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Stéphane Bouché
Universitat de les Illes Balears

Leonor Modesto
Universidade Católica Portuguesa and IZA

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IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

Altruism, Human Capital and Environmental Preservation in a Globalized Economy

This paper analyzes the impact of trade openness on education and environmental preservation choices in a two country model where both countries only differ in their shares of skilled workers. Parents may invest in their children's education increasing their probability to become skilled and in maintenance investment in order to preserve present and future environmental quality. Under autarky, unskilled individuals in the skill scarce economy are unable to invest in education due to borrowing constraints. Moreover, only skilled individuals of the latter economy choose to invest in environmental preservation. Openness to trade modifies relative factor prices and increases pollution. This allows for human capital convergence between both economies and induces all skilled individuals to contribute to environmental preservation in the free trade equilibrium. However, overall environmental quality decreases, suggesting a potential trade-off between income convergence at the global level and environmental preservation. We also focus on the optimal allocation under free trade and conclude that a maintenance investment subsidy should be implemented for skilled individuals but not necessarily for unskilled ones.

JEL Classification: D64, F18, F64, I25

Keywords: altruism, environmental preservation, international trade, human capital

Corresponding author:
Stéphane Bouché
Universitat de les Illes Balears
Department of Applied Economics
Carretera de Valldemossa, km 7.5
07122 Palma de Mallorca
Spain

E-mail: s.bouche@uib.es

1 Introduction

The intergenerational aspects of education and environmental maintenance decisions have given rise to a large set of theoretical contributions in economics. In this paper, we study the impact of trade openness on individuals' decisions concerning these particular intergenerational investments.

The literature on education and social mobility has highlighted the importance of indivisible investment and borrowing constraints. Under these assumptions the models of Galor and Zeira (1993) and Eckstein and Zilcha (1994) generate different skill classes and intergenerational income inequality. Individuals with lower wages might not be able to invest in their children's education thus generating persistence in intergenerational income inequality. On the empirical side, using cross country and panel data, Flug et al. (1998) show that the lack of financial markets seems to have a negative impact on human capital accumulation. Using a sample of 78 countries, Christou (2001) documents that the severity of borrowing constraints is inversely related to human capital accumulation. While these findings are particularly salient in developing countries, the intergenerational income correlation in countries like the U.S. also seems to confirm the importance of borrowing constraints.[1] However, by affecting relative factor prices, openness to trade might play an important role in relaxing borrowing constraints and fostering human capital accumulation. Owen (1999) provides empirical evidence on the positive relationship between trade openness and investment in human capital. Arbache et al. (2004) find that education levels rose in Brazil after trade liberalization, while Edmonds et al. (2010) document that trade liberalization in India reduced the costs of schooling.

In the theoretical contributions of Cartiglia (1997) and Ranjan (2001) trade might foster human capital accumulation. In Cartiglia (1997), trade liberalization in a skill-scarce country reduces the returns to education but also the cost of latter. The weakening of credit constraints results in higher investment in human capital. In Ranjan (2001) the effect operates through the changes in the distribution of income and wealth. However, these papers do not solve for the autarky equilibrium, analyzing instead the impact of trade openness on a small open economy. Our contribution is closer to the work of Ranjan (2003), who considers a North-South model, and shows that trade might allow an economy stuck in a poverty trap to converge to the equilibrium of the high-income economy. We depart from the framework of Ranjan (2003) in two respects. First, while Ranjan (2003) considers warm-glow altruism, we assume dynastic altruism as in Barro (1974).[2] Second and most importantly, we consider that individuals value environmental

[1]Concerning the U.S., Solon (1992) obtains a correlation around 0.4 while Charles and Hurst (2003) find the pre-bequest correlation in log wealth to be equal to 0.37. Keane and Wolpin (2001) estimate a structural model for the U.S. and conclude that borrowing constraints are indeed severe.

[2]Dynastic altruism implies that parents' utility depends on their children's utility, which in turn depends on expected wages.

quality and can voluntary contribute to environmental preservation. We thus study jointly the implications of trade openness on both investment in education and environmental preservation choices.

The literature on environmental preservation has highlighted the limited capacity of short-lived individuals to take into account the impact of their decisions on future generations (see, e.g., John and Pecchenino, 1994; Bovenberg and Heijdra, 1998). In most models that consider short-lived individuals, the latter are not altruistic towards their children and only take into account the impact of environmental quality on their own utility. A few contributions have however integrated altruistic behavior in models with environmental constraints. Jouvet et al. (2000) introduce dynastic altruism into a standard overlapping generations (OLG) model with environmental quality and physical capital. Asheim and Nesje (2016) consider a two-sector model where one form of capital is more productive than the other but leads to negative environmental externalities. Finally, Karp (2017) in an OLG model with paternalistic altruism, considers a differential game setting where the only state variable is related to environmental quality. In all cases, the presence of altruism is not sufficient to achieve the first-best outcome due to the public good nature of environmental quality, a point already highlighted earlier by Howarth and Norgaard (1995). In this paper, we follow the approach of Jouvet et al. (2000) and consider an OLG model with dynastic altruism. This implies that there exists an individual threshold value for the altruism factor, above which individuals are ready to contribute to environmental maintenance investment. This threshold value depends on individual income and on the level of environmental quality that would prevail in the absence of individual environmental investment. By affecting the income of individuals and the level of environmental quality in the absence of environmental investment, openness to trade modifies the threshold value and in turn the incentive of individuals to contribute to environmental preservation.

There has been an increasing number of empirical studies investigating the link between openness to trade and environmental quality. Most of the evidence from these studies is mixed. For example, Frankel and Rose (2005) estimate the effect of trade on environmental quality for a given level of income per capita and conclude that there is little evidence of environmental degradation. Baek et al. (2009) show that trade and income positively affected environmental quality in developed countries and China. Managi et al. (2009) find that most of the results depend on the pollutant and the country considered. Trade is found to benefit environmental quality in OECD countries, and the authors highlight that the impact is large in the long-run, after the dynamic adjustment process has taken place. Finally, Le et al. (2016) use cross-country panel data and find a negative relationship between trade openness and environmental quality for their global sample of 98 countries. However, results seem to vary significantly with income differences. Empirical evidence thus seems to suggest that, following trade openness, environmental quality might increase or decrease. In our framework, trade openness will affect both pollution and the willingness to invest in environmental quality. Therefore, the full impact of trade on environmental quality will depend on the relative magnitude of those two effects.

An account of the results is as follows. Considering two countries that only differ in their share of skilled workers we find that, in the autarky equilibrium, all individuals in the skill-abundant economy are able to invest in their children's education, while unskilled workers are constrained in the skill-scarce economy. Concerning environmental maintenance, our autarky equilibrium is characterized by positive investment only from skilled individuals in the skill-scarce economy. Openness to trade modifies relative factor prices and allows unskilled individuals in the latter economy to invest in education, while preserving the initial situation in the skill-abundant economy. The additional number of skilled workers increases pollution and, combined with the change in wages, modifies the willingness of individuals to invest in environmental preservation. Therefore, the level of environmental quality at the free trade equilibrium can both increase or decrease, depending on the relative importance of these two effects. However, in our numerical example we find that environmental quality decreases, implying a potential trade-off between income convergence and environmental preservation. We then focus on the optimal allocation under free trade and conclude that a maintenance investment subsidy must be implemented for skilled individuals, while this is not necessarily the case for unskilled ones due to their large marginal utility of consumption.

The paper is organized as follows. Section 2 presents the model. In Section 3 we characterize the autarky equilibrium. In Section 4 we study the impact of trade openness on education and environmental preservation investment. Section 5 presents some numerical simulations in order to highlight the main results of the paper. Section 6 focuses on the optimal allocation under free trade, while section 7 presents our concluding remarks. A final appendix contains all the proofs.

2 The model

Consider a world consisting of two economies that only differ in terms of the stock of skilled workers. For simplicity we label North the economy with a larger share of skilled workers and South the economy with a smaller share of skilled workers. Variables in the South are indexed by an asterisk.

2.1 Production

The production side of the economy is similar to Ranjan (2003). Each economy produces a unique non-tradable final good Y using two tradable intermediate goods X^s and X^u.

The production of the final good is given by

$$Y = A(X^s)^{1-\alpha}(X^u)^{\alpha},$$

where $\alpha \in (0,1)$ is the share of X^u in production and A the level of TFP. The final good is used for consumption and chosen as the numeraire. The prices of the two intermediate inputs are denoted by p^s and p^u. There is perfect competition in the three product markets. The optimal choice for intermediate inputs then implies

$$p^s = (1-\alpha)A(X^s)^{-\alpha}(X^u)^{\alpha}, \quad (1)$$

$$p^u = \alpha A(X^s)^{1-\alpha}(X^u)^{\alpha-1}. \quad (2)$$

Then, we can easily obtain the demand for the two inputs as

$$X^s = \frac{(1-\alpha)Y}{p^s},$$

$$X^u = \frac{\alpha Y}{p^u},$$

implying that relative demand is given by

$$\frac{X^s}{X^u} = \frac{(1-\alpha)p^u}{\alpha p^s}.$$

There are two factors of production: skilled labor S and unskilled labor U, which are used to produce the intermediate goods. Total population in both economies is equal to $L > 1$ so that $S + U = L$. The wage of a skilled worker is denoted by w^s and the one of an unskilled worker by w^u.

As in Cartiglia (1997), there is an education sector which requires skilled workers as teachers. We suppose that a constant teacher-students ratio γ is needed, with $\gamma \in [0,1)$, so that

$$S^e = \gamma M,$$

where M is the number of students and S^e the number of teachers. In each period, the supply of skilled workers will be divided between the education sector S^e and the production of intermediate inputs S^s, so that $S = S^e + S^s$.

For algebraic simplicity and following Ventura (1997), we assume that X^s only uses skilled labor while X^u uses only unskilled labor. The production functions for the intermediate inputs are then given by $X^s = S^s$ and $X^u = U$. As we also assume perfect competition in the two factors markets, optimality implies that $p^s = w^s$ and $p^u = w^u$.

From the full-employment condition for the two factors of production, the relative supply of intermediate inputs is

$$\frac{X^s}{X^u} = \frac{S^s}{U}.$$

The market clearing condition for intermediate goods implies therefore the following

$$\frac{p^u}{p^s} = \frac{w^u}{w^s} = \frac{\alpha(S - S^e)}{(1-\alpha)(L-S)}, \tag{3}$$

so that relative prices and wages are uniquely determined by the number of skilled workers and teachers in the economy.

