

125



Family policies: What does the standard endogenous fertility model tell us

Thomas Baudin

September 2010

ENVIRONMENTAL ECONOMICS & MANAGEMENT MEMORANDUM



UCL
Université
catholique
de Louvain

Chair Lhoist Berghmans
in Environmental Economics
and Management

Center for Operations Research
and Econometrics (CORE)

Family Policies: What Does The Standard Endogenous Fertility Model Tell Us?

Thomas Baudin*
CORE and IRES

September 22, 2010

Abstract

Very few studies have explored the optimality properties of the "standard model" of fertility where parents must determine their optimal trade-off between quality and quantity. The present paper works to fill that gap and find three main results. First, when there exist positive externalities in the accumulation of human capital, it is optimal to subsidize education *and* to tax births. Second, when the Social Welfare Function does not consist of the average utility, the social returns on educational investments can be weaker than the private returns when the optimal population growth rate is negative. In this case, the optimal economic policy consists in subsidizing births and taxing education. Finally, when the health expenditure is introduced as another source of positive externalities, it can be optimal to tax the parental health expenditure to decentralize the first-best path even if this expenditure is always too low at the laissez-faire equilibrium.

JEL codes: D10,H21,J13,J18 .

Keywords: Fertility, Education, Family Policy, Mortality, Quality Quantity Trade-off

*This research is part of the ARC project 09/14-018 on "sustainability" (French speaking community of Belgium). It has also benefited from financial and scientific support from the Chair Lhoist Berghmans in Environmental Economics and the Paris School of Economics. I am especially grateful to Bertrand Wigniolle, David de la Croix, Pierre Pestieau, Cécilia Garcia Peñaloza, Thomas Seegmuller, Omar Licandro and Victor Hiller for their invaluable help. I would like to thank an associate editor and two referees for insightful comments that lead to a substantial revision of the paper. The traditional disclaimer applies. Address correspondence to: Thomas Baudin, CORE, Bureau b.117, Voie du Roman Pays 34, B-1348 Louvain-la-Neuve, Belgium.

1 Introduction

The economic analysis of fertility entered the modern era with the contribution of Becker [1960]. This contribution paved the way for analyzing fertility behaviors with the tools of the Marginalist Revolution. Becker [1960], Becker & Tomes [1973] and Becker & Lewis [1976] represent fertility at the family level as the result of a rational decision-making process. In addition to the usual commodities that were already present in microeconomic theory, parents value both the quantity of children (the number of children they give birth to) and their quality. Parents therefore must determine their optimal trade-off between quality and quantity. In recent years, the Unified Growth Theory has put such a trade-off between quality and quantity at the heart of the explanation of long-run growth and development.¹

All these contributions have resulted in a unified framework that I here call the "standard model of endogenous fertility." Surprisingly, very few studies have explored the optimality properties of the trade-off between quality and quantity in this model.² The present paper works to fill that gap, especially by emphasizing that the standard model of fertility displays non-intuitive optimality properties and provides unusual recommendations for economic policy.³

The standard model of endogenous fertility displays three main characteristics. First, parents value the number of their offspring (quantity) as well as their future quality. The valuation of children's quality can take either an altruistic or a non-altruistic form. When parents are altruistic toward their children as in Becker & Barro [1988] and Razin & Ben Zion [1975], the future well-being of their children enter their own utility function. Thus, their preferences are dynastic. In the alternative representation, as presented in Becker & Lewis [1973] and Galor & Weil [1999], parents are not altruistic, but are characterized by a joy of giving or a warming glow; that is, they directly value their children's human capital, their wealth, their health status, the financial bequest they give them, or other properties inherent to the children. This representation of parental preferences has been

¹Among many others, see Galor & Weil [1996,1999], Galor & Moav [2002], De la Croix & Doepke [2003], Kalemli-Ozcan [2003].

²I provide a review of this literature in section 2.

³Notice that, in this paper, family policies are limited to tax - transfer policies. In reality, family policies include a large set of instruments like, for instance, coercive policies and preventive actions.

avored by the recent Unified Growth Theory (UGT hereafter).⁴ Second, whatever the representation that is chosen, parents maximize their expected utility subject to a non-linear budget constraint.⁵ There is therefore a trade-off between quality and quantity. Third, at least in the recent literature, models explicitly assume the existence of inefficiencies in the production of child quality (see Galor [2005]). Quality of children is almost always represented by their human capital. In other words, when parents choose their optimal trade-off between quality and quantity, they do not internalize that their private investment will improve the overall efficiency of the human capital accumulation process. It implies that, at the laissez-faire equilibrium, their arbitrage between quality and quantity cannot be optimal.

Intuitively, because only positive externalities exist in the accumulation of human capital, one can expect that a subsidy on education spending financed by a lump-sum transfer will decentralize the social optimum. In the present paper, I show that this intuition is not precisely correct. I demonstrate this through three important findings:

First, the first-best social optimum cannot be decentralized with less than two Pigouvian taxes⁶ and one lump-sum transfer. In the case where no difference exists between social and individual welfare functions (Millian Social Welfare Function),⁷ these Pigouvian taxes consist of a subsidy to education expenditure and a tax on births. Such a result comes from the parental budget constraint, where quality and quantity enter multiplicatively. This non-linearity implies that distorting the cost of quality to correct human capital externalities distorts, in turn, the total cost of quantity: children become cheaper. A tax on child births must be implemented to correct this second distortion. In other words, though fertility is not a source of externalities, it has to be taxed. This result is robust to changes in the model of fertility that is chosen.

Second, I show that when the Millian Social Welfare Function (SWF hereafter) is no

⁴See Galor [2005] for a review of this literature.

⁵This non-linearity is fundamental in models of trade-off between quality and quantity. Because quality is provided to each child (with or without equity), its cost crucially depends on the quantity choices. Then the parental budget constraint is no longer linear.

⁶Notice that I only focus on linear taxation. Without inequalities, it is not a strong assumption because redistribution is not a matter of concern. Fan & Stark [2008] consider the impact of heterogeneity on welfare and policy analyses.

⁷A Millian Social Welfare Function consists of the average utility in the economy while a Benthamite Social Welfare Function consists of the total utility in the economy.

longer used, the optimal tax-transfer policy can involve taxing education and subsidizing births. I construct a SWF that allows for the existence of a social preference for the population stock. The Benthamite utility function consists in a special case of this SWF.⁸ The existence of a social preference for the population stock introduces two additional effects: (i) Agents do not take into account that, when they make a child, they make it easier for future generations to reach a larger population size. In other words, they do not internalize the social returns on their investment in the quantity of children. (ii) If there exists a social preference for the population stock, there also exists a preference for the largest generations relative to the smallest ones.⁹ Thus, the social return on the investment in human capital of one's generation will depend on its size relative to previous and subsequent ones. Formally, it is optimal to transfer welfare from smaller to bigger generations. Thus, when the optimal population growth rate is positive, all other things being equal, the social return on the educational investment is higher than the private return. Indeed, this investment will benefit a growing number of agents, so it is optimal to subsidize education spending. Conversely, if the optimal population growth rate is negative, the largest generations are the current generations and it is optimal to disincentivize parents to invest in their children's human capital in order to transfer utility from future to present generations. In other words, *ceteris paribus*, the social return on education investment is lower than the private return, and it is optimal to tax education.

My third main result comes from the introduction of endogenous child mortality that is a natural extension of endogenous fertility models to address for instance the issue of the demographic transition. It changes the nature of the trade-off between quality and quantity. Indeed, parents not only have to decide how to allocate their spending between quality and quantity, they also have to decide their optimal strategy to reach their desired number of children. In other words, they face a trade-off between quality and quantity of surviving children in which their health expenditure will be a source of externalities.

In this extended model, higher parental health expenditure reduces child mortality. Furthermore, the average level of health spending has a negative impact on child mortality. The

⁸Blackorby [2006] provides an enlightening discussion on the caveats of both the Millian and Benthamite SWF.

⁹This effect could be partially mitigated by the use of negative utility functions without changing the main results of the paper. This will be more deeply discussed hereafter

literature of development economics provides strong evidence that overall health quality is one of the main determinants of individual health quality. For instance, Dasgupta [1993] shows that 45 percent of all deaths in developing countries can be imputed to infectious and parasitic diseases. Private health expenditure helps reduce the probability of being infected when an agent is in contact with disease. Therefore, a higher average level of health expenditure reduces the probability of death in all families. This positive externality implies that the private health expenditure is too low at the competitive equilibrium.

Here, I only consider the Millian case for simplicity. Reaching optimality requires, once again, subsidizing education and taxing births. Now, the taxation of births plays the role of an indirect subsidy on health expenditure. Indeed, it increases the cost of quantity relative to the cost of health. To reach the same number of surviving children, parents tend to increase their health expenditure and to give birth to less children. For strong externalities on health expenditure, the indirect subsidy will not be sufficient to reach optimal health expenditure at the competitive equilibrium. Therefore, the private health expenditure has to be subsidized.¹⁰ Conversely, if the externality on health is weak relative to that on education (small indirect subsidy), it is optimal to tax health expenditures in addition to births.

The recommendation to tax births in complement to subsidies for education and health, can be analyzed in the light of some empirical evidence from China and Sub-Saharan Africa. Both regions face a problem of overpopulation and have implemented alternative strategies to reduce fertility. My paper's results are obviously theoretical and cannot reproduce the very complex demographic, economic and political conditions of these countries. However, it provides some bases from which their strategies can be called into question.

China is experimenting with a specific fiscal scheme on births that subsidizes the first birth and strongly taxes subsequent ones. However, empirical studies such as those of Kanbur & Zhang [2003] and Fan & Zhang [2000] show that investment in education and health is insufficient in China. The present paper proposes an alternative fiscal scheme that would reallocate public funds from the first birth subsidy to the promotion of education and health, without a loss of efficiency in birth control. However, a polemical interpretation of my results

¹⁰Once again, I focus on linear taxation. I do not deal with health as a pure public good. Doing so would make less plausible that taxing health expenditure is optimal.

indicate that, if the Chinese optimal fertility rate is closed but inferior to two children per family, then the Chinese government policy that consists in taxing births and providing weak public spending on education is optimal.

Sub-Saharan African countries have implemented several family planning programs that strongly promote investment in health and education. However, a recent report from the World Bank [2007] shows that these programs have been inefficient in reducing the net fertility rate in a large majority of these countries. This paper demonstrates that one reason why these policies have been inefficient could lie in the fact that they did not increase the relative cost of quantity. It shows that more attention should be paid to the implementation of a fiscal scheme that would explicitly sanction births.

The rest of the paper is organized as follows. In Section 2, I present the contributions of the present paper to the existing literature. In section 3, the benchmark model is presented. Its recommendations in terms of family policies are discussed. I show that my main results are robust to the adoption of alternative standard models of endogenous fertility. In section 4, I introduce endogenous child mortality and public health. Section 5 discusses the paper's empirical implications for China and Sub-Saharan Africa, and section 6 provides concluding remarks.

2 Contribution to the Existing Literature

My aim is to determine the tax-transfer policy that will decentralize the first-best social optimum. Such an exercise is very typical in the public economics literature, and it consists of determining the distortions that ensure that decentralized individual decisions will lead to the social optimum. In the present framework, I apply this standard methodology to a non-standard problem. Indeed, quality and quantity of children are special goods that cannot be exchanged on a market.^{11,12}

¹¹Following Boulding [1964], a recent paper by De la Croix and Gosseries [2007] relaxes this assumption by assuming the existence of a market of procreation rights that can be exchanged. It finally consists in a system of tax or allowance on the quantity of children. They do not investigate, however, the reasons why governments are not satisfied with their national fertility. Then, the present paper can be considered as a complement to this literature.

¹²I assume that the government can observe the agent's behaviors and expectations, it allows to decentralize the first best social optimum. This assumption is strong but fundamental because it shows that the standard problem of trade-off between quality and quantity (externalities on human capital and non linearity of

Eckstein and Wolpin [1985] paved the way in exploring the optimality of fertility behaviors in a model where parents face a trade-off between quantity and quality. They assume a non-dynastic utility function, wherein parents value the number of their children and their future consumption. Considering Diamond's growth model with endogenous fertility, they show that, at the laissez-faire equilibrium, stationary fertility is lower than the fertility rate that maximizes welfare at the steady state. This result arises because parents do not take into account the impact of their fertility on the stationary interest rate.

Another foundational paper comes from Nerlove *et al* [1982], who explore the optimality of fertility rates in an economy where parents are altruistic and characterized by perfect foresight. They show that the choice of different SWF lead to an alternative judgment about the competitive fertility rate. Indeed, using a Benthamite SWF implies that the competitive fertility rate is lower than optimal while using a Millian SWF can imply a competitive fertility rate that is either lower or higher than optimal. Finally, the Benthamite SWF always leads to a higher optimal fertility rate than the Millian SWF.^{13,14}

The present paper extends the contributions of these earlier papers by focusing on the maximization of welfare across dynamics instead of only at a steady state. Then, I determine an economic policy that decentralizes the first-best path. Both Eckstein & Wolpin and Nerlove *et al*, conclude that competitive fertility has to be corrected by economic policies because of the existence of externalities on fertility choices. In this paper, even if there is no externality on quantity, the existence of externalities on human capital accumulation (quality of children) implies that it is optimal to tax or subsidize births in addition to subsidizing education. I also show that this result remains valid in both altruistic and non-altruistic models.

Golosov *et al* [2007] explore the optimality of fertility rates in a Barro-Becker model

the parental budget constraint) structurally generates non-optimal laissez faire equilibria *regarding both education and fertility choices*. Adding alternative externalities on fertility or studying second order optima will interestingly contrast this result.

¹³Spiegel [1993] extends the Nerlove *et al*'s framework to Rawlsian social preferences. He shows that a poll tax on births enables the government to decentralize the social optimum of the economy.

¹⁴An alternative literature explores the problem of optimal fertility rates with models of endogenous fertility where the quality of children is exogenous. See for instance, Groezen *et al*. [2003] and Loupias & Wigniolle [2004]. Another recent literature is interested in the determination of optimal family policies in a framework where there exist some constraints on the feasible set of economic policy. See for instance, Balestrino *et al* [2000] and Cigno & Pettini [2002].

[1988] using their notions of A and P efficiency that I will present in more detail in the core of the paper. They show that, when there exist external effects that are confined inside the family, perfect altruism implies that "the time series of populations [...] is optimal." It has to be noticed that such a result would be different if the set of externalities that is explored were to include technological externalities, such as learning by doing. In the present paper, the existence of dynastic altruism will not prevent the competitive population growth rate to differ from the optimal one because external effects are not confined to the family.

3 The Benchmark model

Since the seminal approach from Becker *et al* [1973,1974,1988], standard models of fertility assume that parents maximize their utility depending on their own consumption, the quantity of their children and their quality, subject to a non-linear budget constraint. Authors have proposed a variety of methods to model this problem. In this section, I focus on the model of Razin & Ben-Zion [1975] where children's education is provided inside the family and parental utility is dynastic. As shown by Nerlove & Rault [1997], the models of Razin & Ben Zion [1975] and Barro & Becker [1988] both are specifications of a more general model. Jones & Schoonbroodt [2009] and Bar & Leukhina [2010] even show that for some parameter restrictions, they are identical. In Section 3, I will show that my fundamental results are validated for alternative utility functions (especially for the Rational Altruism of Barro & Becker and non-dynastic preferences as used in Unified Growth models). I will also show that when education is not provided by parents, but by teachers, as in the work of De la Croix & Doepke [2003], education becomes a source of both positive and negative externalities and, as a result, it can be the case that private education spending has to be taxed.

3.1 The Competitive Equilibrium

The model consists of an overlapping generations economy with L_t adult agents who live for two periods: childhood and adulthood. Children receive education from their parent and do not consume commodities. This education investment is denoted e_t and consists of a

schooling time directly provided by the parent.¹⁵ It improves the children's future human capital h_{t+1} such that:¹⁶

$$h_{t+1} = l(e_t, h_t, \bar{h}_t), \quad l'_1 > 0, l''_{11} \leq 0, l'_2 > 0, l''_{22} \leq 0, l'_3 > 0, l''_{33} \leq 0 \quad (1)$$

Function l is strictly increasing and concave with respect to all its arguments. This production function of human capital is closed to this used in De la Croix & Doepke [2003]. I assume non-increasing return to scale. There is an intra-family transmission of human capital: the human capital of parents h_t positively influences the future human capital of children. It can be understood as a quality effect of the schooling time. Moreover, I assume the existence of a Lucas-type aggregate externality: the average level of human capital in the population \bar{h}_t has a positive impact on children's future human capital.¹⁷ Thus, parents do not take into account that their children's human capital affects the production function of other people's grandchildren. Notice that, following equation (1), e_t can be expressed as a function of h_t , \bar{h}_t and h_{t+1} such that: $e_t = e(h_{t+1}, h_t, \bar{h}_t)$ and $e'_1 > 0$, $e'_2 < 0$, $e'_3 < 0$.

When a child born at $t - 1$ becomes an adult, he has to choose his consumption level C_t , the number of his children N_t and their education e_t . For simplicity, families are monoparental. Individual decisions satisfy the following budget constraint:

$$C_t + \left[\frac{\sigma}{\xi} + \phi \right] w_t h_t X_t + \theta w_t h_t \Omega(X_t) \cdot e_t = w_t h_t \quad (2)$$

where $X_t \equiv \xi N_t$ denotes the number of surviving children at the end of period t and $\xi \in]0, 1[$ the fraction of children who survive to age five. ξ is exogenous in this section, but will be endogenized hereafter. There is no uncertainty about the reproductive success of a family.¹⁸ Each child born takes a part $\sigma \in]0, 1[$ of its parent's time endowment that is normalized to one. Moreover, each surviving child consumes an extra part ϕ of this time.¹⁹ So the cost of

¹⁵Providing education is the unique way to transmit wealth to children. There is no financial bequest contrary to Barro & Becker [1988] and Eckstein & Wolpin [1985] for instance.

¹⁶Notice that for all function $\Gamma(\alpha_1, \alpha_2, \dots, \alpha_n, \dots)$, Γ'_n represents the partial derivative of Γ with regard to α_n .

¹⁷This assumption is in line with Lucas [1988] and De la Croix & Doepke [2003].

