abstract

This paper studies the relationship between real cycles and balanced growth by comparing transition dynamics generated by labour supply shocks for neoclassical models of growth. These models differ with respect to the exogeneity of labour supply and the specification of intertemporal utility. The predicted reaction to a change in labour supply growth varies considerably between these models - both in magnitude and direction - as a result of (i) whether labour supply is exogenous or not, and (ii) the specification of the utility function. To quantify the relationship between cyclical adjustments and balanced growth, simulations are run for three population growth experiments.

JEL code: E32, J22

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[1] I am indebted to Henri de Groot, Lex Meijdam, Anton van Schaik, and Sjak Smulders for useful comments. Lex Meijdam also kindly provided the software to run the simulations and helped me to program the computer.

While the growth theory literature of the 1960s is replete with discussions of dynamic behavior of the models studied, little effort was made to relate this behavior to the characteristics of economies associated with the business cycle. For example, labor supply did not play a particularly important role in the growth theory literature yet it is central to any theory attempting to address the phenomenon of business cycles. (Plosser, p. 54, 1989)

1. Introduction

In neoclassical growth theory, balanced economic growth is driven by labour supply growth and the rate of technical advance. However, this steady state might never be reached in reality since the environment in which economic activity takes place is not stable over time. Changes in the determinants of the steady state level and/or growth rate of aggregate production will bring the economy to move from one transition path to another. These determinants include demographic factors, the institutions affecting technical change, consumer preferences, institutional arrangements, as well as a whole range of more or less exogenous factors such as climate, natural resource endowments and so forth. Out of the steady state, the growth rate is guided by the attractor that brings the economy back onto its balanced growth path. Neoclassical growth theory may thus be more 'endogenous' than commonly is claimed. As Brander (1992) points out, we are in fact not dealing with an exogenous growth theory, only with a theory that assumes exogenous technical progress to explain long term growth in per capita terms.

The notion of the unstable environment can be used to integrate long and short term economic performance. Real Business Cycle (RBC) theory has become famous in this respect. However, RBC models have often been criticized for their unrealistic assumptions with respect to the source of fluctuations. Mostly, uncertainty about technical progress is held responsible for the erratic pattern of economic activity in the short run. In this paper, shocks in labour supply (due to demographic transition, changes in labour participation, migration, and so forth) are considered as a candidate to explain cyclical co-movements in a number of economic variables.

Another related issue is the impact of labour input growth on the steady state properties of the model. The theoretical relationship between population growth and steady state per capita production levels hinges crucially on the specification of the intertemporal utility function. Two versions of intertemporal utility are commonly employed in the literature. Blanchard and Fischer (1989) and others define intertemporal utility as the discounted sum of instantaneous utility, *unweighted* by population size. Following

Blanchet and Kessler (1991, p.142), we will refer to this type of criterion as the 'Millian' criterion. Alternatively, Lucas (1988), Barro and Sala-i-Martin (1995) and others have employed a specification of intertemporal utility where instantaneous utility is *weighted* by the size of the population in each period. Henceforth, this type of utility function will be denoted as the 'Benthamite' criterion (*cf.* Blanchet and Kessler, 1991, p.142).

Both the Millian and the Benthamite criterion are built into the neoclassical growth model where infinitely-lived representative agents maximize intertemporal utility. In the Benthamite economy, the steady state per capita level of capital and production is invariant to the population growth rate. At a higher rate of population growth, people increase their savings because they are concerned with the well-being of the new members of the family. The increased demand for capital to create jobs for the newcomers is exactly met by the rise in savings. In contrast, the solution for the Millian economy depends - among other factors - on population growth. When population growth increases, people again are more willing to save but this effect no longer compensates for the increased need for capital. Consequently, the steady state capital and output level per head are lower when population growth is higher.

Since the impact of population growth on the steady state properties of the model differs considerably in the Benthamite and the Millian economy, transition dynamics will also vary. This paper compares transition dynamics generated by labour supply shocks for both the Benthamite and Millian economies in the case of exogenous and endogenous labour supply. Shocks in labour input growth change the optimal consumption plan of economic agents. Since agents with perfect foresight immediately react to new information on demographic changes, (new) transition dynamics set in at the announcement date. The basic models are extended to include disutility of work, and the familiar result that agents' optimal labour time depends positively on the optimal savings rate is replicated. Simulations are presented for three population growth experiments.

Related studies are, for instance, Cutler *et.al.* (1990) and Yoo (1994). The economic consequences of the expected ageing of the American population - due to the baby boom during the sixties - are studied in Cutler *et.al.* (1990). They consider a neoclassical growth model with a Benthamite type of utility function, exogenous labour supply, and varying relative sizes of the self-supporting and dependent populations in the course of the ageing process. Simulation results are presented under alternative demographic assumptions. The economic effects of the U.S. baby boom are analysed in Yoo (1994). He considers three exogenous growth models, *viz.* the neoclassical growth model, the dependency-ratio growth model by Cutler *et.al.* (1990), and an overlapping-generations growth model. Yoo (1994) employs a Millian type of utility function for the first and third model, while he uses the Benthamite criterion in the second model. In this paper we seek to compare the macroeconomic consequences of demographic change for neoclassical models of growth, differing with respect to (i) the exogeneity of labour supply, and (ii) the specification of the utility function.

The rest of the paper is organized as follows. Section 2 recapitulates the basic neoclassical model with optimal savings behaviour based on the Millian criterion. The dynamics are studied in a phase diagram for three population growth experiments. In the first experiment we consider a temporary and expected increase in population growth, the second experiment is a permanent and expected increase in population growth, and in the third experiment we look at a situation where economic agents initially believe that the expected increase in population growth is permanent until the news becomes available that population growth returns to its initial rate. Section 3 extends the basic Millian model by allowing for disutility of labour. Section 4 presents the Benthamite version of the neoclassical growth model, for both specifications of labour supply. The three experiments and simulation results are discussed in section 5, and section 6 briefly concludes.

2. The Millian economy with exogenous labour supply (model A)

The benchmark of the discussion is the basic neoclassical growth model, developed by Solow (1956) and others. This section briefly recapitulates the basic growth model in a setting where agents maximize intertemporal utility by optimally choosing the savings rate based on a Millian type of criterion function. The relationship between population growth shocks and transition dynamics is analyzed. Agents with perfect foresight can anticipate future changes in the population growth rate and thereby generate cyclical movements between balanced growth paths.

The production process combines capital K and labour L to produce one single homogeneous commodity. The production function is given by $Y=Y(K,EL)$, where E is the technology level. Y is aggregate output and is concave with respect to both factors of production separately so $Y_K>0$, $Y_{KK}<0$, $Y_L>0$, $Y_{LL}<0$, where subscripts denote partial derivatives. The production process is subject to decreasing returns to the accumulation of a single factor input, but exhibits constant returns to scale when both factors are accumulated at a uniform rate. Suppose that production possibilities are given by the following Cobb-Douglas function

$$Y = AK^{\alpha}(EL)^{1-\alpha}, \tag{1}$$

where A is a constant, L is inelastically supplied labour, and α $(1-\alpha)$ is the production elasticity of capital (labour). The question of how fast diminishing returns to the factors of production set in is governed by α which is by assumption between 0 and 1. Accumulation of the non-reproducible factor of production - labour - is governed by

$$L = L(0)e^{nt}, \tag{2}$$

where $L(0)$ is the initial labour force, n is the growth rate of the labour force, and t equals time. Technology is labour-augmenting (Harrod-neutral) and is assumed to develop exogenously over time, so

$$E = E(0)e^{gt}, \tag{3}$$

where $E(0)$ is the starting level of technology, and g is the rate of technical progress. In intensive form, production, consumption, and capital are defined as $y \equiv Y/EL$, $c \equiv C/EL$, and $k \equiv K/EL$. The production function can thus be rewritten as $y = Ak^{\alpha}$. In equilibrium, total output must equal total demand. The resource constraint of this economy is therefore given by

$$\dot{k} = y - c - (n+g+\delta)k, \tag{4}$$

where a dot represents a time derivative, and δ represents capital depreciation.