2.2 Household behavior

We consider an OLG model where each individual lives for two periods, having a descendant at the beginning of the second period of life. We also assume that each individual only makes decisions, consumes and works during the second period of his life. Young individuals just go to school, and can become skilled following the investment of their parents in education. Individuals are supposed to be altruistic towards their children, which may lead them to invest in their descendant's education and in environmental maintenance. We assume the following utility function with dynastic altruism, for an adult individual at period t:

$$V_t = u(c_t) + v(N_t) + \beta E(V_{t+1}),$$

where c_t is his consumption, N_t the aggregate level of environmental quality and $E(V_{t+1})$ the expected utility of his direct descendant. Finally $\beta \in (0,1)$ is the altruism factor. We assume that both functions $u(.)$ and $v(.)$ are twice continuously differentiable with $u'(.) > 0$, $u''(.) < 0$, $v'(.) > 0$, $v''(.) < 0$ for all $c > 0$ and $N > 0$. In addition, the Inada conditions $\lim_{c\to 0} u'(c) = \infty$, $\lim_{c\to\infty} u'(c) = 0$, $\lim_{N\to 0} v'(N) = \infty$ and $\lim_{N\to\infty} v'(N) = 0$ hold.

The evolution of environmental quality is given by

$$N_t = N_{t-1} + b(H - N_{t-1}) - \kappa(Y_t^* + Y_t) + \eta Z_t,$$

where $H > 0$ is the natural level of environmental quality and $0 < b < 1$ is the recovery speed of the environment. We assume that world output is the only polluting activity and that pollution abatement occurs according to a linear technology. Denoting by $Z_t \geq 0$ the total amount of resources devoted to environmental maintenance investment, the improvement of environmental quality at time t amounts to ηZ_t. Moreover $\eta > \kappa > 0$ implying that the net effect of producing one unit of output and devoting it to environmental maintenance is positive.

We take the standard approach of a Cournot-Nash equilibrium where each individual takes the others' contributions to the public good as given. So, from the point of view of an individual, environmental quality evolves according to

$$N_t = N_{t-1} + b(H - N_{t-1}) - \kappa(Y_t^* + Y_t) + \eta \overline{Z}_t + \eta z_t^h,$$

where $\overline{Z} \geq 0$ is the sum of other individuals' contributions and z^h the individual contribution of agent h. At each period, environmental maintenance contributions must be non-negative, i.e., $z_t^h \geq 0$ for all h and t.

Since education employs skilled workers, the individual cost of tuition is given by the wage of a teacher multiplied by the teacher-students ratio, that is γw_s. The budget constraint of an individual of type i, where $i = \{s, u\}$, is then given by $w_t^i = c_t^i + \gamma w_t^s + z_t^i$ if the individual invests in education and by $w_t^i = c_t^i + z_t^i$ if she does not invest in education. When an individual invests in education, her child will obtain a level of education $e = 1$ and become a skilled worker with probability π. When parents do not invest in their children's education, a young individual receives a lower education level $\overline{e}$, which is also its probability to become skilled. For education to remain valuable, we impose $\overline{e} < \pi$.

It should be noted that since $\gamma < 1$, a skilled individual can always choose to invest in the education of its child. On the contrary, it is possible that an unskilled worker is constrained. This happens when $w^u < \gamma w^s$. We should thus distinguish between the case where unskilled workers are constrained, $w^u < \gamma w^s$, and the case where no one is constrained, $\gamma w^s < w^u < w^s$.

Since the educational investment decision of parents is a discrete choice, the individual must compare its utility in both situations $j = \{\varepsilon, n\varepsilon\}$, where $j = \varepsilon$ if she invests in the education of her child and $j = n\varepsilon$ if she does not. The value function of an individual of type i, with $i = \{s, u\}$, such that $w^i > \gamma w^s$, is then given by

$$V_t^i = \max\left\{V_t^{i,\varepsilon}, V_t^{i,n\varepsilon}\right\}$$

where $V_t^{i,j}$, with $j = \{\varepsilon, n\varepsilon\}$, is the solution of the following problem

$$\begin{aligned}
V_t^{i,j}(N_{t-1}) &= \max\left\{u(c_t^{i,j}) + v(N_t) + \beta\phi_j V_{t+1}^s(N_t) + \beta(1-\phi_j)V_{t+1}^u(N_t)\right\}, \\
s.t. \qquad z_t^{i,j} &\geq 0, && (4)\\
c_t^{i,j} &= w_t^i - \gamma d_j w_t^s - z_t^{i,j}, && (5)\\
N_t &= N_{t-1} + b(H - N_{t-1}) - \kappa(Y_t^* + Y_t) + \eta\overline{Z}_t^{i,j} + \eta z_t^{i,j}, && (6)
\end{aligned}$$

where $z_t^{i,j}$ denotes the individual contribution to environmental maintenance at time t of an individual of type i with education decision j, while $\overline{Z}_t^{i,j}$ denotes the contributions of the other individuals so that $Z_t = \overline{Z}_t^{i,j} + z_t^{i,j}$. Moreover $\phi_j = \pi$ if $j = \varepsilon$ and takes the value $\overline{e}$ otherwise. Also d_j is a variable that takes the value 1 if $j = \varepsilon$ and takes the value zero otherwise.

Let $\rho_t^{i,j}$, $\lambda_t^{i,j}$, and μ_t be the multipliers associated to constraints (4), (5) and (6) respectively. The first-order and envelope conditions are

$$\begin{aligned}
u'(c_t^{i,j}) &= \lambda_t^{i,j}, \\
\eta\mu_t + \rho_t^{i,j} &= \lambda_t^{i,j}, \\
v'(N_t) + \beta V'_{t+1}(N_t) &= \mu_t, \\
\rho_t^{i,j} z_t^{i,j} &= 0, \\
V'_t(N_{t-1}) &= (1-b)\mu_t.
\end{aligned}$$

We then obtain

$$\rho_t^{i,j} = u'(c_t^{i,j}) - \eta[v'(N_t) + \beta V'_{t+1}(N_t)],$$

and

$$\beta V'_{t+1}(N_t) = \beta(1-b)[v'(N_{t+1}) + \beta V'_{t+2}(N_{t+1})].$$

Combining both expressions and substituting forward, we obtain

$$\rho_t^{i,j} = u'(c_t^{i,j}) - \eta \sum_{k=0}^{\infty} [\beta(1-b)]^k v'(N_{t+k}). \tag{7}$$

This expression characterizes the intratemporal allocation between consumption and environmental quality. Since individuals are altruistic, they will take into account the impact of environmental preservation on their descendants' welfare. If $z_t^{i,j} > 0$, as $\rho_t^{i,j} = 0$, we obtain

$$u'(c_t^{i,j}) = \eta \sum_{k=0}^{\infty} [\beta(1-b)]^k v'(N_{t+k}),$$

implying that the marginal utility of consumption is equal to the discounted sum of marginal utilities of environmental quality. The individual takes into account the impact of maintenance investment on all the following generations with an effective discount factor equal to $\beta(1-b)$. If $z_t^{i,j} = 0$, as $\rho_t^{i,j} > 0$, we obtain

$$u'(c_t^{i,j}) > \eta \sum_{k=0}^{\infty} [\beta(1-b)]^k v'(N_{t+k})$$

implying that the marginal utility of consumption is larger than the marginal benefit of investing in environmental preservation.

Returning now to the educational investment of parents we have that

$$\begin{aligned} V_t^{i,\varepsilon} &= u(w_t^i - \gamma w_t^s - z_t^{i,\varepsilon}) + v(N_t) + \beta\pi V_{t+1}^s + \beta(1-\pi)V_{t+1}^u, \\ V_t^{i,n\varepsilon} &= u(w^i - z_t^{i,n\varepsilon}) + v(N_t) + \beta\overline{e}V_{t+1}^s + \beta(1-\overline{e})V_{t+1}^u \end{aligned}$$

where $z_t^{i,\varepsilon}$ and $z_t^{i,n\varepsilon}$ denote the optimal choices. Therefore, an individual of type i with $w^i > \gamma w^s$ will invest in education if and only if

$$\beta(\pi - \overline{e})(V_{t+1}^s - V_{t+1}^u) \geq u(w_t^i - z_t^{i,n\varepsilon}) - u(w_t^i - \gamma w_t^s - z_t^{i,\varepsilon}). \tag{8}$$

Expression (8) states that the discounted benefit of investing in education must be larger or equal to the current utility loss due to this investment.[3]

3 Autarky equilibrium

In the following, we restrict our attention to steady-state equilibria. This is the standard approach in models with dynastic altruism (see, for example Jouvet et al., 2000; Alonso-Carrera et al., 2007). In addition, as discussed in the introduction, the impact of trade openness on environmental quality seems to be large in the long run when the dynamic adjustment has already taken place (Managi et al., 2009).

3.1 Investment in environmental maintenance

We first focus on investment in environmental maintenance. At the steady-state, using expression (7) we obtain

$$\rho^{i,j} = u'(c^{i,j}) - \frac{\eta}{1-\beta(1-b)}v'(N), \tag{9}$$

with

$$\rho^{i,j} z^{i,j} = 0.$$

These expressions are similar to the ones obtained in Jouvet et al. (2000) where there is no intragenerational heterogeneity.

When an individual of type i with education choice j chooses to not contribute to environmental maintenance ($z^{i,j} = 0$), as $\rho^{i,j} > 0$, using (9) and (6) evaluated at the steady state, we have that

$$\frac{\eta}{1-\beta(1-b)}v'\left(H - \frac{1}{b}[\kappa(Y^* + Y) - \eta\overline{Z}^{i,j}]\right) \leq u'(w^i - \gamma d_j w^s). \tag{10}$$

[3]We assume that in the case where the individual is indifferent, he will invest in education.

Therefore, the willingness to invest in environmental maintenance is a function of the altruism factor β. Indeed, there exists a threshold value

$$\overline{\beta}^{i,j} = \frac{1}{(1-b)} \left(1 - \frac{\eta v'(H - \frac{1}{b}[\kappa(Y^* + Y) - \eta \overline{Z}^{i,j}])}{u'(w^i - \gamma d_j w^s)} \right), \tag{11}$$

above which individuals of type i with education decision j are ready to contribute to environmental maintenance. If $\beta < \overline{\beta}^{i,j}$, the marginal cost of maintenance investment is larger than the marginal utility of environmental quality and the optimal level of contribution is equal to zero. If $\beta \geq \overline{\beta}^{i,j}$, the marginal cost of maintenance investment is equal to the marginal utility of environmental quality and the optimal level of contributions is positive. In this last case $\rho^{i,j} = 0$ and the optimal level of contributions for an individual of type i with education choice j, $z^{i,j} > 0$, solves

$$u'(w^i - \gamma d_j w^s - z^{i,j}) = \frac{\eta}{1 - \beta(1-b)} v'(N), \tag{12}$$

where

$$N = H - \frac{1}{b}[\kappa(Y^* + Y) - \eta(\overline{Z}^{i,j} + z^{i,j})]. \tag{13}$$

The next proposition characterizes the behavior of any two agents with different net wages concerning environmental contributions.