¹⁸So, unlike the models of Sah [1991] and Kalemli-Ozcan [2003] which assume uncertainty, parents will not overshoot their number of children to ensure the compliance of their optimal fertility rate. See Baudin [2010] for a complete discussion on the necessary conditions leading to undershooting rather than overshooting. Here, because child death is assumed to occur before age five, parents can rapidly ensure the replacement of dead children.

¹⁹Note that $\frac{\sigma}{\xi} + \phi < 1$. $\theta > 0$ is a scalar that allows the relative education costs to vary.

a surviving child is greater than the cost of a non surviving child. The opportunity cost of quantity is equal to $\left[\frac{\sigma}{\xi} + \phi\right] w_t h_t X_t$, where w_t denotes the wage per unit of efficient work. This total cost of quantity includes the ineffective costs engaged for non-surviving children. Consequently, it is negatively dependent on the child survival rate.

The cost of one unit of education is not affected by variations in the child mortality rate. Indeed, no educational investment is engaged until a child reaches age five. The total cost of education is concave in X_t ; one unit of education can benefit more than one child. $\theta w_t h_t \Omega(X_t) \cdot e_t$ is the cost of giving e_t units of education to X_t children with $1 \geq \Omega'(X_t) \geq 0$ and $\Omega''(X_t) \leq 0$.²⁰ If education is a pure public good inside the family ($\Omega(X_t) = 1$), providing e_t units of education to one child implies the same cost as providing e_t units to X_t children. If education is a pure private good inside the family ($\Omega(X_t) = X_t$), one unit of education benefits only one child.

The price of the final good is normalized to one. It is produced in quantity Y_t , following linear technology:

$$Y_t = AH_t \tag{3}$$

where A is a productivity factor and H_t is the total amount of human capital in the workforce. At the labor market's equilibrium, H_t is:

$$H_t = \left[1 - \left(\frac{\sigma}{\xi} + \phi\right) X_t - \theta e_t \Omega(X_t)\right] h_t L_t \tag{4}$$

The workforce participation of parents consist in their remaining time after childbearing and educating their children. Furthermore, as the labor market is competitive, the wage equals the workers' marginal productivity:

$$w_t = A \tag{5}$$

As in Razin & Ben-Zion [1975], the utility of an agent born in $t-1$, with perfect foresight,²¹

²⁰As shown by Willis [1973], because the cost of education are less intensive in parental time, an increase in the parental income implies a substitution of quality to quantity. $\Omega'(X_t) \leq 1$ ensures the existence of scales economies in childrearing.

²¹I assume that agents formulate perfect expectations in order to ease the resolution of the problem. However, assuming alternative expectations would not alter my main results given that the Social Planner can perfectly observe private expectations.

is represented as:²²

$$V_t = \max \{u(C_t, X_t) + \beta V_{t+1}\} \quad (6)$$

where $u(.,.)$ is strictly increasing and concave in its arguments and $\lim_{\Psi_t \rightarrow 0} u'_{\Psi_t} = +\infty$ for $\Psi_t = \{C_t, X_t\}$. V_t denotes the maximal utility of an adult born in $t - 1$. His current utility depends on his own consumption and the number of his surviving children X_t . I assume that parents value the number of surviving children and not the number of children born. This implies that child mortality is a source of disutility. Parental altruism is dynastic, each agent values his children's discounted welfare per capita. β denotes the parental discount rate. I assume a dynastic utility function because it equalizes the maximization horizon of both individuals and the Social Planner. If I had chosen to assume non-altruistic preferences like in Becker & Tomes or in Unified Growth models, I would have to either focus on the stationary solutions to the problem or to assume the existence of an ad hoc social discount rate introducing artificial dynamics inefficiencies. I discuss this problem in the next section.

Iterating (6) to $t = +\infty$, I obtain the equivalence with the centralized problem²³ where the objective can be written as the following:

$$\max_{C_s, X_s, e_s} V_t = \sum_{s=t}^{+\infty} \beta^{s-t} u(C_s, X_s) \quad (7)$$

A parent born in $t - 1$ determines his optimal demands (C_t^*, X_t^*, e_t^*) by maximizing V_t with respect to L_{t+1} and h_{t+1} ²⁴ subject to (1),(2) and the definition $\frac{L_{t+1}}{L_t} = X_t$. I obtain the following first order conditions with respect to L_{t+1} and h_{t+1} :²⁵

²²Notice that, as mentioned by Nerlove and Rault [1997], this utility function is additively separable and so, consists in a specific case of $V_t = V(C_t, X_t, V_{t+1})$.

²³A necessary condition to obtain such an equivalence is: $\lim_{T \rightarrow +\infty} \beta^T U(C_T, X_T) = 0$. X_t being the number of surviving children, it is bounded by $\frac{1}{\xi + \phi}$ the maximal number of children a wife can give birth to. So, this condition will always be satisfied when income and so consumption are bounded at the steady state. If the economy reaches a balanced growth path where consumption grows at a constant rate, the previous condition has to be assumed what is the case for the rest of the paper.

²⁴Note that, h_{t+1} depends on the family's human capital, the average human capital and the educational choices of parents. As parents know the level of h_t and \bar{h}_t when they determine e_t ; choosing e_t is equivalent to choosing h_{t+1} . The same reasoning does apply to X_t . Then, I solve the problem by maximizing with respect to state variables as proposed by Challier & Michel [1996].

²⁵To ensure global concavity of the problem, its Hessian Matrix is assumed to be negative semi-definite.

$$-\beta \frac{X_{t+1}^*}{X_t^*} = \frac{u'_{X_t} - Ah_t^* \left(\frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_t} e [h_{t+1}^*, \cdot, \cdot] \right) u'_{C_t}}{Ah_{t+1}^* \left(\frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_{t+1}} e [h_{t+2}^*, \cdot, \cdot] \right) u'_{C_{t+1}} - u'_{X_{t+1}}} \quad (8)$$

$$\frac{u'_{C_{t+1}}}{u'_{C_t}} = \frac{\theta h_t^* \Omega(X_t^*) e'_1 [h_{t+1}^*, \cdot, \cdot]}{\beta [1 - (\frac{\sigma}{\xi} + \phi) X_{t+1}^* - \theta \Omega(X_{t+1}^*) (e [h_{t+2}^*, \cdot, \cdot] + h_{t+1}^* e'_2 [h_{t+2}^*, \cdot, \cdot])]} \quad (9)$$

Notice that, ex post, at the equilibrium of the labor market, $\bar{h}_t^* = h_t^*$. By assumption, there is no inequality of human capital. The competitive equilibrium is described by the set $\{C_t^*, X_t^*, e_t^*, h_t^*, h_{t+1}^*, H_t^*, Y_t^*, w_t^*\}_{t=0}^{t=+\infty}$, satisfying equations $\{(1) - (5), (8), (9)\}_{t=0}^{t=+\infty}$. The presence of externalities makes private choices on education inefficient. Parents do not consider the positive effect of their educational investment on the overall efficiency of human capital accumulation. It follows that the competitive equilibrium cannot correspond to the social optimum. The next sub-sections derive the social optimum of the economy and compare it to the competitive equilibrium.

3.2 The Social Optimum

Defining the social optimum when the size of population is endogenous demands a discussion of two concepts: optimality and social welfare. When the size of the population is endogenous, comparing two equilibria requires comparing two situations in which the number of agents is different. This makes the use of the standard concept of Pareto efficiency inadequate. Golosov *et al* [2007] propose the *A* and *P* efficiency concepts. With the *A*-efficiency concept, one equilibrium dominates another if it is preferred by all the agents who live in the two equilibria. With the *P*-efficiency concept, agents who are not born are characterized by well-defined preferences, so an equilibrium dominates if it is preferred by all the agents who could be born in the two equilibria. In other words, agents who are not born in the dominant equilibrium but would be born in the other effectively prefer not to be born.²⁶ As shown by Golosov *et al*, following the concept of efficiency that is chosen, the ranking of

²⁶Blackorby *et al* [2005] investigate the concept of critical levels of utility which, if "enjoyed by an added person without changing the utilities of the existing population, leads to an alternative which is as good as the original". One major issue of this literature lies in the choice of critical levels.

equilibria can differ.²⁷ In this paper, I focus on maximizing the utility of current generations but I will show that social optimums do not necessary dominate competitive equilibria in the sense of *A*-efficiency.

As mentioned in the introduction, another critical point lies in the choice of a welfare function. In the literature, two functions are usually opposed: the Millian SWF corresponding to the utility of the representative agent, and the Benthamite SWF corresponding to the total utility in the economy.²⁸ In this paper, I propose a formulation of the SWF that embodies these two cases and intermediary ones. Let W_0 denote the SWF:

$$W_0 = \sum_{t=0}^{+\infty} \beta^t f(L_t) u(C_t, X_t) \quad (10)$$

where $f'(L_t) \geq 0$ and $u(C_t, X_t) > 0 \forall (C_t, X_t) > (0, 0)$.²⁹ $f(L_t)$ denotes the social preference for the population stock. Because $f'(L_t)$ is strictly positive, for a fixed per capita utility level \bar{u} , the Social Planner prefers larger populations.³⁰ Notice that, when $f(L_t) = L_t$, the Social

²⁷Michel & Wigniolle [2008] propose the concepts of *RC*-Efficiency and *CRC*-Efficiency that refine *A*-Efficiency. With the *RC*-Efficiency concept, an equilibrium dominates another if it is not possible to improve the situation of a generation without reducing the utility of at least another generation what is equivalent to *A*-Efficiency with homogenous agents. With the *CRC*-Efficiency, an equilibrium dominates another if it improves the utility of one generation without reducing the utility and the size of other generations. Conde-Ruiz *et al* [2004] propose the concept *u*-Efficiency that adapts *P*-efficiency to models where number of children is continuous.

²⁸A large set of papers dealing with optimality in endogenous fertility models attribute a Millian objective to the Social Planner. In this representation, the social planner tries to maximize the utility of the representative agent *at the steady state*. See Groezen *et al.* [2003], Loupias & Wigniolle [2004], Zhang [2003], Zhang & Zhang [2007], etc. Notice that, contrary to Spiegel [1993], I do not deal with Rawlsian objectives.

²⁹Following Jones & Schoonbroodt [2007,2009], the case where $u(C_t, X_t) < 0 \forall (C_t, X_t) > (0, 0)$ and $f'(L_t) < 0$ also makes sense and has to be fully analyzed. This is done in Appendix B. Notice that the main results of the paper are not changed.

³⁰It also means that the social benefit of increasing the fertility of one generation leaving other generations' fertility unchanged is higher than its private benefit:

$$\frac{\partial W_0}{\partial X_t} = \beta^t f(L_t) u'_{X_t} + \sum_{s=t}^{+\infty} \beta^s u(C_s, X_s) f'_{L_s} \frac{\prod_{j=0}^{s-1} X_j}{X_t} L_0 = f(L_t) \frac{\partial V_0}{\partial X_t} + \sum_{s=t}^{+\infty} \beta^s u(C_s, X_s) f'_{L_s} \frac{\prod_{j=0}^{s-1} X_j}{X_t} L_0 > \frac{\partial V_0}{\partial X_t} \quad (11)$$

However, this doesn't mean that increasing the size of one generation, let's say L_t , keeping the size of other generations constant always lead to a higher Social Welfare. Indeed:

$$\frac{\partial W_0}{\partial L_t} = \beta^t \left[f'_{L_t} u(C_t, X_t) - f(L_t) u'_{X_t} + \frac{f(L_{t-1})}{\beta L_{t-1}} u'_{X_{t-1}} \right] \quad (12)$$

To increase L_t keeping L_{t+1} constant, X_{t-1} has to increase while X_t has to decrease. The global effect of such a change crucially depends on the way the Social Planner evaluates the welfare of generations born in $t-2$ and $t-1$.

Welfare function is Benthamite, whereas when $f(L_t) = 1$, it is Millian. For tractability of results, I assume that $\frac{f(\ell)}{f(\eta)} = F\left(\frac{\ell}{\eta}\right)$ with $F'\left(\frac{\ell}{\eta}\right) > 0$, $F(1) = 1$ and $F(\cdot)$ being twice differentiable.³¹ To ensure that the Social Welfare Function (SWF) is bounded, I assume $\lim_{T \rightarrow +\infty} \beta^T f(L_T) = 0$.³² I also assume that there is no asymmetric information such that the Social Planner can observe all parental preferences, constraints, abilities and expectations.

The resource constraint of the economy implies that, at each date, total production equals total consumption such that:

$$C_t L_t = A h_t \left(1 - \left[\frac{\sigma}{\xi} + \phi \right] X_t + \theta \Omega(X_t) \cdot e_t \right) L_t \quad (13)$$

Then, the Social Planner has to maximize (10) with respect to $\{C_t, X_t, h_{t+1}\}_{t=0}^{t=+\infty}$ and subject to $\{(1), (13)\}_{t=0}^{t=+\infty}$. The social optimum is defined by the set $\{\widehat{C}_t, \widehat{X}_t, \widehat{e}_t, \widehat{h}_t, \widehat{h}_{t+1}, \widehat{H}_t, \widehat{Y}_t\}_{t=0}^{t=+\infty}$ satisfying equations $\{(1), (3), (4), (13)\}_{t=0}^{t=+\infty}$ and, at each date t , both following first order conditions with respect to L_{t+1} and h_{t+1} :³³

$$-\frac{1}{\beta} = \frac{\varepsilon_L^f u(\cdot, \widehat{X}_{t+1}) + F(\widehat{X}_t) \frac{\widehat{X}_{t+1}}{\widehat{X}_t} \left[A \widehat{h}_{t+1} \left(\frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_{t+1}} e \left[\widehat{h}_{t+2}, \cdot, \cdot \right] \right) u'_{C_{t+1}} - u'_{X_{t+1}} \right]}{u'_{X_t} - A h_t \left(\frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_t} e \left[\widehat{h}_{t+1}, \cdot, \cdot \right] \right) u'_{C_t}} \quad (14)$$

$$\frac{u'_{C_{t+1}}}{u'_{C_t}} = \frac{\theta h_t \Omega(X_t) e'_1 \left[\widehat{h}_{t+1}, \cdot, \cdot \right]}{\beta F(\widehat{X}_t) \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) \widehat{X}_{t+1} - \theta \Omega(\widehat{X}_{t+1}) \left(e \left[\widehat{h}_{t+2}, \cdot, \cdot \right] + \widehat{h}_{t+1} \left(e'_2 \left[\widehat{h}_{t+2}, \cdot, \cdot \right] + e'_3 \left[\widehat{h}_{t+2}, \cdot, \cdot \right] \right) \right) \right]} \quad (15)$$

where $\varepsilon_v^g \equiv \frac{\partial g}{\partial v} \frac{v}{g}$ denotes the elasticity of g with respect to v . Obviously, at the social optimum, all of the existing externalities are taken into account. In this economy, there exist two types of externality: (i) a Lucas-type externality in the accumulation of human capital and (ii) when $f'(L_t)$ is strictly positive, parental preferences differ from the preferences of the Social Planner since parents do not value the population stock.³⁴

³¹An intuitive formulation of $f(L_t)$ consists in the Cobb-Douglas case such that $f(L_t) = L_t^{1-\kappa}$ with $\kappa \in [0, 1]$. If $\kappa = 0$, the objective function is Benthamite and, if $\kappa = 1$, it is Millian.

³²This condition is equivalent to $\lim_{T \rightarrow +\infty} \beta^T f\left(L_0 \prod_{t=0}^T X_t\right) = 0$. Because fertility is bounded by the maximal number of children a parent can give birth to, a sufficient condition to ensure that the SWF is bounded is

$\lim_{T \rightarrow +\infty} \beta^T f\left(L_0 \left[\phi + \frac{\sigma}{\xi}\right]^{-T}\right) = 0$. It follows that, for a Cobb-Douglas specification such that $f(L_t) = L_t^{1-\kappa}$, $\beta < \left(\phi + \frac{\sigma}{\xi}\right)^{1-\kappa}$ ensures that SWF is bounded whatever $\kappa \in [0, 1]$.

³³To ensure global concavity of the problem, its Hessian matrix is assumed to be negative semi-definite.

³⁴This is also the case when $u(C_t, X_t) < 0$ and $f'_L < 0$. See Appendix B.

3.3 The Optimal Tax-Transfer Policy

In order to decentralize the social optimum, the government has to implement a public policy that makes the competitive equilibrium $\{C_t^*, X_t^*, e_t^*, h_t^*, h_{t+1}^*, H_t^*, Y_t^*\}_{t=0}^{t=+\infty}$ coincide with the social optimum $\{\widehat{C}_t, \widehat{X}_t, \widehat{e}_t, \widehat{h}_t, \widehat{h}_{t+1}, \widehat{H}_t, \widehat{Y}_t\}_{t=0}^{t=+\infty}$.

In this section, I discuss the optimal tax-transfer policies in the Millian case where $f'(L_t) = 0$ and in the more general case where $f'(L_t) > 0$. In the Millian case, the only externality is the Lucas-type externality on human capital accumulation that makes parents undervalue the return on their investment in children's human capital. There is no difference between social and private preferences. It therefore seems intuitive that the implementation of a subsidy on education financed by a lump tax would ensure the decentralization of the social optimum. However, one major result of this paper is that this policy cannot decentralize the first-best equilibrium. Indeed, because the budget constraint is not linear, subsidizing education spending reduces the total cost of children, so an additional tax on child births is needed.