On the consumption side it is assumed that the representative infinitely-lived agent maximizes intertemporal utility, in the Millian economy defined as

$$U = \int_0^{\infty} u(c_i)e^{-\rho t}dt, \tag{5}$$

where U is the present value of future utility per head, $c_i \equiv C/L$, and ρ is the subjective rate of time preference. Instantaneous utility $u(c_i)$ is of the CRRA-type, *i.e.* $u(c_i)=\ln(c_i)$, where the rate of risk aversion and the intertemporal elasticity of substitution are unity. The present value Hamiltonian is defined by

$$H = \ln(c_i) + \lambda\left[y - \frac{c_i}{E} - (n+g+\delta)k\right], \tag{6}$$

where λ is the shadow price of capital accumulation. The first order conditions for a maximum are

$$H_{c_i} = 0 \quad \rightarrow \quad u_{c_i} = \frac{\lambda}{E}, \tag{7}$$

$$H_k = -\dot{\lambda} + \rho\lambda \quad \rightarrow \quad \frac{\dot{\lambda}}{\lambda} = \rho - y_k + (n+g+\delta). \tag{8}$$

The optimal consumption decision is given by eq. 7. In the optimum the marginal utility of one additional unit of intensive consumption equals the shadow price of intensive capital ($\lambda=1/c$) so that the consumer is indifferent between consuming an additional unit of the good and increasing future consumption possibilities by adding this good to the capital stock. This gives, after rearranging, the Euler equation of the optimal dynamic consumption path

$$\frac{\dot{c}_i}{c_i} = y_k - n - \delta - \rho. \tag{9}$$

In the steady state the growth rate of consumption per head equals g so that

$$y_k^* = r^* = n+g+\delta+\rho, \tag{10}$$

where r is the real rental rate on capital. This is the well-known Ramsey rule. Notice that the steady state rental rate on capital will rise when population growth is higher, so that the steady state capital intensity must be lower in the presence of diminishing returns to capital accumulation. The steady state savings rate (σ^*) can be written as

$$\sigma^* = \alpha\frac{n+g+\delta}{n+g+\delta+\rho}, \tag{11}$$

which follows from eqs. 1 (intensively written), 4, 10, and the condition $\dot{k}=0$. From this expression it can be shown that the optimal savings rate is positively related to the rate of population growth: $\sigma^*_n>0$. The steady state solution for the capital and output intensity is

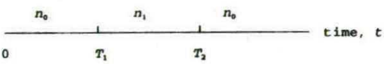
$$k^* = A^{\frac{1}{1-\alpha}}\left[\frac{\alpha}{n+g+\delta+\rho}\right]^{\frac{1}{1-\alpha}}, \tag{12}$$

$$y^* = A^{\frac{1}{1-\alpha}}\left[\frac{\alpha}{n+g+\delta+\rho}\right]^{\frac{\alpha}{1-\alpha}}. \tag{13}$$

Consumer preferences, population growth, and technology together determine the steady state outcome of this economy. k^* and y^* are positively related to A and α, and negatively related to n, δ, ρ, and g. Other parameters being equal, convergence in capital and output intensity is conditional on the country-specific growth rate of labour input.

Population growth shocks

Suppose that the economy is hit by a shock in period T_1:



A population growth shock $n_1\neq n_0$ is defined to be *temporary* if $\{T_1,T_2\}\in\mathbb{R}^+$, $T_1<T_2$, *permanent* if $T_1\in\mathbb{R}^+$, $T_2\to\infty$, $T_1<T_2$, and *anticipated* if $T_1>0$. The phase diagram in figure 1 helps to illustrate transition dynamics for different types of population growth shocks. To get the intuition, firstly consider the case of a permanent and unexpected rise in population growth. As follows from eq. 11, the steady state savings rate rises so that (from eq. 4) the $\dot{k}$-line shifts downward. From the Ramsey rule it follows that the rental rate on capital must rise in response to the rise in population growth so that the $\dot{c}$-line shifts to the left. At the time of the population growth shock, agents immediately change their savings behaviour and the economy jumps from A to C. At point C the economic system is on its new saddle path leading to its new steady state position in B. The new steady state is characterized by a decline in both the consumption intensity and the capital intensity.

In the first experiment, we consider the case when the population growth shock is anticipated and temporary. In figure 1, the economic system will jump from A to somewhere below D at the time that the news of the future rise in population growth becomes available to the agents. When the population growth shock actually occurs, the economy is adjusting towards its saddle path Z'Z' along an unstable arm. Agents know that the initial population growth rate is restored at some future date T_2, and they anticipate this future negative population growth shock by adjusting their consumption plans downward. In the phase diagram the system moves along an unstable arm to ZZ. The economy arrives at ZZ (between G and A) at time $t=T_2$ when the original population growth rate is restored. From then on, the economy converges along the stable arm ZZ back to its steady state at point A.

The second experiment looks at the effects of a permanent and anticipated population growth shock. People anticipate the future decline in steady state capital intensity (the *capital dilution* effect) by immediately lowering the savings rate. This is illustrated in the figure by the jump from A to D. At point D the economic system is not on its stable arm and consequently moves away from its original steady state until the population growth shock actually takes place. At that moment, the system arrives at point E. From then on the economy gradually converges towards its new steady state at point B.

Finally, the role of 'news' is studied in the third experiment. When agents at $t=0$ believe that the population growth shock is permanent, the system moves along the path ADEF. Suppose that news becomes available to agents at time T_2 when point F is reached. The news is that the population growth shock is not permanent but terminates at time T_2. The system then jumps from F to G and subsequently moves along the saddle path ZZ in the direction of A.

The lead structure of expectations is closely related to the initial jump of consumption intensity. When there is no lead in the expectation of the future population growth shock, *i.e.* when the shock is unanticipated, the economy jumps from A to C when the shock actually occurs. The other extreme case is when agents know that at some date in the far future $T_1 \gg 0$ population growth will be higher. The initial change in savings behaviour will be very small, so D is very close to A. The higher is T_1, the lower is the initial jump from A to D.

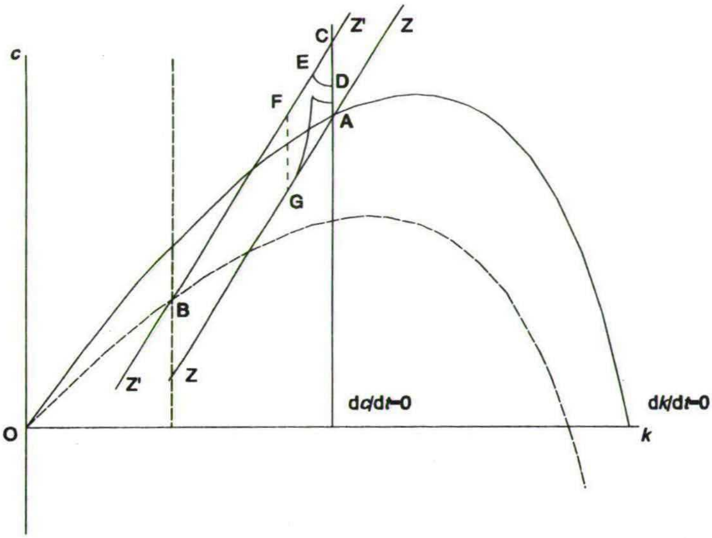


Figure 1: The Millian economy with exogenous labour supply

3. The Millian economy with endogenous labour supply (model B)

In the previous section it has been shown that agents respond to anticipated future population growth shocks by intertemporal substitution of consumption possibilities. Labour supply was assumed to be inelastic. This section relaxes the latter assumption by introducing disutility of labour in the agent's decision problem. The extension presented in this section is thus reminiscent to the Real Business Cycle approach.[2] The important difference with the RBC literature is the underlying source of the fluctuations. RBC theory usually analyzes the effect of technology shocks while in this paper the effects of population growth shocks are considered. The representative agent faces two decisions: he has to decide upon both the optimal savings rate and the optimal labour time. In response to future changes in the population growth rate, the agent now has two instruments for intertemporal substitution.

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[2] *Cf.* Kydland and Prescott (1982), Plosser (1989). Stadler (1994) gives an excellent overview.

