# Evolution of environmental concern and the dynamics of pollution*

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**Abstract**

Although the evolution of environmental concern has exhibited a very similar pattern in industrialized and developing nations so that it has been widely demonstrated to be now as spread in both kind of countries, many pollutions have steadily increased within the latter group while it has mostly declining in the former one. To explain the rise of environmental concern as well as how it can lead to two different pollution trends, we develop a dynamic model within which the evolution of pollution and the formation of environmental concern are both endogenous. We set up an overlapping generations model where heterogeneous individuals with respect to environmental attitudes make decisions over the accumulation of pollution and capital. Furthermore environmental attitudes are intergenerationally transmitted through social interactions and pollution interacts with this socialisation process.

We find that a high proportion of environmentally concerned agents needs not be associated with stabilisation of pollution and that a sufficiently clean technology related to the accumulation of pollution is also required. If not clean enough, then the model predicts a high share of people concerned with the environment associated with pollution experiencing an upward pattern.

Besides, we rely on a numerical exemple to examine the dynamic path of pollution when the technology associated to pollution is clean. We find that pollution experiences first increases followed by a phase of decline. This non-monotonic evolution of pollution is also described in the *Environmental Kuznets Curve* litterature. In our setting, however, the U-shape is not an “inevitable” result of growth so that policy implications are rather different. Precisely, we put forward the short run and long run beneficial impact of an education policy.

**keywords:** Overlapping generations, pollution, environmental concern, cultural transmission, education policy.
**JEL Classification:** Q50, D90, J11.

## 1 Introduction

Many authors have recently increase their interest toward the environmental concern, a social movement appeared in the early seventies which has developed during the last decades. An important issue is to understand how does it spread, as well as the link with pollution especially because the way in which it can be involved in solving environmental problems has huge potential policy implications (mostly in terms of education).

The aim of the present paper is to shed light on the link between the endogenous evolution of environmental attitudes and the dynamics of pollution to show why, depending on technology involved in the pollution's production process, the spread of environmental concern need not be

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associated with the stabilisation of the pollution stocks. In fact, the conventional wisdom suggests that, inducing the change of agents' destructive behaviour, the spread of environmental concern would consistently lead to the reduction of environmental degradations. Hence, the different trends of pollution between various nations have frequently been ascribable to differences in the relative importance of environmental concern. The extansive Environmental Kuznets Curve's litterature, within which, authors work on the theoretical basis of a possible non-monotonic evolution of pollution is precisely pointing in that direction. Indeed, they argue that a phase of increasing pollution followed by a declining one can arise from the evolution of income. More particularly, to account for the downard segment, a commonly advanced argument for consumption-based pollution (among others, see McConnel [1997]) is that, when income rises people are more concerned about the environment and this in turn leads to less environmental degradations. Hence in countries where pollution is increasing we should expect a low share of people concerned with environmental degradations while in countries where pollution experiences a downard pattern this share should be high. Furthermore those nations where environmental concern is not widespread should be the poorer ones.

Actually, empirical evidences widely challenge the two latter statements. Indeed, on the one hand, many pollutions within the developing world have shown upward pattern while the same pollutions have mostly decreased in industrialized nations. On the other hand, number of studies based on different international surveys have shown that the development of environmental values has not been not confined to industrialized nations but that it has been rather a worlwide phenomenon (Dunlap, Gallup and Gallup [1992], Brechin and Kempton [1994], Dunlap and Mertig [1995], Brechin [1999], Dunlap and York [2008]). Especially, air pollutants as for instance, nitrogen dioxide ($NO_2$) are experiencing a declining pattern in most developed nations : in Germany, United States and United Kingdom, it has respectively undergone a 48%, 12% and 26% decrease between 1995 and 2000 (UNEP (2012)). Besides, the HOP survey has revealed that the share of people concerned with air pollution in the three latter nations was around 60% (60, 60, 52 respectively) in 1992. On the other hand nitrogen dioxide levels are mostly rising within the developing world : in Brazil, India and Mexico, during the same period it has respectively undergone a 59%, 34%, and 28% increase. However, it cannot be ascribable to a low share of people concerned with air pollution since the same study has reveals that it reached 70%, 64% and 77% in 1992 in the respective nations.

Those empirical resutlts lead us to the main objectives of this paper. First we want to challenge the affluence hypothesis and explain why both rich and poor nations have reached a high share of environmentally concerned people. We will consider environmental concern as a dynamical variable whose evolution does not rely on the evolution of incomes. Furthermore, we want to show that the evolution of environmental concern is indeed involved in the dynamics of pollution altough its impact on the evolution of environmental degradations has been rather different in different nations. Hence, we need a dynamical framework within which the share of environmentally concerned people as well as pollution are both endogenous while pollution evolves through individual actions.

First of all, the fact that income is not decisive for environmental concern suggests that it cannot be understood in terms of monetary value. This is further emphazised by Kempton and Brechin [1994] who argue that "surveys measuring environmental values via willingness to pay cash question, already reflect a strong bias toward economic measures of worth. The conclusion that the poor lack environmental concern is generated by the measurement instrument.". On the other hand, many authors seem to agree that perception is a good measure of the degree of concern so that it has almost always been used in the extensive related litterature. In this article, therefore, we operationalize environmental concern as a perception. More precisely, we consider agents which are not able to correctly assess the actual stock of pollution because as justified in Schumacher and Zou [2008] they are naturally more able to perceive environmental stimulus than absolute levels. This is also emphazied by many authors in environmental psychology who make use of the comparison with a frog which immediately jumps out if suddenly plunged into hot water while it would never realize the danger if water would be heated gradually to the same temperature. Thereby, in our setting agents are not affected by the level of pollution but by the variation of the level of pollution. They consider the level within which they have lived as a benchmark, against which the new level is assessed. Variations in concern for the environment are captured by the relative importance of this benchmark which stands for the amount of pollution considered as neutral. Hence, we consider two types of agents which differ in the following manner:

1. People concerned about pollution are convinced of an harmful human impact on its natural environment so that the preceeding level of pollution is thought to be already high. Consequently for those agents, the reference level is relatively close to zero so that the new level of pollution is perceived as high, and they are strongly affected by it.

2. The other type of agents strongly trust in science and innovation. They think there is no limits to growth because technological progress is able to solve environmental problems. Hence in their point of view, the preceeding level could not be harmful and their reference level is high. However they cannot denie observed changes in their natural environment and are still affected by pollution when it increases compared to the benchmark.

With this formalization, environmental concern relies mostly on individual beliefs and values. This is just confirmed by an exhaustive litterature which have tried to explain variations of the concern for environmental issues (among others see Van Liere and Dunlap [1980] for a wide review). In many studies demographic variables have been shown to be slightly relevant to assess the degree of concern while cognitive ones have been demonstrated to explain a large share of observed variations. In other words, environmental concern is linked to some cultural aspect so that, it is likely that, as for other cultural attitudes, social interactions are the driving forces which explain the diffusion within a population. Hence rather than income rise, we assume that intergenerational cultural transmission is responsible for the evolution of environmental concern and we use the framework developed by Bisin and Verdier [1998, 2000] to describe this process. Furthermore, it is clear for many authors that rising pollution has also been a driving force in the spread of environmental concern (Inglehart [1995], Brechin [1999]). However the role played by objective environmental conditions still remains a puzzling question. As pointed out by Dunlap and Merting [1997] "a simple stimulus-response model of the role of objective environmental problems is much too simplistic [...] and ignores the documented complexities of environmental perception.". Hence pollution must interact in the socialization process who drives the evolution of environmental perceptions but it could occur at different stages of the transmission mechanism. We think it is realistic to assume it interacts with parental point of view (through the desire to transmit its own attitude toward environment). This is not crucial for the consistency of our results since the same conclusion can be obtained assuming pollution interacts with children's point of view.

We consider overlapping generations since it is the appropriate demographic structure to study the intergenerational cultural transmission of environmental concern. Furthermore it is particularly suitable to the study of environmental issues for which finitely lived agents undertake actions that have long-lasting effects, a feature which relies on the stock nature of many pollutions. Indeed, we also consider a model where pollution arises in a accumulative way, a process which is linked furthermore, to the accumulation of capital. More particularly, we use the framework developed by John and Pecchenino [1994]. In this model, agents make decisions over the accumulation of capital to consume later and the abatement of pollution which takes the form of a voluntary contribution. In fact, voluntary contributions have a non negligible role in environment, despite the high number of potential contributors. Good exemples are recycling actions, the purchase of green product or hybrid cars. It seems to be linked to the lenght of the living period : if at time $t$, agents rationnaly consider their contribution as negligible (sorting one milk carton clearly does not have a significant impact on pollution), they live a long enough period, to think the sum of their own contributions is likely to significantly affect pollution (sorting all the waste generated during one life does impact pollution). Besides, in this model, capital accumulated by a given generation affects pollution undergone by the next generation through their consumption. To consider the accumulation of capital and its link with the pollution accumulation process is essential for our results. Indeed, we would like to show that a high share of environmentally concerned agents is not sufficient to reach a stationnary state even when pollution evolves through individual agents' decisions. Especially, we would like to shed light on the role of the available technology related to pollution. We show that if it is not clean enough, even though they are highly concerned with pollution, individuals do not act for the reduction of pollution. It is consitent with a widely developed litterature studying the existence of barriers to pro-environmental behaviour (Kollmuss and Agyeman [2002], Stern [2000]). Within this field, authors have put forward that attitudes as the perception of harmful impacts of pollution do not always lead to pro-environmental behaviour and have pointed out the role played by what they called "external factors". Among those factors, they mentionned two important ones which are the institutions as well as the technology. Furthermore, the crucial role played by the technology related to pollution is also supported by emprirical studies such as those concerning air pollution which reveal that for many developing countries rising air pollutants such as nitrogen dioxyde are ascribable to a stock of old and highly polluting vehicules (Faiz [1993, 2000], Fenger [1999]). Our model captures the role of this technological factor in the following way. The capital accumulated by generation born at some date $t$ affects pollution undergone by agents of the next generation as well as their wages. The overall impact on pollution can be either positive or negative depending on the relative strengh of the consumption externality and the efficiency of abatement. If negative (positive externality), which means that the technology is suffciently clean (such that the rise of wages allow to overcome the impact of additionnal units of consumption), they always act for the reduction of pollution as soon as it becomes too high. In this case therefore, when the share of environmentally concerned individuals is relatively high a steady state always exists which is stable. If, however, the capital accumulated, positively affects pollution (negative externality), which stands for a quite polluting technology, those highly concerned with pollution are too much affected on the one hand, while the difficulty of reducing pollution expressed in consumption units is extremely high. Hence they always prefer to increase consumption even if this results into further rises in pollution. As a consequence, when the share of environmentally concerned individuals is relatively high, a steady state never exists and a significant number of environmentally concerned individuals can thus be associated with an increasing stock of pollution. Hence, in this model, the long run behavior of pollution is not due to the evolution of income. Rather, it can be ascribable to the degree of environmental concern within a population with a given technology for the production of pollution.

This accounts for a part of what can be empirically observed, but such a result is still too static to challenge the income hypothesis and does not encompass the whole story. Indeed, we also have to explain why we can oberve a high share of highly concerned individuals in various nations independently of the level of wealth. Furthermore, since we challenge the rational for a non-monotonic evolution of pollution, that is an increasing phase followed by a phase of decline, can we still predict such a non monotonic path (observed for various pollutions in industrialized countries) if wealth is not involved. Actually, the introduction of a cultural transmission mechanism to describe the evolution of environmental attitudes allows to complete the theory. First, the full model can predict the two contrasting situations described before : that is a high share of environmentally concerned people in industrialized as well as in developing nations associated with two different trends related to the evolution of pollution. Indeed, we show that when the technology is clean, a stable steady state exists and it is characterized by an heterogeneous population for which, the share of people concerned with environemental issues is relatively high. No other stable steady states do exist whatever the available technology for the accumulation of pollution. More particularly, when the technology is rather polluting, the model predicts that both pollution and environmental concern will increase such that, after several iterations, we can observe a high proportion of agents with environmental concern while pollution is following an upward path. The intuition is as follows. As in Bisin and Verdier [1998, 2000], cultural transmission is the result of two types of social interactions: vertical transmission inside the family, and oblique transmission within the society by peers, the first one depending on an economic choice which takes the form of a parental effort. Intuitively, a stable stationnary state with a heterogeneous population exists if agents' effort is higher whenever their cultural trait is in minority. In the general framework of Bisin and Verdier, this is always true when the two kinds of transmission are substituable in the technology of transmission. Indeed, the "cultural substitution" hypothesis means that parents have incentives to reduce their effort when transmission of their trait outside the family, by the society, works better. In our framework, however, the relative effort is also affected by the level of pollution which, in turn, depends upon the composition of the population with regard to environmental concern. According to the technology, the share of environmentally concerned agents does not affect pollution in the same direction. We can proove that, as long as the technology is clean enough, the effort of agents who belong to a minority is still lower so that a stationnary state always exists. As opposed, when the technology is rather polluting, the relative effort of those parents in majority is higher and a stationnary state with an heterogeneous population does not exist. In this case, the economy never converges since only steady states characterized by heterogeneous population can be stable.

Finally, applying our model to a numerical exemple in the clean technology case, we observe a non-monotonic evolution of pollution. Our model still predict a phase of increasing pollution followed by a phase of decline, at least for countries which are endowed with a sufficiently clean pollution technology. However, contrary to what is argued within the EKC litterature, this pattern is not an "inevitable" result of growth. Rather, it is due to the casual dynamic link between pollution and the distribution of environmental concern. We find a role for some country specific parameters in the maximum level reach by pollution as well as in the timing of the transition to a declining phase and we discuss different policy implications thant those proposed by the EKC litterature. Especially we shed light on the potential benefits of an education policy.

