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October 2006

ENVIRONMENTAL
ECONOMICS & MANAGEMENT
MEMORANDUM

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Family altruism with a renewable resource and population growth

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October 30, 2006

Abstract

We develop an overlapping-generation model *à la* Diamond with a non-constant population growth in which households privately own a natural renewable resource and have a family-altruism resource bequest motive. The natural resource can be either extracted and sold to the producing firms as a production factor, or bequeathed to the offspring to increase his adult disposable income. With a numerical application we analyze how family altruism interplays with population growth to shape the dynamics of the whole economy. We also highlight the role of altruism in the case of two negative demographic shocks. The simulations show that the pressure on the natural resource is not necessarily reduced when the population size is lower. Transmission mechanisms between generations and general equilibrium effects may yield unexpected outcomes. In particular, we show that, depending on the shock, the family altruism can play a positive or a negative role for resource preservation.

Acknowledgments: We are grateful to the editor and an anonymous referee for having helped us improve the article. We also thank Jean-Paul Ledant for key insights in forest management. This research was partially supported by the research projects ACI Economic Modeling of Sustainable Development (French Ministry of Research) and ClimNeg (Belgian Science Policy). The usual disclaimers apply.

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1 Introduction

Population growth is recognized as a critical variable for many environmental challenges in many countries, notably by influencing the availability of natural resources. The example of forests is an interesting one. Most of the world's original forests have been lost due to the expansion of human activities, and future declines in the per capita availability of forests, especially in developing countries, are likely to raise major challenges for both biodiversity conservation and human well-being. Today, over 2.2 billion people live in 46 countries with less than 0.1 hectare of forested land per capita, an indicator of critically low levels of forest cover. Based on medium population projections and current deforestation trends, by 2025 the number of people living in forest-scarce countries could reach 3.2 billion in 54 countries.[1] In such a context, avoiding excessive population growth is generally advocated as a prerequisite to sustainability in many developing countries by alleviating a too high pressure on the natural resources thanks to a lower extraction rate.

Actually, the impact of population growth on natural resources availability remains disputed in the literature. Many papers focus on the key-role of overpopulation (Abernathy (1993), Avise (1993), Holdren (1992), among others) but empirical evidence does not clearly support that point of view. Li (1991), for example, stresses that China's forested area changed from 8% in 1949 to 12 % in 1984 and to 8% again in 1988, while population was growing steadily during that period. By analyzing cross-correlations between national socio-economic indicators (including population growth) and the rate of forest cover change, FAO (2001) shows that the only variable that comes near significance is the proportion of rural population. Still, it only accounts for 14% of the variation in forest cover at national level. Clearly, the deforestation process is a complex phenomenon involving physical, climatic, political and socio-economic forces. Would a smaller population size necessarily yield a lower resource extraction and, thereby, guarantee resource preservation?

The purpose of our paper is to show that such a conjecture is far too mechanical as it does neglect the dynamical effects of population changes on the whole economy and the resource dynamics. Our objective is to analyze how economic dynamics and transmission mechanisms of a natural resource among generations interplay with population dynamics. Different population trends may yield different accumulation processes of man-made and natural forms of capital, thus leading to some unexpected outcomes. Studying these issues requires to use a dynamic general equilibrium model of the economy with an adequate representation of the transmission of resources between generations.

[1]Source: Population Action International, People in the Balance Update 2006. See also the statistics from FAO (2001).

In this article we use an dynamic general equilibrium overlapping generations model in which a natural renewable resource (a forest) is used beside man-made capital and labor to satisfy the needs of a growing population.

A vast literature already deals with natural renewable resources in an OLG framework. Our paper adds to this literature by many features. Most of the time, papers on forestry study the bequest of timber between generations without modeling a final good production sector, (see Amacher *et al.* (1999), Ollikainen (1998)). In our model we consider the production process of a consumption-investment good like in the Diamond model (1965). Furthermore, we consider two stocks in the economy, the natural resource and man-made capital. Both enter the production function, besides labor. In the forest literature with OLG, the papers sometimes do not consider the production process and, if they do, they generally do not include the aggregate stock of physical capital beside labor and the extracted resource (see Koskela *et al.* (2000) and (2002), Olson and Knapp (1997)). We are particularly interested in the transition path, notably in reaction to a demographic shock, whereas most of the papers only focus on steady states. More importantly, the transmission mechanism of the natural resource between generations is an original one in our model. In the literature this transmission generally takes two forms, either by selling the unextracted resource stock or by bequeathing it. Usually, when the resource is sold, households are assumed to be selfish (Koskela *et al.* (2002), Mourmouras (1991)) whereas, in the other type of transmission, households are assumed to have a resource bequest motive. In many papers the assumed bequest motive is based on the altruism *à la* Barro (1974). In such a setting, parents care about their offspring's utility (Amacher *et al.* (1999)). As Becker (1993) admits, this form of intergenerational concern requires human foresight capacities that are beyond the capacities of the most prescient. Alternatively, parents may be assumed to have a joy-of-giving resource bequest motive (Ollikainen (1998) and Bréchet and Lambrecht (2006)). In this paper we use the family altruism model of transmission originally developped in a framework without natural resource (see Lambrecht *et al.* (2005) and Lambrecht *et al.* (2006)). In their contribution, parents are assumed to care about their offspring's adult income and bequests are made under the form of the *numeraire* good. In our model, the children's adult disposable income also enters the utility function of each family head but the extracted resource is a source of income for young adults and the non-extracted resource stock constitutes the means of the bequest. Our extension of the family-altruism model needs more attention and explanations. Hence the paper will start with a presentation of the ins and out of this model, extended to resource bequests.

The paper is organized as follows. In the following section we present and justify our choice of the family-altruism model. Section 3 presents the model, *i.e.* the dynamics of the population and renewable resource, the family-altruism resource bequest motive and the individuals' and firms' behavior. A special attention will be paid on the family altruism bequest motive and the way it interferes with the population dynamics. The competitive temporary and intertemporal equilibrium are defined and characterized in Section 4. Section 5 presents a numerical application of the model and a reference scenario which will help us to highlight its main dynamic properties. With this application Section 6 analyzes the impacts of two demographic shocks on the economy and the renewable resource, the first one being a temporary drop in the population size, the other one being a permanent slowdown of the fertility factor. Lastly, Section 7 draws some conclusions.