The basic neoclassical model of section 2 can easily be extended to include disutility of work by changing the instantaneous utility function to

$$u(c_i, f) = \ln(c_i) - \frac{\beta\eta}{\eta+1} f^{\frac{\eta+1}{\eta}}, \tag{14}$$

where f is the agent's fraction of time devoted to productive activity and $0 \leq f \leq 1$; β is a parameter measuring the relative weight of labour time in the utility function; η is the elasticity of substitution of labour across periods (*cf.* Blanchard & Fischer, 1989).[3] A small η is associated with less willingness of individuals to substitute labour intertemporally. As η becomes very large, the marginal disutility of labour becomes approximately constant. Notice that eq. 14 corresponds to the specification in section 2 when β=0, since disutility of labour enters in an additively separable fashion. Our earlier (implicit) assumption that the rate of risk aversion (θ) is unity is chosen to simplify the analysis. A more general utility function in which θ is larger than 1 cannot support steady state growth when the solution of the optimal labour time is constrained to be an interior solution. In the steady state, consumption per capita grows at a constant rate g and the optimal fraction of time spent on work must be constant. Under more general preferences this would imply that the system converges to a solution where it is optimal not to supply any labour time at all. More specifically, by setting θ equal to 1 it is assumed that the income and substitution effects of labour time exactly cancel: the increase in real wages over time causes agents to work longer but this effect is compensated by the income effect which tends to increase the demand for leisure.

The static solution of this model is depicted in figure 2. Labour input f is measured on the horizontal axis and is between 0 and 1. Consumption per head c_i is measured

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[3] Barro and Sala-i-Martin (chapter 9, 1995) take a utility function of the form

$$u(c_i, f) = \frac{c_i^{1-\theta} e^{(1-\theta)\omega(f)} - 1}{1-\theta},$$

where $\omega_f < 0$, $\omega_{ff} \leq 0$, and θ is the rate of risk aversion. This specification implies that the partial derivative of the marginal utility from consumption with respect to the fraction of time spent on working is only zero when the rate of risk aversion is set to unity. They also only consider the special case in which θ=1. Applying L' Hôpital's rule to this utility function shows that the limit of $u(c_i, f)$ as θ approaches 1 is $\ln(c_i)+\omega(f)$. In this case, the utility function is separable between c_i and f.

vertically. The map of indifference curves (denoted by U in figure 2) is convex towards the origin: a rise in labour effort must be compensated by a more than proportionate rise in consumption per head to keep utility constant, *cf.* eq. 14. The resource constraint $c_i=(Y-\dot{K}-\delta K)/L$ is drawn as a concave function of labour input (locus RR in figure 2), due to the presence of diminishing returns to labour input in the production process. The optimum (f^*,c_i^*) is reached at point A where the indifference curve U is tangent to the resource constraint RR. This is the static solution. In a dynamic context, the diagram shows an upward movement in the resource constraint RR as agents accumulate capital through time. Because of ongoing economic growth, agents reach higher levels of utility over time. Since income and substitution effects exactly cancel in our specification of the utility function, f^* remains constant and point A moves upward at steady state speed of g per time unit. Therefore, an interior solution can also be found for the dynamic model.

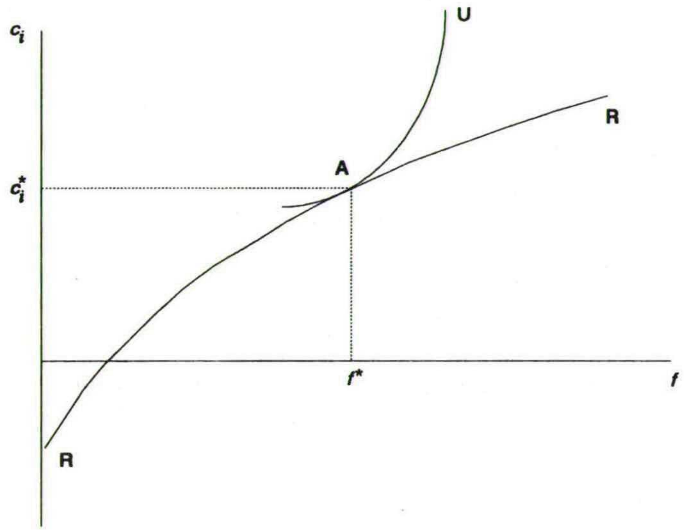

Figure 2: The static solution of the Millian economy with endogenous labour supply

The Hamiltonian is now formulated as

$$H = \ln(c_i) - \frac{\beta\eta}{\eta+1} f^{\frac{\eta+1}{\eta}} + \lambda[Y - c_i L - \delta K], \tag{15}$$

where Y is now given by $Y=AK^{\alpha}(fEL)^{1-\alpha}$. The relevant first order conditions are

$$H_{c_i} = 0 \quad \rightarrow \quad u_{c_i} = \lambda L, \tag{16}$$

$$H_f = 0 \quad \rightarrow \quad -u_f = \lambda Y_f, \tag{17}$$

$$H_K = -\dot{\lambda} + \rho\lambda \quad \rightarrow \quad \frac{\dot{\lambda}}{\lambda} = \rho + \delta - Y_K. \tag{18}$$

Equation 16 gives the optimal consumption decision. At the optimum the marginal utility of one additional unit of the consumption good equals the shadow price of capital ($\lambda=1/C$) so that the consumer is indifferent between consuming an additional unit of the good and increasing future consumption possibilities by addition of this good to the capital stock. Equation 17 gives the optimal time allocation decision. The marginal cost of an additional unit of labour time must equal its marginal benefit. When f is low, labour is relatively scarce and the marginal contribution to utility by relaxing the constraint by one unit is high. People are thus willing to supply more labour time until the marginal loss of utility equals the marginal gain in utility. The third condition gives the dynamic path of the shadow price of capital. From the first two FOC it follows that

$$\lambda = \frac{u_{c_i}}{L} = -\frac{u_f}{Y_f} \quad \rightarrow \quad \frac{1/c_i}{L} = \frac{\beta f^{\frac{1}{\eta}}}{(1-\alpha)Y/f}. \tag{19}$$

This expression states that the marginal utility of consumption must equal the marginal disutility of work. After rearranging (making use of $c_i \equiv C/L$ and $1-\sigma \equiv C/Y$), this gives the agent's optimal steady state labour time

$$f^{*} = \left(\frac{1-\alpha}{\beta(1-\sigma^{*})}\right)^{\frac{\eta}{\eta+1}} = \left(\frac{1-\alpha}{\beta}\frac{n+g+\delta+\rho}{n+g+\delta+\rho-\alpha(n+g+\delta)}\right)^{\frac{\eta}{\eta+1}}. \tag{20}$$

f^{*} increases with σ^{*} (given by eq. 11[4]), and decreases with α, β, and η. The intuition is as follows. A higher savings rate corresponds to a flatter time profile of the shadow price of capital because diminishing returns to capital accumulation set in more quickly (*cf.* eq. 18). This slower decline of the shadow price over time can be thought of as a higher value of the shadow price at any point in time. Thus, from eq. 19, it follows that the marginal utility of consumption and the marginal disutility of work must be higher at any time. Labour time thus increases in response to a rise in the savings rate. When α rises (and $1-\alpha$ declines), labour becomes less productive and it is optimal for the agent to decrease its labour time. When more weight is attached to leisure, *i.e.* β rises, the optimal labour time declines. Finally, as the willingness to substitute labour intertemporally increases, *i.e.* as η rises, the solution for the optimal labour time shifts further away from its outcome without intertemporal substitution possibilities. As $\eta \to \infty$, the optimal labour time converges to the minimum value of $(1-\alpha)/\beta(1-\sigma^{*})$. As η tends to zero, the solution converges to the case when labour is supplied exogenously, *i.e.* $f^{*}=1$.

Define $y \equiv Y/fEL$, $c \equiv C/fEL$, and $k \equiv K/fEL$. Since $1-\sigma = c/Ak^{\alpha}$, differentiating eq. 20 with respect to time gives the growth rate of the fraction of labour time

$$\frac{\dot{f}}{f} = \frac{\eta}{\eta+1}\left(\alpha\frac{\dot{k}}{k} - \frac{\dot{c}}{c}\right), \tag{21}$$

$$\frac{\dot{k}}{k} = Ak^{\alpha-1} - \frac{c}{k} - \left(n+g+\frac{\dot{f}}{f}+\delta\right), \tag{22}$$

$$\frac{\dot{c}}{c} = \alpha Ak^{\alpha-1} - \left(n+g+\frac{\dot{f}}{f}+\delta+\rho\right). \tag{23}$$

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[4] Since disutility of work enters in an additively separable fashion in the utility function, the Ramsey-rule is identical to eq. 10 so that the expression for the savings rate is again given by eq. 11.