Our paper is first related to the litterature who study environmental issues in a dynamic OLG framework. We use the setting proposed by John and Pecchenino [1994] which has been taken up by Schumacher and Zou [2008] from which we come even closer using their idea of pollution perception. Both articles, however, consider a representative agent while we are dealing with an heterogeneous society. In this respect, we are more related to those who study the effect of the distribution of some variable among agents on the dynamics of pollution (Jouvet and al [2000], Ikefuji and Horii [2007], Raffin [2010]). However, they mostly focus on the existence of a poverty-environment trap while we interest in the non existence of some stationnary levels of pollution and capital (possibility of endless increase of pollution) under plausible conditions as well as to the dynamics of pollution. On the other hand, few consider endogenous changes of population as we do. In this respect we come closer to Bisin and Verdier [1998, 2000] and all the related litterature which study the intergenerational transmission of cultural traits and values (among others Baudin [2010], Ponthière [2010], Hiller [2011]). Finally a link can also be established with authors who explain why environmental concern does not lead to the reduction of environmental degradations in developing nations as Torras and Boyces [1998] for instance, who put forward the essential role played by the institutional context and the distribution of power.

The remainder of this paper is organized as follows. In section 2, we set up the framework related to pollution and capital accumulation, which is an extension of Schumacher and Zou [2008] to a society where individuals are heterogeneously concerned with environmental issues. In order to the simplify the analytical analysis, in this first part we consider the composition of the population is fixed to characterize some dynamical properties. Then, in section 3, we study the general model where the distribution of environmental concern has been endogenized through a cultural transmission model based on Bisin and Verdier [1998, 2000] within which pollution interacts. Finally, in section 4, we rely on a numerical exemple to highlight and discuss some important implications. Section 5 concludes.

# 2 The model

Let consider a perfectly competitive economy with an overlapping generations structure. Time is discrete and goes from $1 \cdots$ to $\infty$. At each date a generation is born and lives for two periods. During the first period agents supply their labor inelastically and earn a wage which can be either saved for future consumption or spend in the abatement of pollution. Following John and Pecchenino [1994] we assume agents have preferences over consumption and the environment and can only derive utility during the second period of life (which stands for a period of retirement).
Each cohort, of constant size $n$, consists in two types of agents who differ through their appraisal of the pollution stock. As highlighted in the introduction, agents of the first type have high perception of the pollution stock because their frame of reference is quite low. They are called "environmentally concerned" agents and they will be associated with the superscript $G$. On the other hand, the second type of agents with a relatively high frame of reference estimates pollution stock is lower than it actually is. They will be denoted by $T$ for "technologists". There are $n_G$ agents of type $G$ and $n_T = n - n_G$ agents of type $T$.

## 2.1 Pollution accumulation

The pollution accumulation process is described by the following equation based on John and Pecchenino [1994]:

$$P_{t+1} = (1-b)P_t + \beta n_G c_t^G + \beta n_T c_t^T - \gamma n_G A_t^G - \gamma n_T A_t^T, \tag{1}$$

where $b \in [0,1]$ is the natural rate of absorption, $\beta > 0$, is the amount of pollution per unit of consumption by agents of the old generation. Hence it stands for the intergenerational externality. On the other hand, $\gamma > 0$ is the effectivness of abatement. $c^i$ and $A^i$, $i \in \{G, T\}$ are respectively the type-$i$ agents' consumption of the generation born at $t-1$, and the type-$i$ agents' abatement of the generation born at $t$.

## 2.2 Agents' behaviour

### 2.2.1 Perception of pollution

The formalisation of the pollution perception comes from Schumacher and Zou [2008]. In a model where agents live for two periods, the amount of pollution, an agent is affected by is

$$H_{t+1} = P_{t+1} - h^i P_t,$$

where $P_t$ (resp. $P_{t+1}$) is the pollution stock at time $t$ (resp. $t+1$). Individuals perceive a level between the stock and the flow from $t$ to $t+1$. $h_i \in [0,1]$ is an individual specific parameter. For a high $h_i$, agent $i$ almost considers as a benchmark the level where he has lived so far ($P_t$ is almost the neutral level). On the contrary agents who care a lot about about environmental problems consider the level where they have lived as already high (their frame of reference is thus closer to zero). The lower $h_i$, the better the perception. Finally we assume $h^G < h^T$.

### 2.2.2 Economic choices

During the first period agents have to choose the mix of abatement-saving which maximises their utility when old. We assume that, for all types of agent, $U : \mathbb{R}^2_{++} \to \mathbb{R}$, is twice continously differentiable and such that $U_c > 0$, $U_{cc} < 0$, $U_H < 0$, $U_{HH} < 0$ and $\lim\limits_{c \to 0} U_c = \infty$.

An agent of type $i$, $i \in \{G, T\}$ faces the following budget constraints :

$$w_t = s^i_t + A^i_t, \tag{2}$$

$$c^i_{t+1} = (1 + r_{t+1})\, s^i_t, \tag{3}$$

where $w_t$ is the agent's wage (whatever his type) at time t, $s^i_t$ is the amount of saving of a type-$i$ individual. $r_t$ is the interest rate at time $t$.

An agent of type $i$ maxmizes $U\left(c^i_{t+1}, H^i_{t+1}\right)$ subject to the budget constraints (2) and (3), as well as to

$$P_{t+1} = (1-b)P_t + \beta n_G c^G_t + \beta n_T c^T_t - \gamma A^i_t - \gamma \bar{A}_t$$

where $\bar{A}_t$ includes abatement spendings of all other agents of the cohort.

$$(1 + r_{t+1}) U^i_c + \gamma U^i_H = 0, \qquad \forall i \in \{G, T\}. \tag{4}$$

Following Zhang [1999] and Schumacher and Zou [2008], for analytical convenience we restrict to simple class of utility functions so that we assume a constant elasticity of substitution between private consumption and the environment.

$$\sigma = -\frac{U_H^i H^i}{U_c^i c^i} > 0, \qquad \forall i \in \{G, T\}. \tag{5}$$

Note that $\sigma$ does not change from one type of agent to another. As highlighted in the introduction, agents do not differ through their relative valuation of the environment but only through their perception of the pollution.

Using (5), let rewrite the FOC as

$$\gamma \sigma s_t^i = P_{t+1} - h^i P_t, \qquad \forall i \in \{G, T\}. \tag{6}$$

At the optimum, agents choose their saving such that positive level of pollution is associated with positive amount of saving. Since $h^G < h^T$, for a given stock of pollution in $t+1$ type-$G$ agents always choose to save more than type-$T$ agents do. This is because for a given stock of pollution, type-$G$ agents feel a higher desutility, so that all else equals, they have to consume more to offset the loss. However note that those agents are more sensitive to a rise in the bequeathed stock of pollution $P_t$. Hence, if pollution at time $t$ increases, they always need to undertake largest actions. In other words, if they choose to increase abatement, they will increase it more than do type-$T$ agents. Nevertheless, if they decide to increase saving on the other hand, they will rise it more. Later we point out the specific circumstances which determinate such a choice.

### 2.3 The representative firm

The productive sector consists in a representative firm which is supposed to be perfectly competitive and which produces using the constant returns to scale production function $Y = f(K)L$. We can normalize by the labor supply so that output per worker can be written as $y = f(k)$, where $k = K/n$. We assume that $f$ meets the following properties : $f^{'} > 0$ and $f^{''} < 0$.

The firm maximizes its profit equalizing each marginal productivity with its market price. Namely the marginal productivity of labour is equalized to the wage rate, whereas the marginal productivity of capital minus its depreciation rate is equalized to the interest rate. Finally total savings of the young generation form the capital at time t+1,

$$w_t = f(k_t) - k_t f'(k_t), \tag{7}$$

$$r_{t+1} = f'(k_{t+1}) - \delta, \tag{8}$$

$$\frac{n_G}{n} s_t^G + (1 - \frac{n_G}{n}) s_t^T = k_{t+1}. \tag{9}$$

For analytical convenience we restrict to a Cobb Douglas production function $f(k_t) = k_t^v$ (Zhang [1999], Schumacher and Zou [2008]) where $v \in [0, 1]$ is the capital share. We further assume full depreciation of captital, that is $\delta = 1$.
In what follows, let denote by $q = \frac{n_G}{n}$, the share of type-$G$ agents.

**Definition 1** (Intertemporal equilibrium)**.** *Given inital conditions* $(k_0, P_0)$*, the intertemporal equilibrium is the sequence* $(k_t, P_t)_{t\in\mathbb{N}}$ *which satisfies the two following equations for each t.*

$$P_{t+1} = \frac{(b\sigma^{'} + \bar{h}(q) - \sigma^{'})}{(1-\sigma^{'})} P_t - \frac{(\beta v + \gamma v - \gamma)\sigma^{'}}{(1-\sigma^{'})} k_t^v, \tag{10}$$

$$k_{t+1} = -\frac{(1 - b - \bar{h}(q))}{\gamma(1-\sigma^{'})} P_t - \frac{(\beta v + \gamma v - \gamma)}{\gamma(1-\sigma^{'})} k_t^v, \tag{11}$$

where $\bar{h}(q) = qh^G + (1-q)h^T$ and $\sigma^{'} = \frac{\sigma}{n} \neq 1$[1].

## 2.4 Existence of steady state

### 2.4.1 Steady states

A steady state exists if some vector (k,P) solves $k_{t+1} = k_t$, $P_{t+1} = P_t$ for all t. There are two steady states: (0,0) and a non-trivial one, which depends upon $q$, so that we denote it by $(\bar{P}(q), \bar{k}(q))$:

$$\bar{P}(q) = \frac{\sigma^{'}\gamma}{1-\bar{h}(q)} \left( \frac{(1-\bar{h}(q))(\beta v + \gamma v - \gamma)}{\gamma(b\sigma^{'} + \bar{h}(q) - 1)} \right)^{\frac{1}{1-v}} \tag{12}$$

$$\bar{k}(q) = \left( \frac{(1-\bar{h}(q))(\beta v + \gamma v - \gamma)}{\gamma(b\sigma^{'} + \bar{h}(q) - 1)} \right)^{\frac{1}{1-v}}. \tag{13}$$

**Definition 2.** *The technology of the pollution's production process*

*We say that* $A_1$ *holds if the effectivness of abatement* $\gamma$ *is high enough compared to the consumption externality* $\beta$ *such that the positive effect of additionnal abatement allowed by the rise of wages, overcomes the negative effect entailed by the rise in consumption, precisely we have* $\beta v + \gamma v - \gamma < 0$*. The technology is "clean".*

*We say that* $A_2$ *holds if the effectivness of abatement is small compared to the consumption externality such that the negative effect entailed by the rise in consumption, overcomes the positive effect of additionnal abatement allowed by the rise of wages, that is* $\beta v + \gamma v - \gamma > 0$*. The technology is "dirty".*

**Proposition 1.** *Existence of a non-trivial steady state*

*Suppose that agents are different enough, especially,* $h^G > b\sigma - 1 > h^T$*,*

*It exists* $\tilde{q} = \frac{b\sigma^{'} + h^T - 1}{h^T - h^G} < 1$ *such that,*

*(1) If the share of agents concerned about pollution is relatively high* ($q > \tilde{q}$)*, a non-trivial steady state exists if, and only if,* $A_1$ *holds.*

*(2) If the share of agents concerned about pollution is small enough* ($q < \tilde{q}$)*, then a non-trivial steady state exists if, and only if,* $A_2$ *holds.*

[1]Note that $P_{t+1}$ and $P_t$ are now measured in per capital units of pollution

For our purpose, it is interesting to investigate the impact of a change in the distribution of environmental concern for the long run state of the economy.

**Proposition 2.** *Impact of an increase of the share of type-G agents, on the long run capital and pollution stocks.*

*(1) If $A_1$ holds, and if $q > \tilde{q}$, then a rise of $q$, the share of type $G$ agents, induces a decrease of the steady state pollution and capital.*

*(2) If $A_2$ holds, and if $q < \tilde{q}$, then a rise of $q$ induces an increase of the steady state pollution and capital.*

*Proof.* Differentiating the functions $\bar{P}(q)$ and $\bar{k}(q)$ with respect to $q$ we obtain,

$$\frac{\partial \bar{P}(q)}{\partial q} = \frac{\bar{P}(h^G - h^T)}{(1-v)(1-\bar{h}(q))} \left( (1-v) + \frac{b\sigma'}{(1 - b\sigma' - \bar{h}(q))} \right) \tag{14}$$

$$\frac{\partial \bar{k}(q)}{\partial q} = - \frac{\bar{k} b\sigma' (h^G - h^T)}{(1-v)(1-\bar{h}(q))(b\sigma' + \bar{h}(q) - 1)}. \tag{15}$$

The sign of the above derivatives depends upon the sign of $b\sigma' + \bar{h}(q) - 1$. If $b\sigma' + \bar{h}(q) - 1 < 0$, which involves $\beta v + \gamma v - \gamma < 0$, then both dervatives are negative; while, if $b\sigma' + \bar{h}(q) - 1 > 0$, which involves $\beta v + \gamma v - \gamma > 0$, then both derivatives are positive.