In the non-Millian case, in addition to the Lucas-type externality on education, there exists an externality on fertility. The optimal policy will consist of a tax-transfers policy on education and births completed by a lump-sum transfer as in the Millian case, but such a policy does not necessarily consist of taxing births and subsidizing education. The social preference for the population stock enriches the model with two mechanisms. First, when adults decide their number of children, they do not take into account that they make it easier to attain a greater population size in the future, which is socially desirable since it will increase the total utility of society. Second, if $L_{t+1} > L_t$, transferring welfare from current to future generations would be socially desirable because it would benefit a larger population.³⁵ In other words, the social returns on education investments would be greater

³⁵This mechanism can also be understood in the light of a comparison between private and social preferences for present. Indeed, at period t , equation (7) indicates that in $t = 0$, the per se private welfare gain of increasing by one unit the consumption of each generation is $u'_{C_0} + \beta u'_{C_1} + \beta^2 u'_{C_2} + \dots + \beta^t u'_{C_t} + \dots$ while the per se social welfare gain of this improvement equals $u'_{C_0} + \beta \frac{f(L_1)}{f(L_0)} u'_{C_1} + \beta^2 \frac{f(L_2)}{f(L_0)} u'_{C_2} + \dots + \beta^t \frac{f(L_t)}{f(L_0)} u'_{C_t} + \dots = u'_{C_0} + \beta F(X_1) u'_{C_1} + \beta^2 F(X_1 X_2) u'_{C_2} + \dots + \beta^t F\left(\prod_{s=0}^{s=t} X_s\right) u'_{C_t} + \dots$

It follows from the definition of $F(\cdot)$ that if population is growing ($X_s > 1$) the social discount rate evaluated by $\beta^t F\left(\prod_{s=0}^{s=t} X_s\right)$ is higher than the private one (β^t). Then the social returns of education are

than the private ones even if the Lucas-type externality did not exist. However, if $L_{t+1} < L_t$, it is socially desirable to transfer utility from future to present generations. To summarize, the Social Planner prefers transferring utility to the generations with the greatest population. The optimal tax-transfer policy will result from the opposition of the two externalities of the model.

Let the set $\{\lambda_t, \Lambda_t, T_t\}_{t=0}^{t=+\infty}$ define an economic policy where $\lambda_t > 0$ (resp $\lambda_t < 0$) consists of the subsidy rate (resp tax rate) on education spending, $\Lambda_t > 0$ (resp $\Lambda_t < 0$) denotes the tax (resp subsidy) on each birth and $T_t \geq 0$ the lump-sum transfer. At each date t , the government budget constraint has to be balanced such that:

$$T_t = \lambda_t \theta e \left(h_{t+1}^*, h_t^*, \bar{h}_t^* \right) \Omega(X_t^*) A h_t^* - \frac{\Lambda_t}{\xi} X_t^* A h_t^* \quad (16)$$

The parental budget constraint then becomes:

$$C_t + \left[\frac{\sigma + \Lambda_t}{\xi} + \phi \right] w_t h_t X_t + (1 - \lambda_t) \theta w_t h_t \Omega(X_t) \cdot e_t = w_t h_t + T_t \quad (17)$$

The competitive equilibrium is now defined by the set $\{C_t^*, X_t^*, e_t^*, h_t^*, h_{t+1}^*, H_t^*, Y_t^*, w_t^*\}_{t=0}^{t=+\infty}$ satisfying equations $\{(1), (3), (4), (5), (17)\}_{t=0}^{t=+\infty}$ and the following first order conditions with respect to L_{t+1} and h_{t+1} :

$$-\beta \frac{X_{t+1}}{X_t} = \frac{u'_{X_t} - A h_t \left(\frac{\sigma + \Lambda_t}{\xi} + \phi + (1 - \lambda_t) \theta \Omega'_{X_t} e[h_{t+1}, \cdot, \cdot] \right) u'_{C_t}}{A h_{t+1} \left(\frac{\sigma + \Lambda_{t+1}}{\xi} + \phi + (1 - \lambda_{t+1}) \theta \Omega'_{X_{t+1}} e[h_{t+2}, \cdot, \cdot] \right) u'_{C_{t+1}} - u'_{X_{t+1}}} \quad (18)$$

$$\frac{u'_{C_{t+1}}}{u'_{C_t}} = \frac{(1 - \lambda_t) \theta h_t \Omega(X_t) e'_1[h_{t+1}, h_t, \bar{h}_t]}{\beta \left[1 - \left(\frac{\sigma + \Lambda_{t+1}}{\xi} + \phi \right) X_{t+1} - (1 - \lambda_{t+1}) \theta \Omega(X_{t+1}) (e[h_{t+2}, h_{t+1}, \bar{h}_{t+1}] + h_{t+1} e'_2[h_{t+2}, h_{t+1}, \bar{h}_{t+1}]) \right]} \quad (19)$$

Since (16) and (17) ensure that the resources constraint is satisfied, it is straightforward that an optimal economic policy has to equalize subsystems $\{(14), (15)\}_{t=0}^{t=+\infty}$ to $\{(18), (19)\}_{t=0}^{t=+\infty}$.

Proposition 1 *Given the parental (perfect) expectations on $\{\lambda_{t+1}, \Lambda_{t+1}, T_{t+1}\}_{t=0}^{t=+\infty}$, there exists a unique vector $\{\lambda_t, \Lambda_t, T_t\}_{t=0}^{t=+\infty}$ that is able to decentralize the first-best path. Given that \widehat{T}_t is directly deduced from the government budget constraint the optimal economic policy is fully described as follows:*

$$\begin{aligned} \widehat{\lambda}_t &= -a_t \widehat{\lambda}_{t+1} + b_t \widehat{\Lambda}_{t+1} + d_t [F(X_t) - 1] - g_t \\ \widehat{\Lambda}_t &= -i_t \widehat{\lambda}_{t+1} + j_t \widehat{\Lambda}_{t+1} - k_t [F(X_t) - 1] - m_t \end{aligned}$$

higher than the private one even if they would not exist any externality on education investments.

Proof. See Appendix A. ■

It appears that once the Social Planner observes the parental expectations on the future values of the instruments, it is always possible to define a unique optimal economic policy. At the steady state, the optimal economic policy is described by the set $\left\{\widehat{\lambda}, \frac{\widehat{\Lambda}}{\widehat{\xi}}\right\}$:

$$\widehat{\lambda} = \frac{-F(X)\varepsilon_3^e - \frac{\beta\varepsilon_L^f X}{Ah\Omega(X)\theta e(1-\beta F(X))} \frac{u}{u'_C} - [1-F(X)] \left[\frac{C}{Ah\Omega(X)\theta e} - \varepsilon_2^e \right]}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \quad (20)$$

$$\frac{\widehat{\Lambda}}{\widehat{\xi}} = - \frac{\frac{\beta\varepsilon_L^f}{[1-\beta F(X)]Ah} \frac{u}{u'_C}}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} - \frac{\Omega'_X \theta e \left[F(X)\varepsilon_3^e + (1-F(X)) \left(\frac{C}{Ah} - \Omega(X)\theta h e'_2 \right) \right]}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \quad (21)$$

In the following sub-sections, I interpret this result at the steady state in the simple case of a Millian SWF and in the general case where the SWF is not Millian.

3.3.1 The Millian Case: $f'(L_t) = 0$

In the Millian case, there is no difference between individual and social preferences. At the steady state, the optimal economic policy is described as follows:

$$\widehat{\lambda} = - \frac{\varepsilon_3^{\widehat{e}}}{1 + \frac{\varepsilon_1^{\widehat{e}}}{\beta} + \varepsilon_2^{\widehat{e}} - \varepsilon_X^\Omega} \quad \frac{\widehat{\Lambda}}{\widehat{\xi}} = - \frac{\Omega'_X \theta \widehat{e} \varepsilon_3^e}{1 + \frac{\varepsilon_1^{\widehat{e}}}{\beta} + \varepsilon_2^{\widehat{e}} - \varepsilon_X^\Omega} \quad \widehat{T} = \frac{A\widehat{h}\theta\widehat{e}\varepsilon_3^{\widehat{e}} \left(\varepsilon_X^\Omega - 1 \right)}{1 + \frac{\varepsilon_1^{\widehat{e}}}{\beta} + \varepsilon_2^{\widehat{e}} - \varepsilon_X^\Omega} \quad (22)$$

The non increasing return to scale in human capital accumulation and $\varepsilon_X^\Omega < 1$ implies that $\widehat{\lambda} > 0$, $\frac{\widehat{\Lambda}}{\widehat{\xi}} > 0$ and $\widehat{T} > 0$.³⁶ Because of the Lucas-type externality, parents do not internalize all the returns on their investment in education. Then, at the competitive equilibrium, their investment in children's human capital is smaller than at the optimum. Thus, a subsidy on private education spending has to be implemented. Such a subsidy decreases the marginal cost of education, which becomes $(1 - \lambda)\theta Ah\Omega(X)$ but it also reduces the marginal cost of quantity, which becomes $\left[\frac{\sigma}{\xi} + \phi \right] w_t h_t + (1 - \lambda)\theta w_t h_t \Omega'_{X_t} \cdot e_t$. Thus, parents give births to too

³⁶Indeed, non increasing returns to scale in education investment ensure that $\varepsilon_{e_t}^{h_{t+1}} + \varepsilon_{h_t}^{h_{t+1}} + \varepsilon_{\overline{h}_t}^{h_{t+1}} \leq 1$, what implies that $\varepsilon_{e_t}^{h_{t+1}} < 1$ and so that $\varepsilon_{h_{t+1}}^{e_t} = \frac{1}{\varepsilon_{e_t}^{h_{t+1}}} > 1$. By (1) and the definition of elasticity, $\varepsilon_{h_t}^{e_t} = - \left| \varepsilon_{h_t}^{h_{t+1}} \varepsilon_{h_{t+1}}^{e_t} \right|$, so $\frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e = \varepsilon_{h_{t+1}}^{e_t} \left[\frac{1}{\beta} - \varepsilon_{h_t}^{h_{t+1}} \right] > 0$. Furthermore, by definition, $\varepsilon_X^\Omega < 1$. Then, $1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega > 0$. As $\varepsilon_3^e < 0$, it follows that $\widehat{\lambda} > 0$, $\frac{\widehat{\Lambda}}{\widehat{\xi}} > 0$ and $\widehat{T} > 0$.

many children at the competitive equilibrium, and a tax on each birth has to be implemented such that the marginal cost of quantity becomes $\left[\frac{\sigma+\Lambda}{\xi} + \phi\right] w_t h_t + (1 - \lambda)\theta w_t h_t \Omega'_{X_t} e_t$.³⁷ Therefore, to decentralize the first-best optimum, the government has to implement a tax on births in addition to the education policy despite the fact that the quantity of children is not a source of externalities. In other words, because of the fundamental non-linearity of the quality-quantity costs structure, three instruments are needed to correct the Lucas-type externality.³⁸

Notice that the first-best optimum dominates all other equilibria in the sense of A , RC , CRC -efficiency. Indeed, it is impossible to improve the welfare of one generation of living agents without reducing the welfare of another generation of living agents. In that case, the social optimum necessarily dominates the competitive equilibrium. Notice that this result crucially comes from the absence of distance between social and private preferences.

3.3.2 The General Case, $f'(L_t) > 0$

When $f'(L_t) > 0$, there exists a difference between individual and social preferences. Indeed, the Social Planner has a preference for the population stock though it is not a concern of individuals. Formally, the optimal tax transfer policy is described by equations (20) and (21) :

$$\widehat{\lambda} = \frac{-F(X)\varepsilon_3^e - \frac{\beta\varepsilon_L^f X}{Ah\Omega(X)\theta e(1-\beta F(X))} \frac{u}{u'_C} - [1-F(X)] \left[\frac{C}{Ah\Omega(X)\theta e} - \varepsilon_2^e \right]}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \equiv \frac{-F(X)\varepsilon_3^e + LHS_\lambda + RHS_\lambda}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \quad (23)$$

$$\frac{\widehat{\Lambda}}{\xi} = \frac{\Omega'_X \theta e F(X) \varepsilon_3^e - \frac{u}{u'_C} \frac{\beta\varepsilon_L^f (1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e)}{[1-\beta F(X)] Ah} - \Omega'_X \theta e (1-F(X)) \left(\frac{C}{Ah} - \Omega(X) \theta h e'_2 \right)}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \equiv \frac{\Omega'_X \theta e F(X) \varepsilon_3^e + LHS_\Lambda + RHS_\Lambda}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \quad (24)$$

The impact of the Lucas-type externality remains the same. The social preference for the size

³⁷As shown by Willis [1973], facing a decrease in the cost of quality, parents can also reduce their fertility rate. In the present case, this can mean, for instance, that the quantity of children is a Giffen good. Indeed, after a decrease in the price of quantity (through the subsidy on education), its "consumption" decreases. Nevertheless, in this case, the optimal economic policy still consists in taxing births to incite parents to make more children.

³⁸When education is a pure public good inside the family ($\Omega'_{X_t} = 0$), taxing births is never necessary to decentralize the first best path. Indeed, education has still to be subsidized but the marginal cost of childbearing does no more depend on the educational investment.

of populations introduces two additional effects. First, the Social Planner prefers the largest generations (for example, distributing one unit of utility per se to a large generation is more enjoyable than distributing one unit of utility to a smaller generation). Thus, when $\hat{X} > 1$ (increasing population), it is optimal to transfer welfare from present to future generations.³⁹ To do so, educational investments of present generations have to be increased. In other words, the social returns on parental investments in education is higher than the private returns because it will benefit a growing population. This mechanism has a positive effect on the optimal value of the subsidy on education ($RHS_\lambda > 0$). Because the parental budget constraint is non-linear, it has also a positive impact on the optimal tax rate on births ($RHS_\Lambda > 0$). In contrast, if the optimal population growth rate is negative ($\hat{X} < 1$), it is socially enjoyable to transfer welfare from future to present generations, which necessitates limiting the parental investment in education. This has a negative impact on both $\hat{\lambda}$ and $\frac{\hat{\Lambda}}{\xi}$ ($(RHS_\lambda, RHS_\Lambda) < (0, 0)$).

The second effect introduced by the existence of a social preference for the size of the population is more straightforward. When deciding their fertility rate, individuals do not take the social preference for the population stock into account.⁴⁰ Individuals therefore underestimate the returns on their investment on childbearing. Ceteris paribus, their fertility rate is too low, which has a negative impact on both $\hat{\lambda}$ and $\frac{\hat{\Lambda}}{\xi}$ ($(LHS_\lambda, LHS_\Lambda) < (0, 0)$).⁴¹ This mechanism has a negative impact on $\frac{\hat{\Lambda}}{\xi}$ (and on $\hat{\lambda}$ because of the non linearity of the parental budget constraint).

As a result, the optimal tax transfer policy consists of subsidizing education and taxing births as in the Millian case only if the Lucas-type externality is strong relative to the preference for the population stock. This is satisfied when $-\varepsilon_3^e > \max \left\{ -\frac{LHS_\lambda + RHS_\lambda}{F(X)}; -\frac{LHS_\Lambda + RHS_\Lambda}{F(X)} \right\}$.

It has to be noticed that when $f'(L_t) > 0$, the social optimum does not necessarily dominates the laissez-faire equilibrium in the sense of A , RC , CRC , P and u efficiency. Indeed, when the two objectives differ, nothing ensures that all living agents in the two equilibria

³⁹When f'_{L_t} is negative, this effect is partially reversed. Nevertheless, Proposition 1 and equations (23) and (24) remain valid when $f'_{L_t} < 0$ and $u(C_t, X_t) < 0$.

⁴⁰Agents do not take into account that when they give birth to a child, they make it easier for future generations to reach larger population size what is socially enjoyable.

⁴¹It is straightforward that $(LHS_\lambda, LHS_\Lambda) < (0, 0)$ because, to ensure that the Social Planner's objective is bounded, the model assumes that $\beta F(\max\{X\}) < 1$.

enjoy a higher welfare at the optimum. Because of the social preference for the population stock, it can be socially enjoyable to give birth to a higher number of agents who receive less welfare than at the laissez-faire (this will be the case when the externality on education investment is weak relative to the social preference for the size of population). Thus, in this sense, the social optimum does not necessarily dominate the laissez-faire equilibrium in the sense of A , RC and CRC -efficiency. Then, because nothing ensures that, for all configuration of the model, the social optimum dominates the competitive equilibrium in the sense of A -efficiency, nothing can ensure such a domination in the sense of P -efficiency.⁴²

In this section, I find two important results. First, in the standard model of endogenous fertility, when there is no difference between private and social preferences, positive externalities on the human capital accumulation process mean that subsidizing education spending is optimal (like in the usual literature) but has to be combined with a tax on each birth. This result comes from the decrease in the marginal cost of quantity induced by education subsidies. Second, when the Social planner is not Millian, despite the fact that education is a source of only positive externalities, subsidizing education is not always optimal. This result comes from the social preference for large generations that distorts the returns to investments in education relative to the returns to investment in the quantity of children.

In the next section, I answer a natural question: "Do the previous results still prevail if I adopt another standard model of fertility?"

4 Alternative "standard" models of endogenous fertility

At least two alternative models could also be considered as standard models of endogenous fertility: the Barro-Becker type model [1988] and the non-altruistic model. I show that adopting these models does not change my main results. I also show that adopting the De la Croix & Doepke's assumption that education is not provided by parents but by teachers can deeply change the nature of the optimal economic policy in the Millian case.

⁴²In this paper, unborn agents are not characterized by well-defined preferences.

4.1 The Dynastic Altruism of Barro and Becker

Becker & Barro [1988] propose a model of fertility where the parental utility function consists of the discounted sum of their dynasty's flow of utility. Parental altruism is endogenous and negatively related to the quantity of children and the current utility of parents is not influenced by their fertility. In such a case, $V_t = \max \{U(C_t) + \beta(X_t) X_t V_{t+1}\}$ with $\beta(X_t) = \beta X_t^{-\varepsilon}$. Starting in period $t = 0$ and normalizing the initial adults to $L_0 = 1$, sequential substitutions lead to:⁴³

$$V_0 = \sum_{t=0}^{+\infty} \beta^t L_t^{1-\varepsilon} U(C_t) \quad (25)$$

where $U(\cdot)$ is strictly increasing and concave in C_t . Following Jones & Schoonbroodt [2007,2009], I assume that: (i) $\varepsilon \in]0, 1[$ when $U(C_t) > 0 \forall C_t > 0$ while, (ii) $\varepsilon > 1$ when $U(C_t) < 0 \forall (C_t) > (0, 0)$.

I did not adopt this utility function in my benchmark model. However, as mentioned by Nerlove and Rault [1997], the Barro and Becker's model, as well as the model designed by Razin and Ben Zion, are specific cases of a more general model.⁴⁴ In this section, I don't assume the existence of a pro-natalist bias: $f(L_t) = 1 \forall L_t$.⁴⁵ Therefore, $W_0 = V_0$.