2 Family altruism

Our motivation is to study the interplay between population growth and the use of a renewable resource with an appropriate approach of altruism. In this section we justify our choice of the *family altruism* hypothesis. More precisely, we shall first explain why we do not retain Barro's (1974) *dynastic altruism* hypothesis or either Andreoni's (1989) *joy-of-giving* approach. Then we shall justify and explain our choice of the *family altruism* hypothesis.

When dealing with the issue of the conservation of a natural resource, an infinite-horizon altruism model like Barro's (1974) is not suited to apprehend what happens in equilibrium, i.e. to understand how private agents interact on market and in their families, when the decision of passing the resource stock on to the next generation is at stake[2]. What makes the equilibrium analysis interesting, in the presence of a natural resource, is that private agents precisely could exhaust the resource because they do not foresee the future consequences of their present decision. Is there nevertheless a chance to maintain the stock of the resource in the long run? Under a Barro (1974) type of altruism the answer to this question is almost always trivially yes : if the chain of bequests

[2] In the literature on intergenerational transfers (e.g. Barro (1974) and Becker (1991)), parents feel concerned about their children through altruistic links. These links are operative when parents make positive transfers of the *numeraire* good to their offspring in order to iron out shocks in their relative well-being. Barro (1974) has formulated a version of the altruistic hypothesis in which altruistic households solve a problem formally equivalent to the infinitely-lived representative agent. When applied to the study of the effects of public debt this so-called *dynastic* altruistic model concludes that households are able to offset any policy aiming at redistributing income between generations through public debt. Barro's (1974) paper was a revival of the Ricardian equivalence argument and gave rise to a large debate on the intergenerational effect of public policies. One among the many criticisms addressed to the dynastic model is that it assumes that the sequence of individuals of one dynasty not only are willing to behave as one decision unit but also have the capacity to foresee the indefinite future, *i.e.* the whole future paths of prices and incomes.

in uninterrupted, the dynasty behaves in equilibrium almost like a benevolent planner, especially if the latter has the same discount factor. To the opposite, a finite-horizon form of altruism leaves the answer to the conservation issue open.

Many kinds of finite-horizon altruisms have been considered in the literature[3]. For example, the *joy-of-giving* resource bequest motive of Andreoni (1989)[4] is compatible with a finite time horizon. However, a clear drawback of this approach is that the magnitude of resource transfers is independent of the relative affluence and, more generally, of the opportunities open the offspring. This approach has been adopted by Bréchet and Lambrecht (2006) in a similar setting.

The *family altruism* model combines the finite horizon feature and the sensitivity the bequest decision to changes in the offspring's economic situation[5]. This is thus a more realistic framework than the dynastic model and a more general approach than the joy-of-giving one. We thus judge it more relevant to study the role of family links in general and the intertemporal equilibrium in the presence of a natural resource.

Our focus is on the role of family transmission of a renewable natural resource in private property. We shall thus concentrate on the bequest of the natural resource out of an altruistic bequest motive and leave aside bequests of the *numeraire* as well as family investment in the human capital of their offspring, under the form of educational expenditures.

Lambrecht *et al.* (2006) include *numeraire* bequests and educational expenditures. They show that families with a binding bequest constraint under-invest in human capital. They fail to exhaust all the marginal gains which could otherwise be achieved by freely trading between present personal utility and future offspring's income. This is equivalent to say that, at the family head's optimum, the return on investment in human capital remains higher than the interest factor. Equalization of the two types of returns fails to occur. In our setting with a natural resource, it would certainly also be the case that family heads hitting their non-negativity constraint on *numeraire* bequests would optimally under-invest in their offspring's income through resource bequest. In other words, they would exploit more of the resource and sell more of it to the

[3]See Michel *et al.* (2006) for a comprehensive survey of altruistic bequest motives, be them with finite or infinite horizons.

[4]This approach is sometimes also labeled the *warm glow* approach.

[5]The idea of family altruism has been developed recently in two papers. Lambrecht *et al.* (2005) use it to study how pay-as-you-go pensions can foster growth in a model with human and physical capital. Lambrecht *et al.* (2006) discuss the implication of the family altruism hypothesis in the public debt policy debate. The main assumption of the family model, as opposed to the dynastic model, is that the decision unit in which intergenerational links are operative is the family, as opposed to the dynasty.

production sector, than in the case of a non-binding constraint. While these types of results are most likely to hold, it would complicate the analysis a great deal to model both types of bequests, especially because in our framework we analyze changes in the population dynamics and these changes affect the degree of altruism, through the number of children per family head. This feature leads us to use a single resource bequest model.

But how can we apply the family altruism approach to framework with a natural renewable resource? The answer to this question is actually rather simple. We just have to cautiously redefine the offspring's adult disposable income under the hypothesis that the natural resource may be exploited by each young generations and sold to the producing firms. The next section will detail our model, and particularly the changes brought to the family-altruism approach when dealing with a natural renewable resource in private property.

3 The model

We model an overlapping-generation (OLG) economy *à la* Diamond (1965). We extend this basic model in two respects. First we assume that individuals leave bequests of natural resource to their offspring out of the family altruism bequest motive (Lambrecht *et al.* (2005), Lambrecht *et al.* (2006)) and second we assume that the size of each generation has its own dynamics along which the growth rate is changing over time.

3.1 The family altruism bequest motive and the fertility factor

We first present the dynamics of the size of generations and then the concept of family altruism applied to the bequests of natural resource.

Let N_t denote the number of young individuals at time t. The generations' size dynamics are governed by the following equation:

$$N_{t+1} = BN_t^{\nu}, \tag{1}$$

with $\nu \in (0, 1)$, $B > 0$ a scale factor and N_{-1} the exogenously-given number of old individuals in the initial period. Whatever the initial N_{-1}, the steady state size of each generations is given by: $N = B^{1/(1-\nu)}$. Consider any time period t on the transition. N_t is the number of young individuals. The number of children who will be young adults at time $t+1$ is denoted by N_{t+1}. We label the ratio N_{t+1}/N_t as the fertility factor. On the transition of the generations' size dynamics, the fertility factor changes and converges to unity. This is at odd with the standard OLG model *à la* Diamond (1965) in which the ratio between the size of a young and an old generation, N_{t+1}/N_t, remains constant. It is often denoted by the factor $1+n$. In line with this notation we will denote our fertility factor by $1 + n_{t+1}$. It is easy to write this fertility factor as a function of the size of the old time t generation. This yields:

$$1 + n_{t+1} \equiv \frac{N_{t+1}}{N_t} = BN_t^{\nu-1}. \tag{2}$$

Let the initial generation's size N_{-1} be less (resp. greater) than the steady state size N. The convergence towards N is monotonically increasing (resp. decreasing). As far as the fertility factor $1 + n_{t+1}$ is concerned, it follows a decreasing (resp. increasing) path toward unity as the generation's size increases (resp.decreases). Since all the households are homogenous, the factor $1 + n_{t+1}$ is also the number of children in each household.