Eq. 22 and 23 are based on eq. 4, 9, and the definition of the intensive form ($k \equiv K/fEL$, and $c \equiv C/fEL \equiv c_i/fE$). This dependent system of equations can be reduced to two equations by substituting eq. 22 and 23 in 21, solving for $\dot{f}/f$, and substituting the solution back in eq. 22 and 23. This yields:

$$\frac{\dot{k}}{k} = Ak^{\alpha-1} - \frac{1}{1+\alpha\eta}\frac{c}{k} - \frac{1+\eta}{1+\alpha\eta}(n+g+\delta) - \frac{\rho\eta}{1+\alpha\eta}, \tag{24}$$

$$\frac{\dot{c}}{c} = \alpha Ak^{\alpha-1} + \frac{\alpha\eta}{1+\alpha\eta}\frac{c}{k} - \frac{1+\eta}{1+\alpha\eta}(n+g+\delta) - \frac{1+\eta(\alpha+1)}{1+\alpha\eta}\rho. \tag{25}$$

Introducing endogenous labour supply changes the pattern of transition dynamics, as can be seen from this dynamic system. The steady state capital and output intensity can be found by setting $\dot{c}/c=0$, and $\dot{f}/f=0$ in eq. 23. This yields

$$k^{*} = A^{\frac{1}{1-\alpha}}\left[\frac{\alpha}{n+g+\delta+\rho}\right]^{\frac{1}{1-\alpha}}, \tag{26}$$

$$y^{*} = A^{\frac{1}{1-\alpha}}\left[\frac{\alpha}{n+g+\delta+\rho}\right]^{\frac{\alpha}{1-\alpha}}. \tag{27}$$

These steady state characteristics coincide with the solution where labour supply is exogenous. However, in the steady state consumption, capital, and output *per head* of the population are lower when labour supply is endogenous ($f<1$) since people care about leisure. Finally, the model implies that working days are longer during the convergence process of countries to the steady state when they start at low capital levels. This is consistent with what can be observed in reality. For example, in Germany annual working hours per person fell from 2316 in 1950 to 1607 in 1989. For the Netherlands these figures are 2208 in 1950 and 1387 in 1987 (data from Maddison 1991, Table C.9).

4. The Benthamite economy

Exogenous labour supply (model A')

In this section we ask ourselves how sensitive the results from the previous sections are with respect to changes in the specification of the utility function. To answer this question, it is assumed in this section that the consumer's maximization problem is based on an intertemporal Benthamite social welfare function by weighting instantaneous utility by family size. Total utility is the discounted sum of instantaneous utility per head times the number of heads, *i.e.*

$$U = \int_0^\infty u(c_i) L e^{-\rho t} dt. \tag{5'}$$

The present value Hamiltonian is now given by

$$H = \ln(c_i)L + \lambda\left[y - \frac{c_i}{E} - (n+g+\delta)k\right], \tag{6'}$$

where λ is - again - the shadow price of capital accumulation. The first order conditions for a maximum are

$$H_{c_i} = 0 \qquad \rightarrow \quad u_{c_i} = \frac{\lambda}{EL}, \tag{7'}$$

$$H_k = -\dot{\lambda} + \rho\lambda \qquad \rightarrow \quad \frac{\dot{\lambda}}{\lambda} = n+g+\delta+\rho-y_k. \tag{8'}$$

The optimal consumption decision is now determined by setting λ equal to $1/c$ *times* the size of the population L. This gives, after rearranging, the Euler equation of the optimal dynamic consumption path

$$\frac{\dot{c}_i}{c_i} = y_k - \delta - \rho. \tag{9'}$$

In the steady state the growth rate of consumption per head equals g so that the Ramsey rule now reads as

$$y_k^* = r^* = g+\delta+\rho, \tag{10'}$$

where r is the real rental rate on capital. Notice that r^* is invariant to changes in the population growth rate in this case. The steady state capital intensity no longer depends on population growth. The steady state savings rate (σ^*) can be written as

$$\sigma^{*} = \alpha \frac{n+g+\delta}{g+\delta+\rho}, \tag{11'}$$

which follows from eqs. 1 (intensive form), 4, 10', and the condition $\dot{k}=0$. The steady state solution for the capital and output intensity is

$$k^{*} = A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{g+\delta+\rho} \right]^{\frac{1}{1-\alpha}}, \tag{12'}$$

$$y^{*} = A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{g+\delta+\rho} \right]^{\frac{\alpha}{1-\alpha}}. \tag{13'}$$

Consumer preferences and technology together determine the steady state outcome of this economy. k^{*} and y^{*} are positively related to A and α, and negatively related to δ, ρ, and g. Contrary to eq. 12 and 13, steady state capital and output intensity are now invariant to population growth. Higher population growth tends to decrease the capital-labour ratio, but this tendency is fully offset by increased savings. This is illustrated in figure 3: a rise in population growth shifts the equilibrium from A to B so that the steady state capital and output intensity are not affected.

This result has important implications, especially from an empirical point of view. Assuming that each country has access to the prevailing level of technology in the world (*cf.* the production function in eq. 1), and abstracting from international differences in consumer preferences, depreciation rates, technical progress, and the factors embodied in the constant A (climate, institutional arrangements, natural resource endowments, and so forth), the world will face unconditional convergence in terms of capital and output intensities. Ultimately, the marginal products of capital and labour will be equalized across countries. Instead of country-specific steady states as in Mankiw *et.al.* (1992), there is only one world steady state which is independent of population growth.

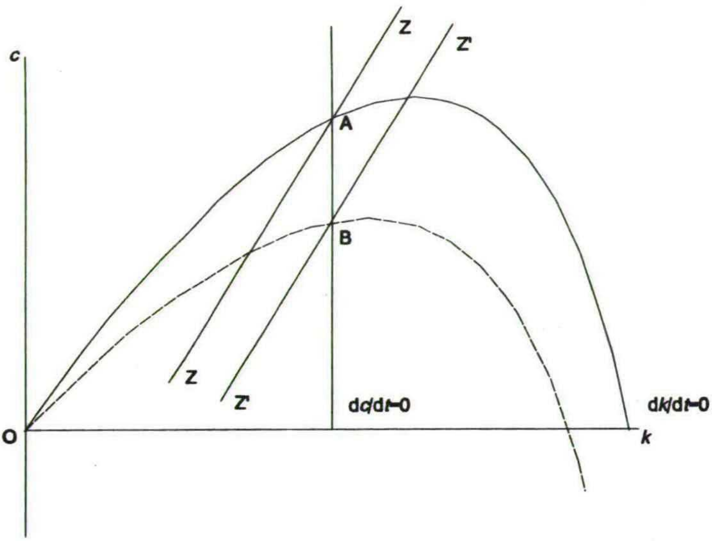

Figure 3: The Benthamite economy where labour supply is exogenous

Endogenous labour supply (model B')

In the second model, the Hamiltonian changes to

$$H = \left[\ln(c_i) - \frac{\beta\eta}{\eta+1} f^{\frac{\eta+1}{\eta}}\right] L + \lambda[Y - c_i L - \delta K], \tag{15'}$$

where Y is again given by $Y = AK^{\alpha}(fEL)^{1-\alpha}$. First order conditions 16 and 17 become

$$H_{c_i} = 0 \quad \rightarrow \quad u_{c_i} = \lambda, \tag{16'}$$

$$H_f = 0 \quad \rightarrow \quad -u_f = \frac{\lambda Y_f}{L}. \tag{17'}$$

Equation 16' gives the optimal consumption decision. At the optimum the marginal utility of one additional unit of per capita consumption equals the shadow price of capital ($\lambda = L/C$) so that the consumer is indifferent between consuming an additional unit of the good and increasing future consumption possibilities through capital accumulation.