The Barro and Becker model does not introduce any additional externality compared to the model of Razin and Ben Zion. The only difference between the two comes from the formulation of individual utility functions. It is therefore intuitive that the two models lead to the same conclusions in term of optimal economic policy. The proof of this result is provided in Appendix C.

4.2 Non Altruistic Model

Recent literature pertaining to the UGT has favored the use of fertility models where parental utility is not dynastic. In other words, parents exhibit imperfect altruism and the quality

⁴³See Becker and Barro [1988].

⁴⁴Nerlove & Rault [1997] present this more general model where $V_t = \max \{u(C_t, X_t) + \beta(X_t) X_t V_{t+1}\}$. In the Becker and Barro specification, $u'_{X_t} = 0$ while in the Razin and Ben Zion model, $X_t \beta(X_t) = \beta$. Jones & Schoonbroodt [2009] and Bar & Leukhina [2010] show that for some joint restrictions on ε and $u(C_t)$, both models are identical. Jones & Schoonbroodt [2007] provide an enlightening study of the relationship between fertility and income in the model of Barro and Becker.

⁴⁵Adding such a natalist bias would be redundant especially thinking to $f(L_t) = L_t^{\varepsilon}$. Furthermore, it is intuitive that the effect of such a bias would be identical to this studied in the Benchmark model.

of children directly enters their utility function. This quality can take the form of human capital (see Galor [2005]), financial bequest (see Becker and Lewis [1973]), health status, etc. Parental utility can be represented by $U(C_t, X_t, h_{t+1})$, which is increasing and strictly concave with respect to all its arguments. Adopting this non-dynastic representation of preferences makes it difficult to properly define a SWF. In this sub-section, I adopt the method of Eckstein and Wolpin [1985] by defining the SWF as the utility of the current generation at the steady state. I determine the optimal economic policy that allows the decentralization of the set of optimal behaviors at the steady state. Another alternative could consist of defining an ad-hoc social discount rate and assuming a dynastic Social Planner. However, in that case, the model introduces artificial positive externalities on fertility and education choices: parents do not take the dynamic returns on their investments into account.

The stationary Millian SWF is $W = U(C, X, h)$. It is maximized with respect to C, X, h and subject to the stationary resource constraint and the human capital production function which are, respectively:

$$C = \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) X - \theta \Omega(X) e \right] Ah \quad (26)$$

$$h_{t+1} = l(e_t, h_t, \bar{h}_t) \quad (27)$$

At the stationary competitive equilibrium, agents maximize $V = U(C, X, h)$ with respect to C, X, h and subject to (27) and the following budget constraint:

$$C + \left[\frac{\sigma}{\xi} + \phi \right] whX + \theta wh \Omega(X) \cdot e = wh$$

There is no difference between individual and social preferences and a Lucas-type externality exists, as in the Benchmark model. An additional intradynastic externality is introduced in this model. Indeed, because parents do not care about the future well-being of their children, when they decide their optimal investment in education, they do not take into account that: (i) they increase their children's future earning abilities $w_{t+1}h_{t+1}$, (ii) they reduce the cost of producing the human capital of their grandchildren in the sense that to reach the same $h_{t+2} = l(e_{t+1}, h_{t+1}, \bar{h}_{t+1})$, their children will need to invest a smaller e_{t+1} , and (iii) they increase the opportunity cost of grandchildren relative to the opportunity cost of providing them with education; indeed the quantity of children is more time-consuming

than children's quality. The addition of this positive intra-dynastic externality on human capital dramatically reinforces the results of Section 1 in the Millian case.

Formally, the optimal economic policy becomes:⁴⁶

$$\hat{\lambda} = \frac{\frac{\hat{c}}{Ah} - \theta\Omega(\hat{X})h(\hat{e}'_2 + \hat{e}'_3)}{\theta\Omega(\hat{X})\hat{h}\hat{e}'_1}, \quad \frac{\hat{\Lambda}}{\xi} = \theta\Omega'(\hat{X})\hat{e}\frac{\frac{\hat{c}}{Ah} - \theta\Omega(\hat{X})h(\hat{e}'_2 + \hat{e}'_3)}{\theta\Omega(\hat{X})\hat{h}\hat{e}'_1} \quad (28)$$

It is straightforward that $(\hat{\lambda}, \frac{\hat{\Lambda}}{\xi}) > (0, 0)$. Finally, it appears that considering dynastic or non-dynastic altruism leads to the same fundamental result: in a Millian economy, in the presence of positive externalities in the accumulation of human capital, an optimal economic policy has to subsidize education and has to tax births. However, in the non altruistic model, nothing can ensure that the economic policy that is optimal at the steady state will also be optimal out of the steady state.

4.3 When education is provided by teachers

De la Croix and Doepke [2003] assume that education is not provided by parents but by teachers. Parents finance a schooling time e_t , the process of accumulation of human capital remains unchanged and the average human capital in the school system is the same as in the whole economy. However, the parental budget constraint and the aggregate human capital in the workforce become respectively:

$$C_t + \left[\frac{\sigma}{\xi} + \phi \right] w_t h_t X_t + \theta w_t \bar{h}_t \Omega(X_t) \cdot e_t = w_t h_t \quad (29)$$

$$H_t = \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) h_t X_t - \theta e_t \Omega(X_t) \bar{h}_t \right] L_t \quad (30)$$

The cost of educating children is no longer an opportunity cost, but a financial cost. The workforce participation of parents consists in their remaining time after childbearing, and teachers do not directly participate in the production of the final good.

For simplicity, I assume that the SWF is Millian. In addition to simplifying the results in a sensible manner, it is intuitive that assuming a non-Millian Social Planner would result in the existence of a preference for larger generations, as in the Benchmark model. Formally,

⁴⁶Both the stationary competitive equilibrium and the stationary optimum are displayed in appendix E.

the optimal economic policy at the steady state is now described by:⁴⁷

$$\hat{\lambda} = \frac{1 + \varepsilon_3^{\hat{e}}}{\varepsilon_2^{\hat{e}} - \frac{\varepsilon_1^{\hat{e}}}{\beta} + \varepsilon_{\hat{X}}^{\Omega}} \quad \frac{\hat{\lambda}}{\xi} = \Omega'_{\hat{X}} \theta \hat{e} \frac{1 + \varepsilon_3^{\hat{e}}}{\varepsilon_2^{\hat{e}} - \frac{\varepsilon_1^{\hat{e}}}{\beta} + \varepsilon_{\hat{X}}^{\Omega}}$$

As in the Benchmark model, parents do not internalize the impact of their investment in human capital at the level of the future average of human capital in the entire population. Thus, they do not consider that, when they invest in their children's human capital, they improve the quality of the school system and so ease the future accumulation of human capital in their dynasty (quality effect). But they also do not take into account that this will in turn increase the cost of future investments in education: indeed, the rise in the average level of teachers' human capital triggers the cost of financing one unit of education (cost effect). This effect is an intra-dynastic negative externality and it can lead to a too high investment in human capital at the competitive equilibrium. The optimal economic policy on education will consist of a tax on education spending when the cost effect is stronger than the quality effect ($|\varepsilon_3^{\hat{e}}| > 1$).⁴⁸ Following De la Croix and Doepke [2003], this condition holds in empirical data. Because no externality exists on fertility, the non-linearity of the parental budget constraint implies that births must be subsidized.

This result highlights that the consideration of the dynamic properties of the standard model of fertility throws into question the common results of education models which do not consider endogenous fertility. It also appears that introducing, in the benchmark model, a mixed education system with both parents and teachers provides richer results. Indeed, even in the Millian case, it can be optimal to tax education and subsidize births despite education being a source of positive externalities.

In the following section, the benchmark model is extended to include endogenous child mortality and private health expenditure. Despite the changes in the nature of the trade-off between quality and quantity, the need to tax births will not be canceled by the introduction of a health expenditure.

⁴⁷See Appendix E for a complete description of the competitive equilibrium, the first best path and the economic policy that allows to decentralize this latter.

⁴⁸By (1), this will be satisfied when the elasticity of h_{t+1} with respect to e_t is greater than the elasticity of h_{t+1} with respect to \bar{h}_t . Indeed, as $\frac{\varepsilon_1^{\hat{e}}}{\beta} > 1$, $\varepsilon_2^{\hat{e}} < 0$ and $\varepsilon_{\hat{X}}^{\Omega} < 1$, $\varepsilon_2^{\hat{e}} - \frac{\varepsilon_1^{\hat{e}}}{\beta} + \varepsilon_{\hat{X}}^{\Omega} < 0$.

5 Optimal Tax-Transfer policy with health expenditure

The child survival rate is currently endogenous. Parents can use health expenditure to reduce their children's probability of dying. In line with Chakraborty [2004], the child survival probability ξ_t is now:

$$\xi_t \equiv \xi(s_t, \bar{s}_t) \quad (31)$$

Parental expenditure on health has a strictly positive and concave influence on children's survival probability, so $\xi'_1 \equiv \frac{\partial \xi(s_t, \bar{s}_t)}{\partial s_t} > 0$ and $\xi''_{11} \equiv \frac{\partial^2 \xi(s_t, \bar{s}_t)}{\partial s_t^2} < 0$. This expenditure represents the health care provided by parents to children. Parental health care covers a large set of expenditures such as hygiene, sanitation improvements and efficient nutrition. \bar{s}_t denotes the average health expenditure in the economy. In line with Dasgupta [1993], $\xi'_2 \equiv \frac{\partial \xi(s_t, \bar{s}_t)}{\partial \bar{s}_t} > 0$ and $\xi''_{22} \equiv \frac{\partial^2 \xi(s_t, \bar{s}_t)}{\partial \bar{s}_t^2} < 0$.

The introduction of an externality on health expenditure implies that the parental choices on s_t will not be efficient at the competitive equilibrium. Intuitively, one can expect that the competitive level of health expenditure will be inferior to its optimal level. However, the existence of educational inefficiency could alter this result because, as previously shown, it decreases the total cost of quantity.

5.1 The Competitive Equilibrium

Parents now have to determine the amount of health expenditure for their children. In other words, they choose X_t and s_t . The addition of an externality on health spending implies that private health investment will not be optimal. Assume that the government introduces a subsidy r_t on health expenditure in accordance with the previous fiscal system. The government budget constraint, for each date t , is now:

$$T_t = \lambda_t \theta e(h_{t+1}, h_t, h_t) \Omega(X_t) w_t h_t - \frac{\Lambda_t w_t h_t}{\xi(s_t, \bar{s}_t)} X_t + r_t s_t \quad (32)$$

When the fiscal scheme is implemented, the familial budget constraint, at date t , is:

$$C_t + (1 - r_t) s_t + \left[\frac{\sigma + \Lambda_t}{\xi(s_t, \bar{s}_t)} + \phi \right] w_t h_t X_t + (1 - \kappa_t) \theta w_t \bar{h}_t \Omega(X_t) \cdot e_t = w_t h_t \quad (33)$$

The final good can now be either consumed or invested in health. Then, a parent born in $t - 1$ determines his optimal demands $(C_t^*, X_t^*, h_{t+1}^*)$ by maximizing V_t with respect to C_t, X_t , and h_{t+1} subject to (1) and (33). As health expenditure does not enter the objective function, parents determine their optimal health expenditure by minimizing $(1 - r_t) s_t + \frac{\sigma + \Lambda_t}{\xi(s_t, \bar{s}_t)} w_t h_t X_t$. It follows that:

$$1 - r_t = \frac{[\sigma + \Lambda_t] \xi'_1(s_t^*, \bar{s}_t^*)}{[\xi(s_t^*, \bar{s}_t^*)]^2} X_t^* w_t h_t^* \quad (34)$$

Parents equalize the marginal return and the marginal cost of the health expenditure $1 - r_t$. The marginal benefit of the health expenditure (*RHS* of (34)) consists of the reduction in the total cost of quantity.⁴⁹ In other words, equation (34) determines the optimal parental spending on health to have X_t surviving children. It also emphasizes that the taxation of births increases the marginal cost of quantity and increases the marginal benefits of the health expenditure.

Using the same method as for previous models, I obtain the same first order conditions with respect to L_{t+1} and h_{t+1} as in the benchmark model given that at each date t , the child survival probability equals $\xi(s_t, \bar{s}_t)$ instead of ξ . So, the competitive equilibrium is now defined by the set $\{C_t^*, X_t^*, e_t^*, h_t^*, h_{t+1}^*, H_t^*, Y_t^*, w_t^*, s_t^*\}_{t=0}^{t=+\infty}$ satisfying equations $\{(1), (3), (4), (5), (8), (9), (33), (34)\}_{t=0}^{t=+\infty}$ given that now $\xi = \xi(s_t, \bar{s}_t)$.

5.2 The Social Optimum

For simplicity's sake, $f(L_t) = 1$ is assumed for each t . The Social Planner maximizes a Millian Social Welfare function $W_0 = \sum_{t=0}^{+\infty} \beta^t u(C_t, X_t)$. He holds a new maximization instrument s_t and faces a new resource constraint at each date t :

$$C_t + s_t = \left[1 - \left(\frac{\sigma}{\xi(s_t, \bar{s}_t)} + \phi + \theta e_t \right) X_t \right] A h_t \quad (35)$$

At the optimum $s_t = \bar{s}_t$. The Social Planner determines the optimal health expenditure by minimizing $\frac{\sigma}{\xi(s_t, \bar{s}_t)} X_t A h_t + s_t$ with regard to s_t . When this is the case, the marginal social cost of health spending (equal to one) is equal to its marginal return. Obviously, the marginal

⁴⁹As mentioned in the Benchmark model, a higher child survival rate decreases the cost of quantity.

social benefit of health spending is higher than the marginal private benefit (calculated in equation (34)). Formally, the optimal decision rule for s_t is:

$$1 = \frac{\sigma \left[\widehat{\xi}'_1(\widehat{s}_t, \widehat{s}_t) + \widehat{\xi}'_2(\widehat{s}_t, \widehat{s}_t) \right]}{[\xi(\widehat{s}_t, \widehat{s}_t)]^2} \widehat{X}_t A \widehat{h}_t \quad (36)$$

The optimal equilibrium now results from the maximization of W_0 with regard to L_{t+1} and h_{t+1} and subject to $\{(1), (35), (36)\}_{t=0}^{t=+\infty}$. Then the social optimum is then described by the set $\left\{ \widehat{C}_t, \widehat{X}_t, \widehat{h}_t, \widehat{s}_t \right\}_{t=0}^{t=+\infty}$ satisfying equations $\{(14), (15), (35), (36)\}_{t=0}^{t=+\infty}$ given that $\xi = \xi(s_t, \bar{s}_t)$ and $f(L_t) = 1 \forall L_t$.

5.3 The Optimal Tax-Transfer Policy At The Steady State

Using the same method as in Proposition 1, it is straightforward that there exists a unique set $\{\lambda_t, \Lambda_t, s_t, T_t\}_{t=0}^{t=+\infty}$ that is able to decentralize the first-best path. An optimal policy at the steady state must make identical systems $\{(14), (15), (36)\}$ and $\{(8), (9), (34)\}$. Consequently, at the steady state, the optimal fiscal scheme is:

$$\widehat{\lambda} = \frac{\varepsilon_3^e}{\varepsilon_X^\Omega - \frac{\varepsilon_1^e}{\beta} - 1 - \varepsilon_2^e} > 0, \quad \widehat{\Lambda} = \theta \Omega'_X e^{\frac{\varepsilon_3^e}{\varepsilon_X^\Omega - \frac{\varepsilon_1^e}{\beta} - 1 - \varepsilon_2^e}} > 0, \quad \widehat{r} = \frac{\xi'_2(\widehat{s}, \widehat{s}) - \frac{\xi'_1(\widehat{s}, \widehat{s}) \theta \Omega'_X e \varepsilon_3^e}{\sigma \left(\varepsilon_X^\Omega - \frac{\varepsilon_1^e}{\beta} - 1 - \varepsilon_2^e \right)}}{\xi'_1(\widehat{s}, \widehat{s}) + \xi'_2(\widehat{s}, \widehat{s})} \quad (37)$$

Optimal values of $\widehat{\lambda}$ and $\widehat{\Lambda}$ are the same as in the previous section (given that the optimal values of \widehat{C} , \widehat{X} and \widehat{h} have changed). This implies that, as in Section 1, a policy of education and health is optimal when it is combined with a tax-transfer policy on births. Here, because the Social Planner exhibits no preference for the population stock, the optimal family policy always consists of a tax on births, a subsidy on education and a tax or a subsidy on health spending. The government budget constraint still has to be balanced by the implementation of a lump-sum tax on each family.

Proposition 2 *When the externality on the health expenditure is strong such that $\varepsilon_s^{\xi(s, \bar{s})} > \bar{\varepsilon}$, the optimal health policy consists of a subsidy. In the opposite case, it is optimal to tax health spending.*

Proof. It is straightforward to show that the parental health expenditure is not optimal at the competitive steady state. At the competitive steady state (without taxation), (34)

and (8) imply $s^* = \varepsilon_s^{\xi(s, \bar{s})} \sigma AhN$. At the optimal steady state, (36) and (14) imply $\hat{s} = \left[\varepsilon_s^{\xi(s, \bar{s})} + \varepsilon_{\bar{s}}^{\xi(s, \bar{s})} \right] \sigma AhN$. It follows that $s^* < \hat{s}$. However $s^* < \hat{s}$ does not ensure that health expenditure should always be subsidized. (34) and (36) indicates that the optimal value of health subsidies is:

$$\hat{r} = 1 - \frac{\varepsilon_s^{\xi(\hat{s}, \hat{s})}}{\varepsilon_s^{\xi(\hat{s}, \hat{s})} + \varepsilon_{\bar{s}}^{\xi(\hat{s}, \hat{s})}} \left(1 - \frac{\hat{\Lambda}}{\sigma} \right)$$

Then, \hat{r} is positive if the following condition holds:

$$\varepsilon_{\bar{s}}^{\xi(\hat{s}, \hat{s})} > - \frac{\theta \Omega'_X e \varepsilon_s^{\xi(\hat{s}, \hat{s})}}{\sigma \left(\varepsilon_X^\Omega - \frac{\varepsilon_1^e}{\beta} - 1 - \varepsilon_2^e \right)} \cdot \varepsilon_3^e \equiv \bar{\varepsilon}$$

■

When health externalities are strong with respect to educational externalities ($\varepsilon_{\bar{s}}^{\xi(\hat{s}, \hat{s})} > \bar{\varepsilon}$), the health expenditure has to be subsidized while the opposite is true when ($\varepsilon_{\bar{s}}^{\xi(\hat{s}, \hat{s})} < \bar{\varepsilon}$). This result comes from the non-linearity of the costs structure. Indeed, the existence of an externality on the health expenditure implies that parents do not internalize all the returns on their investment in children's health. The comparison of (34) with $\Lambda = r = 0$ and (36) indicates that the health expenditure at the competitive steady state is lower than at the optimal steady state. However, when education is subsidized, a tax on births has to be implemented. When this is the case, the cost of quantity is increased relative to the cost of health, so parents tend to increase their health expenditure. The tax on births plays the role of an indirect subsidy on health. Finally, the sign of \hat{r} is determined by the difference between the intensity of externalities on both health and education investments. If the externality on health is relatively strong ($\varepsilon_{\bar{s}}^{\xi(\hat{s}, \hat{s})} > \bar{\varepsilon}$), the indirect subsidy will not be sufficient to reach \hat{s} , so \hat{r} will be positive. Conversely, if the externality on health is relatively weak ($\varepsilon_{\bar{s}}^{\xi(\hat{s}, \hat{s})} < \bar{\varepsilon}$), the indirect subsidy exceeds the necessary health subsidy. Therefore, \hat{r} will be negative meaning that health expenditure have to be taxed.