□

### 2.4.2 Interpretation

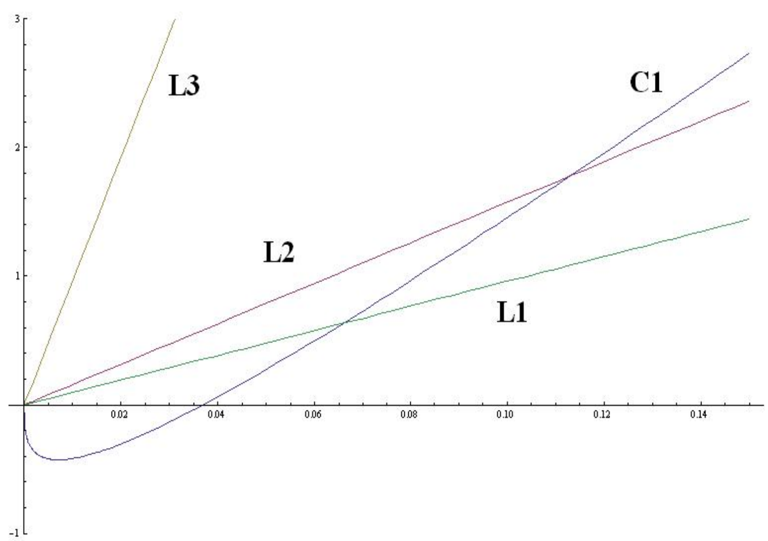


Figure 1: Phase diagram in the (k,P) space when $A_1$

Figure 1 corresponds to the situation in which $A_1$ holds. We draw the curve which describes the evolution of pollution ($C1$) with respect to capital, as well as the aggregated optimal choices lines for different composition of the population in regards to environmental attitudes ($L1$ for $q = 1$, $L2$ for $\tilde{q} < q < 1$, $L3$ for $q = 0$). As observable through the shape of $C1$, with the clean technology, a low stock of capital corresponds to a low stock of pollution. Hence, for some low values $(k, P)$, pollution is relatively low (compared to capital), so that all agents have incentive to increase saving.

When the society consits in only type-$G$ agents ($L1$), pollution becomes too high (compared to saving) for a vector $(k, P)$ relatively low since agents are highly affected by pollution. Now, when the society consists in either types of agents ($L2$), less agents are affected by pollution so that the level of pollution for which the whole society decide to increase abatement instead of saving is higher. Finally, when the society consits in only type-$T$ agents ($L3$), that is agents slightly affected by the level of pollution, pollution is never sufficiently high (compared to saving). No thresold of pollution exists which sufficiently affects agents such that they have incentive to increase abatement instead of saving. They always spend additional wage in saving and pollution never stop to rise.

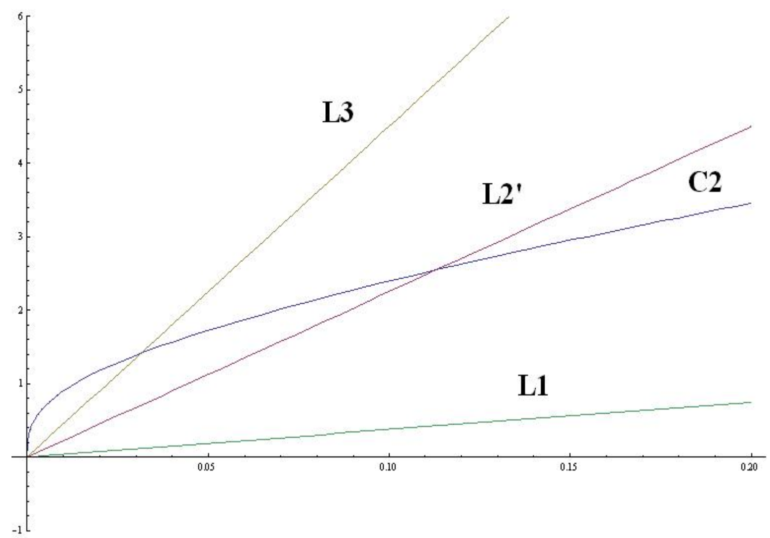


Figure 2: Phase diagram in the (k,P) space when $A_2$ holds

Figure 2 stands for the $A_2$ case. On this graph, the evolution of pollution with respect to capital is described by $C2$, and the aggregated optimal choices lines for different composition of the population are also drawn (($L1$ for $q = 1$, $L2^{'}$ for $0 > q > \tilde{q}$, $L3$ for $q = 0$). With this technology, as opposed to the first case, a low stock of capital is associated with a high pollution stock. For some low $(k, P)$, pollution is relatively high compared to the stock of capital, so that all agents are too much affected by pollution and have incentive to increase saving (since it increases more than pollution thanks to decreasing marginal returs).

When the society consists in only type-$T$, even if pollution is quite high, they perceive it as low since they are slightly affected so that they can satisfy with a relatively high level of pollution compared to the capital stock. However, type-$G$ are highly affected so that for them, the same level is too high to be compensated by the relatively low level of capital. Hence, type-$G$ need to compensate for too high pollution so that they have incentive to increase saving (and so they increase pollution). As a consequence, when $q$ is higher ($L2^{'}$), the level of pollution for which the whole society stop to increase saving and have incentive to increase abatement is higher. When $q$ is even higher ($L3$), pollution is always too high compared to the stock of capital so that agents never have incentives to stop increasing saving. They would always spend additionnal wage in saving for consumption and pollution never stop to rise.

### 2.5 Stability of the non-trivial steady state

**Proposition 3.** *A necessary condition for local stability.*

*(1) When $A_1$ holds, stability of the steady state requires that the cost of an additionnal unit of saving be relatively high ($\sigma^{'} < 1$) along the transistion path.*

*(2) When $A_2$, stability of the steady state requires that the cost of an additionnal unit of abatement be relatively high ($\sigma^{'} > 1$) along the transition path.*

*Proof.* To study the local stability of the non-trivial steady state, we linearize the two-dimensional map composed of equations (12) and (13) around $(\bar{P}(q), \bar{k}(q))$. Denote by $Df_2$ the jacobian matrix, we have

$$Df_2(\bar{k}, \bar{P}) = \begin{pmatrix} -\frac{v(b\sigma^{'}+\bar{h}(q)-1)}{(1-\bar{h}(q))(1-\sigma^{'})} & -\frac{(1-b-\bar{h}(q))}{\gamma(1-\sigma^{'})} \\ -\frac{\sigma^{'}v\gamma(b\sigma^{'}+\bar{h}(q)-1)}{(1-\bar{h}(q))(1-\sigma^{'})} & \frac{(b\sigma^{'}+\bar{h}(q)-\sigma^{'})}{(1-\sigma^{'})} \end{pmatrix}.$$

Its characteristic polynomial can be written as

$$P(\lambda) = \alpha_0\lambda^2 + \alpha_1\lambda + \alpha_2,$$

where $\alpha_0 = (1-\sigma^{'})(1-\bar{h}(q))$, $\alpha_1 = \sigma^{'}(b-1)(\bar{h}(q)-1) + vb\sigma^{'} - (1-\bar{h}(q))(v+\bar{h}(q))$, and $\alpha_2 = -\bar{h}(q)v(b\sigma^{'}+\bar{h}(q)-1)$.

The steady state is locally stable if each eigenvalue of the above matrix is of magnitude less than one. We denote by $\lambda_1 = \frac{-\alpha_1+\sqrt{\Delta}}{2\alpha_0}$ and $\lambda_2 = \frac{-\alpha_1-\sqrt{\Delta}}{2\alpha_0}$ the roots of $P$. We want to show that, at least one of the two roots of the characteristics polynomial will be of magnitude higher than 1 if, on the one hand $\sigma^{'} > 1$ and $\beta v+\gamma v-\gamma < 0$, or if, on the other hand, $\sigma^{'} < 1$ and $\beta v+\gamma v-\gamma > 0$.

(1) Let consider the case $\beta v + \gamma v - \gamma < 0$. The existence of a steady state implies $\alpha_2 > 0$ since $b\sigma^{'}+\bar{h}(q)-1$ is negative. Suppose that $\sigma^{'} > 1$ which implies $\alpha_0 < 0$. Then ${\alpha_1}^2 - 4\alpha_0\alpha_2 > {\alpha_1}^2$ (since $4\alpha_0\alpha_2 < 0$) so that $\sqrt{\Delta} > \alpha_1$. Hence $\lambda_1 = \frac{-\alpha_1+\sqrt{\Delta}}{2\alpha_0} < 0$. Especially, we show that we always have $\lambda_1 < -1$. $\lambda_1 < -1 \Rightarrow -\alpha_1 + 2\alpha_0 > -\sqrt{\Delta}$ which is equivalent to $\Delta > (-\alpha_1 + 2\alpha_0)^2$ (since $-\alpha_1 + 2\alpha_0 > \sqrt{\Delta} \Leftrightarrow \lambda_2 < -1$ and we are done), or also to $\alpha_1 - \alpha_2 - \alpha_0 < 0$. However, after simplification, we find $\alpha_1 - \alpha_2 - \alpha_0 = (v-1)(\bar{h}(q)-1)(b\sigma^{'} + \bar{h}(q) - 1)$ which is negative since $b\sigma^{'} + \bar{h}(q) - 1$ is negative. Finally, when $\beta v + \gamma v - \gamma < 0$ and $\sigma^{'} > 1$, one of the eigenvalues, is always lower than $-1$ and the steady state is unstable.

(2) Let consider the case $\beta v + \gamma v - \gamma > 0$ which implies $\alpha_2 < 0$ since $b\sigma^{'} + \bar{h}(q) - 1$ is positive. Consider $\sigma^{'} < 1$ which implies $\alpha_0 > 0$. Then $\Delta = {\alpha_1}^2 - 4\alpha_0\alpha_2 > {\alpha_1}^2$ so that $\sqrt{\Delta} > \alpha_1$. Hence $\lambda_1 = \frac{-\alpha_1+\sqrt{\Delta}}{2\alpha_0}$ is always positive, but this is not the case for $\lambda_2$, which, we will we show, is always lower than $-1$ as long as $\sigma^{'} < 1$. This is equivalent to $2\alpha_0 - \alpha_1 < \sqrt{\Delta}$, or $\Delta > (-\alpha_1 + 2\alpha_0)^2$

(since $\lambda_1 > 0 \Leftrightarrow 2\alpha_0 - \alpha_1 > -\sqrt{\Delta}$). When $\alpha_0 > 0$, this is equivalent to $\alpha_1 - \alpha_2 - \alpha_0 = (v-1)(\bar{h}(q)-1)(b\sigma^{'} + \bar{h}(q) - 1) > 0$ which is always positive since $b\sigma^{'} + \bar{h}(q) - 1 > 0$. Hence, when $\beta v + \gamma v - \gamma > 0$ and $\sigma^{'} < 1$, one of the eigenvalues is always lower than $-1$ and the steady state is unstable. □

Finally we show that a high share of environmentally concerned individuals needs not be associated with stabilisation of pollution and that a sufficiently clean technology related to the accumulation of pollution is also necessary. Hence, we explain why a high share of environmentally concerned does not always lead to regulate pollution such that it can eventually stabilize, however we do not account for the high share of environmentally concerned individuals in poor nations. Besides, without making the income hypothesis, does we still predict a non-monotonic evolution of pollution? A full model requires to consider the evolution of environmental concern.

# 3 Model with endogenous distribution of environmental concern

In the following the distribution of environmental concern is no longer constant. We allow for a cultural transmission mechanism which relies on Bisin and Verdier's works [1998, 2001].
Children are born naive and adopt a defined kind of environmental attitude through imitation and social learning. Socialization is the result of two interacting types of transmission : transmission inside the family called "direct transmission" and socialization outside by peers, called "oblique transmission". More precisely, each child is first exposed to his parents' cultural trait (the perception of pollution for us) and adopts it with probability $e_i$, $i \in \{G, T\}$. If not, which occurs with probability $(1 - e_i)$, he is socialized to the cultural trait of a role model choosen randomly in the population. Thus if direct transmission failed, probabilities to pick up trait $G$ and $T$ are respectively $q_t$ and $1 - q_t$.
Let $P_t^{ij}$ be the probability for a child from a family with perception $i$ to be socialized to trait $j$ at time $t$. We have the following transistion probabilities :

$$\begin{aligned} P_t^{GG} &= e_t^G + (1 - e_t^G)q_t, \qquad P_t^{GT} = (1 - e_t^G)(1 - q_t), \\ P_t^{TT} &= e_t^T + (1 - e_t^T)(1 - q_t), \quad \text{and} \quad P_t^{TG} = (1 - e_t^T)(q_t). \end{aligned}$$

We can characterize the dynamic law for the share of agents with environmental concern in the population,

$$q_{t+1} = q_t + q_t(1 - q_t)(e^G - e^T). \tag{16}$$

Furthermore, in this model, socialization is an economic choice of parents which purposefully attempt at transmitting their own environmental attitude. As in Bisin and Verdier, the desire to transmit comes from cultural intolerance hypothesis which is that the gain to have a child with the same cultural trait is always higher than the gain to have a child with a different trait. Furthermore, here we assume that cultural intolerance is endogenous and that it depends upon the perceived level of pollution. The underlying intuition is that the gain to have a child with the same cultural trait is linked to the relative advantage the parents judge this trait provide in given external conditions. As highlighted by Bisin and Verdier [2010], "The preference on the part of parents for sharing their cultural trait with their children can depends on the economic and social conditions". This is because the child might feel relatively less advantaged when having his parents' trait depending on its specific living conditions. Precisely, we suppose the following. Let denote by $V_t^{ij}(H_{t+1}^i)$ the gain for a parent of type $i$, $i \in \{G, T\}$, to have a child of type $j$ at time $t$, such that $\Delta V^i(H_{t+1}^i) = V_t^{ii}(H_{t+1}^i) - V_t^{ij}(H_{t+1}^i)$ stands for the cultural intolerance function.

**Assumption 1.** *For all $i, j \in \{G, T\}$, $V_t^{ij} : \mathbb{R}^+ \to \mathbb{R}^+$. Besides,*

1. *We have,*
   a. $\frac{dV^{GG}}{dH^G} > 0$,
   b. $\frac{dV^{GT}}{dH^G} < 0$,
   c. $V^{GG}(H^G) > V^{GT}(H^G) \quad \forall\, H^G > 0$,
   d. $\Delta V^G(H^G)$ *positive and increasing,*
   e. $\Delta V^G(0) = 0$.