Equation 17' gives the optimal time allocation decision. The marginal cost of an additional unit of labour time must equal its marginal benefit. When f is low, labour is relatively scarce and the marginal contribution to utility by relaxing the constraint by one unit is high. People are thus willing to supply more labour time until the marginal loss of utility equals the marginal gain in utility. From these conditions it follows that

$$\lambda = u_{c_t} = -\frac{Lu_f}{Y_f}. \tag{19'}$$

This expression states that the marginal utility of consumption must equal the marginal disutility of work. The agent's optimal labour time is now given by

$$f^* = \left(\frac{1-\alpha}{\beta(1-\sigma^*)}\right)^{\frac{\eta}{\eta+1}} = \left(\frac{1-\alpha}{\beta}\frac{g+\delta+\rho}{g+\delta+\rho-\alpha(n+g+\delta)}\right)^{\frac{\eta}{\eta+1}}. \tag{20'}$$

From 9' it follows that eq. 23 now reads as

$$\frac{\dot{c}}{c} = \alpha A k^{\alpha-1} - \left(\frac{\dot{f}}{f}+g+\delta+\rho\right). \tag{23'}$$

The reduced system of equations is given by:

$$\frac{\dot{k}}{k} = Ak^{\alpha-1} - \frac{1}{1+\alpha\eta}\left(\frac{c}{k}+n\right) - \frac{1+\eta}{1+\alpha\eta}(g+\delta) - \frac{\rho\eta}{1+\alpha\eta}, \tag{24'}$$

$$\frac{\dot{c}}{c} = \alpha Ak^{\alpha-1} + \frac{\alpha\eta}{1+\alpha\eta}\left(\frac{c}{k}+n\right) - \frac{1+\eta}{1+\alpha\eta}(g+\delta) - \frac{1+\eta(\alpha+1)}{1+\alpha\eta}\rho. \tag{25'}$$

Finally, the steady state capital and output intensity can be found by setting $\dot{c}/c=0$ and $\dot{f}/f=0$ in eq. 23'. This yields

$$k^* = A^{\frac{1}{1-\alpha}}\left[\frac{\alpha}{g+\delta+\rho}\right]^{\frac{1}{1-\alpha}}, \tag{26'}$$

$$y^* = A^{\frac{1}{1-\alpha}}\left[\frac{\alpha}{g+\delta+\rho}\right]^{\frac{\alpha}{1-\alpha}}. \tag{27'}$$

Again, these steady state characteristics coincide with the case of exogenous labour supply. Now that the models are fully specified, we can turn to the experiments in the next section.

5. Three experiments

To quantify the economy's response to demographic transition, three experiments are numerically simulated in this section. Simulations were run for the following set of parameters:

parameter	α	β	δ	η	θ	ρ	n	g
model A,A'	0.3	-	0.03	-	1	0.03	0.01	0.02
model B,B'	0.3	1.8	0.03	5	1	0.03	0.01	0.02

Table 1: Parameter values

The parameter values in table 1 are chosen in order to find realistic solutions for our model. To be consistent with the empirical observation that approximately thirty percent of national income accrues to capital and seventy percent accrues to labour, we set the production elasticity of capital, α, equal to 0.3 (since the production technology is Cobb-Douglas). Following Mankiw *et.al.* (1992), we assume $\delta+g=0.05$. This implies an annual rate of technical progress of two percent when capital depreciates at an annual rate of three percent (*cf.* footnote 6 in Mankiw *et.al.*, 1992). The rate of risk aversion, θ, is set at unity for reasons discussed in section 3. Average investment as a percentage of Gross Domestic Product amounts to 21.1% for the U.S. 1960-85 period (*cf.* Mankiw *et.al.* 1992). Therefore, we set the subjective rate of time preference, ρ, equal to 0.03 to find a steady state savings rate of 20% in the Millian economy (from eq. 11), or 22.5% in the Benthamite economy (from eq. 11'). Average annual population growth in the OECD countries over the 1870-1988 period is near 1 percent (*cf.* Maddison, Table C.8, 1991). Therefore, we take n=0.01. Finally, the parameters that determine the disutility of work, β and η, imply that f is approximately 0.5, so that individuals spend the same amount of time on market and non-market activities in the steady state.

Experiment 1: Anticipated temporary population growth shock

(n_0=0.01, n_1=0.03, T_1=5, T_2=10)

In the first experiment, the economy's reaction to a temporary and fully anticipated population growth shock is investigated. At the start of the experiment, agents know that the population growth rate between $t=T_1$ and $t=T_2$ is two percentage points higher than before and after this interval. In the Millian models (A and B) this population growth shock will temporarily reduce the steady state capital and output intensity, as opposed to the Benthamite models (A' and B') where only the steady state savings rate will be affected. Therefore, in the first two models agents immediately start to raise consumption intensity (*viz.* from A to somewhere below D in figure 1 for model A) until at $t=T_1$ the actual change in population growth takes place. By doing so, people consume some capital in the short run to anticipate the temporary fall in steady state capital intensity. Subsequently the consumption intensity drops, since agents anticipate the return to the original steady state capital intensity. This goes on until at $t=T_2$ the original population growth rate is restored. In figure 1, the economy then arrives at its original stable arm ZZ, somewhere to the north east of point G. From then on consumption gradually converges to its original steady state intensity, and the economy moves back to point A.

When labour supply is endogenous (model B), transition dynamics are reinforced and the convergence process accelerates. The temporary rise in population growth will cause savings to go down to anticipate the temporary fall in steady state capital intensity. Therefore, to obey eq. 19, people are going to spend less time at work. Since $k \equiv K/fEL$, K should fall strongly to match the decline in k. Therefore, the savings rate will be more volatile than in model A.

When the Benthamite criterion is employed in the consumption/saving problem, there is no capital dilution to be expected from the temporary population growth shock. Since people care about the utility of the members of their family, they will speed up the accumulation of capital to account for the increased need for capital when the population boom actually takes place. Therefore, consumers lose in the short run, as opposed to model A and B. When labour supply is endogenous, the short term negative effect on consumption is magnified. This is caused by the induced rise in the savings rate, which will be accompanied by longer working days which further tends to depress capital intensity. Savings therefore need to be higher than in case of exogenous labour supply. In the long run, the original population growth rate is restored and the initial consumption intensity is retained.

Because of the dissimilarities in savings behaviour between the Millian and Benthamite economy, the fraction of time spent working also shows a different time pattern. In the Millian economy, people work less in the short run because of the drop in the savings rate. Thereafter, labour time goes up because savings increase to restore the initial capital intensity. In the Benthamite economy, a higher savings rate is needed to accumulate capital for the newcomers so that more time is allocated to work.

Consequently, capital and output intensity decrease in the short and medium term in the Millian economy but are unaffected in the long term. In response to a temporary population boom, this economy will face a temporary recession. In the Benthamite case, capital and output intensity rise in the short run, fall in the medium run, and eventually return to their initial levels. A temporary boom in economic activity is followed by a temporary recession in this experiment.

Experiment 2: Anticipated permanent population growth shock

(n_0=0.01, n_1=0.03, T_1=5, $T_2 \rightarrow \infty$)

In the second experiment, the economy's reaction to a permanent and fully anticipated population growth shock is investigated. At the start of the experiment, agents know that the population growth rate from $t=T_1$ on will be two percentage points higher. In model A and B this population growth shock will permanently reduce the steady state capital and output intensity, as opposed to model A' and B' where only the steady state savings rate is permanently affected. Therefore, in the first two models agents immediately start to raise consumption intensity (*viz.* from A to D in figure 1 for model A) until at $t=T_1$ the actual change in population growth takes place. By doing so, people consume some capital to anticipate the permanent fall in steady state capital intensity. Subsequently the consumption intensity falls, and the economy moves along its new saddle path Z'Z' towards point B in figure 1.

When labour supply is endogenous (model B), transition dynamics are reinforced and the convergence process accelerates. The permanent rise in population growth will cause savings to go down to anticipate the permanent fall in steady state capital intensity. Therefore, to obey eq. 19, people are going to spend less time at work. Since $k \equiv K/fEL$, K should strongly fall to accomplish a decline in k. Therefore, the savings rate will be more volatile than in model A.