Proposition 1. *Consider two agents* 1 *and* 2 *that differ in terms of net wages so that* $w^1 - \gamma d_j^1 w^s > w^2 - \gamma d_j^2 w^s$*:*

1. *Either* $z^{1,j} > z^{2,j} \geq 0$ *or* $z^{1,j} = z^{2,j} = 0$.
2. *If* $z^{1,j} > z^{2,j} > 0$*, then* $c^{1,j} = c^{2,j}$ *and the difference in terms of environmental contributions* $z^{1,j} - z^{2,j} = (w^1 - \gamma d_j^1 w^s) - (w^2 - \gamma d_j^2 w^s) > 0$.
3. *If* $z^{1,j} > z^{2,j} = 0$ *or* $z^{1,j} = z^{2,j} = 0$*, then* $c^{1,j} > c^{2,j}$.
4. *For any* $z^{i,j} > 0$*:*

$$\frac{dz^{i,j}}{d\beta} = -\frac{(1-b)u'(c^{i,j})}{[1 - \beta(1-b)]u''(c^{i,j}) + \eta^2 v''(N)/b} > 0. \tag{14}$$

Proof. See Appendix A $\square$

Several important conclusions can be drawn from Proposition 1. First, all individuals that decide to invest in environmental maintenance enjoy the same consumption level and the difference in income is allocated to additional environmental contributions. If the individual is sufficiently altruistic, the weight of its descendants' utility in terms of environmental quality and education level outweighs a possible increase in consumption. If we interpret the altruism factor as a standard discount factor, our model highlights that if the discount factor is sufficiently large, individuals are ready to reduce consumption today in order to provide additional utility to their descendants tomorrow.

Second, environmental quality is a normal good since individuals with a larger net wage always allocate higher amounts of resources to environmental preservation. Third, the consumption level of individuals that invest in environmental maintenance is always larger than the one of individuals that are not willing to invest in environmental maintenance. Finally, expression (14) provides the impact of an increase of the altruism factor on environmental contributions. The level of individual contribution increases with the level of altruism while the consumption level decreases. The more altruistic are individual agents, the more they are ready to reduce their consumption level in order to increase their offspring's welfare.[4]

Our next step consists in establishing a ranking of net wages between our four type of agents. In order to establish the latter, we need to analyze the education investment decision of individuals agents.

3.2 Investment in education

We start by deriving a condition under which unskilled individuals are constrained at the steady-state, which using (3) is equivalent to

$$\frac{w^u}{w^s} = \frac{\alpha(S - S^e)}{(1-\alpha)(L-S)} < \gamma.$$

When the latter inequality is satisfied, unskilled individuals do not invest in education so that, as $M = S$, we have $S^e = \gamma S$ and the previous condition can be written as

$$S < \underline{S} = \frac{\gamma(1-\alpha)L}{\alpha(1-\gamma) + \gamma(1-\alpha)}. \tag{15}$$

We are interested in an equilibrium where in the South economy, unskilled individuals are constrained so that $S^* < \underline{S}$ while in the North economy, all individuals are able to invest in education so that $S > \underline{S}$. However, in the latter economy we also need to ensure that $w_s > w_u$ so that there is an incentive to invest in a child's education. This is always the case provided that

$$\frac{w^u}{w^s} = \frac{\alpha(S - S^e)}{(1-\alpha)(L-S)} < 1.$$

[4]Note that if we had $b = 1$, the level of consumption would not depend on the level of altruism. In this case, the level of environmental quality is not transmitted from one generation to the next and the only incentive to invest in environmental maintenance is related to life-cycle utility.

In the following we will focus on the case where all individuals invest in education in the North economy so that $S^e = \gamma L$, the previous condition becoming

$$S < \overline{S} = [1 - \alpha(1 - \gamma)]L, \tag{16}$$

and in the North economy $\underline{S} < S < \overline{S}$. The next Proposition derives a condition under which all non-constrained individuals decide to invest in their children's education.

Proposition 2. *Denote by σ the steady state value of the coefficient of relative risk aversion. In the North and the South, all non-constrained agents invest in education if and only if*

$$\sigma \leq \min\{\sigma_s, \sigma_n\},$$

where for the South economy σ_s solves

$$\beta(\pi - \overline{e}) = \frac{u(w^s - z^{s,n\varepsilon}) - u[(1-\gamma)w^s - z^{s,\varepsilon}]}{u(w^s - z^{s,n\varepsilon}) - u(w^u - z^{u,n\varepsilon})},$$

while for the North economy σ_n solves

$$\beta(\pi - \overline{e}) = \frac{u(w^u - z^{u,n\varepsilon}) - u(w^u - \gamma w^s - z^{u,\varepsilon})}{u[(1-\gamma)w^s - z^{s,\varepsilon}] - u(w^u - \gamma w^s - z^{u,\varepsilon})}.$$

Proof. See Appendix B □

Proposition 2 shows that all non-constrained individuals will decide to invest in education if for a given value of $\beta > 0$, the coefficient of relative risk aversion in consumption σ is sufficiently small. In this case, individuals are ready to reduce present consumption in order to increase their children's probability to become skilled from $\overline{e}$ to π. Individuals have a higher incentive to invest in education the larger the altruism factor β as well as the difference between π and $\overline{e}$. Note that for a given value of σ, investment in education cannot be guaranteed since the latter might require $\beta > 1$. In the forthcoming numerical analysis, we will choose a specific value for the coefficient of relative risk aversion and compute the range of values for β that ensure positive investment in education on the part of all non-constrained agents.

In the following, we focus on a steady-state equilibrium where $\beta < 1$ and the conditions presented in Proposition 2 are always satisfied. However, we still need to ensure that the steady-state values of skilled workers in both economies are compatible with restrictions (15) and (16). In the South, where only skilled agents invest in education, the difference equation governing the number of skilled workers is given by

$$S^*_{t+1} = \pi S^*_t + \overline{e}(L - S^*_t),$$

which at the steady-state equilibrium implies

$$S^* = \frac{\overline{e}L}{1-\pi+\overline{e}}. \tag{17}$$

In the North, where all agents invest in education, the difference equation governing the number of skilled workers is simply given by

$$S_{t+1} = \pi L,$$

which directly implies

$$S = \pi L. \tag{18}$$

Using expressions (15), (16), (17) and (18), to ensure that $S^* < \underline{S} < S < \overline{S}$ we formulate the following assumption.

Assumption 1. *The following parameter restriction is satisfied:*

$$\frac{\overline{e}}{1-\pi+\overline{e}} < \frac{\gamma(1-\alpha)}{\alpha(1-\gamma)+\gamma(1-\alpha)} < \pi < 1-\alpha(1-\gamma).$$

The latter assumption ensures that unskilled individuals are constrained in the South while they are not in the North but the wage of skilled workers is still larger than the one of unskilled workers in the latter economy.

3.3 Wages and production

Having obtained the number of skilled workers S and the number of teachers S^e in each country, we are now able to derive a ranking of net wages for all types of individuals.

Lemma 1. *In the equilibrium without trade, $w^{u*} < w^u - \gamma w^s < (1-\gamma)w^s < (1-\gamma)w^{s*}$ if and only if*

$$(1-\gamma)\overline{e} < \pi - \gamma, \tag{19}$$

and

$$\left[\frac{(1-\gamma)\overline{e}}{\pi-\gamma}\right]^{1-\alpha} < 1 - \frac{\gamma(1-\alpha)(1-\pi)}{\alpha(\pi-\gamma)}. \tag{20}$$

Proof. See Appendix C ☐

In the previous lemma, condition (19) ensures $U/S^e < U^*/S^{e*}$ so that the ratio of unskilled to skilled workers is larger in the South which implies $w^s < w^{s*}$. Condition (20) not only requires the latter inequality to be satisfied but also the difference between U/S^e and U^*/S^{e*} to be sufficiently large so that $w^{u*} < w^u - \gamma w^s$. Indeed, it can be noted that w^{u*} is decreasing in U^*/S^{e*} while $w^u - \gamma w^s$ is decreasing in U/S^e.

Having characterized the ranking of wages, it is useful to determine which economy produces a larger amount of the final good given its quantities of skilled and unskilled labor. In this case, we are looking for conditions guaranteeing that $Y > Y^*$, so that output is increasing in the amount of skilled workers. Using the quantity of skilled workers and students in both economies, the quantity of the final good produced in both economies is given by:

$$Y = A(\pi - \gamma)^{1-\alpha}(1-\pi)^{\alpha} L, \tag{21}$$

and

$$Y^* = \frac{A[(1-\gamma)\overline{e}]^{1-\alpha}(1-\pi)^{\alpha} L}{1-\pi+\overline{e}}. \tag{22}$$

A necessary and sufficient condition for output in the North to be larger than in the South is

$$\left[\frac{(1-\gamma)\overline{e}}{\pi-\gamma}\right]^{1-\alpha} < 1-\pi+\overline{e}. \tag{23}$$

As expected, a larger share of the skilled intermediate input, $1-\alpha$, in the production of the final good increases the output difference between North and South. The parameters increasing the number of skilled workers in both economies, π and $\overline{e}$, have an ambiguous effect on this output difference since a larger number of skilled individuals in the North also implies the need for teachers in order to educate these additional students. Finally, the output difference is decreasing in the teacher-student ratio, γ, since the larger amount of skilled individuals in the North requires also a larger amount of teachers for education purposes. In the following, we assume that condition (23) is always satisfied so that final output is increasing in the number of skilled individuals.

3.4 Individual threshold values of the altruism factor and environmental contributions

We now return to the decision to contribute to environmental maintenance. Recall that a given individual will only invest in environmental maintenance if the altruism factor is larger than its personal threshold value, i.e., if $\beta > \overline{\beta}^{i,j}$, with $\overline{\beta}^{i,j}$ given in (11). From (11) we observe that the altruism factor for which individuals start to contribute to the public good is smaller for wealthier individuals, implying that environmental maintenance investment is increasing in income.

Since in the South only skilled individuals invest in education, while in the North both skilled and unskilled workers invest in the education of their offspring, we denote by $\overline{\beta}^{i}$ the threshold value of the altruism factor of an individual of type i in the North and by $\overline{\beta}^{i*}$ the corresponding threshold value in the South. We have that $\overline{\beta}^{s} = \overline{\beta}^{s,\varepsilon}$, $\overline{\beta}^{u} = \overline{\beta}^{u,\varepsilon}$, $\overline{\beta}^{s*} = \overline{\beta}^{s*,\varepsilon}$ and $\overline{\beta}^{u*} = \overline{\beta}^{u*,n\varepsilon}$.

Proposition 3. *In the autarky equilibrium, the threshold values of the altruism factor satisfy* $\overline{\beta}^{s*} < \overline{\beta}^{s} < \overline{\beta}^{u} < \overline{\beta}^{u*}$.

Proof. See Appendix D □

In our Cournot-Nash setting, any individual i foresees correctly that if $\beta = \overline{\beta}^{i,j}$, any other individual with an income smaller than $w^i - \gamma d_j w^s$ will choose a contribution level equal to zero following the results obtained in Proposition 1.

We now focus on the equilibrium values of environmental quality. For a given individual, if $\overline{\beta}^{i,j} < \beta < 1$, the level of private voluntary contributions $z^{i,j}$ solves (12)-(13). Depending on the actual level of the altruism factor β, several cases could be considered. We then formulate the following assumption.