2. *On the other hand,*
   a. $\frac{dV^{TT}}{dH^T} < 0$,
   b. $\frac{dV^{TG}}{dH^T} > 0$,
   c. $V^{TT}(H^T) > V^{TG}(H^T) \quad \forall\, H^T > 0$,
   d. $\Delta V^T(H^T)$ *positive and decreasing,*
   e. $\lim_{H^T \to \infty} \Delta V^T(H^T) = 0$.

Actually, this means that for an agent of type $G$, the higher the perceived level of pollution, the more he thinks his child needs to be aware of the danger he is going to incur in order to act accordingly, the higher the relative gain to have a child of his own type. On the contrary, for a type-$T$ agent, the lower the perceived pollution, the more he thinks his child his child would rather not worry about environmental degradations and trust in science, the higher the relative gain to have a child of its own type. The statement 1.5 implies that type-$G$ parents do not demonstrate cultural intolerance toward technologists if there is no pollution, while statement 2.5 means that type-$T$ parents are not intolerant toward environmentally concerned children if pollution is dramatically high.

Finally we assume socialization is costly. The parental effort implies a welfare loss which can be understood as time spend with the child. This effort is denoted by $C(e_i)$ with $C(e_i) = \frac{e_i^2}{2C}$, where $C$ is a positive constant.

### 3.1 Agents' choices

Agents live for three periods but are passive when child. We assume a two-stages maximisation process. During the adulthood, agents first choose their optimal combination of abatement-saving according to their concern for pollution. Then when their choices related to the economic sphere are made, they make their educational choices (to tranmsit their cultural trait). Hence, and because we assume the transmission effort enters separately in utility, we can deal with the socialization problem irrespective of the optimal saving-abatement choice. The same first order conditions hold for the economic problem.

The socialization problem for each agent of type $i$, $i \in \{G, T\}$, is then to choose $e^i$ to maximize

$$\theta\left(P_t^{ii} V_t^{ii}(H_{t+1}^i) + P_t^{ij} V_t^{ij}(H_{t+1}^i)\right) - C\left(e^i\right),$$

leading to the following optimal effort functions for agents of type $G$ and $T$ respectively,

$$e_t^G = C\theta(1 - q_t)\Delta V^G(H_{t+1}^G), \qquad e_t^T = C\theta q_t \Delta V^T(H_{t+1}^T),$$

where $\theta$ is a discount factor. We can already see that $e^G$ and $e^T$ do not necessarily respect the cultural substitution property, as defined in Bisin and Verdier [2001] which means that parents who belong to a minority have more incentives to transmit their own trait than those who belong to a majority. On the one hand, direct and oblique transmission are substitutes in the socialization process. Namely, parents of type $i$ have less incentives to socialize their child whenever the cultural trait $i$ is more widespread in the population because transmission by peers works better. On the other hand, parental efforts are also sensitive to the variations of $q$ through the variations of the perceived pollution level which affects cultural intolerance. Hence, depending on the direction and the magnitude of this second effect, the overall impact of $q$ on $e^i$ can be of either sign. Indeed, calculating the derivatives,

$$\frac{\partial e_t^G}{\partial q_t} = -C\theta\Delta V^G(H_{t+1}^G) + C\theta(1 - q_t)\frac{d\Delta V^G}{dH^G}\frac{\partial P_{t+1}}{\partial q_t},$$

$$\frac{\partial e_t^T}{\partial q_t} = C\theta\Delta V^P(H_{t+1}^T) + C\theta q_t \frac{d\Delta V^T}{dH^T}\frac{\partial P_{t+1}}{\partial q_t},$$

we see that the second term can be of either sign depending on the impact of $q$ on pollution at $t+1$. Note, that we always have $e^G(0) > 0$, $e^T(0) = 0$ and $e^G(1) = 0$, $e^T(1) > 0$[2]. This means that when the population is perfectly homogeneous, it is always true that parents who belongs to the cultural majority make lower effort, since, in this particular case it is nil.

Since $H^i_{t+1}$ is a function of the variables at time $t$, which can be written as $H^i\left(P_t, k_t, q_t\right)$, let replace $H^i_{t+1}$ in the intolerance functions to have an optimal parental effort depending exclusively on the variables at $t$,

$$e^G(k_t, P_t, q_t) = C\theta(1-q_t)\Delta V^G(H^G\left(P_t, k_t, q_t\right)),$$
$$e^T(k_t, P_t, q_t) = C\theta q_t \Delta V^T(H^T\left(P_t, k_t, q_t\right)).$$

By substituting those functions in (16), we obtain the dynamic law of the share of type-$G$ agents. Therefore, in the system we are going to study, all variables are predeterminated.

**Definition 3** (Intertemporal Equilibirum)**.** *Let $(k_0, P_0, q_0)$ be the vector of intial values. The intertemporal equilibrium is the sequence $(k_t, P_t, q_t)_{t\in\mathbb{N}}$ which satisfies for each $t$, the following system of equations*[3]

$$k_{t+1} = -\frac{(1-b-\bar{h}(q_t))}{\gamma(n-\sigma')}P_t - \frac{(\beta v + \gamma v - \gamma)}{\gamma(n-\sigma')}k_t^v, \tag{17}$$
$$P_{t+1} = \frac{(b\sigma' + \bar{h}(q_t) - \sigma')}{(n-\sigma')}P_t - \frac{(\beta v + \gamma v - \gamma)\sigma'}{(n-\sigma')}k_t^v, \tag{18}$$
$$q_{t+1} = q_t + q_t(1-q_t)(e^G(P_t, k_t, q_t) - e^T(P_t, k_t, q_t)). \tag{19}$$

### 3.2 Steady states

**Proposition 4.** *Existence of steady sates with cultural transmission of environmental concern.*

*(1) If $A_1$ holds, the system admits two steady states. One is characterized by a perfectly homogeneous population of environnmentally concerned people : $(\bar{P}(1), \bar{k}(1), 1)$ and it is unstable. The other one is characterized by a heterogeneous population within which, the share of agents concerned about pollution is relatively high : $(\bar{P}(\bar{q}), \bar{k}(\bar{q}), \bar{q})$ with ($\bar{q} > \tilde{q}$), with $\tilde{q}$ defined as in Proposition (1). It can be stable for large combination of the parameters.*

*(2) If $A_1$ holds, the system will have only one steady state characterized by a perfectly homogeneous population of technologist agents : $(\bar{P}(0), \bar{k}(0), 0)$ which is unstable. There will have no heterogeneous steady state unless the impact of pollution on the socialization process be negligible.*

*Proof.* Existence of steady states.

A steady state of the three-dimensional system is a vector $(k, P, q)$ which solves $k_{t+1} = k_t$, $P_{t+1} = P_t$,

[2]In addition, $\frac{\partial e_t^T}{\partial q_t}(0) = C\theta\Delta V^T > 0$ and $\frac{\partial e_t^G}{\partial q_t}(1) = -C\theta\Delta V^G > 0$.

[3]The variable $q_t$ can be rationnal as long as we restrcit to the case $\Delta V^i : \mathbb{R} \to \mathbb{Q}$, $\forall i \in \{G, T\}$. Indeed, it implies $e^i \in \mathbb{Q}$ and hence $q_t \in \mathbb{Q}$. The behaviour of the dynamical system is decribed by a map $G : \mathbb{R}_2 \times \mathbb{Q} \to \mathbb{R}_2 \times \mathbb{Q}$. However, for the sake of simplicity, we study the same function $G$ which maps $\mathbb{R}_3$ into $\mathbb{R}_3$.

$q_{t+1} = q_t$ for all t. (As we have ever seen the point (0,0) solves the two first equations so that a vector (0,0,q) solves the whole system if q solves the third equation).

Let $S_1 = \{\{k(q), P(q)\}, q \in [0, \tilde{q}[\}$, and $S_2 = \{\{k(q), P(q)\}, q \in ]\tilde{q}, 1]\}$ be the sets of non-trivial steady states for the two-dimensional system respectively when $\beta v + \gamma v - \gamma$ is positive or negative. Necessary and sufficient conditions for the three-dimensional system to be at steady state is thus the vector $(\bar{P}, \bar{k})$ belongs to one either of the two sets (according to the sign of $\beta v + \gamma v - \gamma$) with q solving the third equation. That is $q = 0$, $q = 1$ and $q$ solving $e_t^G - e_t^P = 0$.
Hence $(\bar{P}(0), \bar{k}(0), 0)$ is a steady state of the whole system when $(\bar{P}(0), \bar{k}(0)) \in S_1$ and $(\bar{P}(1), \bar{k}(1), 1)$ is a steady state of the relevant system if $(\bar{P}(1), \bar{k}(1)) \in S_2$. Furthermore the third equation admits a solution for $q$ solving $e_t^G - e_t^T = 0$ which is equivalent to

$$\frac{1}{1-q} = 1 + \frac{\Delta V^G(H_{t+1}^G)}{\Delta V^T(H_{t+1}^P)}. \tag{20}$$

As we know that the solution of the whole system $(\bar{P}, \bar{k}, \bar{q})$ must be such that $(\bar{P}, \bar{k})$ are in either $S_1$ or $S_2$ we can fetch the solution in the restricted sets where $(\bar{P}, \bar{k})$ are solutions of the two-dimensional system. That is, in either of the two following sets : $S_1 \times [0, \tilde{q}[$ or $S_2 \times ]\tilde{q}, 1]$.

The system admits a fixed point $(\bar{k}, \bar{P}, \bar{q})$ where $0 < q < 1$ if the equation

$$\frac{1}{1-q} = 1 + \frac{\Delta V^G(P(q)(1-h_G))}{\Delta V^T(P(q)(1-h_P))}, \tag{21}$$

i. has at least one solution in $[0, \tilde{q}[$, when $\beta v + \gamma v - \gamma > 0$, $(\bar{P}(q), \bar{k}(q)) \in S_1$;

ii. has at least one solution in $]\tilde{q}, 1]$, when $\beta v + \gamma v - \gamma < 0$, $(\bar{P}(q), \bar{k}(q)) \in S_2$.

To study the existence of $q$ let define

$$\Psi(q) = \frac{1}{1-q}, \quad q \in [0, 1]$$

and

$$\Phi_1(q) = 1 + \frac{\Delta V^G(P(q)(1-h_G))}{\Delta V^T(P(q)(1-h_P))} = 1 + \frac{\Delta V^G(q)}{\Delta V^T(q)}, \quad q \in [0, \tilde{q}[\,, (P(q), k(q)) \text{ in } S_1,$$

$$\Phi_2(q) = 1 + \frac{\Delta V^G(P(q)(1-h_G))}{\Delta V^T(P(q)(1-h_P))} = 1 + \frac{\Delta V^G(q)}{\Delta V^T(q)}, \quad q \in ]\tilde{q}, 1]\,, (P(q), k(q)) \text{ in } S_2.$$

We need to determine wheither $\Phi_1(q) - \Psi(q) = 0$ admits a solution on $[0, \tilde{q}[$ on the one hand, and weither $\Phi_2(q) - \Psi(q) = 0$ has a solution on $]\tilde{q}, 1]$ on the other hand.

(1) Now let study the existence of some fixed points (different than the one where $q$ is zero) on $S_1 \times [0, \tilde{q}[$.

$\Psi$ is strictly increasing on $[0, \tilde{q}[$, $\Psi(0) = 1$ and $\Psi(\tilde{q}) = \frac{1}{1-\tilde{q}} > 1$.
On the other hand,

$$\forall q \in [0, \tilde{q}[ \quad \frac{d\Phi_1(q)}{dq} = \frac{dP(q)}{dq} \times \frac{\frac{d\Delta V^G(H^G(q))}{dH^G}(1-h_G)\Delta V^T(H^T(q)) - \frac{d\Delta V^T(H^T(q))}{dH^T}(1-h_T)\Delta V^G(H^G(q))}{(\Delta V^T(H^T(q)))^2}.$$

By assumption, $\frac{d\Delta V^G}{dH^G} > 0$ and $\frac{d\Delta V^P}{dH^P} < 0$. The second term of the product is thus positive and $\frac{\partial \Phi_1}{\partial q}$ has the same sign as $\frac{\partial P}{\partial q}$ on $[0, \tilde{q}[$. We know, from the study related to the economic sphere, that $\frac{\partial P(q)}{\partial q} > 0 \; \forall q \in [0, \tilde{q}[$ (see section 2.). So that $\Phi_1$ is strictly increasing on $[0, \tilde{q}[$.

Moroever, $\Phi_1(0) = 1 + \dfrac{\Delta V^G(0)}{\Delta V^P(0)}$ is strictly superior to 1 since, by assumption, the functions $\Delta V^G$ and $\Delta V^P$ are striclty positive as long as for $i \in \{G, T\}$ $H^i > 0$, which is true, since here $H^i = P(0)(1-h_i) > 0$.

Furthermore we have,

$$\begin{aligned}
\lim_{q \to \tilde{q}^-} \quad & P(q) = +\infty, \\
\lim_{H^G \to \infty} \quad & \Delta V^G(H^G) = \delta < \infty, \\
\lim_{H^P \to \infty} \quad & \Delta V^P(H^P) = 0,
\end{aligned}$$

so that $\Phi(\tilde{q}) = \lim_{q \to \tilde{q}^-} \Phi_1(q) = +\infty$[4].