When the Benthamite criterion is employed in the consumption/saving problem, there is no capital dilution to be expected from the permanent population growth shock. Since people care about the utility of the members of their family, they will speed up the accumulation of capital to account for the increased need for capital when the population boom actually takes place. Therefore, consumers lose in the short run, as opposed to models A and B. When labour supply is endogenous, the short term negative effect on consumption is magnified. This is caused by the induced rise in the savings rate, which will be accompanied by longer working days which further tends to depress capital intensity. Savings therefore need to be higher than in the case of exogenous labour supply. In the long run, consumption intensity is lower than initially.

Because of differences in savings behaviour between the Millian and Benthamite economy, the fraction of time spent on working also shows a different time pattern. In the Millian economy, people work less in the short run to accompany the drop in the savings rate. Thereafter, labour time goes up because savings increase to restore the initial capital intensity. In the Benthamite economy, a higher savings rate is needed to accumulate capital for the newcomers so that more time is allocated to work.

Consequently, capital and output intensity decline in the Millian economy. In response to a permanent population boom, this economy goes into a permanent recession. In the Benthamite case, capital and output intensity rise in the short and medium run, and eventually return to their initial levels. A temporary boom in economic activity is the result of this experiment.

A summary of the basic results is given in table 2:

	Experiment 1	Experiment 2
Model A	Temporary mild recession	Permanent recession
Model B	Temporary wild recession	Permanent recession
Model A'	Temporary wild boom, followed by temporary wild recession	Temporary wild boom
Model B'	Temporary mild boom, followed by temporary mild recession	Temporary mild boom

Table 2: The production pattern in two experiments

Note: A recession (boom) is defined as a period in which production intensity falls below (rises above) its original steady state value. A temporary deviation ultimately vanishes, while in case of a permanent deviation the economy does not return to its original steady state level, even in the long run.

Experiment 3: Unanticipated return to the initial population growth rate

(until t=10: n_0=0.01, n_1=0.03, T_1=5, $T_2 \to \infty$

thereafter: n_0=n_1=0.01, T_1=T_2=0)

The role of news is investigated in the third experiment. At the start of the experiment, agents believe that the population growth rate from $t=T_1$ on will be two percentage points higher. However, at $t=T_2$ population growth unexpectedly returns to its initial rate. Until $t=T_2$, the reaction of the economy is similar to the second experiment (for model A, the system moves along ADEF in figure 1). At $t=T_2$ the original population growth rate is retained, and people immediately change their consumption plans. In model A and B, consumption will fall so as to speed up capital accumulation to restore the original steady state. Consumption strongly rises in model A' and B' since less savings are needed to maintain constant capital intensity.

6. Conclusion

By allowing for variations in labour supply growth, transition dynamics generate real cycles in neoclassical growth models. The intensity and shape of these cyclical movements strongly depend on the functional form of the intertemporal utility function and on the assumed exogeneity of labour supply.

Related studies (*cf.* Cutler *et.al.* 1990, and Yoo 1994) do not explicitly consider the consequences of the assumptions with respect to labour supply and intertemporal utility. For instance, in Yoo's paper the effects of an unexpected and temporary increase in the population growth rate are explored. For the neoclassical growth model based on the Millian criterion, he concludes that the baby boom depresses capital intensity in the production process. However, the capital-labour ratio is invariant to the population growth rate when a Benthamite criterion function is employed (which is the case in Yoo's second model). Thus, the choice of the intertemporal utility function is an important candidate to explain that simulation results differ between the 'neoclassical growth model' and the 'dependency-ratio growth model'. Therefore, simulation results presented in these studies are not expected to be robust to changes in the specification of intertemporal utility and labour supply growth. Awareness of the sensitivity of the model's solution is essential to any study that seeks to shed light on the macroeconomic consequences of demographic transition.

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Experiments

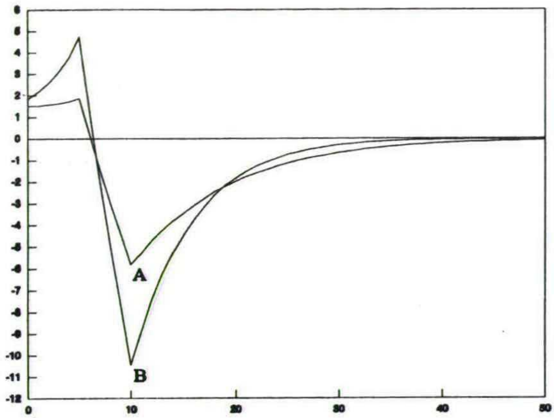
Experiment 1:	Anticipated temporary population growth shock
Experiment 2:	Anticipated permanent population growth shock
Experiment 3:	Unanticipated return to the initial population growth rate
Model A:	Millian economy with exogenous labour supply
Model B:	Millian economy with endogenous labour supply
Model A':	Benthamite economy with exogenous labour supply
Model B':	Benthamite economy with endogenous labour supply

In the following diagrams time is on the horizontal axis and the deviation in % from the original steady state value is on the vertical axis.

Experiment 1

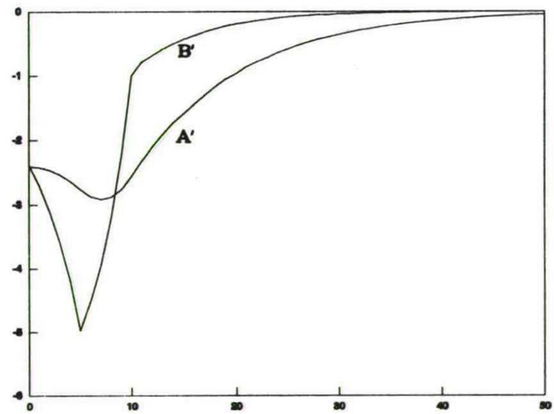
Consumption in Millian Economy

(Exp. 1)

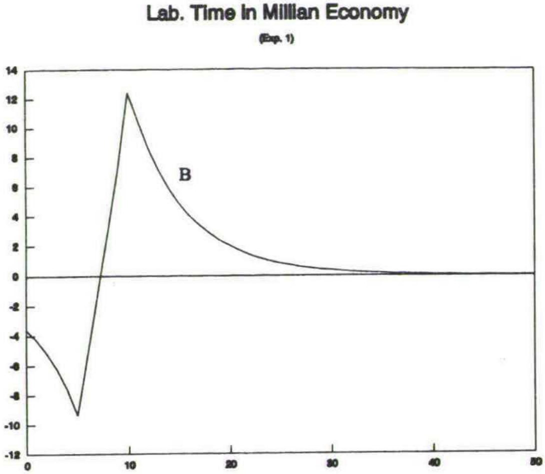


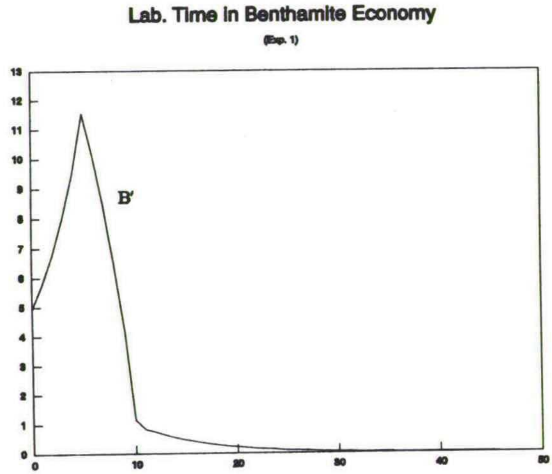
Consumption in Benthamite Economy

(Exp. 1)