Assumption 2. *The common altruism factor satisfies*

$$\overline{\beta}^{s*} < \beta < \overline{\beta}^{s} < \overline{\beta}^{u} < \overline{\beta}^{u*}.$$

The latter assumption implies that in the autarky equilibrium, only skilled agents in the South decide to invest in environmental maintenance. We focus on this particular equilibrium since it corresponds to the numerical results obtained in section 5. Using (13) we can compute the steady-state value of environmental quality which is given by

$$N = H - \frac{\kappa A(1-\pi)^{\alpha}}{b}\left\{(\pi-\gamma)^{1-\alpha} + \frac{[(1-\gamma)\bar{e}]^{1-\alpha}}{1-\pi+\bar{e}}\right\}L + \frac{\eta\bar{e}z^{s*}}{b(1-\pi+\bar{e})}L, \tag{24}$$

where z^{s*} is the solution to the following equation:

$$u'[(1-\gamma)w^{s*} - z^{s*}] = \frac{\eta}{1-\beta(1-b)}v'(N). \tag{25}$$

From Proposition 1 and Lemma 1 we conclude that in the competitive equilibrium $c^{s*} > c^{s} > c^{u} > c^{u*} > 0$ and $z^{s*} > z^{s} = z^{u} = z^{u*} = 0$.

We also derive the steady-state utilities for our four type of agents. In the North, the steady-state utility of a skilled individual is given by

$$V^s = u(c^s) + v(N) + \beta[\pi V^s + (1-\pi)V^u],$$

while for an unskilled individual we have

$$V^u = u(c^u) + v(N) + \beta[\pi V^s + (1-\pi)V^u].$$

Combining both expressions, we obtain

$$V^s = u[(1-\gamma)w^s] + \frac{1}{1-\beta}\{\beta\pi u[(1-\gamma)w^s] + \beta(1-\pi)u(w^u - \gamma w^s) + v(N)\},$$

and

$$V^u = u(w^u - \gamma w^s) + \frac{1}{1-\beta}\{\beta(1-\pi)u(w^u - \gamma w^s) + \beta\pi u[(1-\gamma)w^s] + v(N)\}.$$

The utility of both agents is an increasing function of their current consumption levels and the discounted utility of their descendants. The children becoming either skilled (with probability π) or unskilled (with probability $1-\pi$). Importantly, agents value the wage of other types of individuals due to the possibility that their children end up with a different skill level than their own. Moreover, individuals value the discounted utility obtained from environmental quality. Proceeding in the same way for the South economy, we obtain

$$\begin{aligned} V^{s*} &= u[(1-\gamma)w^{s*} - z^{s*}] + \frac{\beta\{[\pi - \beta(\pi - \overline{e})]u[(1-\gamma)w^{s*} - z^{s*}] + (1-\pi)u(w^{u*})\}}{(1-\beta)[1-\beta(\pi-\overline{e})]} \\ &\quad + \frac{v(N)}{1-\beta}, \end{aligned}$$

and

$$V^{u*} = u(w^{u*}) + \frac{\beta\{[1-\overline{e} - \beta(\pi-\overline{e})]u(w^{u*}) + \overline{e}u[(1-\gamma)w^{s*} - z^{s*}]\}}{(1-\beta)[1-\beta(\pi-\overline{e})]} + \frac{v(N)}{1-\beta}.$$

In this case, the expressions for both utilities are more complex due to the asymmetry between both type of individuals concerning the probability of their children to become skilled. While skilled individuals can expect that their children will also become skilled with probability π, unskilled individuals can only expect the same outcome for their children with probability $\overline{e}$. In addition, both agents take into account that if their descendant end up being of a different type, this will also affect the future probabilities of being skilled. This concludes our analysis of the steady-state equilibrium in autarky. We are now ready to focus on the implications of free trade in the current framework.

4 Trade

Suppose that in period t, both economies are in their respective steady-state equilibria so that $S = \pi L$ and $S^* = \overline{e}L/(1-\pi+\overline{e})$. This implies, using (3), that the relative price of X^u, that is $p^u/p^s = w^u/w^s$ is smaller in the South if and only if

$$(1-\gamma)\overline{e} < \pi - \gamma,$$

which is the same condition as the one guaranteeing that $w^s < w^{s*}$ in the autarky equilibrium. In this case, the South has a comparative advantage in the production of the unskilled labor intermediate good while the North has a comparative advantage in the production of the skilled labor intermediate good.

We now suppose that both economies open up to trade at a specific time T_W. Since agents are forward looking, trade liberalization must be unanticipated. After opening to trade, the world will behave like a closed economy with the following initial condition $S_t^W = (S_t + S_t^*)/2$. From (3) the relative prices and wages in period T_W for the world economy will be given by

$$\left(\frac{p_t^u}{p_t^s}\right)^W = \left(\frac{w_t^u}{w_t^s}\right)^W = \frac{\alpha(S_t^W - S_t^{eW})}{(1-\alpha)(L - S_t^W)}.$$

Both countries will face these relative prices from T_W onward. Depending on the value of S_t^W, there are two possible outcomes.

If $S_t^W \leq \underline{S}$, unskilled individuals of both countries become constrained. Factor prices do not allow for any intergenerational mobility and the amount of skilled workers in both countries converges to

$$S = S^* = \frac{\overline{e}L}{1-\pi+\overline{e}}.$$

If $S_t^W > \underline{S}$, unskilled individuals in the South become unconstrained and invest in education. Using (15), (18) and (17) a necessary and sufficient condition for this outcome to occur is

$$\frac{2\gamma(1-\alpha)}{\alpha(1-\gamma)+\gamma(1-\alpha)} < \pi + \frac{\overline{e}}{1-\pi+\overline{e}}.$$

If the previous restriction is satisfied, the world economy converges to the level of human capital of the North: $S^W = \pi L$. We know from Assumption 1 that

$$\frac{\overline{e}}{1-\pi+\overline{e}} < \frac{\gamma(1-\alpha)}{\alpha(1-\gamma)+\gamma(1-\alpha)} < \pi,$$

implying that convergence to the level of human capital of the North is guaranteed either if the efficiency of the education system π is sufficiently large or if the difference in the number of skilled workers across the two countries when they open up to trade is not too large.

In this case, from (3), we obtain that in the free trade steady-state, relative prices and wages are equal across countries and given by

$$\left(\frac{p^u}{p^s}\right)^W = \left(\frac{w^u}{w^s}\right)^W = \frac{\alpha(\pi-\gamma)}{(1-\alpha)(1-\pi)}.$$

In addition, the number of skilled workers is also the same across countries. It should be noted that the free trade steady-state is reached in one period since once trade liberalization occurs, unskilled workers in the South immediately invest in education in period T_W. The accumulation of skilled workers become $S_{T_W+1} = \pi L$ and the steady-state is reached at period $T_W + 1$. Note that in our model one period is the time needed to educate one generation.

The decision concerning environmental maintenance investment is the same as in the closed economy case. However, the threshold values under which individuals are ready to provide environmental bequests are different. Since the South experiences an increase in skilled labor while the number of skilled in the North is unchanged, the level of world output and therefore pollution increase in the steady-state with free trade. The impact of trade openness is thus driven by the increase in skilled labor in the South, S^*. The latter affects the wage levels in the South w^{s*} and w^{u*}. We denote by z_W^s and z_W^u the environmental contributions in the North in the free trade equilibrium and equivalently z_W^{s*} and z_W^{u*} in the South. The next Proposition identifies the impact of trade openness on the threshold values of the altruism factor.

Proposition 4. *In the free trade equilibrium:*

1. *Individuals of type i in both countries are identical so that $z_W^s = z_W^{s*}$ and $z_W^u = z_W^{u*}$ while the threshold values of the altruism factor satisfy $\overline{\beta}_W^s = \overline{\beta}_W^{s*} < \overline{\beta}_W^u = \overline{\beta}_W^{u*}$,*
2. *$\overline{\beta}_W^s < \overline{\beta}^s$,*
3. *$\overline{\beta}_W^u < \overline{\beta}^u < \overline{\beta}^{u*}$ if*

$$2\pi z_W^s < \frac{\overline{e}}{1 - \pi + \overline{e}} z^{s*}. \tag{26}$$

where z^{s*} is the solution to equation (25).

Proof. See Appendix F □

Similarly to the autarky equilibrium, the willingness to contribute to environmental preservation is larger for the skilled than for the unskilled individuals due to income differences. Expression (26) defines a sufficient condition so that the willingness of unskilled individuals to contribute to environmental preservation is larger in the free trade equilibrium. This inequality can easily be interpreted in economic terms. It states that the threshold value below which unskilled individuals will decide to contribute to environmental preservation is smaller with free trade if the contribution of skilled individuals is larger in autarky. If this is not the case, the willingness of unskilled individuals to contribute might not increase, despite the increase in pollution. Unskilled individuals can consider that the contribution on the part of skilled individuals is sufficient under free trade. One of the implications of the last Proposition is that an increase in pollution increases the likelihood that individuals, enjoying an increase in income after trade, invest in environmental quality if the remaining contribution of other individuals is not too large. Indeed, we will only observe a decrease in the threshold of unskilled individuals, $\overline{\beta}_W^u < \overline{\beta}^u$, if the total contribution of skilled individuals $2\pi z_W^s$ is not too large.

This argument is not necessarily valid for individuals experimenting a decrease in income (skilled workers in the South) since the impact of a decrease in environmental quality on the threshold value might be compensated by the decrease in income. However, in the present framework, as $\overline{\beta}_W^s = \overline{\beta}_W^{s*}$, if skilled individuals in the North decide to invest in maintenance investment, skilled individuals in the South will also decide to do so despite of a decrease in income.

Under Assumption 2, $\overline{\beta}^{s*} < \beta < \overline{\beta}^s < \overline{\beta}^u < \overline{\beta}^{u*}$, so that only skilled individuals in the South invest in environmental preservation under autarky. We now assume that the fall in the threshold value of skilled individuals in the North obtained with free trade ($\overline{\beta}_W^s < \overline{\beta}^s$) is sufficient to induce all skilled individuals to contribute to environmental maintenance, i.e.:

Assumption 3. $\overline{\beta}_W^s < \beta$

So, under Proposition 4 and Assumption 3 two different free trade equilibria may occur. In the first one $\beta < \overline{\beta}_W^u$ and unskilled individuals do not invest in environmental maintenance. In the second one, as $\overline{\beta}_W^u < \beta$, these agents decide to do so.

Case I. In this case, we have $\overline{\beta}_W^s < \beta < \overline{\beta}_W^u$, implying that $z_W^u = 0$ and $z_W^s > 0$. Using the steady-state value of w^s, the solution for z_W^s in this case is implicitly given by

$$u'\left[(1-\gamma)(1-\alpha)A\left(\frac{1-\pi}{\pi-\gamma}\right)^{\alpha} - z_W^s\right] = \frac{\eta}{1-\beta(1-b)}v'\left[H - \frac{2}{b}(\kappa Y - \eta\pi L z_W^s)\right],$$

where

$$Y = A(1-\pi)^{\alpha}(\pi-\gamma)^{1-\alpha}L.$$

In this case, we obtain $c_W^s > c_W^u > 0$ and $z_W^s > z_W^u = 0$.