Let define the continous function $g^1(q) = \Phi_1(q) - \Psi(q)$, we have $g^1(0) > 0$, $\lim_{q \to \tilde{q}^-} g^1(q) = \infty$. For $g^1(q) = 0$ to have solution on $[0, \tilde{q}[$, a necessary condition is $g^1$ to be decreasing on some interval $[q_1, q_2]$, with $q_1 \geq 0$ and $q_2 < \tilde{q}$, or $\frac{dg^1}{dq} = \frac{d\Phi_1}{dq} - \frac{d\Psi}{dq} < 0$ on $[q_1, q_2]$. That is, we need to find $\frac{d\Phi_1}{dq} < \frac{d\Psi}{dq}$ on the relevant interval. However, $\frac{d\Psi}{dq} = \frac{1}{(1-q)^2}$ is precisely low for low values of q, so that, the necessary condition does not hold if the derivative of $\Phi_1$ is not small enough. More particularly, $g^1$ must decrease sufficiently such that it reaches the x-axis. Then for that condition to be true, $\frac{dg^1}{dq}$ must be negative enough, that is $\frac{d\Phi_1}{dq}$ has to be very close to zero.

Therefore, a steady state is unlikely on $S_1 \times [0, \tilde{q}[$. It requires that the impact of a change in pollution on the transmission process $\frac{d\Phi_1}{dq}$ be negligible so that the effect of cultural substitution (a change in the cultural composition of the population), $\frac{d\Psi}{dq}$, which is weak, overcomes it[5].

(2) Let study the existence of solutions in $]\tilde{q}, 1]$.

[4] $\Delta V^G(H^G)$ cannot be infinite, otherwise the optimal effort, which stands for the probability of direct transmission, could be higher than one as long as $C$, or $\theta$, are not zero. Likewise, $\Delta V^T(H^T)$ must be finite in zero.

[5] To make sure of the unlikelihood of a steady state and to confirm the conditions on its existence, we relied on a numerical exemple. This is presented in Appendix.

$\Psi$ is strictly increasing on $]\tilde{q},1]$. $\Psi(1) = \lim_{q\to 1}\Psi(q) = +\infty$ and as we just noted $\Psi(\tilde{q})$ is a finite number which is superior to one.

On the other hand, the derivative of $\Phi_2$ on the interval $]\tilde{q},1]$ has the same sign as $\frac{\partial P}{\partial q}$ on the same interval. From our study we know that the latter is negative on $]\tilde{q},1]$. So that $\Phi_2$ is stictly decreasing on $]\tilde{q},1]$.

At q=1, $\Phi_2(1) = 1 + \dfrac{\Delta V^G(P(1)(1-h_G))}{\Delta V^P(P(1)(1-h_P))}$ is a finite number supeior to one.

Besides, $\lim_{q\to\tilde{q}^+} P(q) = +\infty$, hence $\Phi(\tilde{q}) = \lim_{q\to\tilde{q}^+}\Phi_1(q) = +\infty$.

Finally, we have $\Phi_2(\tilde{q}) > \Psi(\tilde{q})$ et $\Phi_2(1) < \Psi(1)$. $\Phi_2$ and $\Psi$ are both continous on $]\tilde{q},1]$. Moreover $\Psi$ is strictly increasing on $]\tilde{q},1]$, while $\Phi_2$ is decreasing on the same interval. According to the intermediate value theorem there is a unique $q \in ]\tilde{q},1]$ such that

$$\Psi(q) = \Phi_2(q)$$

. □

### 3.2.1 Interpretation regarding existence of a steady state

A steady state with an heterogeneous distribution of environmental attitudes always exists if the technology is such that abatement is quite effective compared to the strengh of consumption externality. The intuition is as follows : in that situation, as soon as pollution increases type-$G$ agents have incentive to increase abatement (unlike type-$T$). The larger the share of agents of type $G$, the higher the number of people who benefit more from a rise in abatement, the higher the rise in total abatement spendings. Hence, an increase in $q$ reduces the level of pollution. Both changes, in environmental conditions on the one hand, in the composition of the population on the other hand alter cultural attitudes in the same direction. Parents of type $G$ reduce their effort not only because transmission by peers works better but also because they feel a relatively lower gain to transmit their own trait since perceived pollution is lower. The reverse is true for individual of type-$T$ so that $q$ eventually decreases. When effectivness of abatement is low while consumption externality is quite high, a steady state associated with heterogeneous population is very unlikely. Actually, when the technology is polluting, as highlited in section 2., type-$T$ agents, as opposed to type-$G$, have incentive to abat more and save less after a rise in pollution (because of the opportunity cost of consumption). Contrary to the case of a clean technology, an increase in $q$ involves a rise of the pollution stock. On the one hand, the substitution effect enables a relative increase of type-$T$ parental effort against type-$G$ and allows a decrease of $q$. On the other hand, the rise in pollution alters relative parental efforts in the opposite direction and favours an increase of $q$. The system will admit a stationnary state if the overall effect is a decrease of $q$, i.e. the magnitude of the substitution effect is higher than the strengh of the impact of pollution. However when $q$ is small, which is precisely the case when the technology is polluting (remember we are working in $[0,\tilde{q}[$), the former effect is very weak. Hence $q$, the fraction of type-$G$ agents will further increases unless the effect of pollution on the socialization process is negligible. Finally, and contrary to the results we have got within our first model, when economic choices and cultural attitudes toward environment are jointly determined it is never sustainable to have a polluting technology, as long as pollution interacts in a non negligible way on the transmission of environmental concern. A clean technology and a high share of environmentally concerned people becomes the necessary and sufficient conditions for the existence of a steady state, that is for "sustainability".

## 3.3 Stability of steady states

### 3.3.1 Stability of the steady states with homogeneous population

**Proposition 5.** *Unstability of the homogeneous stationnary population.*

*(1) The steady state characterized by an homogeneous population of agents with environmental concern* $(\bar{P}(1), \bar{k}(1), 1)$ *(existing if (and only if) the technology is clean* $(\beta v + \gamma v - \gamma < 0)$*) is unstable.*

*(2) The steady state characterized by an homogeneous population of technologist agents* $(\bar{P}(0), \bar{k}(0), 0)$*, (existing if (and only if) the technology is polluting* $(\beta v + \gamma v - \gamma > 0)$*) is unstable.*

*Proof.* To study the local stability of each steady state let linearize the system consisting of equations (16), (17) and (18) around $(\bar{P}(0), \bar{k}(0), 0)$ on the one hand $(\beta v + \gamma v - \gamma > 0)$, and around $(\bar{P}(1), \bar{k}(1), 1)$, on the other hand $(\beta v + \gamma v - \gamma > 0)$.

(1) The Jacobian matrix evaluated at $(\bar{P}(0), \bar{k}(0), 0)$ is

$$\begin{pmatrix} \frac{-v(b\sigma' + \bar{h}(0) - 1)}{(1-\bar{h}(0))(n-\sigma')} & -\frac{(1-b-\bar{h}(0))}{\gamma(n-\sigma')} & \frac{\gamma(h^G - h^P)}{(n-\sigma')}\bar{P} \\ \frac{-\sigma'\gamma v(b\sigma' + \bar{h}(0) - 1)}{(1-\bar{h}(0))(n-\sigma')} & \frac{(b\sigma' + \bar{h}(0) - \sigma')}{(n-\sigma')} & \frac{(h^G - h^P)}{(n-\sigma')}\bar{P} \\ 0 & 0 & 1 + e^G(0) - e^T(0) \end{pmatrix}.$$

We can express its characteristic polynomial as

$$Q_1(\lambda) = ([1 + e^G(0) - e^T(0)] - \lambda)(\alpha_0\lambda^2 + \alpha_1\lambda + \alpha_2),$$

where $\alpha_0$, $\alpha_1$ and $\alpha_2$ are defined as in section 2.5. The second term of this product is precisely $P(\lambda)$, the characteristic polynomial of $Df_2$ defined in section 2.5, evaluated at $q = 0$. Hence, two of the eigenvalues can be of magnitude less than one as long as the two-dimensional system of section 2 is stable. That is $Df_2$ has two eigenvalues of magnitude less than one (which requires especially $\sigma' > n$). However, the third eignevalue is equal to $1 + e^T(0) - e^G(0)$. This is always higher than one since the socialization mechanism implies $e^G(0) > 0$ and $e^T(0) = 0$. Hence, the system consisting of (16), (17) and (18) is never stable around $(\bar{P}(0), \bar{k}(0), 0)$.

(2) The Jacobian matrix evaluated at $(\bar{P}(1), \bar{k}(1), 1)$ is

$$\begin{pmatrix} \frac{-v(b\sigma' + \bar{h}(1) - 1)}{(1-\bar{h}(1))(n-\sigma')} & -\frac{(1-b-\bar{h}(1))}{\gamma(n-\sigma')} & \frac{\gamma(h^G - h^P)}{(n-\sigma')}\bar{P} \\ \frac{-\sigma'\gamma v(b\sigma' + \bar{h}(1) - 1)}{(1-\bar{h}(1))(n-\sigma')} & \frac{(b\sigma' + \bar{h}(1) - \sigma')}{(n-\sigma')} & \frac{(h^G - h^P)}{(n-\sigma')}\bar{P} \\ 0 & 0 & 1 + e^T(1) - e^G(1) \end{pmatrix}.$$

Its characteristic polynomial can be express as

$$Q_2(\lambda) = ([1 + e^T(1) - e^G(1)] - \lambda)(\alpha_0\lambda^2 + \alpha_1\lambda + \alpha_2).$$

Again if stability holds for the two-dimensional system studied in section 2.5. (especially, $\sigma^{'} < n$), then two of the eigeinvalues are of magitude less than one. Then, the three-dimensional system is stable if and only if $\lambda_3 = 1 + e^T(1) - e^G(1)$, has absolute value less than one. However within our set up, $e^T(1) > 0$ while $e^G(1) = 0$, so that we always have $\lambda_3 > 1$ and the system consisting of (16), (17) and (18) is never stable around $(\bar{P}(1), \bar{k}(1), 1)$.

□

### 3.3.2 Stability of the steady state with heterogeneous population

When linearizing the system at $\left(\bar{P}(\bar{q}), \bar{k}(\bar{q}), \bar{q}\right)$, we obtain the following Jacobian matrix

$$\begin{pmatrix} \frac{-v(b\sigma^{'}+\bar{h}(\bar{q})-1)}{(1-\bar{h}(\bar{q}))(n-\sigma^{'})} & -\frac{(1-b-\bar{h}(\bar{q}))}{\gamma(n-\sigma^{'})} & \frac{\gamma(h^G-h^P)}{(n-\sigma^{'})}\bar{P} \\ \frac{-\sigma^{'}\gamma v(b\sigma^{'}+\bar{h}(\bar{q})-1)}{(1-\bar{h}(\bar{q}))(n-\sigma^{'})} & \frac{(b\sigma^{'}+\bar{h}(\bar{q})-\sigma^{'})}{(n-\sigma^{'})} & \frac{(h^G-h^P)}{(n-\sigma^{'})}\bar{P} \\ \frac{-G(\bar{q},\bar{P})\sigma^{'}\gamma v(b\sigma^{'}+\bar{h}(\bar{q})-1)}{(1-\bar{h}(\bar{q}))(n-\sigma^{'})} & \frac{G(\bar{q},\bar{P})(b\sigma^{'}+\bar{h}(\bar{q})-\sigma^{'})}{(n-\sigma^{'})} & 1+\frac{G(\bar{q},\bar{P})(h^G-h^T)\bar{P}}{(n-\sigma^{'})} + \bar{q}(1-\bar{q})\beta C(-\Delta V^T - \Delta V^G) \end{pmatrix},$$

where

$$G(\bar{q}, \bar{P}) = \bar{q}(1-\bar{q})\beta C\left((1-\bar{q})\frac{\partial \Delta V^G}{\partial H^T} - \bar{q}\frac{\partial \Delta V^T}{\partial H^T}\right).$$

Expressions of the eigenvalues are far more complicated so that we rely on a numerical exemple to study the local stability. Contrary to the other steady states, we find that this one could be stable for large combinations of the parameters. We also observe that $\sigma^{'} < n$ is still necessary for stability.

### 3.3.3 Interpreting stability

The steady state characterized by an homogeneous population, either in the clean technology case ($q = 1$) or when technology is polluting ($q = 0$), is always unstable whatever the interaction between the pollution generated by the economic sphere and the cultural composition of the population. Actually, what matters is the effect of economic choices on capital and pollution on the one hand, and the effect of cultural choices on the cultural composition of the population on the other hand. Hence no matter if the former effect enables the economy to converge to a stationnary state, the system will never be stable because cultural choices lead to move away from full homogeneity of the population. Actually, vertical and oblique transmission are cultural substitutes, so that, all else equal, parents have less incentives to socialize their children, the more widely dominant are their environmental values in the population. In the limit of a perfectly homogeneous population of type $G$ or $T$, parents of type $G$ or $T$, respectively, do not directly socialize their child. The cultural substitution property makes homogeneous distributions of environmental concern unstable.

Conversely, the stability of the steady state characterized by an heterogeneous population crucially depends upon the interaction between the economic sphere, and the cultural sphere which is linked to the value of $\sigma^{'}$. First, as long as $\sigma^{'} < n$, economic as well as cultural choices enable the convergence of capital and pollution stocks. Actually, the cultural composition of the population affects the economic sphere in strengthening the effect of economic choices on the stocks of capital and pollution. On the one hand, as more detailed in section 2, as long as $\sigma^{'} < n$ a rise in the bequeathed stock of pollution encourages agents to increase abatement and enables convergence toward a stationnary state (since abatement is efficient). On the other hand, agents of type $G$ are precisely those who increase more abatement since they are sensitive to pollution. Hence an increase of the share of type-$G$ agents allows for stability because it lowers the increase of capital and pollution in strenghtening the stabilizing effect of aggregated economic actions.