Let us now describe how we apply the concept of family altruism to our model with bequests of resource. We define the family as a decision unit which survives for two periods. It is composed of a family head, namely an individual over his life cycle, and his $1 + n_{t+1}$ children during the first period of their life cycle (adulthood). As a result, each individual is a member of the family started by his parent one period before and starts his own family when he is young. His own family lives for two periods. Altruism is assumed to be descendant, i.e. parents care about their children but not the reverse.

The difference between a typical *household* of the Diamond's (1965) model and a *family* in Lambrecht *et al.*'s (2006) model is the following. Families are actually equivalent to Diamond's (1965) households plus the next households during their adulthood[6].

The preferences of a family head are defined over his life cycle consumption, c_t and d_{t+1}, and over their $1 + n_{t+1}$ children's adult disposable income ω_{t+1}[7]. With such preferences, the sequence of altruistic descendants of the same time $t = 0$ founding father, does not behave as a single dynasty and there is no need to foresee the indefinite future.

Let us now discuss the extensions which our paper brings to the standard family-altruism model. First of all, the fertility factor $1 + n_{t+1}$ and, hence the size of families $2 + n_{t+1}$, changes over time. The generation's size dynamics is increasing and concave which has a very simple implication. If the size of generations increases toward the steady state, the family size decreases[8] and, as times goes by and generations follow each other, the family heads care about the

[6]During childhood, individuals make no decision.

[7]In the dynastic model, preferences are defined over consumptions and the children's utility, which is formally equivalent to the infinite sum of utilities defined over the whole sequence of consumptions of all generations.

[8]In the standard family altruism model with constant population growth, the family size remains constant like the fertility factor.

adult disposable incomes of less and less children[9]. The population dynamics thus introduces a trend in the utility function. This means that preferences are *time-dependant*, which will play a key role in our results.

We assume the utility function to be additively separable:

$$U_t = (1-\beta)u_1(c_t) + \beta u_2(d^e_{t+1}) + (1+n_{t+1})\gamma u_3(\omega^e_{t+1}), \tag{3}$$

where d^e_{t+1} and ω^e_{t+1} are respectively the expected second-period consumption and the expected adult disposable income of each of the $1+n_{t+1}$ children.

The other extension to the standard family altruism model concerns the expectations formed by the family head on the adult disposable incomes ω^e_{t+1}. To understand this, we need to present the sources of revenues of a young individual. Each young individual works and extracts a renewable resource in the first period of his life. More precisely, he supplies to firms (i) one unit of labor inelastically on the labor market, for a real wage w_t, and (ii) the quantity e_t of extracted resource on the resource market, for a real price q_t. Each time t family head has to form expectations about the real wage and resource price at time $t+1$, namely he has to try to decide about the value of, respectively, w^e_{t+1} and q^e_{t+1}. Moreover he has to form expectation about the extraction behavior if his offspring, e^e_{t+1}. As a result the expected adult disposable income of a young individual, as anticipated by a time t family head, is the following:

$$w^e_{t+1} + q^e_{t+1}e^e_{t+1} = \omega^e_{t+1}. \tag{4}$$

3.2 The renewable resource dynamics

We assume that there exists a renewable resource in private property. At any time t, each family head inherits a share z_{t-1} of the family resource stock. This individual stock has its own natural return, which yields Cz^{ζ}_{t-1}, with $C > 0$ a scale factor, to each family heads. In the absence of extraction this stock Cz^{ζ}_{t-1} is shared among the $1+n_{t+1}$ children. Thus the dynamics of the families' resource stock without extraction writes as follows:

$$z_t = \frac{Cz^{\zeta}_{t-1}}{1+n_{t+1}}, \tag{5}$$

with $\zeta \in (0,1)$. Without extraction, the family head's resource stock converges to a steady state equal to[10] $z = C^{1/(1-\zeta)}$.

[9] The reverse is true for a decreasing population.

[10] Indeed $1+n_{t+1}$ tends to unity.

3.3 The individuals' problem

We now characterize the behavior of the family heads. We make the assumption that their utility function is of the log-linear type:

$$U_t = (1-\beta)\log c_t + \beta \log d^e_{t+1} + (1+n_{t+1})\gamma \log \omega^e_{t+1}. \quad (6)$$

As we already explained, the first period income of a young family head is $\omega_t = w_t + q_t e_t$. This first-period income is shared between consumption c_t and saving s_t. This is summarized by the first-period budget constraint:

$$w_t + q_t e_t = c_t + s_t. \quad (7)$$

The amount of resource which has not been extracted, i.e. $Cz^{\zeta}_{t-1} - e_t$, is bequeathed equally to the $1+n_{t+1}$ children by the family head. This means that the dynamics of the families' resource stock with extraction is given by:

$$z_t = \frac{Cz^{\zeta}_{t-1} - e_t}{1+n_{t+1}}. \quad (8)$$

When old, individuals hold the firms' capital stock through their savings and earn a capital income which they entirely consume. As anticipated from period t, this summarized by :

$$R^e_{t+1} s_t = d^e_{t+1}, \quad (9)$$

where R^e_{t+1} is the expected interest factor on saving s_t, i.e. one plus the expected interest factor r^e_{t+1}, and d^e_{t+1} is the expected old-age consumption.

As explained before young family heads form expectations to evaluate the adult disposable income of their offspring. This is given by equation (4). They can sustain their offspring's adult disposable income by increasing their resource bequests[11]. Indeed equation (4) can be re-written as follows:

$$w^e_{t+1} + q^e_{t+1}\left[\left(\frac{Cz^{\zeta}_{t-1} - e_t}{1+n_{t+1}}\right)^{\zeta} - (1+n_{t+2})z^e_{t+1}\right] = \omega^e_{t+1}. \quad (10)$$

Family heads maximize their utility (6) under the constraints (7), (9) and (10) and taking prices and expectations as given. The solution to this problem can be characterized by studying the saving and the resource extraction decisions, i.e. by studying the following problem obtained after substitution:

$$\max_{s_t, e_t} (1-\beta)\log(w_t + q_t e_t - s_t) + \beta \log(R^e_{t+1} s_t)$$
$$+ (1+n_{t+1})\gamma \log\left(w^e_{t+1} + q^e_{t+1}\left[\left(\frac{Cz^{\zeta}_{t-1} - e_t}{1+n_{t+1}}\right)^{\zeta} - (1+n_{t+2})z^e_{t+1}\right]\right). \quad (11)$$

[11]In this paper we rule out bequest of the *numeraire* like in most altruistic models.