Case II. In the second equilibrium, all individuals decide to invest in environmental maintenance so that $\overline{\beta}_W^s < \overline{\beta}_W^u < \beta$. In this case, the steady-state value of environmental quality is given by

$$N = H - \frac{2L}{b}\left\{\kappa A(1-\pi)^{\alpha}(\pi-\gamma)^{1-\alpha} - \eta[\pi z_W^s + (1-\pi)z_W^u]\right\}, \tag{27}$$

where z_W^s and z_W^u solve the following system of equations:

$$u'[(1-\gamma)w^s - z_W^s] = \frac{\eta}{1-\beta(1-b)}v'(N), \tag{28}$$

$$u'(w^u - \gamma w^s - z_W^u) = \frac{\eta}{1-\beta(1-b)}v'(N). \tag{29}$$

Expressions (28) and (29) are respectively the best responses of skilled and unskilled individuals for our Cournot-Nash equilibrium with free trade. We obtain $c_W^s = c_W^u > 0$ and $z_W^s > z_W^u > 0$.

The implementation of free trade has several implications for welfare in both countries. One of the main effects consists in increasing the level of human capital in the South which reduces income inequality in this country since $w^s - w^u < w^{s*} - w^{u*}$. However, in the North, the distribution of wages remains the same after opening the borders to free trade. We observe (23) that as skilled labor in the world increases so does world production. This means that the reduction in income inequality in the South is associated with an increase in pollution at the world level. The increase in pollution modifies in turn the willingness of individuals to contribute to environmental preservation. As derived in Proposition 4, free trade can lead to a situation where unskilled individuals decide to contribute to the public good. In addition, the increase in pollution will also affect the level of contributions from skilled individuals in both countries.

We now compare the steady-state values of environmental quality in the autarky and free trade equilibria. From expressions (24) and (27), we note that the steady-state value of environmental quality is larger in the free trade equilibrium where all agents invest in environmental preservation if and only if

$$\underbrace{2\eta[\pi z_W^s + (1-\pi)z_W^u] - \eta\frac{\bar{e}z^{s*}}{1-\pi+\bar{e}}}_{\eta(Z_W - Z)} > \underbrace{\kappa A(1-\pi)^\alpha \left\{(\pi-\gamma)^{1-\alpha} - \frac{[(1-\gamma)\bar{e}]^{1-\alpha}}{1-\pi+\bar{e}}\right\}}_{\kappa(Y-Y^\star)} \tag{30}$$

i.e., if and only if the difference between the total environmental abatement under free trade and the total environmental abatement under autarky is larger than the increase in pollution due to free trade. Note that the previous expression also applies to the free trade equilibrium in the case where only skilled agents invest in environmental maintenance by setting $z_W^u = 0$. In the following section, we focus on a numerical example in order to assess the impact of free trade on environmental quality and welfare for realistic parameter values.

Finally, we compute the equilibrium utilities of both type of individuals with free trade. For skilled individuals in both countries, we obtain

$$V_W^s = u[(1-\gamma)w^s - z_W^s] + \frac{1}{1-\beta}\{\beta\pi u[(1-\gamma)w^s - z_W^s] + \beta(1-\pi)u(w^u - \gamma w^s - z_W^u) + v(N)\},$$

and for unskilled ones

$$V_W^u = u(w^u - \gamma w^s - z_W^u) + \frac{1}{1-\beta}\{\beta(1-\pi)u(w^u - \gamma w^s - z_W^u) + \beta\pi u[(1-\gamma)w^s - z_W^s] + v(N)\}.$$

These expressions are similar to the utilities obtained in autarky for the North economy. However, in this case, we take into account that both type of individuals might invest in environmental preservation. Note that, if unskilled individuals do not invest in environmental preservation we simply set $z^u_W = 0$ in the previous expression.

5 Numerical simulations

We proceed with some numerical simulations of the autarky and free trade steady-states in order to highlight the implication of trade openness on environmental quality and welfare. We first need to choose specific functional forms for our functions $u(.)$ and $v(.)$. We choose a logarithmic formulation in both cases implying

$$u(c) = \ln(c),$$

and

$$v(N) = \delta \ln(N).$$

where $\delta \in (0, 1)$. The relative preference for environmental quality δ is set at 0.8 so that consumption is slightly more important than environmental quality in adulthood.

The parameters governing the dynamics of environmental quality take the following values: $\kappa = 0.1$, $\eta = 0.2$, $b = 0.5$ and $H = 5$. The value of κ implies that one tenth of world output is transformed into pollution and we set a slightly larger value for η. The value of b is difficult to choose since it depends on the definition of environmental quality and the specificity of the pollution process (see, for example Jouvet et al., 2010). We then choose to follow Acemoglu et al. (2012) and set a value of 0.5 for b. The parameter H influences the level of N at the steady-state. We set $H = 5$ in order to ensure that the marginal utility of consumption is larger than the one of environmental quality when agents choose not to invest in environmental preservation. This requirement will become clear in the following.

We now focus on the production and education parameters. We assume that the share of skilled intermediate goods in production α is equal to 0.45 while the probability to become skilled following parental investment π is equal to 0.5. Furthermore, the teacher-student ratio γ is set at 0.1. Since in the North

$$\frac{w^u}{w^s} = \frac{\alpha(\pi - \gamma)}{(1 - \alpha)(1 - \pi)},$$

this combination of parameters implies a ratio $w^u/w^s = 0.65$ or equivalently a skill premium close to 1.54 which is in line with average skill premia in OECD countries. The value of γ implies that in the South it must be the case that $w^{u*}/w^{s*} < 0.1$ so that unskilled individuals are constrained and unable to invest in their children's education.

Since in the South

$$\frac{w^{u*}}{w^{s*}} = \frac{\alpha(1-\gamma)\overline{e}}{(1-\alpha)(1-\pi)},$$

we choose $\overline{e} = 0.08$ implying $w^{u*}/w^{s*} = 0.08$ and unskilled individuals are unable to invest in education due to borrowing constraints. Finally, we choose to set $L = 2$ as a benchmark in order to ensure some free-riding behavior on the part of individual agents.

Our choice concerning A and H is based on the necessity to satisfy the following restriction in equilibrium. When $z^{s*} = 0$, from (10), it must be the case that

$$u'\left[(1-\gamma)w^{s*}\right] > \frac{\eta}{1-\beta(1-b)}v'(N).$$

Using our specific functional forms and the results from Proposition 1, this condition is equivalent to

$$\frac{H}{A} > \frac{\eta(1-\gamma)(1-\alpha)}{1-\beta(1-b)}\left[\frac{1-\pi}{(1-\gamma)\overline{e}}\right]^{\alpha} + \frac{\kappa(1-\pi)^{\alpha}L}{b}\left\{(\pi-\gamma)^{1-\alpha} + \frac{[(1-\gamma)\overline{e}]^{1-\alpha}}{1-\pi+\overline{e}}\right\},$$

which imposes a restriction on the ratio H/A. With the values assigned above, we ensure that the previous condition is satisfied for any value of $\beta \in (0,1)$. Finally, the benchmark values of the parameters ensure that trade openness implies convergence of the world economy to the level of human capital of the North since

$$\pi > \frac{2\gamma(1-\alpha)}{\alpha(1-\gamma)+\gamma(1-\alpha)}.$$

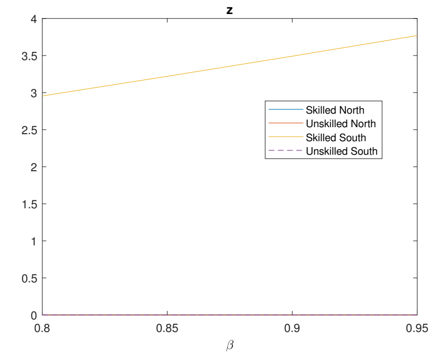
Our numerical strategy consists in computing the equilibrium values of z^i and N for all possible values of $\beta \in (0,1)$. In this way, we are able to identify the altruism thresholds $\overline{\beta}^i$ for which our different individuals will decide to invest in environmental maintenance. However, its not guaranteed that all unconstrained individuals will invest in their children's education for any value of β. We then compute the minimal value of β for which all unconstrained individuals invest in education given our particular functional form for $u(.)$. Using the results from Proposition 2, we conclude that all individuals invest in education for values of $\beta > 0.8$. The latter is the minimum value for which unskilled individuals in the North decide to invest in education given our parameterization. We then restrict our attention to values of $\beta \in (0.8,1)$.

Parameter	Notation	Value
Coefficient of relative risk aversion in consumption	σ	1
Relative preference for environmental quality	δ	0.8
Impact of pollution	κ	0.1
Impact of maintenance investment	η	0.2
Regeneration rate of the environment	b	0.5
Natural level of environmental quality	H	5
TFP	A	10
Share of skilled intermediate good in production	α	0.45
Share of skilled workers in the population	π	0.5
Teacher-student ratio	γ	0.1
Probability to get skilled without investment in education	$\bar{e}$	0.08
Total population in each country	L	2

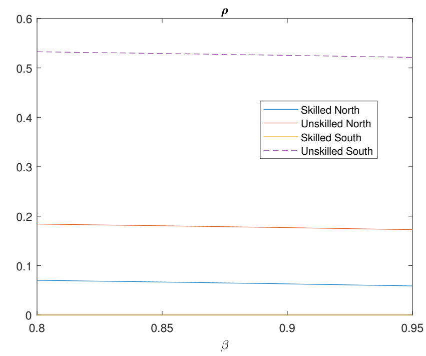
Table 1: Parameter values

The results of our simulations for the autarky equilibrium are presented in Figure 1. As can be observed from panel (a), only skilled individuals in the South decide to invest in environmental preservation when $\beta \in (0.8, 1)$. In accordance with the results from Proposition 1, the contribution level z^{s*} is increasing in the altruism factor β. Panel (b) plots the values of ρ for each type of individual. As β increases, the willingness to contribute to environmental quality increases as well. However, a value of $\beta > 1$ would be required for the remaining individuals to start contributing to environmental quality. Intuitively, agents with larger income levels are ready to contribute for smaller values of β. We provide in panel (c) the consumption levels of our four type of agents. In accordance with the results from Proposition 1, the contributing individuals also enjoy larger consumption levels. For the rest of agents, the consumption ranking depends uniquely on the difference in terms of net wages. Moreover, while the consumption level of non-contributing agents is constant, the one of skilled individuals in the South is decreasing in β as these agents devote a larger income share to environmental preservation. Panel (d) represents the level of environmental quality which is increasing in the altruism factor given that the latter entails larger contribution levels from skilled individuals in the South. Finally, we compute the steady-state utilities for our four types of individuals in panel (e). It is interesting to note that both agents in the North enjoy larger utility levels than skilled agents in the South despite of a lower income in both cases. This is due to the fact that living in the South economy entails the additional risk of having an unskilled child which will be unable to invest in education.