To summarize, the present section provides two results. First, in a Millian economy, whenever it is optimal to subsidize education *and* health, it is optimal to tax births. Second, when the social returns on the health expenditure are low relative to the social return on education expenditure, the optimal family planning program consists of the promotion of education financed by the taxation of health and births and a lump-sum tax. Conversely, when the social returns on health expenditure are high relative to social returns on education,

the optimal family planning program consists in the promotion of education and health financed by the taxation of births and a lump-sum tax.⁵⁰ This optimal policy has, in fact, two main objectives. The first is to modify the parental trade-off between quality and quantity by inciting parents to transfer a part of their spending on fertility toward educational investment. The second objective is to modify the parental trade-off between fertility and health. In order to reach the same number of surviving children, parents are incited to invest less in the quantity of children.

6 Some Empirical Issues At Stake

In this section, I discuss the main theoretical conclusions of the model in the light of some empirical evidence. I show that these conclusions could enrich the set of family policies that are implemented in countries facing the problem of overpopulation. It should be clear that the simplicity of the model does not allow it to reproduce the very complex demographic puzzles that confront these countries. The discussion is therefore limited to general statements.

Countries that face over-population problems implement policies to slow their population growth rate. Two examples are particularly illuminating: China and Sub-Saharan Africa. Although these two regions both face overpopulation, their family policies have been noticeably different. This section reflects on improvements that could be made to these countries' policies in light of the fiscal scheme proposed in this paper.

A recent report from the World Bank [2007] states that 31 of the 35 countries with the highest fertility rates are located in Sub-Saharan Africa. For the majority of these countries, fertility rates remained stable over the last few decades at greater than six children per woman. However, the vast majority of these countries have implemented family planning programs in collaboration with international organizations such as the World Bank.

The World Bank's report [2007] emphasizes that the main factor driving high fertility rates is the persistent parents desire for a large number of children. In other words, the too high fertility rates in Sub-Saharan Africa do not result from a lack of family planning

⁵⁰Following Dasgupta [1993], the social returns on health expenditure are high. Then, the promotion of education and health financed by the taxation of births is a more realistic conclusion.

programs. The report asserts that efforts must be made to reduce the desired fertility. To do so, it recommends improving education and health programs at the local level. However, education indicators have increased since the sixties. Between 1990 and 2006, the net primary school enrollment rate increased from 50 to 70 percent. In the same period, the youth and adult literacy rates increased as well.⁵¹ This noticeable improvement in education rates has not been sufficient to reduce fertility rates.

The present paper does not recommend increasing spending on family planning programs. It proposes complementing family planning programs with taxes on births that would finance education and health. Without taxing births, these programs reduce the net cost of the children's quantity, creating conditions for the number of children desired to remain high.

Obviously, it is unclear whether it is feasible to implement a tax on births in a population that is largely engaged in an informal economy.⁵² However, increasing the costs associated with increases in the quantity of children should be considered as a policy instrument for family planning.

China also implements family policy to reduce its population growth rate. However, its strategy differs from family planning programs in Sub-Saharan Africa. Since 1980, China has implemented the "One-Child" policy which strongly constrains families' fertility. It is a system that provides generous subsidies for the first birth and imposes very high taxes on the subsequent births. If parents decide to have a second child without being permitted to do so, they lose a large part of their retirement pension, their child care allowance and other social advantages. Furthermore, some physical sanctions have been implemented in rural areas. This fiscal scheme is different from the one proposed in this paper, as the Chinese policy does not tax all births at the same rate. The first birth is subsidized while subsequent births are heavily taxed.

The high tax on subsequent births is a very efficient incentive to have only one child. Thus, the large majority of families are subsidized to reach the target of one child per family making the "One-Child" Policy very costly. The policy does not produce revenue to

⁵¹In Sub-Saharan Africa, the youth literacy rate was 64% in 1990 and 73% in 2006. The adult literacy rate was 54% in 1990 and 61% in 2006. See Appendix F for a more complete description.

⁵²Furthermore, some of these countries are facing other complex problems such as political instability, starvation and HIV pandemic that are well beyond the scope of this paper. These problems have a direct and significant effect on fertility and education behaviors.

finance education and health policies, so there is nothing to ensure that the relative costs of education and health will reach their optimal value. Indeed, a large body literature stresses the insufficiency of the public expenditure on health and education in Chinese rural areas where the large majority of the population is concentrated (for example, see Kanbur & Zhang [2003] and Fan & Zhang [2000]).

The results of this paper indicate that some marginal changes in the One-Child policy could improve the overall efficiency of Chinese family planning policy. These results suggest that all births should be taxed to avoid effective costs. The amount saved by the Chinese government could be invested in more ambitious education and health policies, thereby reducing the large inequalities between urban and rural areas. *Theoretically*, this system would not increase the overall cost of the Chinese family planning program and would lead to the same fertility rates. It would, however, increase health and education investments. Furthermore, the Chinese family policy is coercive, while the economic policy proposed in this paper is non-coercive. If the two policies are equally efficient, the non-coercive policy should be implemented because it improves welfare.

Note that a "naive" interpretation of the model could lead to an alternative analysis. The Chinese government's objective to reach a fertility rate inferior to two children per family could reveal that the Chinese optimal population growth rate in the long-run is negative and that there exists a preference for large generations. Then the policy of low subsidies on education spending would be optimal because it transfers welfare from future to present generations.

7 Conclusion

The present paper analyses optimal family policies in the standard model of trade-off between quality and quantity. Given the non-linearity of the parental budget constraint, subsidizing education and health will be optimal if a tax (or a subsidy) on births is also implemented. Indeed, a subsidy on education reduces both the cost of educational investment and the total cost of fertility. This result applies for a large set of Social Welfare Functions, including Millian and Benthamite functions. Obviously, the model concludes that taxing births without financing education and health is also not optimal.

Finally, the fiscal scheme proposed in this model is quite simple: education and health expenditures are promoted by the taxation of births and lump-sum transfers. This scheme could improve the overall efficiency of family policies currently implemented in China and Sub-Saharan Africa. The main objective of the present investigation was to explore the family policy recommendations of the standard endogenous fertility model. As a natural extension of this work, future research should integrate countries' specificities to make quantitative proposals for economic policy and to provide a more precise discussion of empirical evidence.

References

- [1] Balestrino A., Cigno A. & Pettini A. [2000] "Endogenous Fertility and the Design of Family Taxation" *International Tax and Public Finance*, Springer, vol. 9(2), p 175-193
- [2] Bar M. & Leukhina O. [2010] Demographic Transition and Industrial Revolution: A Macroeconomic Investigation, *Review of Economic Dynamics*, vol. 13(2), p 424-451
- [3] Baudin T. [2010] "Optimal Trade-Off Between Quality and Quantity Under Uncertain Child Survival", mimeo, paper available at <http://thomasbaudin.host22.com/EUncertain%20Child%20Survival.pdf>
- [4] Becker G.S & Barro R.J., [1988]. "A Reformulation of the Economic Theory of Fertility," *The Quarterly Journal of Economics*, MIT Press, vol. 103(1), p 1-25, February
- [5] Becker G.S. & Lewis H.G. [1973] "On the Interaction Between the Quantity and Quality of Children" *The Journal of Political Economy*, vol. 81(2) Part 2 New Economic Approach to Fertility, p 279-288
- [6] Becker G.S. & Tomes N. [1976] "Child Endowments and the Quantity and Quality of Children" *The Journal of Political Economy*, vol. 84 (4) Part 2, Essays in Labor Economics in Honor of H.G. Lewis, p 143-162
- [7] Blackorby C. & Bossert W. & Donaldson D. [2005] "Population Issues in Social Choice Theory, Welfare Economics and Ethics", *Econometric Society Monographs* (39)

- [8] Blackorby C. & Bossert W. & Donaldson D. [2006] "Population Ethics", *Cahiers de recherche 2006-15*, Université de Montréal, Département de sciences économiques
- [9] Boulding K. [1964]. "The Meaning of the Twentieth Century". London: George Allen and Unwin Ltd.
- [10] Chakraborty S. [2004] "Endogenous Lifetime and Economic Growth", *Journal of Economic Theory*, vol. 116(1), p 119-137
- [11] Challier M.C. & Michel P. [1996] *Analyse Dynamique des Populations. Les Approches Démographiques et Economiques*, Economica, Paris
- [12] Cigno A. & Pettini A. [2002] "Taxing family size and subsidizing child-specific commodities?", *Journal of Public Economics*, vol. 84(1), p 75-90
- [13] Conde-Ruiz J.I., Giménez E.L. & Pérez-Nievas M. [2004] "Millian Efficiency with Endogenous Fertility", *Working Papers 2004-13*, FEDEA
- [14] Dasgupta [1993] "An Inquiry Into Well-Being and Redistribution", Oxford University Press, New-York
- [15] De La Croix D. & Doepke M. [2003] "Inequality and Growth: Why Differential Fertility Matters?" *The American Economic Review*, American Economic Association, vol. 93(4), p 1091-1113
- [16] De La Croix D. & Gosseries A. [2007] "Procreation, Migration, and Tradable Quotas, in Population Aging, Intergenerational Transfers and the Macroeconomy", in R. Clark, A.Mason and N. Ogawa eds, Edward Elgar Publishing, p 227-249
- [17] Eckstein Z. & Wolpin K.I. [1985] "Endogenous fertility and optimal population size", *Journal of Public Economics*, vol. 27(1), p 93-106
- [18] Fan C.S. & Stark O. [2008] "Looking At The Population Problem Through The Prism Of Heterogeneity: Welfare And Policy Analyses", *International Economic Review*, vol 49(3), p 799-835

- [19] Fan S. & Zhang X. [2000] "Public Investment And Regional Inequality In Rural China", *EPTD Discussion Paper n°71*
- [20] Galor O. & Weil D.N. [1996] "The Gender Gap, Fertility, and Growth", *American Economic Review*, vol 86(3), p374-387
- [21] Galor O. and Weil D.N [1999]. "From Malthusian stagnation to modern growth", *American Economic Review*, vol. 89, p150-154.
- [22] Galor O. [2005] "From Stagnation to Growth: Unified Growth Theory", in: Philippe Aghion & Steven Durlauf (ed.), *Handbook of Economic Growth*, edition1, vol 1, chapter 4, p171-293 Elsevier
- [23] Golosov M., Jones L.E. & Tertilt M [2007] "Efficiency with Endogenous Population Growth," *Econometrica*, Econometric Society, vol. 75(4), p1039-1071
- [24] Groezen B.V., Leers T. and Meijdam L. [2003] "Social security and endogenous fertility: pensions and child allowances as siamese twins", *Journal of Public Economics*, vol. 87(2), p 233-251
- [25] Jones L. E. & Schoonbroodt A. [2007] Complements versus Substitutes and Trends in Fertility Choice in Dynastic Models, *NBER Working Paper 13680*, National Bureau of Economic Research
- [26] Jones L. E. & Schoonbroodt A. [2009] Complements versus Substitutes and Trends in Fertility Choice in Dynastic Models: Additional Appendix, Working paper, University of Southampton, available at <http://www.economics.soton.ac.uk/staff/alicesch/research.html>
- [27] Kalemli-Ozcan S. [2003] "A stochastic Model of Mortality, Fertility and Human Capital Investment", *Journal of Development Economics*, vol. 70(1), p 103-118
- [28] Kanbur R. & Zhang X. [2005], "Spatial Inequality in Education and Health Care in China", *China Economic Review*, vol. 16(2), p 189-204

- [29] Loupias C. & Wigniolle B. [2004] "Régime de retraite et chute de natalité : évolution des moeurs ou arbitrage micro-économique?", *Annales d'Economie et de Statistiques*, vol. 73, p 63-99
- [30] Lucas R.J. [1988] "On the mechanics of economic development", *Journal of Monetary Economics*, vol. 22(1), p 3-42
- [31] Michel P. & Wigniolle B. [2007] "On Efficient Child Making", *Economic Theory*, Springer, vol. 31(2), p 307-326
- [32] Nerlove M., Razin A. & Sadka E. [1986] "Some Welfare Theoretic Implications of Endogenous Fertility", *International Economic Review*, vol 27(1), p3-31
- [33] Nerlove M. & Raut L.K. [1993] "Growth models with endogenous population: A general framework", *Handbook of Population and Family Economics*, in: M. R. Rosenzweig & Stark, O. (ed.), edition 1, volume 1, chapter 20, p 1117-1174
- [34] Razin A. & Ben-Zion U. [1975] "An Intergenerational Model of Population Growth", *American Economic Review*, vol. 65(5), p 923-33
- [35] Sah R.K. [1991] "The Effect of Child Mortality Changes on Fertility Choice and Parental Welfare", *The Journal of Political Economy*, vol. 99(3), p 582-606
- [36] Spiegel [1993] "Rawlsian optimal population size", *Journal of Population Economics*, vol.3, p 363-373.
- [37] Willis R.J. [1973] "A New Approach To The Economic Theory Of Fertility Behavior", *The Journal of Political Economy*, vol. 81(2), S14-S64
- [38] World Bank [2007] "Population Issues in the 21st century: the role of the World Bank" *Health, Nutrition and Population Discussion Paper*
- [39] Zhang J [2003] "Optimal debt, endogenous fertility, and human capital externalities in a model with altruistic bequests", *Journal of Public Economics*, vol. 87(7-8), p 1825-1835

- [40] Zhang J. & Zhang J. [2007] "Optimal social security in a dynastic model with investment externalities and endogenous fertility", *Journal of Economic Dynamics and Control*, vol. 31(11), p 3545-3567

Appendix A

Analyzing sub-systems $\{(14), (15)\}_{t=0}^{t=+\infty}$ to $\{(18), (19)\}_{t=0}^{t=+\infty}$, it appears that the set $\{\lambda_t, \Lambda_t\}_{t=0}^{t=+\infty}$ has to ensure that, at each date t , the first order conditions with respect to L_{t+1} and h_{t+1} at the competitive equilibrium is identical to the first order condition with respect to L_{t+1} and h_{t+1} at the optimum. Doing so, I obtain the following system of equations, given the initial conditions $(L_0, h_0) > (0, 0)$ and that $\forall t, X_t^* = \widehat{X}_t$ and $h_t^* = \widehat{h}_t$:

$t = 0$

$$\frac{\widehat{X}_0}{\widehat{X}_1} \frac{u'_{X_0} - A\widehat{h}_0 \left(\frac{\sigma + \Lambda_0}{\xi} + \phi + (1 - \lambda_0)\theta\Omega'_{X_0} e[\widehat{h}_1, \cdot, \cdot] \right) u'_{C_0}}{A\widehat{h}_1 \left(\frac{\sigma + \Lambda_1}{\xi} + \phi + (1 - \lambda_1)\theta\Omega'_{X_1} e[\widehat{h}_2, \cdot, \cdot] \right) u'_{C_1} - u'_{X_1}} = \frac{u'_{X_0} - A\widehat{h}_0 \left(\frac{\sigma}{\xi} + \phi + \theta\Omega'_{X_0} e[\widehat{h}_1, \cdot, \cdot] \right) u'_{C_0}}{\varepsilon_L^f u(\cdot, \widehat{X}_1) + F(\widehat{X}_0) \frac{\widehat{X}_1}{\widehat{X}_0} \left[A\widehat{h}_1 \left(\frac{\sigma}{\xi} + \phi + \theta\Omega'_{X_1} e[\widehat{h}_2, \cdot, \cdot] \right) u'_{C_1} - u'_{X_1} \right]} \quad (38)$$

$$\frac{F(\widehat{X}_0) \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) \widehat{X}_1 - \theta\Omega(\widehat{X}_1) \left(e[\widehat{h}_2, \cdot, \cdot] + \widehat{h}_1 \left(e'_2[\widehat{h}_2, \cdot, \cdot] + e'_3[\widehat{h}_2, \cdot, \cdot] \right) \right) \right]}{1 - \left(\frac{\sigma + \Lambda_1}{\xi} + \phi \right) X_1 - (1 - \lambda_1)\theta\Omega(X_1) \left(e[h_2, \cdot, \cdot] + h_1 e'_2[h_2, \cdot, \cdot] \right)} = \frac{1}{1 - \lambda_0} \quad (39)$$

$t = 1$

$$\frac{\widehat{X}_1}{\widehat{X}_2} \frac{u'_{X_1} - A\widehat{h}_1 \left(\frac{\sigma + \Lambda_1}{\xi} + \phi + (1 - \lambda_1)\theta\Omega'_{X_1} e[\widehat{h}_2, \cdot, \cdot] \right) u'_{C_1}}{A\widehat{h}_2 \left(\frac{\sigma + \Lambda_2}{\xi} + \phi + (1 - \lambda_2)\theta\Omega'_{X_2} e[\widehat{h}_3, \cdot, \cdot] \right) u'_{C_2} - u'_{X_2}} = \frac{u'_{X_1} - A\widehat{h}_1 \left(\frac{\sigma}{\xi} + \phi + \theta\Omega'_{X_1} e[\widehat{h}_2, \cdot, \cdot] \right) u'_{C_1}}{\varepsilon_L^f u(\cdot, \widehat{X}_2) + F(\widehat{X}_1) \frac{\widehat{X}_2}{\widehat{X}_1} \left[A\widehat{h}_2 \left(\frac{\sigma}{\xi} + \phi + \theta\Omega'_{X_2} e[\widehat{h}_3, \cdot, \cdot] \right) u'_{C_2} - u'_{X_2} \right]} \quad (40)$$

$$\frac{F(\widehat{X}_1) \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) \widehat{X}_2 - \theta\Omega(\widehat{X}_2) \left(e[\widehat{h}_3, \cdot, \cdot] + \widehat{h}_2 \left(e'_2[\widehat{h}_3, \cdot, \cdot] + e'_3[\widehat{h}_3, \cdot, \cdot] \right) \right) \right]}{1 - \left(\frac{\sigma + \Lambda_2}{\xi} + \phi \right) X_2 - (1 - \lambda_2)\theta\Omega(X_2) \left(e[h_3, \cdot, \cdot] + h_2 e'_2[h_3, \cdot, \cdot] \right)} = \frac{1}{1 - \lambda_1} \quad (41)$$

...