The first-order conditions are:

$$\frac{1-\beta}{w_t+q_te_t-s_t}=\frac{\beta}{s_t}, \tag{12}$$

$$\frac{(1-\beta)q_t}{w_t+q_te_t-s_t}\leq\frac{\gamma q^e_{t+1}\zeta\left(\frac{Cz^\zeta_{t-1}-e_t}{1+n_{t+1}}\right)^{\zeta-1}}{w^e_{t+1}+q^e_{t+1}\left[\left(\frac{Cz^\zeta_{t-1}-e_t}{1+n_{t+1}}\right)^{\zeta}-(1+n_{t+2})z^e_{t+1}\right]}. \tag{13}$$

The last condition holds with equality if extraction is positive. Instead it holds with inequality when optimal extraction is zero, *i.e.* when, at zero extraction, the marginal benefit from extraction in terms of consumption c_t is larger then the marginal loss in terms of the offspring's expected adult disposable income ω^e_{t+1}. In the sequel we focus on the case of optimal positive extraction, i.e. the case when, at zero extraction, the marginal benefit of extraction is smaller than the marginal gain. Savings can be written as a function of extraction e_t:

$$s_t=\beta(w_t+q_te_t). \tag{14}$$

and the second condition with equality can be re-written as:

$$(1-\beta)q_t\left[w^e_{t+1}+q^e_{t+1}\left[\left(\frac{Cz^\zeta_{t-1}-e_t}{1+n_{t+1}}\right)^{\zeta}-(1+n_{t+2})z^e_{t+1}\right]\right]$$
$$-\gamma q^e_{t+1}\zeta\left(\frac{Cz^\zeta_{t-1}-e_t}{1+n_{t+1}}\right)^{\zeta-1}(w_t+q_te_t-s_t)=0. \tag{15}$$

Thus we have a system of two equations in the variables s_t and e_t

It easy to shed light on the family head decision problem by building the family income and the family intertemporal budget constraint. In the Diamons's (1965) model, the life cycle income and budget constraint are built by adding up the incomes and expenditures of the whole life cycle in present value. In the family model, we simply add up all the incomes and expenditures of the life cycle plus the definition of the adult disposable incomes of the $1+n_{t+1}$ children, in present value, *i.e.* we add the present value of equations (7), (9) and (4) times $(1+n_{t+1})$. Denote the family intertemporal income by Ω_t, we have that:

$$\Omega_t\equiv w_t+q_te_t+\frac{1+n_{t+1}}{R^e_{t+1}}(w^e_{t+1}+q^e_{t+1}e^e_{t+1})=c_t+\frac{d^e_{t+1}}{R^e_{t+1}}+\frac{1+n_{t+1}}{R^e_{t+1}}\omega^e_{t+1}. \tag{16}$$

This family budget displays in the RHS the three utility elements over which preferences are defined. Those are the three items of expenditures of the family head. Any increase in the family income Ω_t is spent over these three items. The buffer used by the family heads to transfer incomes from the c_t to d^e_{t+1} is saving s_t and the one used to transfer income from c_t to ω^e_{t+1} is resource bequest z_t.

3.4 The firms' problem

The representative firm produces the output Y_t by combining three production factors capital K_t, labor L_t and extracted resource E_t with a Cobb-Douglas technology:

$$Y_t = AK_t^{\alpha_K} L_t^{\alpha_L} E_t^{\alpha_E}. \tag{17}$$

Considering factor prices as given, namely the real interest factor R_t, the real wage w_t and the real resource price q_t, the representative firm maximizes its profit in real terms π_t by choosing its demands of capital, labor and resource. We define the real profit as follows:

$$\pi_t = AK_t^{\alpha_K} L_t^{\alpha_L} E_t^{\alpha_E} - R_t K_t - w_t L_t - q_t E_t. \tag{18}$$

The first-order conditions are given by:

$$q_t = \alpha_E A \left(\frac{K_t}{L_t}\right)^{\alpha_K} \left(\frac{E_t}{L_t}\right)^{\alpha_E - 1}; \tag{19}$$

$$R_t = \alpha_K A \left(\frac{K_t}{L_t}\right)^{\alpha_K - 1} \left(\frac{E_t}{L_t}\right)^{\alpha_E}; \tag{20}$$

$$w_t = \alpha_L A \left(\frac{K_t}{L_t}\right)^{\alpha_K} \left(\frac{E_t}{L_t}\right)^{\alpha_E}. \tag{21}$$

The firm hires the services of capital, labor and resource up to the point where their respective marginal productivities equal their respective price.

4 The competitive equilibrium

We first analyze the temporary equilibrium of period t and then the intertemporal equilibrium.

4.1 The time t temporary equilibrium

We now turn to the definition and characterization of the time t temporary equilibrium. At any time period t, we consider the following variables as given:

- the aggregate capital stock K_t, which depends on past saving decisions ($K_t = N_{t-1} s_{t-1}$);
- the family inherited resource stock z_{t-1}, which depends on past extraction decision and past family resource bequest ($z_{t-1} = (C z_{t-2}^{\zeta} - e_{t-1})/(1 + n_{t+1})$);
- the young generation size N_t, which is follows from the population dynamics ($N_t = B N_{t-1}^{\nu}$);

- the expectations on the next period:
  - real wage w_{t+1}^e,
  - resource prices q_{t+1}^e.

For all t, we define the temporary time t equilibrium as:

- a vector of prices R_t, w_t, q_t,
- individual quantities c_t, s_t, e_t, z_t, d_t,
- aggregate quantities $Y_t, K_t, L_t, E_t, N_{t+1}$,

such that

- all agents, families and firm, maximize their objective function subject to their constraints,
- all markets, *i.e.* output, capital, labor and resource, clear.