Experiment 1, continued





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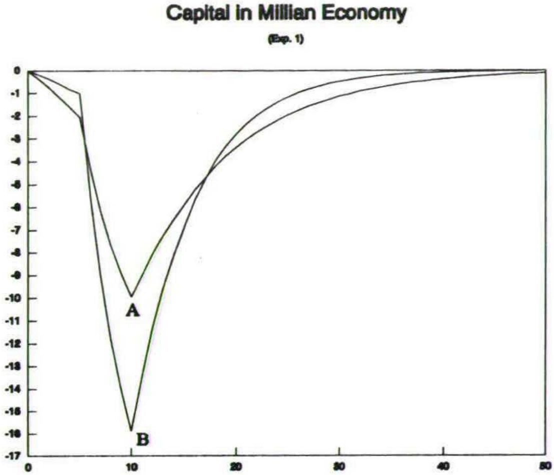
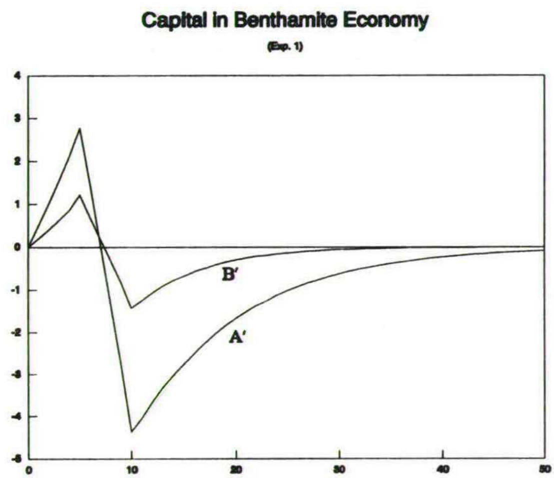
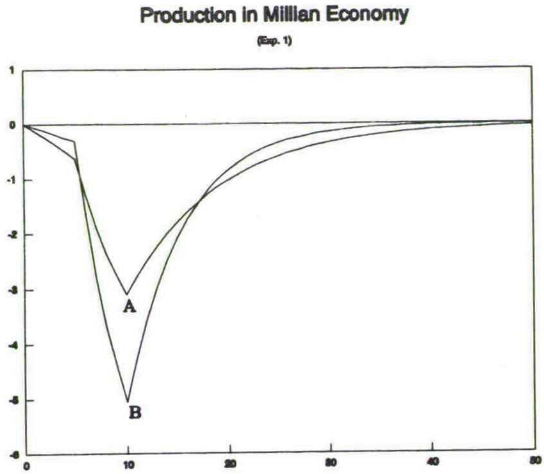
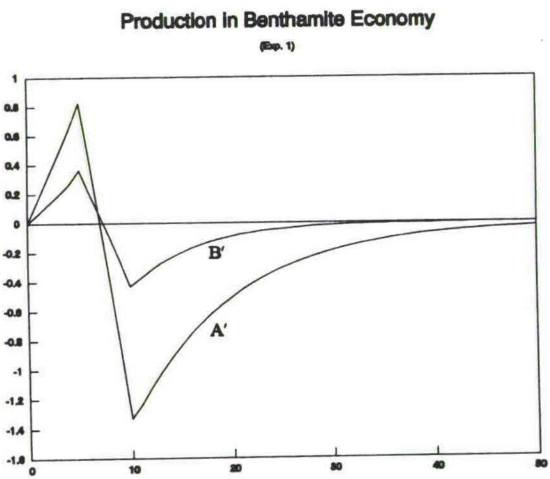




Experiment 1, continued

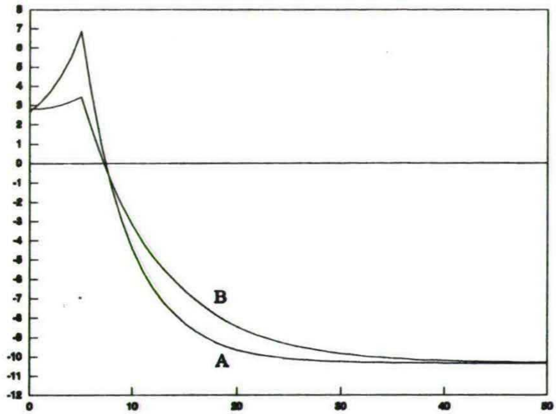




Experiment 2

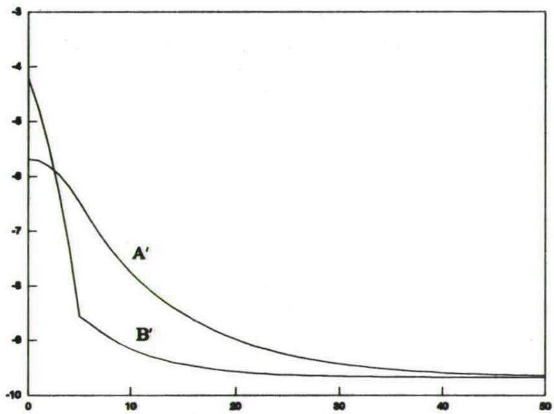
Consumption in Millian Economy

(Exp. 2)

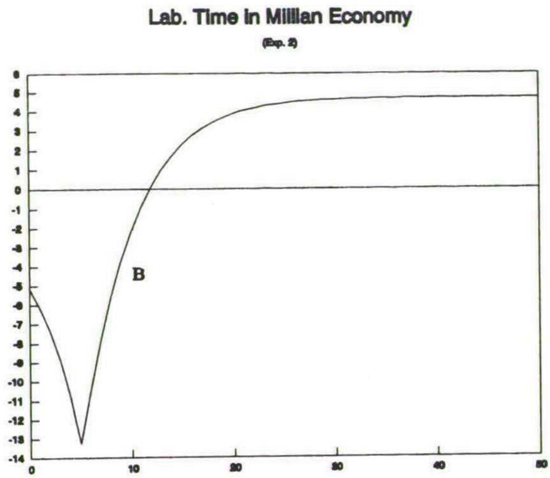


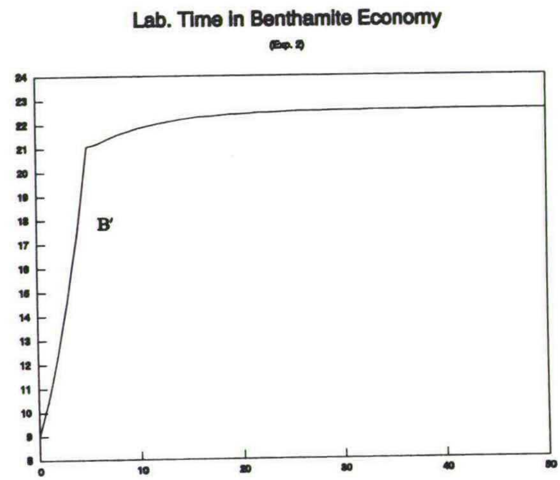
Consumption in Benthamite Economy

(Exp. 2)