Secondly, the cultural choices enable the convergence toward the heterogeneous composition of the population. Importantly, when $\sigma^{'} < n$ the cultural substitution property holds, that is parental effort of type-$i$ decreases with the fraction of type-$i$. On the one hand, the technology of direct socialization allows for cultural substitution property : parents have less incentives to socialize their children whenever their cultural trait is more widely dominant because direct and oblique transmission act as substitutes. Nevertheless a sufficient condition for cultural substitution to hold, involves the impact of the distribution of environmental concern, at some $t$, on the next pollution stock. In fact, since pollution favours the transmission of environmental concern (through the intolerance functions), an increase of the fraction of environmentally concerned have to imply the reduction of pollution in order to reduce the desire to transmit. As we just point out in the first paragraph, it is precisely the case when $\sigma^{'} < n$.

Hence the system can converge to an heterogeneous steady state but $\sigma^{'} < n$ is a necessary condition.

Thereby, we find that, as long as the technology related to pollution is not clean enough, the economy will never converge toward a stationnary state. Instead, numerical applications show that all variables always increase (this is true for a large combination of the parameters). We can conclude, that after several iterations we will observe a high share of environmentally concerned individuals whatever the technology. If clean, then it has to be associated with pollution relatively close to stabilisation. If not clean enough however, it can only be associated with rising pollution.

### 3.4 A numerical application

In this section, we apply our model to a numerical exemple. We choose a parameters combination which meets the different constraints (including positivity of abatement): $h^G = 0,35$, $h^T = 0,9$, $\beta = 2,5$, $\gamma = 3$, $\upsilon = \frac{1}{3}$, $b = 0,3$, $\sigma^{'} = 0,4$, $\theta = 0,7$, $C = 2$. We also select some functional forms for the functions $\Delta V^i$. In particular we choose $\Delta V^G(H^G_{t+1}) = 1 - e^{-H^G_{t+1}}$ and $\Delta V^T(H^T_{t+1}) = e^{-H^T_{t+1}}$ (this choice is justified in appendix).

#### 3.4.1 The up and fall of pollution

As shown in figure 3, our model predicts a transition from a phase of increasing pollution to a declining one. However, this non-monotonic evolution is not an “inevitable” result of growth. Instead, here it is due to the casual dynamic relashionship with the composition of the population with regards to environmental attitudes.

Departing from a low share of agents concerned with the environment, whatever the initial stock of pollution, since slightly affected, agents consume a lot so that pollution significantly increases. This rise of pollution associated with a low fraction of environmentally concerned favors the transmission of this environmental attitude. Hence environmental concern develops, but as long as it is not widespread enough (and since preceeding stock have highly risen up), pollution still increases.

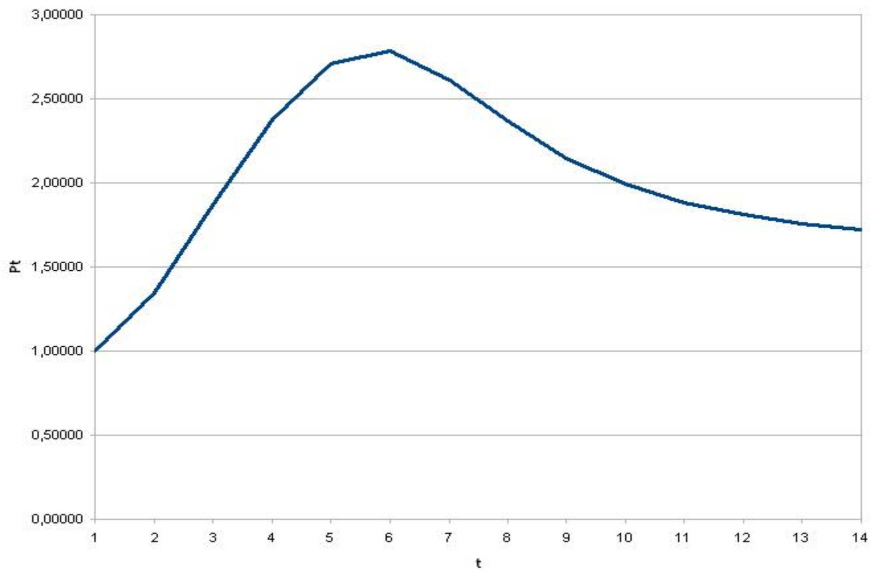


Figure 3: Evolution of $Pt$ ($P_0 = 1$, $k_0 = 0,1$, $q_0 = 0,05$)

However, at some $t$, further rise of pollution implies a sufficient increase in the share of environmentally concerned individuals such that pollution is reduced. Once, the share of agents concerned has reached this relatively high value, it necessarily varies within a relatively small interval. Indeed, the impact of cultural substitution as well as the slight effect of the limited decreases in pollution implie low variations of the distribution of environmental attitudes. Finally, since the fraction of environmenfirst increase of pollution followed by subsequent decreasestally concerned individuals remains high, pollution decreases continously.

Intuitively, the speed of transmission of the environmental concern determines the dynamics of pollution. Precisely we would like to put foward some factors which are involved and examine their precise role. Figures 4, 5, 6 represent the evolution of pollution for different values of $q_0$, the initial share of agents concerned with the environment.

As shown in those graphs, the initial distribution of environmental attitudes plays a crucial role with regards to the dynamic pattern of pollution. Indeed it determines the level as well as the turning point. Precisely, the higher the initial share of individual concerned with the environment, the more delated the reaching of the declining phase and the higher the maximum level of pollution.

We also look for the role of the transmission cost. The graphs on figures 7, 8, 9 represent the evolution of pollution for decreasing values of this cost (increasing values of the parameter $C$).

Likewise, this factor determines the level and timing of the turning point. Indeed, a higher transmission cost implies a higher maximum level of pollution and extends the phase of growing stocks of pollution.

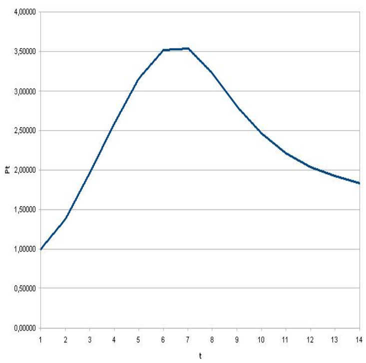

Figure 4: Evolution of $Pt$ ($P_0 = 1,\ k_0 = 0,1,\ q_0 = 0,02$)

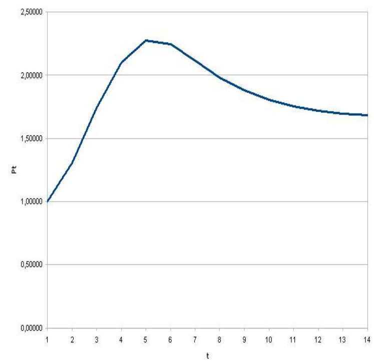

Figure 5: Evolution of $Pt$ ($P_0 = 1,\ k_0 = 0,1,\ q_0 = 0,10$)

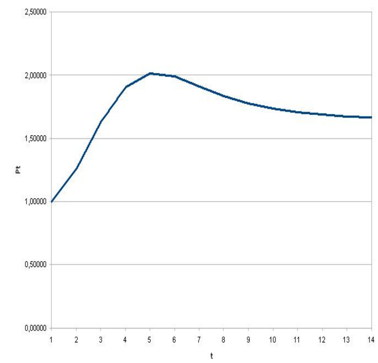

Figure 6: Evolution of $Pt$ ($P_0 = 1,\ k_0 = 0,1,\ q_0 = 0,15$)

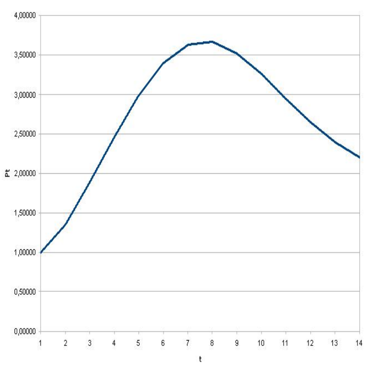

Figure 7: Evolution of $Pt$ for $C = 1$ ($P_0 = 1,\ k_0 = 0,1,\ q_0 = 0,05$)

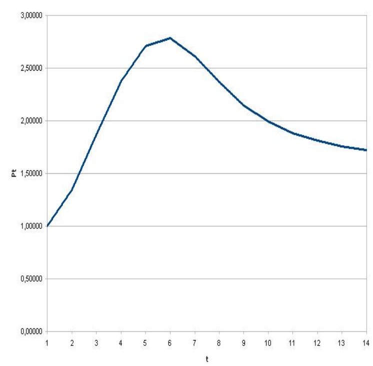

Figure 8: Evolution of $Pt$ for $C = 2$ ($P_0 = 1,\ k_0 = 0,1,\ q_0 = 0,05$)

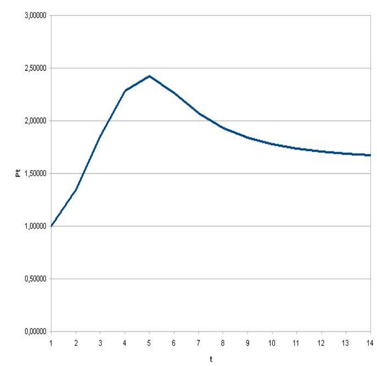

Figure 9: Evolution of $Pt$ for $C = 3$ ($P_0 = 1,\ k_0 = 0,1,\ q_0 = 0,05$)

### 3.4.2 Implications

First, this model can explain why some pollutions have reached significantly higher levels in some developed countries. For instance, it can account for the siginificantly higher levels of nitrogen dioxide emissions ($NO_2$) reached in the United States, which were twice the level observed in most industrialized countries, and particularly within European Union (such that although currently declining, those levels are still significantly higher in the U.S). Hence, this can be due to initially lower share of people with environmental concern, that is significantly higher proportion of agents firmly convinced about the ability of science to solve environmental issues.

As well, it can shed light on the reasons for the extremely higher levels reached by various pollutions in developing nations, which are now declining (in particular $SO_2$, TSP). Indeed, in those nations the opportunity cost of time is higher so that could be the cost of transmission.

Finally, this numerical application allows to study intersting policy implications. Indeed, any education policy trying to favor the transmission of environmental concern will provide significant welfare improvements. Imagine, for instance, an effort of the government $E$, which exogenously increases the direct transmission probability of trait $G$ (such that the new direct transmission probability of trait $G$ is now $e^{G'} = E \times C\theta(1-q_t)\Delta V^G(H^G_{t+1}))$[6]. As shown in the graph below such a policy entails short run welfare benefits because it reduces pollution along the transition path. Furthermore we can easily show that it provides long run benefits as well since it also reduces steady state pollution.

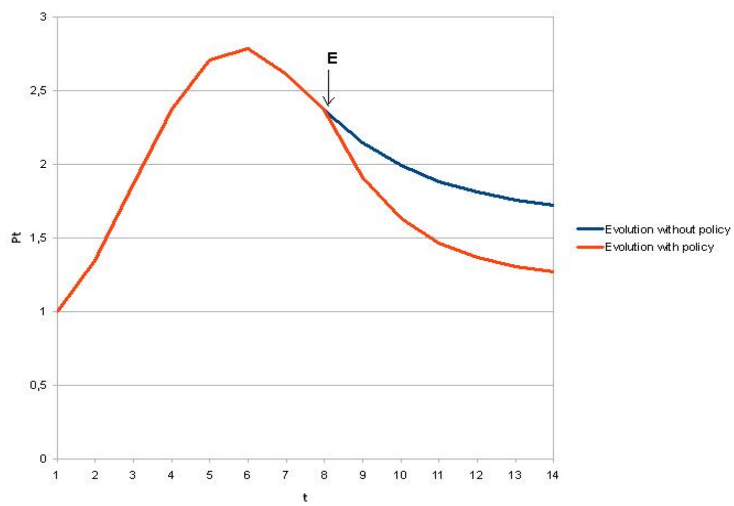


Figure 10: Evolution of $Pt$ before and after the implementation of an education policy ($P_0 = 1$, $k_0 = 0,1$, $q_0 = 0,05$)

[6]It can be any policy which targets children as, for instance, awarness workshops at primary school

## 4 Conclusion

The link between environmental concern and the reduction of environmental degradations, as well as the link between income and environmental concern are very often assumed to be consistently positive. Hence, few studies have been able to explain the spread of environmental concern in developing countries as well as the fact that it has been associated with an upward pattern of pollution in those nations. Our set up encompasses an original specification of environmental concern and allows to put forward an important factor, which is the ease of reducing pollution in terms of its opportunity cost in consumption units. Hence it sheds light on the role of the technology related to the accumulation of pollution. We show that it is not sufficient to have a high share of agents concerned with environmental issues and that the existence of a steady state also requires a clean pollution technology.

Furthemore endogenizing environmental attitudes, we can account for the spread of environmental concern in developing nations since it is not due to the income's rise, here, but to an intergenerational transmission process in which pollution interacts. Precisely, our model predicts that we will observe a high share of people concerned with the environment after several iterations. If technology is clean, on the one hand, it is associated with pollution relatively close to stabilize. But if not, it is associated with rising pollution.

Finally, a numerical application of our model predicts that for countries where technology is sufficiently clean, pollution increases and then declines. It is interesting since this non-monotonic evolution is not an "inevitable" product of growth but can be ascribable to the causual dynamic relashonship with the distribution of environmental attitudes. Hence implications in policy terms are rather different. Especially, we show that an education policy can have substantial beneficial effects for the short run as well as for the long run environment.

This setting encompasses several limitations which can be valuable extensions. First it could be appropriate to consider a political economy framework. Moroever, it would be interesting to consider endogenous pollution saving technical change and its relashionship with endogenous environmental attitudes.