We characterize the time t equilibrium values of the above endogenous variables as a function of the variables considered as given, $\{K_t, z_{t-1}, N_t, w_{t+1}^e, q_{t+1}^e, z_{t+1}^e\}$. First, the conditions of equality between supply and demand of, respectively, labor, capital and resource are given by:

- $N_t = L_t$ (exogenous labor supply);
- $K_{t+1} = N_t s_t$;
- $N_t e_t = E_t$.

This implies that the equilibrium prices are given by:

- $R_t = R(\frac{K_t}{N_t}, \frac{E_t}{N_t}) \equiv \alpha_K A \left(\frac{K_t}{N_t}\right)^{\alpha_K - 1} \left(\frac{E_t}{N_t}\right)^{\alpha_E}$;
- $q_t = q(\frac{K_t}{N_t}, \frac{E_t}{N_t}) \equiv \alpha_E A \left(\frac{K_t}{N_t}\right)^{\alpha_K} \left(\frac{E_t}{N_t}\right)^{\alpha_E - 1}$;
- $w_t = w(\frac{K_t}{N_t}, \frac{E_t}{N_t}) \equiv \alpha_L A \left(\frac{K_t}{N_t}\right)^{\alpha_K} \left(\frac{E_t}{N_t}\right)^{\alpha_E}$.

Let $k_t = K_t/N_t$ and $e_t = E_t/N_t$. In equilibrium, we thus write the system of two equations in saving s_t and extraction e_t by replacing prices w_t and q_t by their equilibrium expressions $w(k_t, e_t)$ and $q(k_t, e_t)$. The solutions of this system of equations can be written as functions of $\{K_t, z_{t-1}, N_t, w_{t+1}^e, q_{t+1}^e, z_{t+1}^e\}$. The other individual variables in equilibrium are thus easily obtained by using the families constraints. As far as aggregate variables are concerned, we can also write them as functions of $\{K_t, z_{t-1}, N_t, w_{t+1}^e, q_{t+1}^e, z_{t+1}^e\}$.

4.2 The competitive intertemporal equilibrium

We now turn to the characterization of the competitive intertemporal equilibrium. We define the competitive intertemporal equilibrium as a sequence of temporary equilibria, given the initial conditions $\{K_0,\ N_{-1},\ z_{-1}\}$ and a rule for the formation of expectations on w^e_{t+1}, q^e_{t+1}.

At this stage it is important to stress the following point. Under the assumption of perfect foresight, family heads would be considered as able to foresee the entire sequence of prices. Indeed, perfect foresight would imply $w^e_{t+1} = w(k_{t+1}, e_{t+1})$ and $q^e_{t+1} = q(k_{t+1}, e_{t+1})$. In other words, family heads at time t would have to compute the next period extraction behavior of their offspring. *In se* this could be fairly well hypothesized. Indeed, his offspring extraction decision is contemporaneous of his second-period of life.

The problem is that the offspring extraction decision in turn will depend on the offspring's expectations about their own children's decision, and so on. To be consistent with our hypothesis that family heads organize their resource bequests decision in a finite entity, we assume myopic expectations, that is,

$$w^e_{t+1} = \alpha_L A k_t^{\alpha_K} e_t^{\alpha_E} \tag{22}$$

$$q^e_{t+1} = \alpha_E A k_t^{\alpha_K} e_t^{\alpha_E - 1} \tag{23}$$

This assumption yields that family heads expect their offspring to extract the same amount as themselves, $z^e_{t+1} = z_t$.

Given the initial condition K_0, N_{-1}, z_{-1} and our rule of expectations, the competitive intertemporal equilibrium with myopic foresight is characterized by a sequence $\{k_{t+1}, e_t, z_t\}_{t=0}^{+\infty}$ which verifies the following system of equations:

$$(1 + n_{t+1})k_{t+1} - \beta(1 - \alpha_K)A k_t^{\alpha_K} e_t^{\alpha_E} = 0, \tag{24}$$

$$(1-\beta)\alpha_E A k_t^{\alpha_K} e_t^{\alpha_E-1}\left(\alpha_L A k_t^{\alpha_K} e_t^{\alpha_E} + \alpha_E A k_t^{\alpha_K} e_t^{\alpha_E-1}\left[\left(\frac{C z_{t-1}^{\zeta} - e_t}{1 + n_{t+1}}\right)^{\zeta} - (1+n_{t+2})z_t\right]\right)$$
$$-\gamma\alpha_E A k_t^{\alpha_K} e_t^{\alpha_E-1}\zeta\left(\frac{C z_{t-1}^{\zeta} - e_t}{1 + n_{t+1}}\right)^{\zeta-1}\left[(1-\alpha_K)A k_t^{\alpha_K} e_t^{\alpha_E} - (1+n_{t+1})k_{t+1}\right] = 0 \tag{25}$$

$$z_t = \frac{C z_{t-1}^{\zeta} - e_t}{1 + n_{t+1}} \tag{26}$$

5 Computational application

This section presents a computational application of our model and a reference scenario with two alternative values for the degree of family altruism, γ.

5.1 Parameters value and computation

The computational version of the model computes the sequence of the temporary equilibria of the economy. It consists of :

- two pre-determined variables: labor supply (N_t) and demand (L_t),
- six simultaneous equations: resource extraction (e_t), bequeathed resource stock (z_t), savings (s_t) and real resource price (q_t), interest factor (R_t) and wage rate (w_t),
- and a set of post-determined variables and identities giving, *e.g.*, the utility level, aggregates variables, etc.
- two expected variables of the next period: wage (w_{t+1}^e) and resource price (q_{t+1}^e).

Initial conditions are K_0, N_{-1} and z_{-1}. Since, in addition to childhood, individuals live for two periods, one period of time represents roughly 25 years. The model runs over a 20-period time span. The implicit equation giving the level of individual extraction is solved with the Newton-Raphson algorithm and the whole model is solved with the Gauss-Seidel algorithm[12]. Table 1 displays the parameters value used in the reference scenario. Most of these values come from conventional practice and do not require further comments. We set up the parameters ν and ζ of the population and resource dynamics such that *(i)* the population steady state is reached within 15 periods of time, *(ii)* the family resource stock without extraction increases over time. Scale parameters have been used for the population and resource own dynamics such that their level at the steady state is higher than one. Two alternative values of γ are considered, a low one (1.1) and a high one (1.5).

< insert Table 1 >

5.2 A reference scenario

The time profile of the main variables is displayed in the set of Figures 1.a to 1.f. Thin lines are for $\gamma = 1.1$ and thick lines for $\gamma = 1.5$.