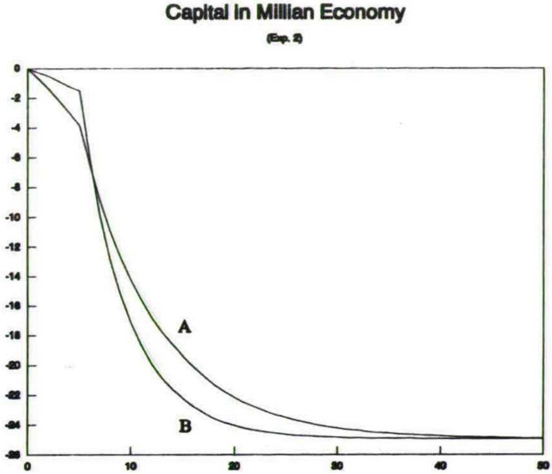


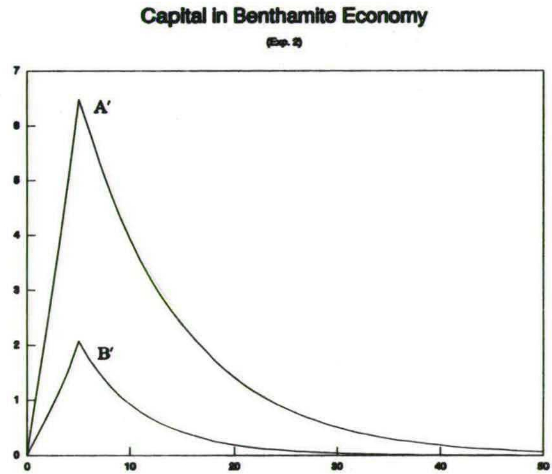
Experiment 2, continued



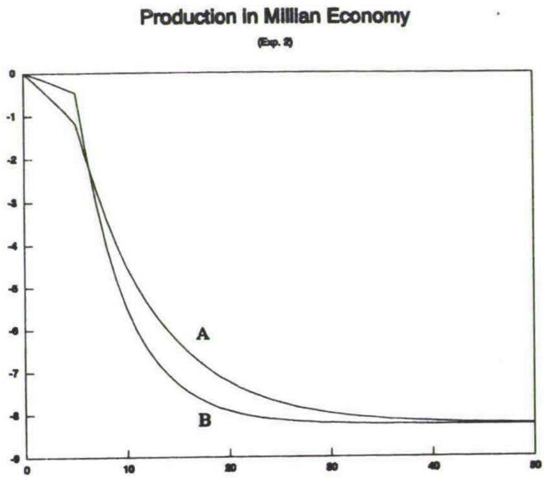


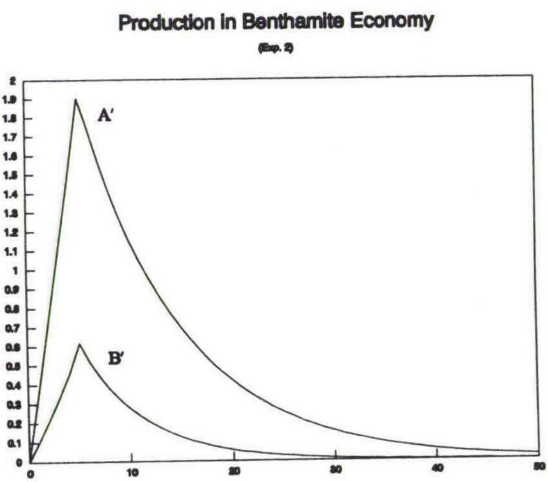
Experiment 2, continued





Experiment 2, continued

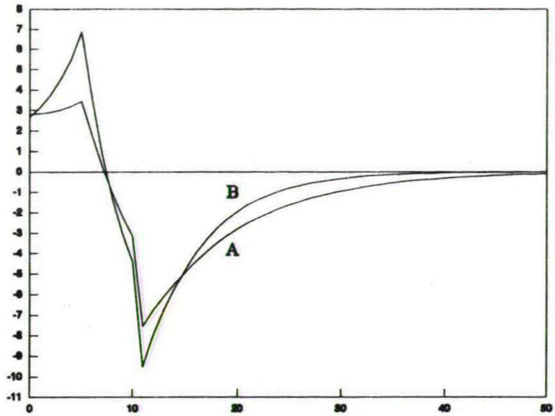




Experiment 3

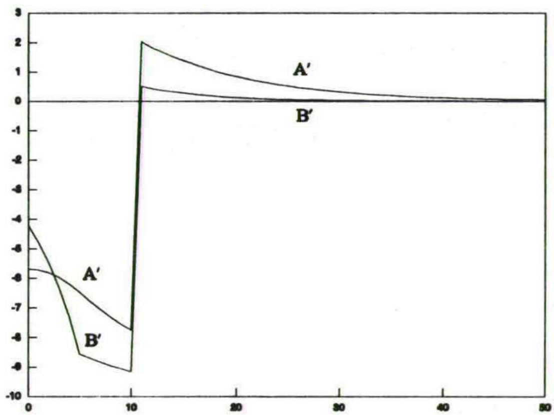
Consumption in Millian Economy

(Exp. 3)

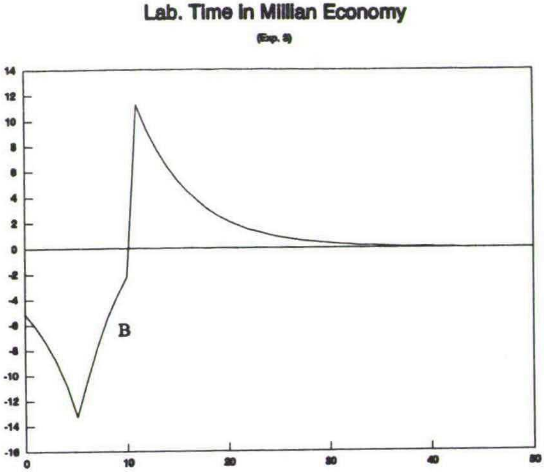


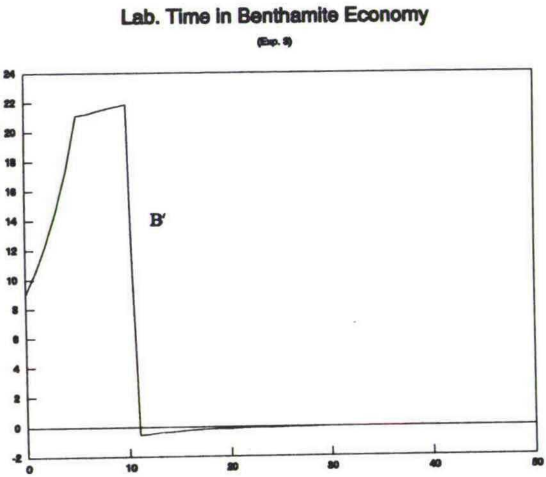
Consumption in Benthamite Economy

(Exp. 3)



Experiment 3, continued

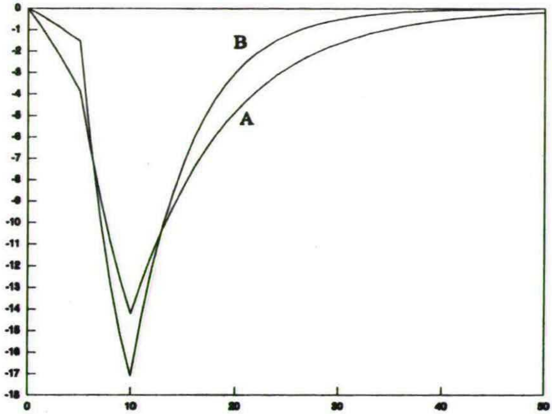




Experiment 3, continued

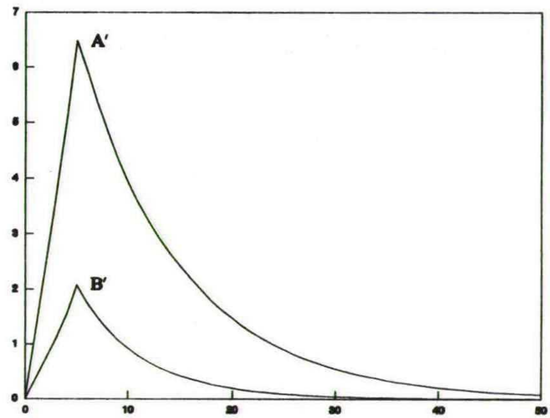
Capital in Millian Economy

(Exp. 3)

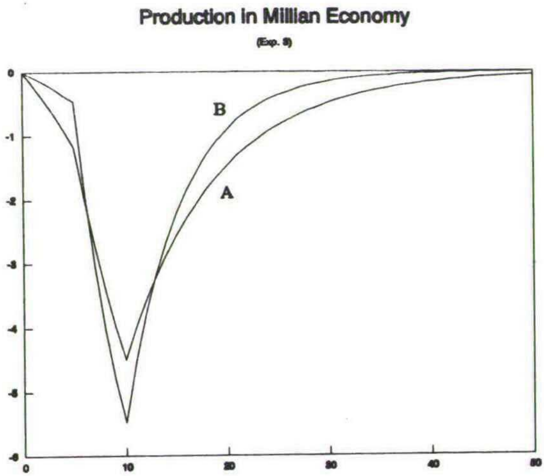


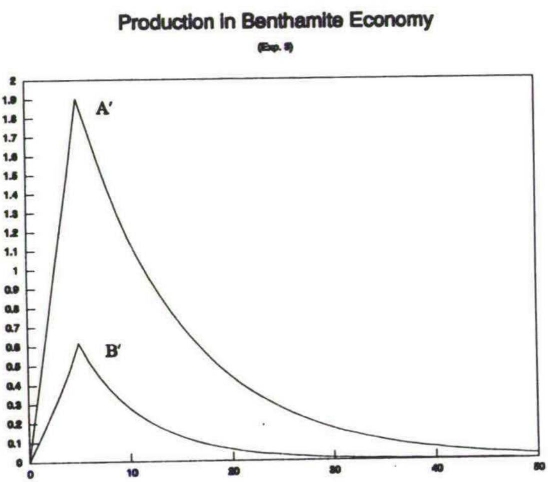
Capital in Benthamite Economy

(Exp. 3)



Experiment 3, continued





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