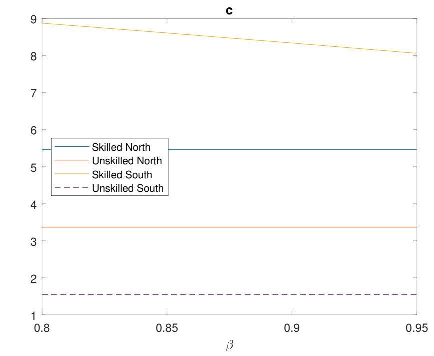
We now focus on the results in an economy with free trade which are presented in



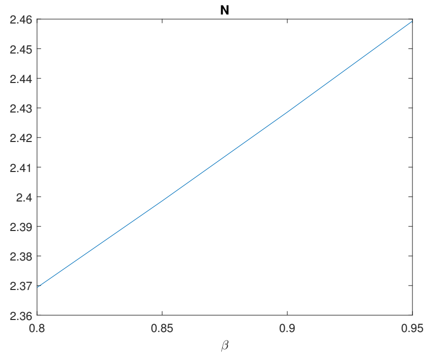
(a) Environmental contributions



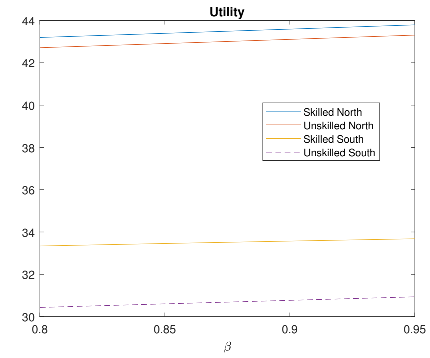
(b) Lagrange multiplier



(c) Consumption



(d) Environmental quality

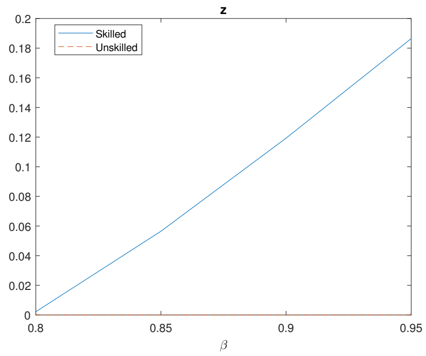


(e) Utility

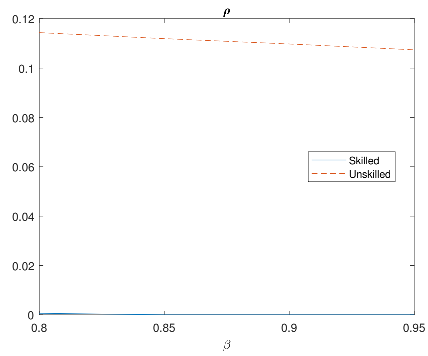
Figure 1: Autarky equilibrium

Figure 2. From panel (a), we observe that skilled individuals in both countries invest in environmental maintenance. The increase in pollution due to free trade induces skilled agents in the North to start contributing to environmental quality. However, unskilled individuals in both countries still decide to free ride given the current pollution level. It can be observed from panel (b) that the values of ρ for unskilled individuals under free trade are below the ones under autarky but the increase in pollution is not sufficient to generate positive contributions on the part of unskilled individuals. Comparing the results from panel (d) to the ones obtained under autarky, we conclude that the level of environmental quality is always smaller under free trade. Despite the fact that skilled individuals in both countries contribute to environmental preservation, the increase in pollution and the drop in the contribution of skilled individuals in the South imply that trade openness has negative consequences on environmental quality in the current framework. Finally, from panel (e), we compare the utilities in both cases and observe that while agents in the South enjoy an increase in utility for all values of β, this is not the case for agents in the North who suffer a utility loss. Since the level of environmental quality is smaller under free trade while wages are constant in the North, individuals in the latter economy must experience a utility loss. While unskilled individuals in the South also experience the fall in environmental quality, they enjoy a larger wage and the possibility to invest in their children's education. Overall, the impact on utility is positive. Finally, concerning skilled individuals in the South, despite of the fall in environmental quality and in wages, they also experience an increase in utility under free trade. This can be rationalized by the fact that having an unskilled child under free trade is less costly in utility terms given that the latter will still be able to invest in education in the future.

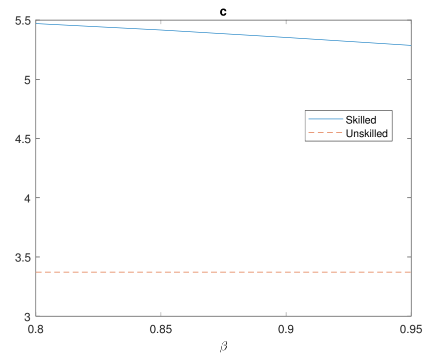
We conclude from our numerical simulations that while trade fosters the accumulation of human capital in the South and the reduction of inequality it also contributes to environmental depletion. Consequently, the utility of individuals in the South increases while the one of individuals in the North decreases. Our model is thus capable of generating a trade-off between income convergence at the world level and environmental preservation. We then consider in the following section the case of a social planner who implements an adequate environmental policy under free trade.



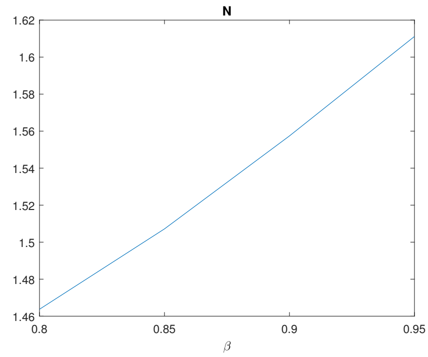
(a) Environmental contributions



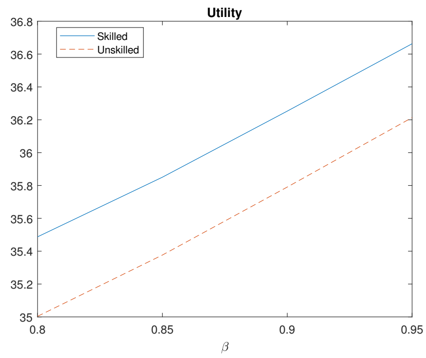
(b) Lagrange multiplier



(c) Consumption



(d) Environmental quality



(e) Utility

Figure 2: Free trade equilibrium

6 Optimal allocation with trade

We now consider a social planner that maximizes the weighted sum of utilities of skilled and unskilled individuals. The weights associated to each type of individuals represent their share of the world population. We assume that the planner's intergenerational discount factor is the same as the one of individuals agents and given by β. The social welfare function is given by

$$W_t = \pi V_t^s + (1-\pi)V_t^u.$$

where π is the share of skilled individuals in the world population and $(1-\pi)$ the share of unskilled individuals under free trade. Since we are focusing on the optimal allocation with trade, the competitive equilibrium is characterized by investment in education from skilled and unskilled individuals in both countries. Free trade is sufficient to relax borrowing constraints so that in terms of education choices, the planner allocation will correspond to the competitive equilibrium. We then choose to consider a planning problem where individuals already invest in education. The role of the social planner is to solve the potential suboptimality related to the levels of environmental quality and consumption.

6.1 Characterizing the optimal allocation

The welfare function being separable between the utilities of both type of agents, we solve for each type of individual separately. The value function for an individual of type i, with $i = \{s, u\}$ such that $w_t^i > \gamma w_t^s$, is then given by

$$\begin{array}{rrcl} & V_t^i(N_{t-1}) & = & \max\left\{u(c_t^i) + v(N_t) + \beta\pi V_{t+1}^s(N_t) + \beta(1-\pi)V_{t+1}^u(N_t)\right\}, \\ s.t. & z_t^i & \geq & 0, \\ & c_t^i & = & w_t^i - \gamma w_t^s - z_t^i, \\ & N_t & = & N_{t-1} + b(H - N_{t-1}) - 2\kappa A(\pi-\gamma)^{1-\alpha}(1-\pi)^{\alpha}L \\ & & & +2\eta L[\pi z_t^s + (1-\pi)z_t^u]\}. \end{array}$$

The variables characterizing the optimal allocation are indexed by a o. Proceeding as before, at the steady-state, we obtain for skilled individuals

$$\rho_o^s = u'(c_o^s) - \frac{2\pi L\eta}{1-\beta(1-b)}v'(N_o), \tag{31}$$

with

$$\rho_o^s z_o^s = 0,$$

and for unskilled ones

$$\rho_o^u = u'(c_o^u) - \frac{2(1-\pi)L\eta}{1-\beta(1-b)} v'(N_o), \tag{32}$$

with

$$\rho_o^u z_o^u = 0.$$

Comparing expressions (31) and (32) with expression (9), we observe that the marginal utility of investing in environmental maintenance is larger in the planner's case. This is due to the standard free riding behavior on the part of all agents in the competitive equilibrium. Moreover, when both $z_o^s > 0$ and $z_o^u > 0$, combining (31) and (32) we obtain

$$\pi u'(w^u - \gamma w^s - z_o^u) = (1-\pi)u'[(1-\gamma)w^s - z_o^s],$$

implying $c_o^u < (>) c_o^s$ if and only if $\pi < (>) 1/2$. While in the competitive equilibrium, all agents that contribute to environmental maintenance enjoy the same consumption levels, this is not necessarily the case in the optimal allocation. The type of agents representing the larger share of the population are also the ones responsible for the largest free riding problem. The planner must then implement an allocation where consumption is smaller for these type of individuals.

It is important to note that optimal environmental contributions are not necessarily positive. Given that we have focused up to now on a free trade allocation where $z^s > 0$, the optimal contribution of skilled individuals is also positive due to free riding behavior. However, the optimal contribution of unskilled individuals could be equal to zero. Given the value of z_o^s, it is possible that the marginal utility of consumption $u'(c_o^u)$ is too large for the value of z_o^u to be positive. The latter would require a sufficiently large income for unskilled individuals.

6.2 Decentralization of the optimal allocation

We now discuss how the optimal allocation can be decentralized. Since free trade solves the inefficiency related to borrowing constraints, only the externality related to the suboptimal level of environmental quality must be internalized. In order to solve the problem related to the public provision of environmental quality, the planner needs to subsidize the private contribution of individual agents for which the optimal contribution is positive. The budget constraint of the government is balanced by imposing lump-sum taxes on the same individuals. The budget constraint for an agent of type i is given by

$$w_t^i - \gamma w_t^s = c_t^i + (1-\tau_t^i) z_t^i + \theta_t^i,$$

where τ_t^i represents an environmental maintenance subsidy and θ_t^i a lump-sum tax. The government faces a budget constraint for each type of individual i which is given by $\tau_t^i z_t^i = \theta_t^i$. In the following, we consider once again two cases depending on whether the optimal contribution of unskilled agents is positive or not.

In the case where $z_o^s > 0$ while $z_o^u = 0$, we obtain at the steady-state $c^u = w^u - \gamma w^s$ and

$$(1-\tau^s)u'(c^s) = \frac{\eta}{1-\beta(1-b)}v'(N).$$

Comparing the latter expression with the one characterizing the optimal allocation, i.e. expressions (31), we obtain

$$\tau^s = 1 - \frac{1}{2\pi L},$$

while $\tau^u = 0$.