< insert Figure 1 >

The model converges to a steady state. Population is growing at a decreasing rate and converges to its steady state value after roughly 15 periods. Given the initial conditions and parameters value, capital per head increases on the

[12]The model runs under the integrated software IODE developed by the Belgian Federal Planning Bureau and publicly available at *www.plan.be*

transition path (after an overshoot due to some initial condition), and so does the family income Ω_t of equation (16). So all aggregates (population, natural resource and aggregate capital stocks) also increase over time in this scenario. Two special features deserve more attention.

The first feature is that, as displayed in Fig.1.f, the utility level is decreasing on the transition path. This originates from the combination of four effects, two positive and two negative. The two positive effects regard consumption when young and adult disposable income of the offspring (ω_{t+1}). They both increase over time. But these two positive effects are more than offset by the two negative effects. The first one concerns consumption when old (d_{t+1}). It decreases, which can be easily understood considering that,

$$d_{t+1} = R_{t+1}s_t = [1 + n_{t+1}] \left[\alpha_k A k_{t+1}^{\alpha_k} e_{t+1}^{\alpha_e}\right]$$

where the first term in brackets is decreasing over time while the second term increases at a decreasing rate. Of course, consumption when old could grow for another set of parameters value or initial conditions[13]. The second negative effect concerns the fertility factor and, consequently the utility weight of the offspring adult disposable income, $(1 + n_{t+1})\gamma$. It is also decreasing over time, as explained in section 2.1.

The second feature is about the influence of family altruism through time. Altruism is the only motive for households not to extract and sell the whole resource stock. So it is straightforward that, if the degree of altruism is too low, then the natural resource may collapse, entailing the collapse of the whole economy. In a slightly different setting[14], Bréchet and Lambrecht (2006) formally demonstrate the possibility of such a result. In this paper with family altruism, numerically, given the parameters value, the lowest value of γ compatible with a positive resource stock is 1.05.

We can now analyze how the degree of altruism shapes the economy by comparing thin and thick lines in the figures. As expected, the higher γ, the higher the family stock of natural resource, as shown in Fig. 1.b. Yet, surprisingly, extraction turns out to be higher, as displayed in Fig. 1.c. This paradox comes from the fact that during the whole transition path families prevent themselves from extracting, thus accumulating a higher natural stock which allows them, at the steady state, to extract more. However, the family extraction rate (Fig. 1.d) is lower, suggesting that the pressure on the resource is reduced. Interestingly, capital intensity also increases with γ (Fig. 1.e). As a consequence, family income increases with γ, and so does the utility level at

[13]Let us note that, consumptions over the life cycle, $c_t + d_{t+1}/(R_{t+1})$, is nevertheless strictly increasing over time in this simulation.

[14]An OLG model with a *joy-of-giving* bequest motive.

the steady state[15].

6 Two demographic shocks

In this section we scrutinize the impacts of two demographic shocks on the economy and the natural resource management.

The first shock will consist in a one-shot drop in the population size, for example due to an epidemic or a war. Technically, it is introduced as a one-third drop in N_3, which represents the size of the young generation at time $t = 3$. The shock is unexpected and does not affect the low of motion of the size of generations. It follows that, at the steady state, the population will recover the level reached in the reference scenario.

The second scenario will consist in a decrease in fertility. Technically, from $t = 3$ onwards the fertility parameter ν is reduced from 0.65 to 0.55. As a result, the population experiences a lower growth rate during the transition path and reaches a lower level at the steady state.

The Figures 2.a and 2.b display the impacts of these two shocks on the population time path. We can now move to the analysis of the impacts of these shocks on the global economy.

< insert Figure 2 >

6.1 A one-shot drop in the population size

The impacts of this shock are displayed in Table 2 hereafter. Keeping in mind that the long run population size is unaffected by the shock, Table 2 shows that all variables, be them aggregate or individual, are also left unchanged in the long run. This shock displays only transitory effects.

< insert Table 2 >

To clearly understand these effects, let us precise the effect of the drop in the population size on its own dynamics. Let x_t and $\widetilde{x}_t$ denote the time t level of a variable x without and with the shock, respectively. The one-period exogenous shock yields $\widetilde{N}_3 < N_3$ and, in period 4, we have that $\widetilde{N}_3 < \widetilde{N}_4 < N_4$. The key variable to look at on the transition path is the fertility factor. For the time $t = 3$ generation, it is given by $1+\widetilde{n}_4 = B\widetilde{N}_3^{\nu-1}$. We therefore observe a temporary jump of the fertility factor, since $1 + \widetilde{n}_4 > 1 + n_4$. Afterward it

[15] Comparing utility levels with different values of γ is of limited interest since the parameters value of the utility function change. But the result that utility level increases with γ still holds since all the arguments of the function increase.

goes back gradually to its steady state value. This explains why the population level is kept unchanged in the long run.

Even though the long run population level remains untouched after the shock, one might expect some relief in the pressure on the resource on the transition path because of a temporarily lower population size.

As a first indicator of demographic pressure, let us start by looking at the response of the aggregate resource stock. Table 2 tells us that it is negatively affected, a result opposite to our initial guess. Two alternative measures of demographic pressure can also be considered: the resource extraction rate, defined as e_t/Cz_t^{ζ}, and the natural resource stock per capita Z_t/N_t. Table 2 shows that the resource extraction rate also falls and that the bequeathed family stock increases. Let us examine the sequence of the effects which explain these results.

Because the number of children suddenly dropped with the demographic shock, each child of generation young in $t = 3$ inherits a higher resource stock. What will then be the arbitrage of these young family heads at time $t = 3$ between their current consumption ($\widetilde{c}_3$), their consumption when old ($\widetilde{d}_4$) and the income of its heirs ($\widetilde{\omega}_4$)? Given that all these are normal goods, young individuals will increase all three. They do so by increasing savings $\widetilde{s}_3$ and the resource bequest $\widetilde{z}_3$, with respect to the level they would have reached without the shock.

As far as extraction ($\widetilde{e}_3$) is concerned, the theoretical impact is ambiguous. There are two opposite effects. The first one is that a higher inherited stock allows a higher extraction and that the induced higher real wage and resource price foster equilibrium extraction. The second one is more complex. The argument runs as follows. The negative demographic shock leads to a higher fertility rate $\widetilde{n}_4$. As a result, the RHS of equation (13) (with equality) increases (through higher n_{t+1}), which means that the marginal utility of the offspring's disposable income. The family heads react to this shock by a lower extraction $\widetilde{e}_3$ ($< e_3$), or equivalently a higher bequest. Indeed decreasing extraction e_t reduces the RHS of (13) and increases its LHS. For the chosen parameter values this negative effect dominates the positive effect.