# 5 Annexes

## 5.1 The unlikelihood of the steady state : a numerical exemple

To verify our conclusions concerning the existence of a steady state when $A_2$ holds, that is the technology is dirty (Proposition 3.2), we have drawn the functions $\Phi_1$ and $\Psi$ on $[0, \tilde{q}[$.
Fisrt we use the following parameters values : $h^G = 0,4$, $h^T = 0,96$, $\beta = 5$, $\gamma = 0,9$, $v = 0,25$, $b = 0,15$, $\sigma^{'} = 1.5$, which have been choosen such such that the different contraints imposed by the economic sphere were met, as well as the agent's abatement was positive.
In order to show that a steady state is unlikely we use different functional forms for the functions $\Delta V^G$ and $\Delta V^T$ (for which the few hypothesis of section 3 hold). Actually, we have made no assumptions on the marginal behaviour of the two functions of interest, but the likelihood of a steady state being linked to the growth rate of $\Phi_1$, in order to have stronger conclusions, it is interesting to test the existence for concave as well as for convexe forms. However some additional restrictions are needed. As highlighted in footnote 2, $\Delta V^G(H^G)$ must have a finite limite when $H^G$ tends to infinity, because $e^G$, as a probability, must be bounded by one. Therefore, since increasing and continous, $\Delta V^G(H^G)$ cannot be convexe on $\mathbb{R}_+$. It can be convexe on some interval, but it necessarily exists some $\tilde{H^G}$ such that for all $H^G \geq \tilde{H^G}$, $\Delta V^G(H^G)$ is concave. Besides, since $\Delta V^T$ is continous, decreasing and such that $\lim_{H^T \to \infty} \Delta V^T(H^T) = 0$, if concave, it cannot be on all its defintion set. Namely, it necessarily exists some $\tilde{H^T}$ such that for all $H^T \geq \tilde{H^T}$, $\Delta V^T(H^T)$ is convexe.
To keep some generality, we want to encompass those different cases. Hence, one the one hand, we consider functional forms such that $\Delta V^G(H^G)$ be concave on $\mathbb{R}_+$ and $\Delta V^T(H^T)$ be convexe on $\mathbb{R}_+$. On the other hand, we consider the case for which $\Delta V^G(H^G)$ is convexe on $[0, \tilde{H^G}]$ and $\Delta V^T(H^T)$ is concave on $[0, \tilde{H^T}]$, where, for $i \in \{G, T\}$, $\tilde{H^i}$ is defined such that $\Delta V^i$ has an inflexion point in $\tilde{H^i}$.
Moroever, we must also take into account the fact that the two functions have to be bounded. We have assumed, $\Delta V^G(H^G) \in [0, \delta_G]$. In addition, we must have $\Delta V^G(H^G) \in [0, \delta_T]$. Namely $\Delta V^T(0)$ must be finite since $e^T$ has to be always lower than one.

For the concave/convexe case, we choose the following functional forms,

$$\Delta V^G(H^G) = a - ae^{\frac{-H^G}{b}} \qquad \text{and} \qquad \Delta V^T(H^T) = ae^{\frac{-H^T}{b}}, \tag{22}$$

and, for the case with an inflexion point we select,

$$\Delta V^G(H^G) = a - ae^{\frac{-{H^G}^2}{b}} \qquad \text{and} \qquad \Delta V^T(H^T) = ae^{\frac{-{H^T}^2}{b}}. \tag{23}$$

The value set is $[0, a[$ for $\Delta V^G$, $]0, a]$ for $\Delta V^T$, so that $C$ can always be choosen such that $e^G$ and $e^T$ are lower than one. We will not try several values of $a$ because it will not impact the function $\Phi_1$ (since it simplifies in the ratio $\frac{\Delta V^G}{\Delta V^T}$). However, the parameter $b$ does affect $\Phi_1$. Precisely, the lower $b$, the lower $|\frac{d\Delta V^i}{dH^i}|$. Hence by varying $b$, we are able to assess the importance for the existence of a steady state, of the magnitude of $\frac{d\Delta V^i}{dH^i}$, or similarly of $\Phi_1^{'}$. In other words, we can check the importance of the impact of pollution on the evolution of environmental concern.

Figures 1, 2, 3 are the graphs for the funtion $\Phi_1^b(q) = 1 + \frac{1-e^{(-P(q)(1-h^G)\frac{1}{b})}}{e^{(-P(q)(1-h^T)\frac{1}{b})}}$ where b takes different values. For figures 4,5 and 6 we used the funtion $\Phi_1^b(q) = 1 + \frac{1-e^{((-P(q)(1-h^T))^2\frac{1}{b})}}{e^{((-P(q)(1-h^P))^2\frac{1}{b})}}$, drawn for the same values of b.

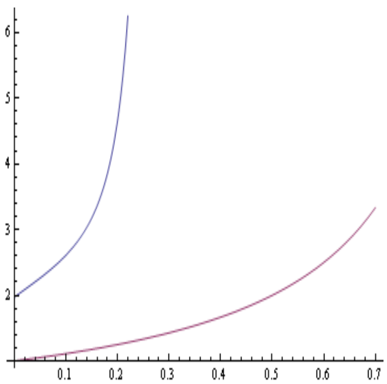


Figure 11: $b = 1$

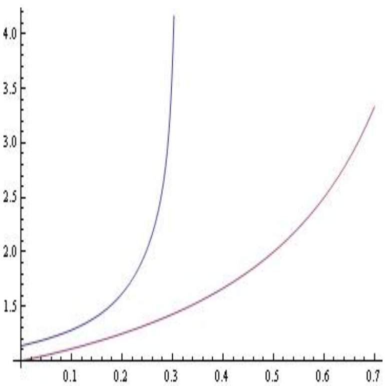


Figure 12: $b = 10$

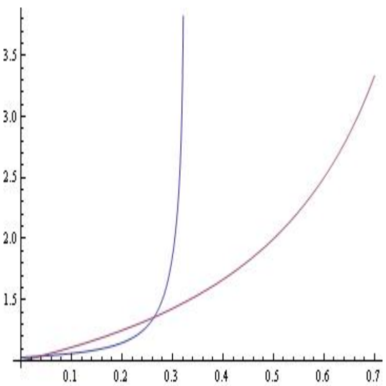


Figure 13: $b = 50$

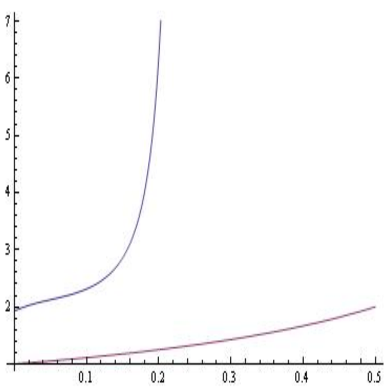


Figure 14: $b = 1$

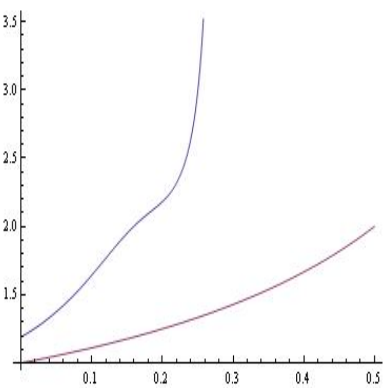


Figure 15: $b = 10$

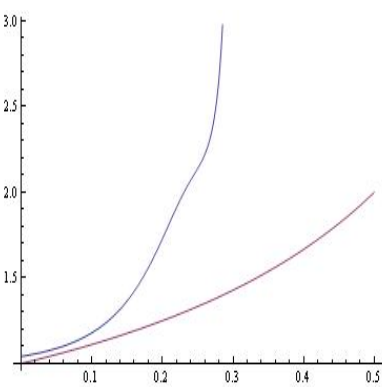


Figure 16: $b = 50$

For this numerical exemple, a steady state exists only on Figure 3 which confirms that it is unlikely. Moroever, as $b$ is reduced, the two curves comes closer such that they are closer to intersect. Finally, an intersection point exits only when $b$ is very small ($b = \frac{1}{50}$ for the first kind of functions and less than $\frac{1}{50}$ for the other kind). Hence the derivative of $\Phi_1$ plays a crucial role in the existence of a steady state, precisely, it has to be very small.

## 5.2 An other socialization mechanism

For the consistency of our results, we study a different mechanism for the cultural transmission of environmental values. We assume that socialization is still the result of direct as well as oblique transmission and that parents try to socialize their child to their own perception. Yet we consider that the role played by pollution is different. Previously, we assumed that pollution interacts with parents' preferences for the transmission of their own trait. Now, let suppose that pollution interacts with children's acceptance of the parental trait. That is, a child with a parent of type G will be socialized to trait G with a higher probability whenever pollution during its childhood is relatively high. As opposed, a child of type T will accept the trait T with a higher probability whenever pollution is lower. The rest of the mechanism is the same except that the cultural intolerance $\Delta V^i$, if still positive, is now exogenous.

Let $\tau^i$ be the probability for a child of type i to be directly socialized, we assume $\tau^i = \tau^i\left(e_t^i, P_t\right)$ where $e_t^i$ is the type-$i$ parental effort and $P_t$ is the pollution when child.

**Assumption 2.** *For all $i \in \{G, T\}$, $\tau^i : \mathbb{R}^{+2} \to [0,1]$. Furthermore,*

1. *The function $\tau^G$ is such that,*
   - *a.* $\frac{\partial \tau^G}{\partial e^G} > 0$
   - *b.* $\frac{\partial \tau^G}{\partial P} > 0$
   - *c.* $\frac{\partial^2 \tau^G}{\partial e^G . \partial P} > 0$
   - *d.* $\tau^G(0, P) = 0$
   - *e.* $\forall P,\ \lim_{e^G \to \infty} \tau^G\left(e^G, P\right) = 1$
   - *f.* $\forall e^G,\ \tau^G\left(e^G, 0\right) = \alpha_1,\ \alpha_1 \in ]0,1]$
   - *g.* $\forall e^G > 0,\ \lim_{P \to \infty} \tau^G\left(e^G, P\right) = 1$
   - *h.* $\frac{\partial^2 \tau^G}{\partial e^{G2}} \leq 0$
   - *i.* $\forall P,\ \frac{\partial \tau^G}{\partial e^G}(0, P) = \alpha_1 > 0$
2. *The function $\tau^T$ is such that,*
   - *a.* $\frac{\partial \tau^T}{\partial e^T} > 0$
   - *b.* $\frac{\partial \tau^T}{\partial P} < 0$
   - *c.* $\frac{\partial^2 \tau^T}{\partial e^T . \partial P} < 0$
   - *d.* $\tau^T(0, P) = 0$
   - *e.* $\forall P,\ \lim_{e^T \to \infty} \tau^T\left(e^T, P\right) = 1$
   - *f.* $\forall e^T,\ \tau^G\left(e^T, 0\right) = \alpha_2 > 0,\ \alpha_2 \in ]0,1]$
   - *g.* $\forall e^T > 0,\ \lim_{P \to \infty} \tau^T\left(e^T, P\right) = 0$
   - *h.* $\frac{\partial^2 \tau^T}{\partial e^{T2}} \leq 0$
   - *i.* $\forall P,\ \frac{\partial \tau^T}{\partial e^T}(0, P) = \alpha_2 > 0$

Hypothesis 1.c means that the parental effort of type-$G$ and the pollution are joint inputs in production of direct socialization probability, as opposed to 2.c which means exactly the reverse. Others hypothesis are quite intuitive.

### 5.2.1 Agents'choices

Agents of either type choose $\tau^i$ to maximise

$$\theta\left(P_t^{ii} V_t^{ii} + P_t^{ij} V_t^{ij}\right) - C\left(e^i\right),$$

where the transition probabilities are given by

$$P_t^{GG} = \tau\left(e_t^G, P_t\right) + (1 - \tau\left(e_t^G, P_t\right))q_t \qquad P_t^{GT} = (1 - \tau\left(e_t^G, P_t\right))(1 - q_t)$$
$$P_t^{TT} = \tau\left(e_t^T, P_t\right) + (1 - \tau\left(e_t^T, P_t\right))(1 - q_t) \qquad P_t^{TG} = (1 - \tau\left(e_t^T, P_t\right))(q_t).$$

The FOC give $e_t^{G*}$ and $e_t^{T*}$ as implicit continous functions of $q_t$ and $P_t$,

$$\frac{\partial \tau^G}{\partial e^G}\theta(1 - q_t)\Delta V^G - \frac{e_t^G}{C} = 0 \qquad \frac{\partial \tau^T}{\partial e^T}\theta q_t \Delta V^T - \frac{e_t^P}{C} = 0.$$

The optimal direct transmission maps are continous functions of $q_t$ and $P_t$ which can be determinated by replacing with the optimal effort functions,

$$\tau^{G*} = \tau^{G}\left(e_t^{G*}(q_t, P_t), P_t\right) = \tau^{G*}(q_t, P_t),$$
$$\tau^{T*} = \tau^{P}\left(e_t^{T*}(q_t, P_t), P_t\right) = \tau^{T*}(q_t, P_t).$$

The intertemporal equilibrium is as in definition 2, except that the functions of direct transmission probability are replaced by the functions $\tau^{i*}(q_t, P_t)$.

### 5.2.2 Steady states

**Proposition 6.** *Existence of steady states*

*The results obtained in section three hold.*

*Proof.* Let $S_1$ and $S_2$ be defined as in section 3. The necessary and sufficient conditions for the system to be at steady state are still the vector $(\bar{P}(q), \bar{k}(q))$ belongs to either $S_1$ or $S_2$ with q solving the third equation. That is $q = 0$, $q = 1$ or $\bar{q}$ such that $\tau^{G^*}(\bar{q}, P_t) - \tau^{T^*}(\bar{q}, P_t) = 0$[7]. Hence, the two steady states characterized by full homogeneity of the population still exist. $(\bar{P}(0), \bar{k}(0), 0)$ is a steady state if the vector $(\bar{P}(0), \bar{k}(0))$ is in $S_1$ and $(\bar{P}(1), \bar{k}(1), 1)$ is a steady state if $(\bar{P}(1), \bar{k}(1))$ belongs to $S_2$. Furthermore, the system admits a fixed point in $S_1 \times [0, \tilde{q}[$, if $\tau^{G*}(q, P(q)) - \tau^{T*}(q, P(q)) = 0$ has at least one solution in $[0, \tilde{q}[$ while it admits a fixed point in $S_2 \times ]\tilde{q}, 1]$, if $\tau^{G^*}(q, P(q)) - \tau^{T^*}(q, P(q)) = 0$ has at least one solution in $]\tilde{q}, 1]$.