...

$t = s$

$$\frac{\widehat{X}_s}{\widehat{X}_{s+1}} \frac{u'_{X_s} - A\widehat{h}_s \left(\frac{\sigma + \Lambda_s}{\xi} + \phi + (1 - \lambda_s)\theta\Omega'_{X_s} e[\widehat{h}_{s+1}, \cdot, \cdot] \right) u'_{C_s}}{A\widehat{h}_{s+1} \left(\frac{\sigma + \Lambda_{s+1}}{\xi} + \phi + (1 - \lambda_{s+1})\theta\Omega'_{X_{s+1}} e[\widehat{h}_{s+2}, \cdot, \cdot] \right) u'_{C_{s+1}} - u'_{X_{s+1}}} = \frac{u'_{X_s} - A\widehat{h}_s \left(\frac{\sigma}{\xi} + \phi + \theta\Omega'_{X_s} e[\widehat{h}_{s+1}, \cdot, \cdot] \right) u'_{C_s}}{\varepsilon_L^f u(\cdot, \widehat{X}_{s+1}) + F(\widehat{X}_s) \frac{\widehat{X}_{s+1}}{\widehat{X}_s} \left[A\widehat{h}_{s+1} \left(\frac{\sigma}{\xi} + \phi + \theta\Omega'_{X_{s+1}} e[\widehat{h}_{s+2}, \cdot, \cdot] \right) u'_{C_{s+1}} - u'_{X_{s+1}} \right]}$$

$$\frac{F(\widehat{X}_s) \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) \widehat{X}_{s+1} - \theta \Omega(\widehat{X}_{s+1}) \left(e[\widehat{h}_{s+2}, \cdot, \cdot] + \widehat{h}_{s+1} \left(e'_2[\widehat{h}_{s+2}, \cdot, \cdot] + e'_3[\widehat{h}_{s+2}, \cdot, \cdot] \right) \right) \right]}{1 - \left(\frac{\sigma + \Lambda_{s+1}}{\xi} + \phi \right) X_{s+1} - (1 - \lambda_{s+1}) \theta \Omega(X_{s+1}) \left(e[h_{s+2}, \cdot, \cdot] + h_{s+1} e'_2[h_{s+2}, \cdot, \cdot] \right)} = \frac{1}{1 - \lambda_s} \quad (42)$$

$t = s + 1$

$$\begin{aligned} & \frac{\widehat{X}_{s+1} u'_{X_{s+1}} - A \widehat{h}_{s+1} \left(\frac{\sigma + \Lambda_{s+1}}{\xi} + \phi + (1 - \lambda_{s+1}) \theta \Omega'_{X_{s+1}} e[\widehat{h}_{s+2}, \cdot, \cdot] \right) u'_{C_{s+1}}}{\widehat{X}_{s+2} A \widehat{h}_{s+2} \left(\frac{\sigma + \Lambda_{s+2}}{\xi} + \phi + (1 - \lambda_{s+2}) \theta \Omega'_{X_{s+2}} e[\widehat{h}_{s+3}, \cdot, \cdot] \right) u'_{C_{s+2}} - u'_{X_{s+2}}} = \\ & \frac{\left(u'_{X_{s+1}} - A \widehat{h}_{s+1} \left(\frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_{s+1}} e[\widehat{h}_{s+2}, \cdot, \cdot] \right) u'_{C_{s+1}} \right)}{\varepsilon_L^f u(\cdot, \widehat{X}_{s+2}) + F(\widehat{X}_{s+1}) \frac{\widehat{X}_{s+2}}{\widehat{X}_{s+1}} \left[A \widehat{h}_{s+2} \left(\frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_{s+2}} e[\widehat{h}_{s+3}, \cdot, \cdot] \right) u'_{C_{s+2}} - u'_{X_{s+2}} \right]} \\ & \frac{F(\widehat{X}_{s+1}) \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) \widehat{X}_{s+2} - \theta \Omega(\widehat{X}_{s+2}) \left(e[\widehat{h}_{s+3}, \cdot, \cdot] + \widehat{h}_{s+2} \left(e'_2[\widehat{h}_{s+3}, \cdot, \cdot] + e'_3[\widehat{h}_{s+3}, \cdot, \cdot] \right) \right) \right]}{1 - \left(\frac{\sigma + \Lambda_{s+2}}{\xi} + \phi \right) X_{s+2} - (1 - \lambda_{s+2}) \theta \Omega(X_{s+2}) \left(e[h_{s+3}, \cdot, \cdot] + h_{s+2} e'_2[h_{s+3}, \cdot, \cdot] \right)} = \frac{1}{1 - \lambda_{s+1}} \quad (43) \end{aligned}$$

...

Equations (38) and (39) characterize a system of 2 equations with 2 unknowns which are $\{\lambda_0, \Lambda_0\}$ given the parental perfect foresight on $\{\lambda_1, \Lambda_1\}$. This system is linear with regards to its unknowns and so, it is straightforward that there exists a unique solution to this system of equations. I can display $\{\lambda_0, \Lambda_0\}$ as a linear function of λ_1 and Λ_1 . It is intuitive that the assumption of perfect foresights does not alter my result because, for any parental expectation on $\{\lambda_1, \Lambda_1\}$, there exist a solution to the sub-system of equations. This reasoning can be applied at each date t .

So, I can determine $\widehat{\lambda}_t$ and $\widehat{\Lambda}_t$ as the values of λ_t and Λ_t making identical equation (18) to equation (14) and equation (19) to (15) for each date t . I obtain the following result:

$$\begin{aligned} \widehat{\lambda}_t &= -a_t \widehat{\lambda}_{t+1} + b_t \widehat{\Lambda}_{t+1} + d_t [F(X_t) - 1] - g_t \\ \widehat{\Lambda}_t &= -i_t \widehat{\lambda}_{t+1} + j_t \widehat{\Lambda}_{t+1} - k_t [F(X_t) - 1] - m_t \end{aligned}$$

with

$$\begin{aligned} a_t &\equiv \frac{\left(1 + \varepsilon_2^{e(h_{t+2}, \cdot, \cdot)} \right) \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot)}{F(X_t) \left[\frac{C_{t+1}}{A h_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\varepsilon_2^{e(h_{t+2}, \cdot, \cdot)} + \varepsilon_3^{e(h_{t+2}, \cdot, \cdot)} \right) \right]} \\ b_t &\equiv \frac{X_{t+1}}{F(X_t) \left[\frac{C_{t+1}}{A h_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\varepsilon_2^{e(h_{t+2}, \cdot, \cdot)} + \varepsilon_3^{e(h_{t+2}, \cdot, \cdot)} \right) \right]} \end{aligned}$$

$$\begin{aligned}
d_t &\equiv \frac{\frac{C_{t+1}}{Ah_{t+1}}}{F(X_t) \left[\frac{C_{t+1}}{Ah_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right) \right]} \\
g_t &\equiv \frac{\theta \Omega(X_t) e(h_{t+2}, \cdot, \cdot) \left[\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right]}{\frac{C_{t+1}}{Ah_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right)} \\
i_t &\equiv \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left[\frac{\left(1 + \varepsilon_2^{e^{(h_{t+2}, \cdot, \cdot)}} \right) \theta e(h_{t+1}, \cdot, \cdot) \Omega'_{X_t}}{F(X_t) \left[\frac{C_{t+1}}{Ah_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right) \right]} + \beta \frac{\varepsilon_{X_{t+1}}^{\Omega} u'_{C_{t+1}} h_{t+1}}{u'_{C_t} h_t X_t} \right] \\
j_t &\equiv \frac{\theta e(h_{t+1}, \cdot, \cdot) \Omega'_{X_t} X_{t+1}}{F(X_t) \left[\frac{C_{t+1}}{Ah_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right) \right]} + \beta \frac{u'_{C_{t+1}} h_{t+1} X_{t+1}}{u'_{C_t} h_t X_t} \\
k_t &\equiv \frac{X_{t+1} \theta \Omega(X_t) e(h_{t+1}, \cdot, \cdot) \left[\varepsilon_{X_t}^{\Omega} \frac{C_{t+1}}{Ah_{t+1}} + \varepsilon_1^{e^{(h_{t+1}, \cdot, \cdot)}} \left(\frac{\sigma}{\xi} + \phi + \Omega'_{X_{t+1}} \theta e(h_{t+2}, \cdot, \cdot) - \frac{u'_{X_{t+1}}}{Ah_{t+1}} \right) \right]}{X_t F(X_t) \left[\frac{C_{t+1}}{Ah_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right) \right]} \\
m_t &\equiv \frac{\theta \Omega(X_t) e(h_{t+2}, \cdot, \cdot) \left[\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right] e(h_{t+1}, \cdot, \cdot) \Omega'_{X_t}}{\frac{C_{t+1}}{Ah_{t+1}} - \theta \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) \left(\frac{e^{(h_{t+2}, \cdot, \cdot)}}{\varepsilon_2} + \varepsilon_3^{e^{(h_{t+2}, \cdot, \cdot)}} \right)} + \beta \frac{\varepsilon_L^f u(\cdot, X_{t+1}) X_{t+1}}{A u'_{C_t} X_t h_t}
\end{aligned}$$

Appendix B

To clarify the exposure of results in section 3.2 and 3.3, I have limited the analysis to the cases where both $u(C_t, X_t)$ and f'_{L_t} are positive. However, as shown by Jones & Schoonbroodt [2007] for the model of Barro & Becker [1988], the case where both $u(C_t, X_t)$ and f'_{L_t} are negative also makes sense and has to be fully studied. Notice that $f''_{L_t L_t} > 0$ ensures the concavity of the problem.

In this case, the condition $\lim_{T \rightarrow +\infty} \beta^T f(L_T) = 0$ and the properties of $f(L_t)$ imply that fertility is bounded below by $X_{MIN} = f^{-1}\left(\frac{1}{\beta}\right)$. When $f(L_t) = L_t^{1-\kappa}$ with $\kappa > 1$, $X_{MIN} = \beta^{\frac{1}{\kappa-1}}$.

It is important to notice that this alternative assumptions don't change my main results. It is straightforward that all mathematical results in sub-sections 3.2 and 3.3 are still valid. So, I obtain the following stationary values for the optimal set of instruments:

$$\hat{\lambda} = \frac{-F(X) \varepsilon_3^e - \frac{\beta \varepsilon_L^f X}{Ah \Omega(X) \theta e(1-\beta F(X))} \frac{u}{u'_C} - [1-F(X)] \left[\frac{C}{Ah \Omega(X) \theta e} - \varepsilon_2^e \right]}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \equiv \frac{-F(X) \varepsilon_3^e + LHS_\lambda + RHS_\lambda}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \quad (44)$$

$$\hat{\frac{\lambda}{\xi}} = \frac{\Omega'_X \theta e F(X) \varepsilon_3^e - \frac{(1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e) \beta \varepsilon_L^f u}{[1-\beta F(X)] Ah u'_C} - \Omega'_X \theta e (1-F(X)) \left[\frac{C}{Ah} - \Omega(X) \theta h e'_2 \right]}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \equiv \frac{\Omega'_X \theta e F(X) \varepsilon_3^e + LHS_\lambda + RHS_\lambda}{1 + \frac{\varepsilon_1^e}{\beta} + \varepsilon_2^e - \varepsilon_X^\Omega} \quad (45)$$

Nevertheless, the sign of both RHS_Λ and RHS_λ are now changed: (i) when $X \in]\beta^{\frac{1}{\kappa-1}}, 1[$, $(RHS_\Lambda, RHS_\lambda) > (0, 0)$ while (ii) when $X > 1$, $(RHS_\Lambda, RHS_\lambda) < (0, 0)$. This can be easily understood remembering the comparison between private and social preferences for present. Indeed, equation (7) indicates that in $t = 0$, the per se private welfare gain of increasing by one unit the consumption of each generation is $u'_{C_0} + \beta u'_{C_1} + \beta^2 u'_{C_2} + \dots + \beta^t u'_{C_t} + \dots$ while the per se social welfare gain of this improvement equals $u'_{C_0} + \beta \frac{f(L_1)}{f(L_0)} u'_{C_1} + \beta^2 \frac{f(L_2)}{f(L_0)} u'_{C_{t+2}} + \dots + \beta^t \frac{f(L_t)}{f(L_0)} u'_{C_t} + \dots = u'_{C_0} + \beta F(X_1) u'_{C_1} + \beta^2 F(X_1 X_2) u'_{C_2} + \dots + \beta^t F\left(\prod_{s=0}^{s=t} X_s\right) u'_{C_t} + \dots$

It follows from the new definition of $F(\cdot)$ that if population is growing ($X_s > 1$) the social discount rate evaluated by $\beta^t F\left(\prod_{s=0}^{s=t} X_s\right)$ is smaller than the private one (β^t). So, if population is increasing, the Social Planner wants to transfer utility from future to present generations. This is done by decreasing the subsidy on education ($RHS_\lambda < 0$) and because the parental budget constraint is not linear, it has a negative impact on $\frac{\hat{\Lambda}}{\hat{\xi}}$. However, if population is decreasing, the Social Discount Rate is higher than the private one ($\beta^t F\left(\prod_{s=0}^{s=t} X_s\right) > \beta^t$) and so, the Social Planner wants to transfer utility from present to future generations.

Notice that this effect is a partial one and that all other mechanisms in the model remain unchanged when both $u(C_t, X_t)$ and f'_{L_t} are negative. Noticeably, LHS_Λ and LHS_λ both remain negative as $\varepsilon_L^f u(C, X) > 0$.

Appendix C

For a constant level of consumption in the long-run, the problem is bounded when $\lim_{T \rightarrow +\infty} \beta^T L_T^{1-\varepsilon} = 0$. If $\varepsilon < 1$, the assumption $\beta < (\frac{\sigma}{\xi} + \phi)^{1-\varepsilon}$ ensures that the previous condition is satisfied. However, this is no more the case when $\varepsilon > 1$. In this case, the problem is bounded only if $X > \beta^{\frac{1}{\varepsilon-1}} \equiv X_{MIN}$. The set of feasible equilibria is smaller.