To summarize, we thus face a temporary decrease in individual extraction, and a temporary increase in the individual family stock. Combining these two effects yields a decreasing extraction rate. Nevertheless the families are less numerous and therefore the aggregate resource stock is lower.

What is the role of the family-altruism bequest motive in these results? To answer this question, we can examine the sensitivity of the variables' responses to the one-shot drop in the population size with respect to the degree of altruism, γ. More specifically, how does the transitory decrease in resource extraction combine with the degree of altruism? As Table 2 shows, the magnitude of the fall in extraction is higher when family heads have a strong altruistic motive. This result can be explained as follows. The parameter γ magnifies the effect of a given change in the population size. In this scenario, it magnifies the increase in the marginal utility of ω_{t+1}. As a result, a larger increase in bequest[16] is needed to re-establish the optimal trade off between the consumption c_t and the offspring's adult disposable income ω_{t+1}. Only the fall in the aggregate stock is lower under strong altruism. The explanation for this result is simple: to compute the aggregate resource stock under strong altruism, we combine (i) the response of the individual resource stock, increasing in γ, and (ii) the response of the number of families, which is independent of γ. As a result the fall in the aggregate resource stock is lower in absolute value for a high degree of altruism.

6.2 A lower fertility rate

Unlike a one-shot drop in the population size, a drop in the fertility parameter ν has a long run effect on the population size. As depicted in Figure 2.b, the population size is lower in the long run. One may expect that the fall in the fertility rate reduces permanently the demographic pressure on the natural resource, leading to a higher long run aggregate resource stock.[17] As revealed in Table 3, the model answers that this is not the case.

< insert Table 3 >

While the population size is reduced in the long run, the aggregate resource stock is smaller as if the demographic pressure had increased. Like we did in the case of the one-shot fall in the population size, we may want to look at the other two alternative measures of the pressure: the resource extraction rate, e_t/Cz_t^{ζ}, and the natural resource stock per capita Z_t/N_t. Actually, in the long run these two indicators are unaffected by the drop in the fertility factor, excluding a relief in the demographic pressure. Interestingly, on the transition path these two indicators show a temporary increase of the demographic pressure on the resource (the extraction rate is higher and the individual resource stock lower).

This result is due to the fact that the shock decreases the marginal utility of the offsprings' disposable income, ω_{t+1} (see RHS of equation (13)). This occurs for two reasons. First, wage and resource revenues increase because of higher capital accumulation and resource extraction. Second, the drop in the fertility factor also decreases the RHS of equation (13). As a consequence

[16] And hence a larger decrease in extraction.

[17] The parameters of the simulations are such that the resource stock is always positive in the long run. Hence we rule out the possibility of resource extinction. For a complete analysis of resource dynamics in a close framework see Bréchet and Lambrecht (2006).

the family head rearranges the trade-off between c_t and ω_{t+1} by reducing his resource bequest.

Again, we can question the role of family altruism in these results. As Table 3 shows, the magnitude of the rise in extraction is actually higher when family heads have a strong altruistic motive. The reason is that the parameter γ magnifies any change in the marginal utility of the offspring's disposable income, be it positive, like in the previous section one-shot drop, or negative like in this scenario. With respect to the one-shot drop in population size, the effects of the shock in fertility go in the opposite direction as far as extraction and bequest are concerned. A higher γ magnifies the decrease in the marginal utility of ω_{t+1}. As a result, a larger decrease in bequest[18] is needed to re-establish the optimal trade off between c_t and ω_{t+1}.

At the steady state, all variables per capita are the same as in the reference scenario. One could have expected that the degree of altruism influences long run responses, as on the transition path. Actually, the growth rate of population is the same (and equal to zero) in the long run without or with the drop of the fertility rate. As a consequence the increase in extraction is only temporary and individual extraction converges to its level without the demographic shock whatever the degree of family altruism. So the long run *level* of the aggregate resource stock depends on the degree of altruism but the magnitude of its long run *response* to the shock in the fertility factor does not depend on the degree of altruism.

7 Conclusion

In this paper we develop a OLG model in which the size of generations evolves across time and converges to a steady state. A private natural renewable resource (a forest) is both extracted and bequeathed out the family altruism bequest motive.

We use this model to study how population growth influences the pressure on the renewable resource and the equilibrium path of the economy. In particular, we highlight the role of family altruism in the case of two demographic shocks: a one-shot drop in population size and a lower fertility rate. These two shocks have specific transitory and long term effects in the resource extraction.

As far as the one-shot drop is concerned, families simultaneously face a transitory decrease in extraction and an increase in the resource stock, thus leading to a decrease in the extraction rate. The overall stock is temporarily reduced. In this case, stronger family altruism reduces the negative impacts of the shock on the aggregate resource stock. In the long run, however all

[18] And hence a larger increase in extraction.

variables goes back to their reference value. When considering a slowdown of fertility, the demographic pressure increases on the transition (higher extraction rate and lower family resource stock) because of an endogenously stronger altruism. So, the stronger the degree of family altruism, the higher the pressure of the resource on the transition. On the long run, all individual variables are untouched, but the total resource stock is reduced, like the population size.

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Table 1 Parameters value

α_k share of capital in output	0.30
α_l share of labour in output	0.60
α_e share of natural resource in output	0.10
β weight of old-age consumption in utility function	0.25
γ degree of family altruism	1.1 or 1.5
ν population own's dynamics	0.65
ζ natural resource own's dynamics	0.65

Figure 1 Two reference scenarios (thin lines: g=1.1 ; **thick lines:** g=1.5**)**