(1)Let begin by studying the existence of solutions in $]\tilde{q}, 1]$. On the one hand we have,

$$\frac{\partial \tau^{G^*}}{\partial q} = \frac{\partial \tau^{G^*}}{\partial e^G}\frac{\partial e^{G^*}}{\partial q} + \frac{\partial \tau^{G^*}}{\partial P}\frac{\partial P}{\partial q}. \tag{24}$$

The second part of the above sum is negative since, by assumption 1.b, $\frac{\partial \tau^G}{\partial P} > 0$ while we have shown in section 2. that $\frac{\partial P}{\partial q}$ is negative on $S_1 \times [0, \tilde{q}[$. By the implicit function theorem applied at the FOC, we have,

$$\frac{\partial e^{G^*}}{\partial q} = -\frac{\frac{\partial^2 \tau^G}{\partial e^G . \partial P} \cdot \frac{\partial P}{\partial q} .(1-q).\theta.\Delta V^G - \frac{\partial \tau^G}{\partial e^G}.\theta.\Delta V^G}{\frac{\partial^2 \tau^G}{\partial e^{G^2}}.(1-q).\theta.\Delta V^G - \frac{1}{C}}. \tag{25}$$

The denominator is strictly negative since $\tau^G$ is assumed to be concave in $e^G$. Besides $\frac{\partial^2 \tau^G}{\partial e^G . \partial P} \cdot \frac{\partial P}{\partial q}.(1-q).\theta.\Delta V^G < 0$ since $\frac{\partial P}{\partial q}$ is strictly negative, while by assumption, $\frac{\partial^2 \tau^G}{\partial e^G . \partial P} > 0$. $\frac{\partial \tau^G}{\partial e^G}$ is assumed to be strictly positive so that the numerator is strictly negative. Hence, $\frac{\partial e^{G^*}}{\partial q} < 0$. Finally, we have $\frac{\partial \tau^{G^*}}{\partial q} < 0$, or the function $\tau^{G^*}$ is strictly decreasing on $]\tilde{q}, 1]$.

[7]There is also a trivial steady sate given by (0,0,q) with $q = 0$ or $q = 1$ or $\bar{q}$.

On the other hand, we have,

$$\frac{\partial \tau^{T*}}{\partial q} = \frac{\partial \tau^{T*}}{\partial e^T}\frac{\partial e^{T*}}{\partial q} + \frac{\partial \tau^{T*}}{\partial P}\frac{\partial P}{\partial q}, \tag{26}$$

whose second part is positive since we assume $\frac{\partial \tau^T}{\partial P} < 0$. By the implicit function theorem,

$$\frac{\partial e^{T*}}{\partial q} = -\frac{\frac{\partial^2 \tau^T}{\partial e^G . \partial P} . \frac{\partial P}{\partial q} . q . \theta . \Delta V^T + \frac{\partial \tau^T}{\partial e^T} . \theta . \Delta V^T}{\frac{\partial^2 \tau^T}{\partial e^{T2}} . q . \theta . \Delta V^T - \frac{1}{C}}. \tag{27}$$

Again, the denominator is strictly negative since $\tau^T$ is also concave in $e^T$. Besides, by assumption 2.a, $\frac{\partial \tau^T}{\partial e^T} > 0$ so that the numerator is positive if $\frac{\partial^2 \tau^T}{\partial e^T . \partial P} . \frac{\partial P}{\partial q} . q . \theta . \Delta V^T > 0$. This is the case since we assume $\frac{\partial^2 \tau^T}{\partial e^T . \partial P} < 0$. Hence $\frac{\partial e^{T*}}{\partial q} > 0$ so that $\frac{\partial \tau^{T*}}{\partial q}$ is strictly positive and the function $\tau^{T*}$ is strictly increasing on $]\tilde{q}, 1]$.

Furthermore, $e^{G*}(1) = 0$ which implies $\tau^{G*}(1) = \tau^G(e^{G*}(1), P(1)) = \tau^G(0, P(1)) = 0$. Besides, we have $\tau^{T*}(1) = \tau^G(e^{T*}(1), P(1)) > 0$, as long as $e^{T*}(1)$ is a finite positive. Suppose not. Then by the implicit definition of $e^{T*}$, we would necessarily have $\frac{\partial \tau^T}{\partial e^T}$ tends to infinity. But this is precisely impossible since $e^{T*}(1)$ is infinite while $\tau^T$ is concave in $e^T$ and $P(1)$ is finite. Hence $e^{T*}(1)$ is a finite positive number.
Hence $\tau^{G*}(1) < \tau^{T*}(1)$.

Moroever, $e^{G*}(\tilde{q}) > 0$ and $\lim_{q \to \tilde{q}} P(q) = +\infty$ so that $\tau^{G*}(\tilde{q}) = 1$ by assumption 1.d. On the other hand, $e^{T*}(1) > e^{T*}(\tilde{q}) > 0$ since $e^{T*}(q)$ is strictly increasing on $]\tilde{q}, 1]$. It enables to be sure that $e^{T*}(\tilde{q})$ is a finite number since $e^{T*}(1)$ is finite. Hence $\tau^{T*}(\tilde{q}) = 0$ since P tends to infinity.
Thus, $\tau^{G*}(\tilde{q}) > \tau^{T*}(\tilde{q})$.

Finally, $\tau^{G*}$ is decreasing and continous while $\tau^{G*}$ is increasing and continous and we have $\tau^{G*}(1) < \tau^{T*}(1)$ on the one hand, and $\tau^{G*}(\tilde{q}) > \tau^{T*}(\tilde{q})$ on the other hand. Hence, we can conclude that equation $\tau^{G*}(q) - \tau^{T*}(q) = 0$ has aunique solution on $]\tilde{q}, 1]$, so that the system admits a unique fixed point on $S_2 \times ]\tilde{q}, 1]$.

(2) Now let study the existence of some steady states (different than the one where q is zero) on $S_1 \times [0, \tilde{q}[$.

First, we have $e^{G*}(0) > 0$, which implies $\tau^{G*}(0) > 0$.
Indeed it is implicitely defined by $\frac{\partial \tau^G}{\partial e^G}(e^{G*}(0), P(0))\theta\Delta V^G - \frac{e^{G*}(0)}{C} = 0$. Suppose $e^{G*}(0) = 0$, then $\frac{\partial \tau^G}{\partial e^G}(0, P(0)) = 0$. However, by assumption, $\frac{\partial \tau^G}{\partial e^G}(0, P) = \alpha_1 > 0 \ \forall P$. Thereby, $e^{G*}(0)$ strictly differs from zero which implies that $\tau^{G*}(0) > 0$.
Besides, $e^{G*}(\tilde{q}) > 0$ so that $\tau^{G*}(\tilde{q}) = 1$.
To highlight that, suppose not. Then $\frac{\partial \tau^G}{\partial e^G}(0, P(\tilde{q})) = 0$ but this is equal to $\alpha_1$ so that $e^{G*}(\tilde{q})$ has

to be strictly positive. Therefore, $\tau^{G*}(\tilde{q}) = \lim_{P\to\infty} \tau^G(e^G, P) = 1$.

On the other hand, we necessarily have $e^{T^*}(0) = 0$ which implies $\tau^{T^*}(0) = 0$.
Moroever we can show that $\tau^{T^*}(\tilde{q}) = 0$.
Indeed since $P$ tends to infinity when $q$ tends to $\tilde{q}$, $\tau^{T^*}(q)$ tends to 0 at least when $e^{T^*}(\tilde{q})$ is a finite number. Suppose it is not, then $\frac{\partial \tau^T}{\partial e^T}\left(e^{G*}(\tilde{q}), P(\tilde{q})\right)$ must tend to infinity but this is precisely impossible since $\frac{\partial \tau^T}{\partial e^T}$ is decreasing with $e^T$ as well as with P while both are infinite. This confirms that $e^{T^*}(\tilde{q})$ is finite so that $\tau^{T^*}(\tilde{q}) = 0$.

Hence, $\tau^{G^*}(0) > \tau^{T^*}(0)$ and $\tau^{G^*}(\tilde{q}) > \tau^{T^*}(\tilde{q})$. To characterize some conditions for the existence of steady states, let define the function $g^2(q) = \tau^{G^*}(q) - \tau^{T^*}(q)$. It is continous and such that $g^2(0) > 0$, $g^2(\tilde{q}) = 1$. A steady state exists if, and only if, $g^2(q) = 0$ has some solutions on $[0, \tilde{q}[$ which requires (at least) that $g^2$ be decreasing on some interval $[{q_1}', {q_2}']$ where ${q_1}' \geq 0$ and ${q_2}' < \tilde{q}$. $\frac{dg^2}{dq} < 0$ is equivalent to $\frac{d\tau^{G^*}}{dq} - \frac{d\tau^{T^*}}{dq} < 0$, which can be rewritten as

$$\frac{\partial \tau^{G^*}}{\partial P}\frac{\partial P}{\partial q} - \frac{\partial \tau^{T^*}}{\partial P}\frac{\partial P}{\partial q} < \frac{\partial \tau^{T^*}}{\partial e^T}\frac{\partial e^{T^*}}{\partial q} - \frac{\partial \tau^{G^*}}{\partial e^G}\frac{\partial e^{G^*}}{\partial q}, \tag{28}$$

Or the effect of pollution on the direct transmission probabilities, which is positive in this case, has to be lower than the impact of the parental efforts on those probabilities. As easily observable, a necessary condition fot this condition to hold, is $\frac{\partial e^{T^*}}{\partial q} > 0$ and $\frac{\partial e^{G^*}}{\partial q} < 0$. The right-hand side can also be decomposed into two distinct parts so that (28) can be rewritten as

$$\frac{\partial \tau^{G^*}}{\partial P}\frac{\partial P}{\partial q} - \frac{\partial \tau^{T^*}}{\partial P}\frac{\partial P}{\partial q} + \left(\frac{\partial \tau^{G^*}}{\partial e^G}\frac{\partial P}{\partial q}\right)\frac{-\frac{\partial^2 \tau^G}{\partial e^G . \partial P}}{\frac{\partial^2 \tau^G}{\partial {e^G}^2} - \frac{1}{C.(1-q).\theta.\Delta V^G}} - \left(\frac{\partial \tau^{T^*}}{\partial e^T}\frac{\partial P}{\partial q}\right)\frac{\frac{-\partial^2 \tau^T}{\partial e^T . \partial P}}{\frac{\partial^2 \tau^T}{\partial {e^T}^2} - \frac{1}{C.q.\theta.\Delta V^T}}$$

$$< \frac{\partial \tau^{T^*}}{\partial e^T}\frac{\frac{\frac{\partial \tau^{T^*}}{\partial e^T}}{q}}{\frac{\partial^2 \tau^T}{\partial {e^T}^2} - \frac{1}{C.q.\theta.\Delta V^T}} - \frac{\partial \tau^{G^*}}{\partial e^G}\frac{\frac{\frac{\partial \tau^{G^*}}{\partial e^G}}{(1-q)}}{\frac{\partial^2 \tau^G}{\partial {e^G}^2} - \frac{1}{C.(1-q).\theta.\Delta V^G}}$$

This means that the total impact of a change in pollution, which encompasses an effect on the probabilities of direct transmission and an "indirect" effect on the optimal parental effort (the second part of the sum on the left-hand side) must be lower than the "cultural substitution" effect induced by a change in the cultural composition of the population.
For this expression to be true, the right-hand side of this inequation (the relative deviation between the marginal variation of the two parental efforts after an increase in $q$) has to be high enough. Note that $\frac{1}{qC\theta\Delta V^T}$ and $\frac{1}{(1-q)C\theta\Delta V^G}$ are negligible as long as for all i, $C\theta\Delta V^i$ is not very close to zero. Let suppose furthermore, that the variations of the second derivatives are negligible compared to the variations of the first derivatives (it can be zero if the second derivatives are constant). Therefore, the relative deviation crucially depends on

$$\frac{(\frac{\partial \tau^{T^*}}{\partial e^T})^2}{q} - \frac{(\frac{\partial \tau^{G^*}}{\partial e^G})^2}{(1-q)} = 1 - \frac{q}{(1-q)} \times \frac{(\frac{\partial \tau^{G^*}}{\partial e^G})^2}{(\frac{\partial \tau^{T^*}}{\partial e^T})^2}.$$

On the one hand, $\frac{q}{(1-q)}$ is low for low values of $q$ (see section 3.). On the other hand, if the necessary condition for $\frac{dg^2}{dq} < 0$ holds, that is $\frac{\partial e^{G^*}}{\partial q} < 0$ and $\frac{\partial e^{T^*}}{\partial q} > 0$, then, by the concavity of the $\tau^{i^*}$, $\frac{\frac{\partial \tau^{G^*}}{\partial e^G}}{\frac{\partial \tau^{T^*}}{\partial e^T}}$

is also precisely low for low values of q.

Hence, when $q$ belongs to $[{q_1}', {q_2}']$, the right hand side of the inequation is particularly low, so that the left-hand side has to be close to zero. Therefore a steady state will not exist if the total impact of pollution on the socialization process is not negligible.

Therefore, we can conclude that, on $S_1 \times [0, \tilde{q}[$, the existence of some steady states is not likely, especially, it will never exist as long as the overall impact of the pollution on the socialization process is not negligible.

$\square$

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