Using the same method as in the Benchmark model, the economic policy that decentralizes the first-best path is the set $\{\lambda_t, \Lambda_t\}_{t=0}^{t=+\infty}$ solving the following system of equations at

each date t :

$$\begin{aligned}
& \frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_t} e(h_{t+1}, \cdot, \cdot) + \beta \frac{(1-\varepsilon)X_t^{-\varepsilon} U(C_{t+1}) + X_t^{-\varepsilon} A h_{t+1} U'_{C_{t+1}} \left[\frac{\sigma}{\xi} + \phi + \theta \Omega'_{X_{t+1}} e(h_{t+2}, \cdot, \cdot) \right] X_{t+1}}{A h_t U'_{C_t}} = \\
& \frac{\sigma + \Lambda_t}{\xi} + \phi + (1-\lambda_t) \theta \Omega'_{X_t} e(h_{t+1}, \cdot, \cdot) + \beta \frac{(1-\varepsilon)X_t^{-\varepsilon} U(C_{t+1}) + X_t^{-\varepsilon} A h_{t+1} U'_{C_{t+1}} \left[\frac{\sigma + \Lambda_{t+1}}{\xi} + \phi + (1-\lambda_{t+1}) \theta \Omega'_{X_{t+1}} e(h_{t+2}, \cdot, \cdot) \right] X_{t+1}}{A h_t U'_{C_t}} \\
& - \theta \Omega(X_t) e'_1(h_{t+1}, \cdot, \cdot) + \frac{\beta X_t^{1-\varepsilon} U'_{C_{t+1}} \left[1 - \left(\frac{\sigma}{\xi} + \phi \right) X_{t+1} - \theta \Omega(X_{t+1}) \left(e(h_{t+2}, \cdot, \cdot) + h_{t+1} e'_2(h_{t+2}, \cdot, \cdot) + h_{t+1} e'_3(h_{t+2}, \cdot, \cdot) \right) \right]}{h_t U'_{C_t}} = \\
& - (1-\lambda_t) \theta \Omega(X_t) e'_1(h_{t+1}, \cdot, \cdot) + \frac{\beta X_t^{1-\varepsilon} U'_{C_{t+1}} \left[1 - \left(\frac{\sigma + \Lambda_{t+1}}{\xi} + \phi \right) X_{t+1} - (1-\lambda_{t+1}) \theta \Omega(X_{t+1}) \left(e(h_{t+2}, \cdot, \cdot) + h_{t+1} e'_2(h_{t+2}, \cdot, \cdot) \right) \right]}{h_t U'_{C_t}} \\
\end{aligned} \tag{46}$$

Given the parental (perfect) expectations on $\{\lambda_{t+1}, \Lambda_{t+1}\}_{t=0}^{t=+\infty}$, there exists a unique vector $\{\lambda_t, \Lambda_t\}_{t=0}^{t=+\infty}$ that is able to decentralize the first-best path. Given that \widehat{T}_t is directly deduced from the government budget constraint, the optimal economic policy is fully described as follows:

$$\begin{aligned}
\widehat{\lambda}_t &= -\widetilde{a}_t \widehat{\lambda}_{t+1} + \widetilde{b}_t \frac{\widehat{\Lambda}_{t+1}}{\xi} - \widetilde{d}_t \varepsilon_3^{e(h_{t+2}, \cdot, \cdot)} \\
\frac{\widehat{\Lambda}_t}{\xi} &= \widetilde{i}_t \widehat{\lambda}_{t+1} + \widetilde{j}_t \frac{\widehat{\Lambda}_{t+1}}{\xi} - \widetilde{k}_t \varepsilon_3^{e(h_{t+2}, \cdot, \cdot)}
\end{aligned}$$

with:

$$\begin{aligned}
\widetilde{a}_t &\equiv \frac{\beta X_t^{1-\varepsilon} h_{t+1} U'_{C_{t+1}} \left(1 + \varepsilon_2^{e(h_{t+2}, \cdot, \cdot)} \right) \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot)}{h_t U'_{C_t} \varepsilon_1^{e(h_{t+1}, \cdot, \cdot)} \Omega(X_t) e(h_{t+1}, \cdot, \cdot)} \\
\widetilde{b}_t &\equiv \frac{\beta X_t^{1-\varepsilon} h_{t+1} U'_{C_{t+1}} X_{t+1}}{\theta h_t U'_{C_t} \varepsilon_1^{e(h_{t+1}, \cdot, \cdot)} \Omega(X_t) e(h_{t+1}, \cdot, \cdot)} \\
\widetilde{d}_t &\equiv \frac{\beta X_t^{1-\varepsilon} h_{t+1} U'_{C_{t+1}} e(h_{t+2}, \cdot, \cdot)}{\theta h_t U'_{C_t} \varepsilon_1^{e(h_{t+1}, \cdot, \cdot)} \Omega(X_t) e(h_{t+1}, \cdot, \cdot)} \\
\widetilde{i}_t &\equiv \frac{\beta X_t^{-\varepsilon} \Omega(X_{t+1}) e(h_{t+2}, \cdot, \cdot) h_{t+1} U'_{C_{t+1}}}{h_t U'_{C_t}} \left[\theta \varepsilon_{X_{t+1}}^\Omega - \frac{\varepsilon_{X_t}^\Omega \left(1 + \varepsilon_2^{e(h_{t+2}, \cdot, \cdot)} \right)}{\varepsilon_1^{e(h_{t+1}, \cdot, \cdot)}} \right] \\
\widetilde{j}_t &\equiv \frac{\beta X_t^{-\varepsilon} X_{t+1} h_{t+1} U'_{C_{t+1}}}{h_t U'_{C_t}} \left[\frac{\varepsilon_{X_t}^\Omega}{\varepsilon_1^{e(h_{t+1}, \cdot, \cdot)}} - 1 \right] \\
\widetilde{k}_t &\equiv \frac{\varepsilon_{X_t}^\Omega X_t^{-\varepsilon} e(h_{t+2}, \cdot, \cdot) h_{t+1} U'_{C_{t+1}}}{\theta \varepsilon_1^{e(h_{t+1}, \cdot, \cdot)} h_t U'_{C_t}}
\end{aligned}$$

The optimal values of the instruments at the steady state are:

$$\widehat{\lambda}_\infty = \frac{-\varepsilon_3^e}{\theta\Omega(X)\left[\frac{\varepsilon_1^e}{\beta X^{1-\varepsilon}} + 1 + \varepsilon_2^e - \varepsilon_X^\Omega\right]} \quad (48)$$

$$\frac{\widehat{\Lambda}}{\widehat{\xi}} = \frac{-e\varepsilon_X^\Omega \varepsilon_3^e}{X\left[\frac{\varepsilon_1^e}{\beta X^{1-\varepsilon}} + 1 + \varepsilon_2^e - \varepsilon_X^\Omega\right]} \quad (49)$$

Proposition 3 $(\widehat{\lambda}_\infty, \widehat{\Lambda}_\infty) > (0, 0) \forall \varepsilon > 0$

Proof. Because $\varepsilon_X^\Omega < 1$ by definition, a sufficient condition to obtain $(\widehat{\lambda}_\infty, \widehat{\Lambda}_\infty) > (0, 0)$ is $P(X) \equiv \frac{\varepsilon_1^e}{\beta X^{1-\varepsilon}} + \varepsilon_2^e > 0$. $P'(X) = \frac{\varepsilon_1^e}{\beta}(\varepsilon - 1)X^{\varepsilon-2}$. Two cases have to be studied: (i) $\varepsilon \in]0, 1[$ and (ii) $\varepsilon > 1$.

Case 1: $\varepsilon \in]0, 1[$

In this case $P'(X) < 0$. So, $P(X)$ reaches its minimum when $X = \frac{1}{\frac{\sigma}{\xi} + \phi} \equiv X_{MAX}$. I get that $\min P(X) = \frac{\varepsilon_1^e}{\beta}(\frac{\sigma}{\xi} + \phi)^{1-\varepsilon} + \varepsilon_2^e > 0$ as $\beta < (\frac{\sigma}{\xi} + \phi)^{1-\varepsilon}$ when $\varepsilon \in]0, 1[$ (see also footnote (37)).

Therefore, $P(X) > 0 \forall X \in]0, X_{MAX}[$. It implies that $(\widehat{\lambda}_\infty, \widehat{\Lambda}_\infty) > (0, 0) \forall \varepsilon \in]0, 1[$.

Case 2: $\varepsilon > 1$

Remember that in this case, $X_{MIN} = \beta^{\frac{1}{\varepsilon-1}}$. In this case $P'(X) > 0$. So, $P(X)$ reaches its minimum when $X = X_{MIN}$. I get that $\min P(X) = \varepsilon_1^e + \varepsilon_2^e > 0$ (see footnote (37)).

Therefore, $P(X) > 0 \forall X \in]X_{MIN}, X_{MAX}[$. It implies that $(\widehat{\lambda}_\infty, \widehat{\Lambda}_\infty) > (0, 0) \forall \varepsilon > 1$.

■

Appendix D

The competitive equilibrium is described by the set $\{C^*, X^*, e^*, h^*, H^*, Y^*, w^*\}$ satisfying equations (1), (2), (3), (4), (5) and the following First Order Conditions:

$$\frac{U'_X}{U'_C} = \left(\frac{\sigma + \Lambda}{\xi} + \phi + \Omega'(X^*)\theta(1 - \lambda)e(h^*, h^*, h^*) \right) Ah^* \quad (50)$$

$$\frac{U'_h}{U'_C} = \theta Ah^* \Omega(X^*)(1 - \lambda)e'_1(h^*, h^*, h^*) \quad (51)$$

The optimal steady state is described by the set $\{\widehat{C}, \widehat{X}, \widehat{h}\}$ satisfying equation (13) and the following First Order Conditions:

$$\frac{U'_X}{U'_C} = \left(\frac{\sigma}{\xi} + \phi + \theta \Omega'(\widehat{X}) e(\widehat{h}, \widehat{h}, \widehat{h}) \right) A \widehat{h} U'_C \quad (52)$$

$$\frac{U'_{h_{t+1}}}{U'_C} = A \left(\widehat{X} \left[\frac{\sigma}{\xi} + \phi \right] + \theta \Omega(\widehat{X}) \left[e(\widehat{h}, \widehat{h}, \widehat{h}) + \widehat{h}(\widehat{e}_1 + \widehat{e}_2 + \widehat{e}_3) \right] - 1 \right) \quad (53)$$

Then, the optimal economic policy makes identical systems $\{(50), (51)\}$ and $\{(52), (53)\}$. The solution of this system of equations is displayed in (28).

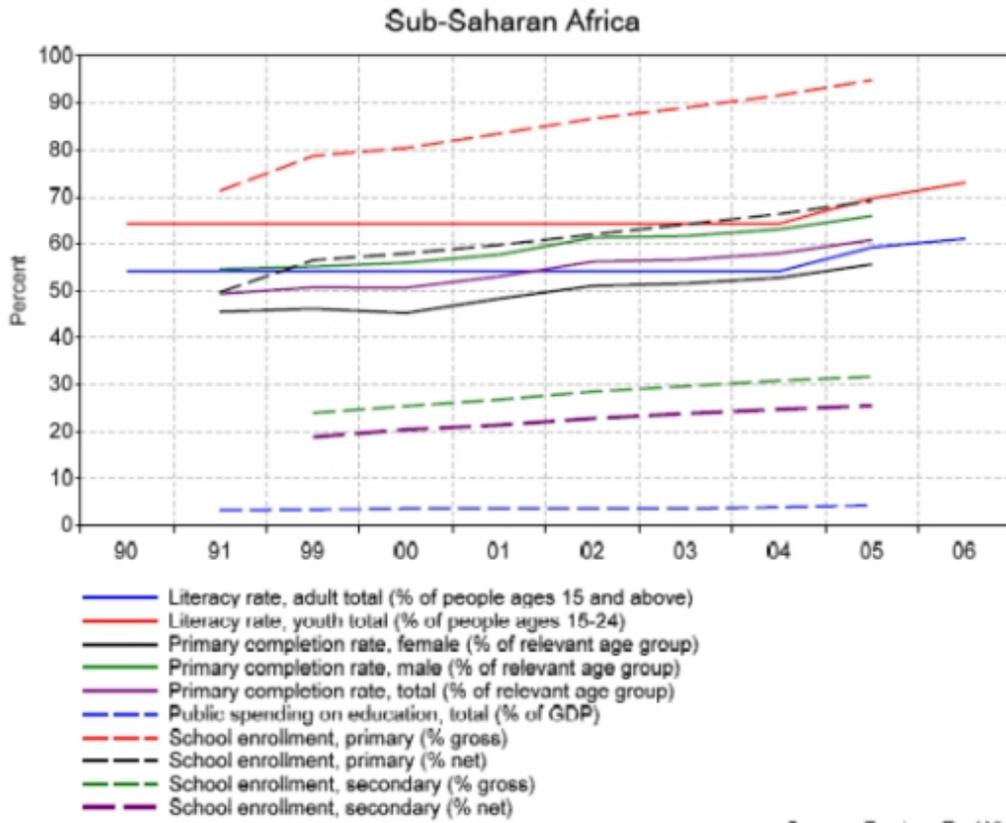
Appendix E

Given that, at the equilibrium $h_t = \bar{h}_t \forall t$, the social optimum is the same as in the Benchmark model. However, the competitive equilibrium is now described by the set $\{C_t^*, X_t^*, e_t^*, h_t^*, h_{t+1}^*, H_t^*, Y_t^*, w_t^*\}_{t=0}^{t=+\infty}$ satisfying equations $\{(1), (3), (5), (29), (30)\}_{t=0}^{t=+\infty}$ and the two following first order conditions with respect to L_{t+1} and h_{t+1} for each date t :

$$\begin{aligned} -\beta \frac{X_{t+1}}{X_t} &= \frac{u'_{X_t} - A h_t \left(\frac{\sigma + \Lambda_t}{\xi} + \phi + (1 - \lambda_t) \theta \Omega'_{X_t} e[h_{t+1}, \cdot, \cdot] \right) u'_{C_t}}{A h_{t+1} \left(\frac{\sigma + \Lambda_{t+1}}{\xi} + \phi + (1 - \lambda_{t+1}) \theta \Omega'_{X_{t+1}} e[h_{t+2}, \cdot, \cdot] \right) u'_{C_{t+1}} - u'_{X_{t+1}}} \\ \frac{u'_{C_{t+1}}}{u'_{C_t}} &= \frac{(1 - \lambda_t) \theta h_t \Omega(X_t) e'_1[h_{t+1}, h_t, \bar{h}_t]}{\beta \left[1 - \left(\frac{\sigma + \Lambda_{t+1}}{\xi} + \phi \right) X_{t+1} - (1 - \lambda_{t+1}) \theta \Omega(X_{t+1}) \bar{h}_{t+1} e'_2[h_{t+2}, h_{t+1}, \bar{h}_{t+1}] \right]} \end{aligned}$$

Finally, changes appear only in the first order condition with respect to h_{t+1} . Using the same method as in the Benchmark model, it is straightforward that there exists a unique vector $\{\lambda_t, \Lambda_t\}_{t=0}^{t=+\infty}$ that is able to decentralize the first-best. After some straightforward calculus, I can display its stationary values:

$$\widehat{\kappa} = \frac{1 + \varepsilon_3^{\widehat{e}}}{\varepsilon_2^{\widehat{e}} - \frac{\varepsilon_1^{\widehat{e}}}{\beta} + \varepsilon_{\widehat{X}}^{\Omega}} \quad \frac{\widehat{\Lambda}}{\xi} = \Omega'_{\widehat{X}} \theta \widehat{e} \frac{1 + \varepsilon_3^{\widehat{e}}}{\varepsilon_2^{\widehat{e}} - \frac{\varepsilon_1^{\widehat{e}}}{\beta} + \varepsilon_{\widehat{X}}^{\Omega}}$$



Source: Reuters EcoWin

Environmental Economics & Management Memoranda

130. Marc FLEURBAEY, Thibault GAJDOS and Stéphane ZUBER. Social rationality, separability, and equity under uncertainty. (also CORE discussion paper 2010/37).
129. Stéphane ZUBER. Justifying social discounting: the rank-discounted utilitarian approach. (also CORE discussion paper 2010/36).
128. Antoine BOMMIER and Stéphane ZUBER. The Pareto principle of optimal inequality. (also CORE discussion paper 2009/9).
127. Thomas BAUDIN. A role for cultural transmission in fertility transitions. *Macroeconomic Dynamics*, 14, 2010, 454-481.
126. Thomas BAUDIN. The optimal trade-off between quality and quantity with uncertain child survival. October 2010.
125. Thomas BAUDIN. Family Policies: What does the standard endogenous fertility model tell us? September 2010.
124. Philippe VAN PARIJS. Un "Sustainable New Deal" pour la Belgique. Forum annuel du Conseil fédéral pour le développement durable, The Square, 16 novembre 2009.
123. Thierry BRECHET, François GERARD, Henry TULKENS. Efficiency vs. stability of climate coalitions: a conceptual and computational appraisal. *The Energy Journal* 32(1), 49-76, 2011.
122. Maria Eugenia SANIN, Skerdilajda ZANAJ. A note on clean technology adoption and its influence on tradable emission permits prices. *Environmental and Resource Economics*, in press, 2010.
121. Thierry BRECHET, Julien THENIE, Thibaut ZEIMES, Stéphane ZUBER. The benefits of cooperation under uncertainty: the case of climate change (also CORE discussion paper 2010/62).
120. Thierry BRECHET, Yuri YATSENKO, Natali HRITONENKO. Adaptation and mitigation in long-term climate policies (also CORE discussion paper).
119. Marc GERMAIN, Alphonse MAGNUS, Henry TULKENS. Dynamic core-theoretic cooperation in a two-dimensional international environmental model. *Mathematical Social Sciences*, 59(2), 208-226, 2010.
118. Thierry BRECHET, Pierre M. PICARD. The price of silence: markets for noise licenses and airports. *International Economic Review*, 51(4), 1097-1125, 2010.
117. Thierry BRECHET, Pierre-André JOUVET, Gilles ROTILLON. Tradable pollution permits in dynamic general equilibrium: can optimality and acceptability be reconciled? (also CORE discussion paper 2010/56).
116. Thierry BRECHET, Stéphane LAMBRECHT. Renewable resource and capital with a joy-of-giving resource bequest motive. *Resource and Energy Economics*, in press, 2010.
115. Thierry BRECHET, Alain AYONG LE KAMA. Public environmental policies: some insights from economic theory. *International Economics* 120(4), 5-10, 2009.
114. Thierry BRECHET, Johan EYCKMANS, François GERARD, Philippe MARBAIX, Henry TULKENS, Jean-Pascal van YPERSELE. The impact of the unilateral EU commitment on the stability of international climate agreements. *Climate Policy*, 10, 148-166, 2010.
113. Thierry BRECHET, Sylvette LY. Technological greening, eco-efficiency and no-regret strategy. March 2010.
112. Thierry BRECHET, Fabien PRIEUR. Can education be good for both growth and the environment? (also CORE discussion paper 2009/19).
111. Carlotta BALESTRA, Thierry BRECHET, Stéphane LAMBRECHT. Property rights and biological spillovers: when Hardin meets Meade. February 2010 (also CORE DP 2010/ ?).
110. Thierry BRECHET, Tsvetomir TSACHEV, Vladimir VELIOV. Markets for emission permits with free endowment : a vintage capital analysis. February 2010 (also CORE DP 2010/ ?).
109. Thierry BRECHET, Fabien PRIEUR. Public investment in environmental infrastructures, growth, and the environment. January 2010 (also CORE DP 2010/ ?).
108. Kirill BORISSOV, Thierry BRECHET, Stéphane LAMBRECHT. Median voter environmental maintenance. February 2010 (also CORE DP 2010/ ?).
107. Thierry BRECHET, Carmen CAMACHO, Vladimir VELIOV. Model predictive control, the economy, and the issue of global warming. January 2010 (also CORE DP 2010/ ?).