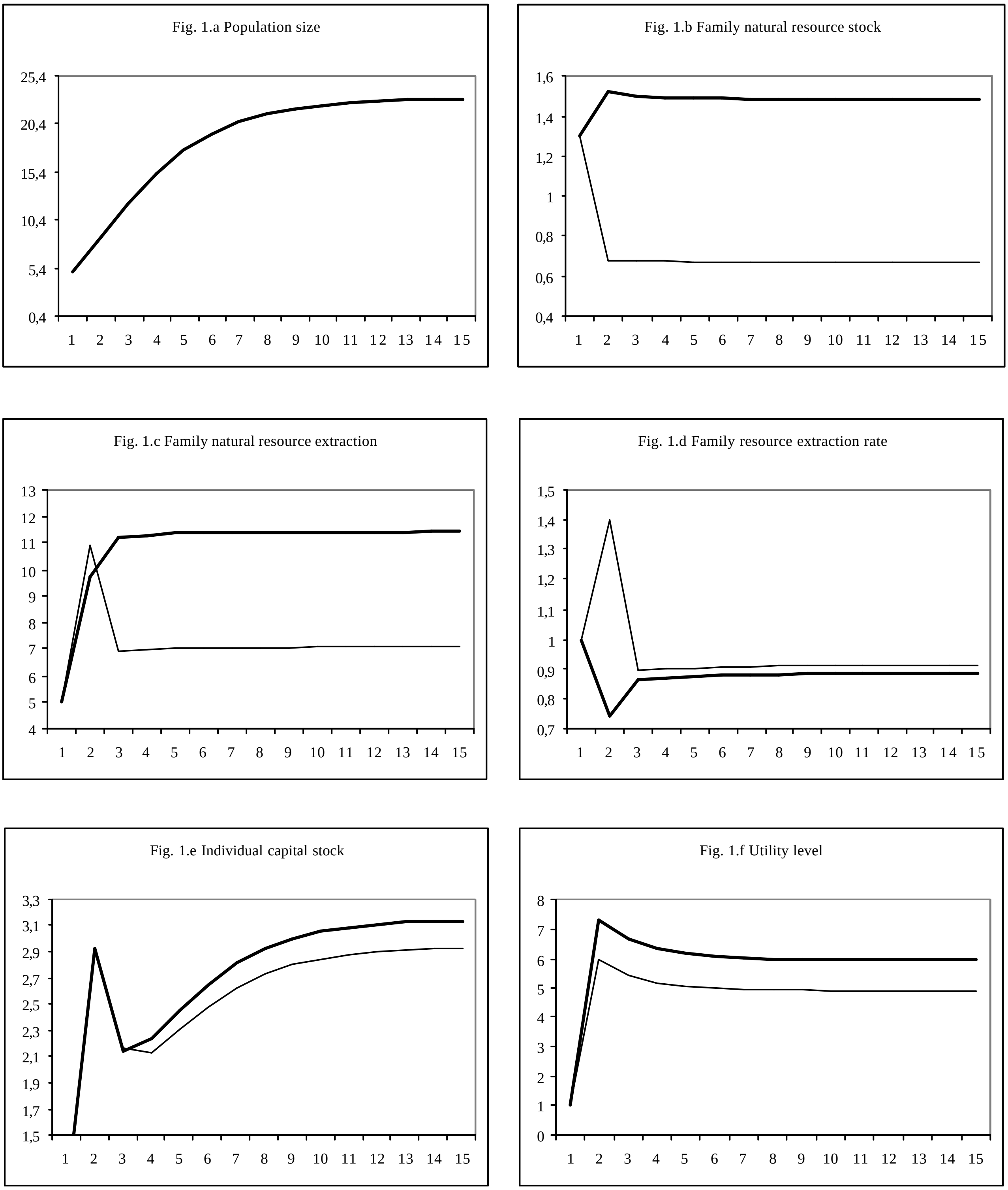

Figure 2. The effects of the two demographic shocks on population

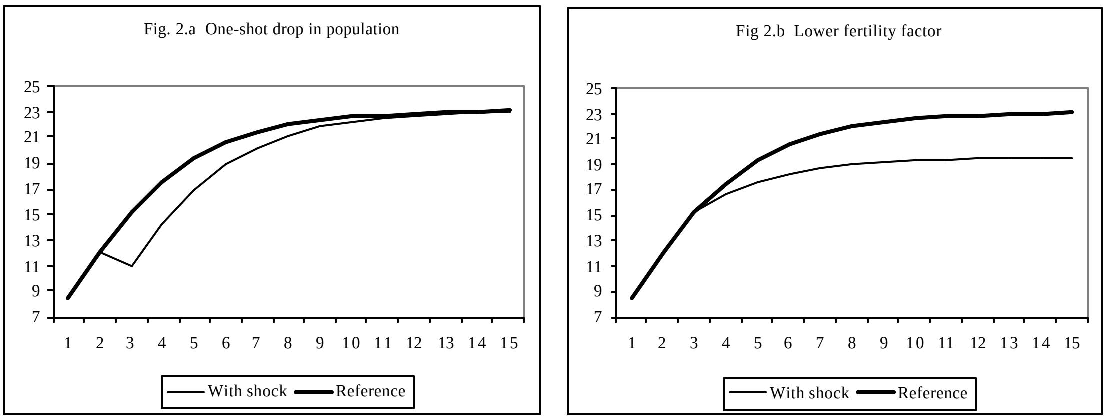

Table 2 **Effects of a one-shot drop in population size**
(% w.r.t. reference scenario, except *)

	t5		t20	
	Low gamma	High gamma	Low gamma	High gamma
Individual variables				
Young-age consumption	-2.37	-2.38	0.00	0.00
Old-age consumption	5.03	5.00	0.00	0.00
Savings	-2.37	-2.39	0.00	0.00
Bequest	-2.37	-2.38	0.00	0.00
Renewable resource				
Individual extraction	-0.33	-0.42	0.00	0.00
Individual stock	0.14	0.17	0.00	0.00
Individual extraction rate* (point of %)	-0.39	-0.47	0.00	0.00
Total stock	-12.56	-12.54	0.00	0.00
Aggregates				
Population	-12.68	-12.68	0.00	0.00
Capital stock	-19.30	-19.33	0.00	0.00

Table 3 **Effects of a lower fertility rate**
(%w.r.t. reference scenario, except *)

	t5		t20	
	Low gamma	High gamma	Low gamma	High gamma
Individual variables				
Young-age consumption	1.65	1.66	0.00	0.00
Old-age consumption	-2.06	-2.05	0.00	0.00
Savings	1.65	1.66	0.00	0.00
Bequest	1.65	1.66	0.00	0.00
Renewable resource				
Individual extraction	0.17	0.23	0.00	0.00
Individual stock	-0.08	-0.12	0.00	0.00
Individual extraction rate* (point of %)	0.20	0.27	0.00	0.00
Total stock	-8.82	-8.86	-15.58	-15.58
Aggregates				
Population	-8.75	-8.75	-15.58	-15.58
Capital stock	-3.70	-3.68	-15.58	-15.58

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