In the case where $z_o^s > 0$ and $z_o^u > 0$, we obtain at the steady-state

$$(1-\tau^s)u'(c^s) = \frac{\eta}{1-\beta(1-b)}v'(N),$$

and

$$(1-\tau^u)u'(c^u) = \frac{\eta}{1-\beta(1-b)}v'(N).$$

Comparing the latter expressions with the ones characterizing the optimal allocation, i.e. expressions (31) and (32), we obtain

$$\tau^s = 1 - \frac{1}{2\pi L},$$

and

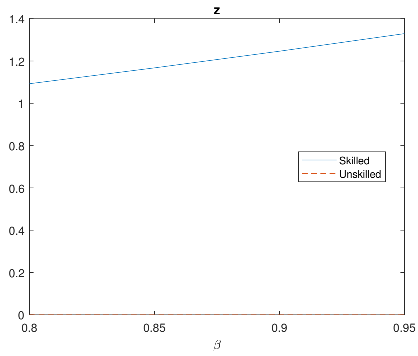
$$\tau^u = 1 - \frac{1}{2(1-\pi)L}.$$

Moreover, we conclude that $\tau^s < (>) \tau^u$ if and only if $\pi < (>) 1/2$. The planner always needs to subsidize at a larger rate the bigger group of individuals since the latter are the ones that generate the most important free riding problem.

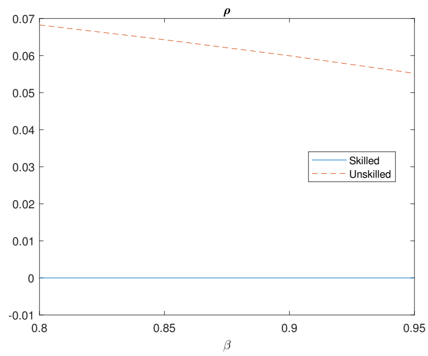
6.3 Numerical results

We proceed in the same way as for the competitive equilibrium and present our numerical results for the optimal allocation in Figure 3.

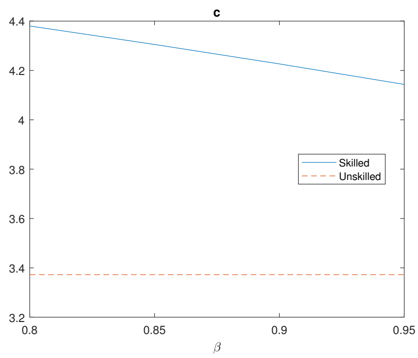
From panel (a), we observe that the planner chooses to implement an allocation where only skilled individuals invest in environmental maintenance for all $\beta \in (0.8, 1)$. The marginal utility of consumption of unskilled individuals is not compatible with positive contributions on the part of this specific population group. The optimal contribution of skilled individuals z_o^s is much larger than the competitive one z_W^s due to the internalization



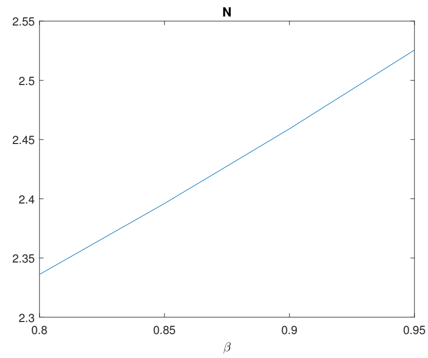
(a) Environmental contributions



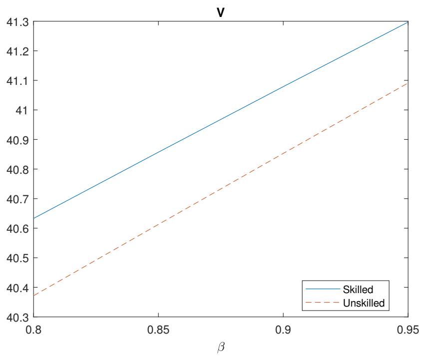
(b) Lagrange multiplier



(c) Consumption



(d) Environmental quality



(e) Utility

Figure 3: Optimal allocation

of free riding behavior. Panel (b) shows that while ρ_o^u is relatively close to zero, the low effective income (net of education investment costs) of unskilled individuals does not allow to implement positive environmental contributions for values of $\beta < 1$. The increase in environmental contribution from z_W^s to z_o^s implies a reduction in the consumption inequality between skilled and unskilled agents as observed in panel (c). The increase in environmental contributions coupled with a level of output that is the same as in the free trade equilibrium allows for an increase in the level of environmental quality as presented in panel (d). We can finally observe from panel (e) that the implementation of an adequate environmental policy allows both type of individuals to enjoy larger welfare levels under the optimal allocation. In order to decentralize the latter, the planner needs to implement a maintenance investment subsidy for skilled individuals $\tau^s = 50\%$. The subsidy is increasing in the number of skilled individuals due to a more stringent free riding problem.

7 Conclusion

In this paper, we have studied the impact of free trade on investment in education and environmental preservation. Under autarky, the equilibrium is characterized by constrained agents in the South that are unable to invest in their children's education and where only skilled agents in the South decide to invest in environmental preservation. By affecting relative factor prices, trade allows for convergence in skill and income levels but generates in return an increase in pollution.

The level of environmental quality under free trade is determined by the interaction between the increase in environmental maintenance and the one in pollution. Our numerical results suggest that overall environmental quality decreases under free trade implying a potential trade-off between income convergence at the global level and environmental preservation. While free trade is sufficient to ensure income convergence, optimal environmental preservation requires the implementation of an appropriate tax policy. The planner will need to implement a maintenance subsidy for skilled individuals but not necessarily for unskilled ones due to their relatively low income and large marginal utility of consumption.

In the present paper, we have assumed that population is constant and equal in both economies. However, it is well documented that education opportunities and fertility decisions are interrelated and may play an important role concerning environmental preservation. Future research could focus on the impact of free trade on population growth and environmental preservation in a similar framework.

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Appendix

A Proof of Proposition 1

Since $\overline{Z}^{i,j} + z^{i,j} = Z$ for all i and j, expressions (12) and (13) imply that when individuals are sufficiently altruistic to invest in environmental quality, we obtain that $c^{i,j}$ is constant across all i and j.

From expression (12), we know that when both agents 1 and 2 invest in environmental maintenance it must be the case that

$$u'(w^1 - \gamma d_j^1 w^s - z^{1,j}) = u'(w^2 - \gamma d_j^2 w^s - z^{2,j}),$$

so that $z^{1,j} > z^{2,j}$. Moreover, we need to prove that the case where agents of type 1 do not invest while agents of type 2 do so is ruled out. If $z^{2,j} > 0$ while $z^{1,j} = 0$ it must be the case that

$$u'(w^1 - \gamma d_j^1 w^s) > u'(w^2 - \gamma d_j^2 w^s - z^{2,j}),$$

which cannot be satisfied since $w^1 - \gamma d_j^1 w^s > w^2 - \gamma d_j^2 w^s$.

By applying the implicit function theorem to the arbitrage condition (12), we obtain expression (14) which is positive since $0 < b < 1$.

B Proof of Proposition 2

We start with the South economy where $w^u < \gamma w^s$. At a steady-state equilibrium, all successive generations of the same type take the same decision concerning educational investment. Unskilled individuals are constrained implying that all generations of unskilled individuals will not invest in education. Concerning skilled individuals, we look for conditions ensuring that inequality (8) is satisfied at the steady state, that is

$$\beta(\pi - \overline{e})(V^s - V^u) \geq u(w^s - z^{s,n\varepsilon}) - [(1-\gamma)w^s - z^{s,\varepsilon}].$$

where

$$\begin{aligned} V^s &= u[(1-\gamma)w^s - z^{s,\varepsilon}] + v(N) + \beta\pi V^s + \beta(1-\pi)V^u, \\ V^u &= u(w^u - z^{u,n\varepsilon}) + v(N) + \beta\overline{e}V^s + \beta(1-\overline{e})V^u, \end{aligned}$$

so that all generations of skilled individuals invest in education. If this is the case, we obtain the following:

$$\frac{\beta(\pi - \overline{e})}{1 - \beta(\pi - \overline{e})} \geq \frac{u(w^s - z^{s,n\varepsilon}) - u[(1-\gamma)w^s - z^{s,\varepsilon}]}{u[(1-\gamma)w^s - z^{s,\varepsilon})] - u(w^u - z^{u,n\varepsilon})}.$$

or

$$\beta(\pi - \overline{e}) \geq \frac{u(w^s - z^{s,n\varepsilon}) - u[(1-\gamma)w^s - z^{s,\varepsilon}]}{u(w^s - z^{s,n\varepsilon}) - u(w^u - z^{u,n\varepsilon})}.$$

Consider two utility functions $u_1(.)$ and $u_2(.)$ that differ in terms of their coefficient of relative risk aversion such that $\sigma_1 < \sigma_2$. Due to the concavity of the utility function, we obtain

$$\frac{u_1(w^s - z^{s,n\varepsilon}) - u_1[(1-\gamma)w^s - z^{s,\varepsilon}]}{u_1(w^s - z^{s,n\varepsilon}) - u_1(w^u - z^{u,n\varepsilon})} < \frac{u_2(w^s - z^{s,n\varepsilon}) - u_2[(1-\gamma)w^s - z^{s,\varepsilon}]}{u_2(w^s - z^{s,n\varepsilon}) - u_2(w^u - z^{u,n\varepsilon})},$$

implying that there exists a sufficiently small value for σ under which skilled individuals always invest in education. We then define σ_s as the value of σ that solves

$$\beta(\pi - \overline{e}) = \frac{u(w^s - z^{s,n\varepsilon}) - u[(1-\gamma)w^s - z^{s,\varepsilon}]}{u(w^s - z^{s,n\varepsilon}) - u(w^u - z^{u,n\varepsilon})}.$$

We next focus on the North economy where $w^u > \gamma w^s$. We proceed in the same way in this case and look for conditions guaranteeing that expression (8) is satisfied for both skilled and unskilled individuals. In this case, as both skilled and unskilled individuals invest in education at the steady state

$$\begin{aligned}
V^s &= u[(1-\gamma)w^s - z^{s,\varepsilon}] + v(N) + \beta\pi V^s + \beta(1-\pi)V^u, \\
V^u &= u(w^u - \gamma w^s - z^{u,\varepsilon}) + v(N) + \beta\pi V^s + \beta(1-\pi)V^u,
\end{aligned}$$

we obtain:

$$V^s - V^u = u[(1-\gamma)w^s - z^{s,\varepsilon}] - u(w^u - \gamma w^s - z^{u,\varepsilon}).$$

For any skilled individual, the investment condition becomes

$$\beta(\pi - \overline{e}) \geq \frac{u(w^s - z^{s,n\varepsilon}) - u[(1-\gamma)w^s - z^{s,\varepsilon}]}{u[(1-\gamma)w^s - z^{s,\varepsilon}] - u(w^u - \gamma w^s - z^{u,\varepsilon})},$$