106. Thierry BRECHET, Tsvetomir TSACHEV and Vladimir M. VELIOV. Prices versus quantities in a vintage capital model. In : *Dynamic Systems, Economic Growth, and the Environment*, Jesus Crespo Cuaresma, Tapio Palokangas, Alexander Tarasyev (eds), *Dynamic Modeling and Econometrics in Economics and Finance* 12, 141-159, 2010.
105. Thierry BRECHET, Pierre-André JOUVET. Why environmental management may yield no-regret pollution abatement options. *Ecological Economics*, 68, 1770-1777, 2009.
104. Thierry BRECHET et Henry TULKENS. Mieux répartir les coûts de la politique climatique. *La vie des idées.fr*, 2009.
103. Thierry BRECHET. Croissance économique, environnement et bien-être. In : Alain Ayong Le Kama, Pour une croissance verte ... et sociale, *La lettre de l'AFSE*, 74:9-13, 2009.
102. Henry TULKENS. Stabilité de l'accord et règles d'allocation initiale des droits d'émission. Commentaire sur le Rapport de Jean Tirole "Politique climatique : une nouvelle architecture internationale", 9 octobre 2009.
101. Giorgia OGGIONI, Yves SMEERS. Evaluating the impact of average cost based contracts on the industrial sector in the European emission trading scheme. *CEJOR* 17:181-217, 2009.
100. Raouf BOUCEKKINE, Marc GERMAIN. The burden sharing of pollution abatement costs in multi-regional open economics. *The B.E. Journal of Macroeconomics*, 9 (1 Topics), 2009.
99. Rabah AMIR, Marc GERMAIN, Vincent VAN STEENBERGHE. On the impact of innovation on the marginal abatement cost curve. *Journal of Public Economic Theory*, 10(6):985-1010, 2008.
98. Maria Eugenia SANIN, Skerdilajda ZANAJ. Clean technology adoption and its influence on tradeable emission permit prices. April 2009 (also CORE DP 2009/29).
97. Jerzy A. FILAR, Jacek B. KRAWCZYK, Manju AGRAWAL. On production and abatement time scales in sustainable development. Can we loose the *sustainability screw* ? April 2009 (also CORE DP 2009/28).
96. Giorgia OGGIONI, Yves SMEERS. Evaluating the impact of average cost based contracts on the industrial sector in the European emission trading scheme. *CEJOR* (2009) 17: 181-217.
95. Marc GERMAIN, Henry TULKENS, Alphonse MAGNUS. Dynamic core-theoretic cooperation in a two-dimensional international environmental model, April 2009 (also CORE DP 2009/21).
94. Henry TULKENS, Vincent VAN STEENBERGHE. "Mitigation, Adaptation, Suffering" : In search of the right mix in the face of climate change, June 2009.
93. Luisito BERTINELLI, Eric STROBL. The environmental Kuznets curve semi-parametrically revisited. *Economics Letters*, 88 (2005) 350-357.
92. Maria Eugenia SANIN, Francesco VIOLANTE. Understanding volatility dynamics in the EU-ETS market: lessons from the future, March 2009 (also CORE DP 2009/24).
91. Thierry BRECHET, Henry TULKENS. Beyond BAT : Selecting optimal combinations of available techniques, with an example from the limestone industry. *Journal of Environmental Management*, 90:1790-1801, 2009.
90. Giorgia OGGIONI, Yves SMEERS. Equilibrium models for the carbon leakage problem. December 2008 (also CORE DP 2008/76).
89. Giorgia OGGIONI, Yves SMEERS. Average power contracts can mitigate carbon leakage. December 2008 (also CORE DP 2008/62).
88. Thierry BRECHET, Johan EYCKMANS, François GERARD, Philippe MARBAIX, Henry TULKENS, Jean-Pascal van YPERSELE. The impact of the unilateral EU commitment on the stability of international climate agreements. (also CORE DP 2008/61).
87. Raouf BOUCEKKINE, Jacek B. KRAWCZYK, Thomas VALLEE. Towards an understanding of tradeoffs between regional wealth, tightness of a common environmental constraint and the sharing rules. (also CORE DP 2008/55).
86. Thierry BRECHET, Tsvetomir TSACHEV, Vladimir VELIOV. Prices versus quantities in a vintage capital model. March 2009 (also CORE DP 2009/15).
85. David DE LA CROIX, Davide DOTTORI. Easter Island's collapse : a tale of a population race. *Journal of Economic Growth*, 13:27-55, 2008.
84. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intertemporal transfers of emission quotas in climate policies. *Economic Modelling*, 26(1):126-143, 2009.

83. Thierry BRECHET, Stéphane LAMBRECHT. Family altruism with renewable resource and population growth. *Mathematical Population Studies*, 16:60-78, 2009.
82. Thierry BRECHET, Alexis GERARD, Giordano MION. Une évaluation objective des nuisances subjectives de l'aéroport de Bruxelles-National. *Regards Economiques*, 66, Février 2009.
81. Thierry BRECHET, Johan EYCKMANS. Coalition theory and integrated assessment modeling : Lessons for climate governance. In E. Brousseau, P.A. Jouvét and T. Tom Dedeurwaerder (eds). *Governing Global Environmental Commons: Institutions, Markets, Social Preferences and Political Games*, Oxford University Press, 2009.
80. Parkash CHANDER and Henry TULKENS. Cooperation, stability, and self-enforcement in international environmental agreements : A conceptual discussion. In R. Guesnerie and H. Tulkens (eds). *The Design of Climate Policy*, CESifo Seminar Series, The MIT Press, 2008.
79. Mirabelle MUULS. The effect of investment on bargaining positions. Over-investment in the case of international agreements on climate change. September 2008
78. Pierre-André JOUVET, Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending : a political economy approach. *Environmental Economics and Policy Studies*, 9(3):177-191, 2008.
77. Fabien PRIEUR. The environmental Kuznets curve in a world of irreversibility. *Economic Theory*, 40(1) : 57-90, 2009.
76. Raouf BOUCEKKINE, Natali HRITONENKO and Yuri YATSENKO. Optimal firm behavior under environmental constraints. April 2008. (also CORE DP 2008/24).
75. Giorgia OGGIONI and Yves SMEERS. Evaluating the impact of average cost based contracts on the industrial sector in the European emission trading scheme. January 2008 (also CORE DP 2008/1).
74. Thierry BRECHET and Pierre-André JOUVET. Environmental innovation and the cost of pollution abatement revisited. *Ecological Economics*, 65:262-265, 2008.
73. Ingmar SCHUMACHER and Benteng ZOU. Pollution perception : A challenge for intergenerational equity. *Journal of Environmental Economics and Management*, 55, 296-309, 2008.
72. Thierry BRECHET et Patrick VAN BRUSSELEN. Le pic pétrolier: un regard d'économiste. *Reflets et Perspectives de la vie économique*, Tome XLVI, n° 4, 63-81, 2007.
71. Thierry BRECHET. L'énergie : mutations passées et mutations en cours. *Reflets et Perspectives de la vie économique*, Tome XLVI, n° 4, 5-11, 2007.
70. Marc GERMAIN, Alphonse MAGNUS and Vincent VAN STEENBERGHE. How to design and use the clean development mechanism under the Kyoto Protocol? A developing country perspective. *Environmental & Resource Economics*, 38(1):13-30, 2007.
69. Thierry BRECHET et Pierre PICARD. Economische instrumenten voor de regulering van de geluidshinder in de omgeving van luchthavens? *Brussels Studies*, nummer 12, 3 december 2007.
68. Thierry BRECHET et Pierre PICARD. Des instruments économiques pour la régulation des nuisances sonores autour des aéroports? *Brussels Studies*, numéro 12, 3 décembre 2007, www.brusselsstudies.be.
67. Thierry BRECHET and Pierre PICARD. Can economic instruments regulate noise pollution in locations near airports? *Brussels Studies*, issue 12, 2007 December the 3rd, www.brusselsstudies.be.
66. Pierre-André JOUVET, Pierre PESTIEAU and Gregory PONTIERE. Longevity and Environmental quality in an OLG model. September 2007 (also available as CORE DP 2007/69).
65. Raouf BOUCEKKINE and Marc GERMAIN. Impacts of emission reduction policies in a multi-regional multi-sectoral small open economy with endogenous growth. February 2007 (also available CORE DP 2007/11).
64. Parkash CHANDER and Subhashini MUTHUKRISHNAN. Green consumerism and collective action. June 2007 (also available as CORE DP 2007/58).
63. Jakub GROWIEC and Ingmar SCHUMACHER. Technological opportunity, long-run growth and convergence. July 2007 (also available as CORE DP 2007/57).
62. Maria Eugenia SANIN and Skerdilajda ZANAJ. Environmental innovation under Cournot competition. June 2007. (also available as CORE DP 2007/50)
61. Thierry BRECHET and Stéphane LAMBRECHT. Family altruism with a renewable resource and population growth. October 2006 (also available as CORE DP 2006/35).

60. Thierry BRECHET, François GERARD and Henry TULKENS. Climate Coalitions: a theoretical and computational appraisal. February 2007 (also available as CORE DP 2007/3).
59. Thierry BRECHET. L'environnement dans tous ses états. *Regards Economiques*, n° 50, 26-32, Avril 2007.
58. Thierry BRECHET and Susana PERALTA. The race for polluting permits. March 2007 (also available as CORE DP 2007/27).
57. Giorgia OGGIONI, Ina RUMIANTSEVA and Yves SMEERS. Introduction of CO₂ emission certificates in a simplified model of the Benelux electricity network with small and industrial consumers. Reprint from *Proceedings of the International Conference on Clean Electrical Power*, Capri, Italy, May 21-23, 2007.
56. Agustin PEREZ-BARAHONA. The problem of non-renewable energy resource in the production of physical capital. January 2007 (also available as CORE DP 2007/8).
55. Thierry BRECHET, Benoît LUSSIS. The contribution of the clean development mechanism to national climate policies. *Journal of Policy Modelling*, 28(9), 981-994, December 2006.
54. Ingmar SCHUMACHER. Endogenous discounting via wealth, twin-peaks and the role of technology. November 2006 (also available as CORE DP 2006/104).
53. Ingmar SCHUMACHER. On optimality, endogenous discounting and wealth accumulation. October 2006 (also available as CORE DP 2006/103).
52. Jakub GROWIEC, Ingmar SCHUMACHER. On technical change in the elasticities of resource inputs. November 2006. (also available as CORE DP 2006/63).
51. Maria Eugenia SANIN. Market Design in Wholesale Electricity Markets. October 2006 (also available as CORE DP 2006/100).
50. Luisito BERTINELLI, Eric STROBL and Benteng ZOU. Polluting technologies and sustainable economic development. June 2006 (also available as CORE DP 2006/52).
49. Marc GERMAIN, Alphonse MAGNUS. Prices versus quantities: Stock pollution control with repeated choice of the instrument. October 2005. *Journal of Computational and Applied Mathematics*, 197 (2006) 437-445.
48. Agustin PEREZ-BARAHONA. Capital accumulation and exhaustible energy resources: a special functions case. September 2006 (also available as CORE DP 2007/9).
47. Philippe TULKENS, Henry TULKENS. The White House and the Kyoto Protocol: Double standards on uncertainties and their consequences. May 2006 (also TERI School of Advanced Studies WP Series #1).
46. Thierry BRECHET, Pierre-André JOUVET. Environmental innovation and the cost of pollution abatement. January 2006 (also available as CORE DP 2006/40).
45. Fabien PRIEUR. The implication of irreversible pollution on the relation between growth and the environment: The degenerate Kuznets curve. February 2006.
44. Thierry BRECHET, Marc GERMAIN, Philippe MONTFORT. Allocation des efforts de dépollution dans des économies avec spécialisation internationale. *Revue Economique*, 57(2), Mars 2006.
43. Ingmar SCHUMACHER and Benteng ZOU. Habit in Pollution, A Challenge for Intergenerational Equity. March 2006 (also available as CORE DP 2006/6).
42. Jean-Charles HOURCADE, P.R. SHUKLA and Sandrine MATHY. Cutting the Climate-Development Gordian Knot – Economic options in a politically constrained world. September 2005.
41. Urs LUTERBACHER. Climate Change, the Kyoto Protocol, and Transatlantic Relations. November 2005.
40. Parkash CHANDER and Henry TULKENS. Cooperation, Stability and Self-Enforcement in International Environmental Agreements: A Conceptual Discussion. July 2005.
39. Paul-Marie BOULANGER et Thierry BRECHET. Le Mécanisme pour un Développement Propre tiendra-t-il ses promesses ? *Reflets et Perspectives de la Vie Economique*, Tome XLIV – 2005 – N° 3, 5-27.
38. Paul-Marie BOULANGER and Thierry BRECHET. Models for policy-making in sustainable development: The state of the art and perspectives for research. *Ecological Economics*, 55, 337-350, 2005.
37. Johan EYCKMANS and Henry TULKENS. Optimal and Stable International Climate Agreements. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

36. Thierry BRECHET and Benoît LUSSIS. The Clean Development Mechanism in Belgian Climate Policy. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)
35. Vincent VAN STEENBERGHE. The impact of banking on permits prices and compliance costs. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)
34. Johan EYCKMANS, Denise VAN REGEMORTER and Vincent VAN STEENBERGHE. Kyoto-permit prices and compliance costs: an analysis with MacGEM. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)
33. Johan EYCKMANS, Bert WILLEMS and Jean-Pascal VAN YPERSELE. Climate Change: Challenges for the World. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)
32. Marc GERMAIN, Stef PROOST and Bert SAVEYN. The Belgian Burden Sharing. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)
31. Ingmar SCHUMACHER. Reviewing Social Discounting within Intergenerational Moral Intuition. June 2005.
30. Stéphane LAMBRECHT. The effects of a demographic shock in an OLG economy with pay-as-you-go pensions and property rights on the environment: the case of selfish households. January 2005.
29. Stéphane LAMBRECHT. Maintaining environmental quality for overlapping generations: Some Reflections on the US Sky Trust Initiative. May 2005.
28. Thierry BRECHET, Benoît LUSSIS. The contribution of the Clean Development Mechanism to national climate policies. April 2005.
27. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intergenerational transfers of pollution rights and growth. May 2005 (also available as CORE DP 2005/42).
26. Maryse LABRIET, Richard LOULOU. From non-cooperative CO₂ abatement strategies to the optimal world cooperation: Results from the integrated MARKAL model. April 2005.
25. Marc GERMAIN, Vincent VAN STEENBERGHE, Alphonse MAGNUS. Optimal Policy with Tradable and Bankable Pollution Permits : Taking the Market Microstructure into Account. *Journal of Public Economy Theory*, 6(5), 2004, 737-757.
24. Marc GERMAIN, Stefano LOVO, Vincent VAN STEENBERGHE. De l'impact de la microstructure d'un marché de permis de polluer sur la politique environnementale. *Annales d'Economie et de Statistique*, n° 74 – 2004, 177-208.
23. Marc GERMAIN, Alphonse MAGNUS, Vincent VAN STEENBERGHE. Should developing countries participate in the Clean Development Mechanism under the Kyoto Protocol ? The low-hanging fruits and baseline issues. December 2004.
22. Thierry BRECHET et Paul-Marie BOULANGER. Le Mécanisme pour un Développement Propre, ou comment faire d'une pierre deux coups. *Regards Economiques*, Ires n° 27, janvier 2005.
21. Sergio CURRARINI & Henry TULKENS. Stable international agreements on transfrontier pollution with ratification constraints. In C. Carraro and V. Fragnelli (eds.), *Game Practice and the Environment*. Cheltenham, Edward Elgar Publishing, 2004, 9-36. (also available as CORE Reprint 1715).
20. Agustin PEREZ-BARAHONA & Benteng ZOU. A comparative study of energy saving technical progress in a vintage capital model. December 2004.
19. Agustin PEREZ-BARAHONA & Benteng ZOU. Energy saving technological progress in a vintage capital model. December 2004.
18. Matthieu GLACHANT. Voluntary agreements under endogenous legislative threats and imperfect enforcement. November 2004.
17. Thierry BRECHET, Stéphane LAMBRECHT. Puzzling over sustainability: an equilibrium analysis. November 2004.

16. Vincent VAN STEENBERGHE. Core-stable and equitable allocations of greenhouse gas emission permits. October 2004. (also available as CORE DP 2004/75).
15. Pierre-André JOUVET Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending. A political economy approach. September 2004. (also available as CORE DP 2004/68).
14. Thierry BRECHET, Marc GERMAIN, Vincent VAN STEENBERGHE. The clean development mechanism under the Kyoto protocol and the 'low-hanging fruits' issue. July 2004. (also available as CORE DP 2004/81).
13. Thierry BRECHET, Philippe MICHEL. Environmental performance and equilibrium. July 2004. (also available as CORE DP 2004/72).
12. Luisito BERTINELLI, Eric STROBL. The Environmental Kuznets Curve semi-parametrically revisited. July 2004. (also available as CORE DP 2004/51).
11. Axel GOSSERIES, Vincent VAN STEENBERGHE. Pourquoi des marchés de permis de polluer ? Les enjeux économiques et éthiques de Kyoto. April 2004. (also available as IRES discussion paper n° 2004-21).
10. Vincent VAN STEENBERGHE. CO₂ Abatement costs and permits price : Exploring the impact of banking and the role of future commitments. December 2003. (also available as CORE DP 2003/98).
9. Katheline SCHUBERT. Eléments sur l'actualisation et l'environnement. March 2004.
8. Marc GERMAIN. Modélisations de marchés de permis de pollution. July 2003.
7. Marc GERMAIN. Le Mécanisme de Développement Propre : Impacts du principe d'additionnalité et du choix de la baseline. January 2003.
6. Thierry BRECHET et Marc GERMAIN. Les affres de la modélisation. May 2002.
5. Marc GERMAIN and Vincent VAN STEENBERGHE. Constraining equitable allocations of tradable CO₂ emission quotas by acceptability, *Environmental and Resource Economics*, (26) 3, 2003.
4. Marc GERMAIN, Philippe TOINT, Henry TULKENS and Aart DE ZEEUW. Transfers to sustain dynamic core-theoretic cooperation in international stock pollutant control, *Journal of Economic Dynamics & Control*, (28) 1, 2003.
3. Thierry BRECHET, Marc GERMAIN et Philippe MONTFORT. Spécialisation internationale et partage de la charge en matière de réduction de la pollution. (also available as IRES discussion paper n°2003-19).
2. Olivier GODARD. Le risque climatique planétaire et la question de l'équité internationale dans l'attribution de quotas d'émission échangeable. May 2003.
1. Thierry BRECHET. Entreprise et environnement : des défis complémentaires ? March 2002. Revue Louvain.

Environmental Economics & Management Memorandum

Chair Lhoist Berghmans in Environmental Economics and Management
Center for Operations Research & Econometrics (CORE)
Université catholique de Louvain (UCL)
Voie du Roman Pays 34
B-1348 Louvain-la-Neuve, Belgium

Hard copies are available upon request : env@core.ucl.ac.be

Papers are available in pdf format on line : <http://www.uclouvain.be/en-21264.html>