For any unskilled individual, the investment condition becomes

$$\beta(\pi - \overline{e}) \geq \frac{u(w^u - z^{u,n\varepsilon}) - u(w^u - \gamma w^s - z^{u,\varepsilon})}{u[(1-\gamma)w^s - z^{s,\varepsilon}] - u(w^u - \gamma w^s - z^{u,\varepsilon})}.$$

Comparing the last two expressions, we notice that skilled individuals will decide to invest in education when unskilled individuals do so provided that

$$u(w^s - z^{s,n\varepsilon}) - u[(1-\gamma)w^s - z^{s,\varepsilon}] \leq u(w^u - z^{u,n\varepsilon}) - u(w^u - \gamma w^s - z^{u,\varepsilon}).$$

We will use the results from Proposition 1 to show that the latter inequality is always satisfied. Notice that if no one invests in environmental quality, the condition becomes

$$u(w^s) - u[(1-\gamma)w^s] < u(w^u) - u(w^u - \gamma w^s),$$

since $u(.)$ is concave. If only skilled individuals that do not invest in education invest in environmental quality the condition becomes

$$u(w^s - z^{s,n\varepsilon}) - u[(1-\gamma)w^s] < u(w^u) - u(w^u - \gamma w^s),$$

since $u(.)$ is concave and $z^{s,n\varepsilon} > 0$. If skilled individuals invest in environmental quality in both cases the condition becomes

$$u(w^u - \gamma w^s) < u(w^u),$$

since from part 2 of Proposition 1, when two agents invest in environmental quality they obtain the same consumption levels. If only unskilled individuals that invest in education do not invest in environmental quality the condition becomes

$$u(w^u - \gamma w^s) < u(w^u - z^{u,n\varepsilon}),$$

since from part 3 of Proposition 1, an agent that invests in environmental quality obtains a larger consumption level that an agent that does not. Finally, if all agents invest in environmental quality, they obtain the same consumption level and the condition is satisfied with equality.

Consider now once again the two utility functions $u_1(.)$ and $u_2(.)$ with $\sigma_1 < \sigma_2$. Due to the concavity of the utility function, we obtain

$$\frac{u_1(w^u - z^{u,n\varepsilon}) - u_1(w^u - \gamma w^s - z^{u,\varepsilon})}{u_1[(1-\gamma)w^s - z^{s,\varepsilon}] - u_1(w^u - \gamma w^s - z^{u,\varepsilon})} < \frac{u_2(w^u - z^{u,n\varepsilon}) - u_2(w^u - \gamma w^s - z^{u,\varepsilon})}{u_2[(1-\gamma)w^s - z^{s,\varepsilon}] - u_2(w^u - \gamma w^s - z^{u,\varepsilon})},$$

implying that there exists a sufficiently small value for σ under which unskilled individuals always invest in education. Let us define σ_n as the value that solves

$$\beta(\pi - \overline{e}) = \frac{u(w^u - z^{u,n\varepsilon}) - u(w^u - \gamma w^s - z^{u,\varepsilon})}{u[(1-\gamma)w^s - z^{s,\varepsilon}] - u(w^u - \gamma w^s - z^{u,\varepsilon})}.$$

It is straightforward to conclude that all non-constrained individuals will invest in education if σ is smaller than both σ_s and σ_n.

C Proof of Lemma 1

We start by deriving a condition under which $w^s < w^{s*}$. In equilibrium, using expressions (1), (17) and (18), the wages of both types of skilled individuals are given by

$$w^s = (1-\alpha)A\left(\frac{1-\pi}{\pi-\gamma}\right)^{\alpha},$$

and

$$w^{s*} = (1-\alpha)A\left[\frac{1-\pi}{(1-\gamma)\overline{e}}\right]^{\alpha},$$

implying that $w^s < w^{s*}$ if and only if condition (19) is satisfied.

We know that $w^u < w^s$ from Assumption 1 and finally we need to derive a condition under which $w^{u*} < w^u - \gamma w^s$. Using expressions (2), (17) and (18), the equilibrium wages of unskilled individuals in both countries are given by

$$w^u = \alpha A\left(\frac{\pi-\gamma}{1-\pi}\right)^{1-\alpha},$$

and

$$w^{u*} = \alpha A\left[\frac{(1-\gamma)\overline{e}}{1-\pi}\right]^{1-\alpha}.$$

implying that $w^{u*} < w^u - \gamma w^s$ if and only if condition (20) is satisfied.

D Proof of Proposition 3

Notice that $z^{s*} = z^{s*,\varepsilon}$, $z^s = z^{s,\varepsilon}$, $z^{u*} = z^{u*,n\varepsilon}$, $z^u = z^{u,\varepsilon}$. Moreover, along a Nash-Cournot equilibrium, each agent i expects correctly that when $\beta = \overline{\beta}^i$ and $z^{i,j} = 0$, any other agent l with $w^l - d_j^l w^s < w^i - d_j^i w^s$ will choose $z^{l,j} = 0$ following the results from Proposition 1. Using expressions (21) and (22) for the output levels of the final good in both countries, we obtain that in the South

$$\overline{\beta}^{u*} = \frac{1}{(1-b)}\left[1 - \frac{\eta v'(N^{u*})}{u'(w^{u*})}\right],$$

where

$$\begin{aligned} N^{u*} &= H - \frac{\kappa A(1-\pi)^{\alpha}}{b}\left\{(\pi-\gamma)^{1-\alpha} + \frac{[(1-\gamma)\overline{e}]^{1-\alpha}}{1-\pi+\overline{e}}\right\}L \\ &\quad + \frac{\eta}{b}\left[\frac{\overline{e}}{(1-\pi+\overline{e})}z^{s*} + \pi z^s + (1-\pi)z^u\right]L, \end{aligned}$$

and

$$\overline{\beta}^{s*} = \frac{1}{(1-b)}\left\{1 - \frac{\eta v'(N^{s*})}{u'[(1-\gamma)w^{s*}]}\right\},$$

where

$$N^{s*} = H - \frac{\kappa A(1-\pi)^{\alpha}}{b}\left\{(\pi-\gamma)^{1-\alpha} + \frac{[(1-\gamma)\overline{e}]^{1-\alpha}}{1-\pi+\overline{e}}\right\}L.$$

In the North we have

$$\overline{\beta}^{u} = \frac{1}{(1-b)}\left[1 - \frac{\eta v'(N^{u})}{u'(w^{u}-\gamma w^{s})}\right],$$

where

$$\begin{aligned} N^{u} = {} & H - \frac{\kappa A(1-\pi)^{\alpha}}{b}\left\{(\pi-\gamma)^{1-\alpha} + \frac{[(1-\gamma)\overline{e}]^{1-\alpha}}{1-\pi+\overline{e}}\right\}L \\ & + \frac{\eta}{b}\left(\frac{\overline{e}z_{*}^{s}}{1-\pi+\overline{e}} + \pi z^{s}\right)L, \end{aligned}$$

and

$$\overline{\beta}^{s} = \frac{1}{(1-b)}\left\{1 - \frac{\eta v'(N^{s})}{u'[w^{s}(1-\gamma)]}\right\},$$

where

$$\begin{aligned} N^{s} = {} & H - \frac{\kappa A(1-\pi)^{\alpha}}{b}\left\{(\pi-\gamma)^{1-\alpha} + \frac{[(1-\gamma)\overline{e}]^{1-\alpha}}{1-\pi+\overline{e}}\right\}L \\ & + \frac{\eta\overline{e}z^{s*}}{b(1-\pi+\overline{e})}L. \end{aligned}$$

The previous expressions imply that $N^{s*} < N^{s} < N^{u} < N^{u*}$. Since $u(.)$ and $v(.)$ are both concave functions, and using the results from Lemma 1, we conclude that $\overline{\beta}^{s*} < \overline{\beta}^{s} < \overline{\beta}^{u} < \overline{\beta}^{u*}$.

E Proof of Proposition 4

We start with the first part of the Proposition. In the free trade equilibrium $S = S^{*} = \pi L$ implying $w^{s} = w^{s*}$ and $w^{u} = w^{u*}$. This implies that individuals of type i are identical across countries. Therefore using (11) we obtain:

$$\overline{\beta}_{W}^{u} = \overline{\beta}_{W}^{u*} = \frac{1}{(1-b)}\left(1 - \frac{\eta v'[H - \frac{\kappa}{b}2A(1-\pi)^{\alpha}(\pi-\gamma)^{1-\alpha}L + \frac{\eta}{b}2\pi L z_{W}^{s})]}{u'(w^{u}-\gamma w^{s})}\right),$$

and

$$\overline{\beta}_{W}^{s} = \overline{\beta}_{W}^{s*} = \frac{1}{(1-b)}\left(1 - \frac{\eta v'[H - \frac{\kappa}{b}2A(1-\pi)^{\alpha}(\pi-\gamma)^{1-\alpha}L]}{u'[w^{s}(1-\gamma)]}\right).$$

Using the results from Lemma 2 and the fact that $u(.)$ and $v(.)$ are concave functions, we obtain that $\overline{\beta}_{W}^{s} < \overline{\beta}_{W}^{u}$.

Concerning the second part of the Proposition, we start by proving that $\overline{\beta}_{W}^{s} < \overline{\beta}^{s}$. Since the net wage $(1-\gamma)w^{s}$ is the same in both equilibria and $z^{u} = z^{u*} = 0$, a necessary and sufficient condition for $\overline{\beta}^s_W < \overline{\beta}^s$ is

$$\kappa A(1-\pi)^\alpha \left\{ \frac{[(1-\gamma)\overline{e}]^{1-\alpha}}{1-\pi+\overline{e}} - (\pi-\gamma)^{1-\alpha} \right\} < \frac{\eta \overline{e} z^{s*}}{1-\pi+\overline{e}},$$

which is always satisfied since $Y^* < Y$.

We now derive the condition under which $\overline{\beta}^u_W < \overline{\beta}^u$ in the free trade equilibrium. Since the net wage $w^u - \gamma w^s$ is the same in both equilibria and from Assumption 2, $z^s = z^u = z^{u*} = 0$, a necessary and sufficient condition for $\overline{\beta}^u_W < \overline{\beta}^u$ is

$$\kappa A(1-\pi)^\alpha \left\{ \frac{[(1-\gamma)\overline{e}]^{1-\alpha}}{1-\pi+\overline{e}} - (\pi-\gamma)^{1-\alpha} \right\} < \frac{\eta \overline{e} z^{s*}}{1-\pi+\overline{e}} - 2\eta\pi z^s_W.$$

Condition (26) in the main text is sufficient to ensure that the previous inequality is satisfied when aggregate production in free trade is larger than in autarky. From Lemma 2, we know that in the autarky equilibrium $\overline{\beta}^u < \overline{\beta}^{u*}$ while in the free trade equilibrium $\overline{\beta}^u_W = \overline{\beta}^{u*}_W$ implying that if $\overline{\beta}^u_W < \overline{\beta}^u$, it is also the case that $\overline{\beta}^u_W < \overline{\beta}^{u*}$.