Environment, Health and Education: What is at stake for the Economic Development?

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Environnement, Santé, Éducation: Quels Enjeux pour le Développement?

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Contents

1. This chapter is a joint work with Fabio Mariani and Agustin Perez-Barahona.

Introduction

La relation entre croissance et environnement a longtemps été et semble toujours controversée (Brock & Taylor (2005)). Pour certains, la croissance est associée à l'émergence de nouveaux risques environnementaux liés à la pollution, à l'impossibilité apparente des pays à lutter contre le réchauffement climatique, à la déforestation, etc... Pour d'autres, elle permet d'améliorer la situation actuelle, de produire plus proprement, notamment grâce à la technologie, de mieux se préserver contre les risques sanitaires, climatiques etc.... Ces deux approches ne sont pourtant pas inconciliables mais plutôt la preuve que ces deux sphères, économique et environnementale, sont intimement liées. En effet, la croissance et l'environnement naturel interagissent à travers de nombreux mécanismes économiques et effets retour (Smulders (1999)). Par exemple, si la croissance nécessite l'utilisation des ressources naturelles, l'environnement lui permet de stimuler la productivité des facteurs de production. De même, l'environnement a une valeur d'existence et donc génère des préoccupations environnementales qui se traduisent par la mise en place de politiques environnementales. Finalement, le développement et l'environnement affectent le bien être de la population.

D'un point de vue empirique et théorique toute une littérature s'est développée autour de cette relation: cette relation est-elle monotone? la croissance est-elle limitée par les ressources naturelles? Quels sont les impacts de la détérioration de l'environnement? Peut-on croître indéfiniment tout en préservant l'environnement. Le nombre important de travaux qui ont été menés autour de l'existence de la courbe de Kuznets environnementale sont le reflet de l'intérêt que les économistes portent à ces questions. Cette thèse participe au débat en exploitant de nouvelles interactions allant de l'environnement vers le développement, notamment à travers la santé ou les choix d'éducation des agents.

L'originalité de cette thèse est de ne pas considérer la relation croissance environnement comme une relation univoque mais plutôt comme le fruit d'interactions. Comme nous tenterons de le démontrer dans cette Introduction, les effets de l'activité économique sur la qualité environnementale d'une part et l'impact de l'environnement sur le développement d'autre part sont aujourd'hui empiriquement avérés. Notre travail souligne que la prise en compte de cette double causalité implique des résultats nouveaux. Notamment, la complémentarité entre l'amélioration des conditions environnementales et les choix en terme de capital humain peut, par exemple, conduire à l'émergence d'une trappe à pauvreté environnementale. Par ailleurs, les modèles que nous présentons fournissent une justification aux disparités en terme de performance environnementale observées dans les données au niveau macroéconomique.

Du développement économique vers la sphère environnementale... Cette première partie nous donnera l'occasion de présenter, d'un point de vue empirique mais aussi théorique, les conséquences du processus de croissance sur l'environnement naturel. Nous montrerons, en particulier, que ces impacts varient avec le niveau même de développement et donc qu'ils ne sont pas constants. Enfin, nous exposerons notre approche du phénomène de croissance, qu'est l'accumulation de capital humain et ses propres effets sur l'évolution de la qualité environnementale.

La courbe de Kuznets Environnementale d'un point de vue empirique

Depuis les années 90, une vaste littérature, notamment économétrique, s'est développée autour d'une problématique commune: l'impact de la croissance sur l'environnement. L'objectif de tous ces travaux est d'envisager l'évolution de la qualité environnementale simultanément à celle du revenu: le phénomène de croissance s'accompagne-t-il d'une augmentation continue de la pollution? Au contraire, le développement peut-il garantir une réduction permanente de la dégradation environnementale? Telles sont les interrogations soulevées dans ces études.

Les travaux pionniers de Grossman & Krueger (1993) ou Selden & Song (1994) mettent en lumière une relation non monotone entre le Produit Intérieur Brut (PIB) *per capita* et la pollution ambiante. Cette relation que l'on nomme désormais communément la Courbe de Kuznets Environnementale (CKE) implique que les premières étapes du développement s'accompagnent d'une dégradation de la qualité environnementale, tandis qu'à partir d'un niveau seuil de revenu, la croissance permet une amélioration des conditions environnementales, ou dit autrement, une réduction de la pollution. L'impact du revenu par tête sur la qualité environnementale change donc de signe (négatif puis positif) au cours du processus de croissance. Traditionnellement, la courbe de Kuznets Environnementale s'explique à travers l'évolution de trois phénomènes et se décompose formellement comme suit:

$$\frac{\dot{E}}{E} = \sum_{i}^{n} \left\{ \frac{\pi_i \epsilon_i}{\sum_j \pi_j \epsilon_j} \left(\frac{\dot{\pi}_i}{\pi_i} + \frac{\dot{\epsilon}_i}{\epsilon_i} \right) \right\} + \frac{\dot{Y}}{Y},$$

avec E, le niveau des émissions, Y la production, π la part du secteur i dans le processus de production et ϵ_i, l'intensité polluante du secteur i. Ainsi, l'évolution du niveau des émissions polluantes peut être interprétée comme un effet de composition (ou de structure) de la production, à travers le taux de croissance $\frac{\dot{\pi}_i}{\pi_i}$, comme un effet technique capturé par le taux de croissance de l'intensité polluante $\frac{\dot{\epsilon}_i}{\epsilon_i}$ et/ou enfin comme le fruit d'un effet d'échelle associé au taux de croissance de la production $\frac{\dot{Y}}{Y}$. Selon Hettige *et al.* (1992), l'effet de composition est le fruit d'un déplacement de l'activité industrielle des pays développés vers les pays en voie de développement, où la régulation environnementale est moins sévère. D'autres comme Arrow *et al.* (1995), suggèrent plutôt que ce phénomène émane de l'évolution de la structure productive des économies développées, qui glissent d'un régime agricole à une production de services, en passant par une phase d'industrialisation, cette dernière étant la plus intensive en pollution. L'effet technique lui permet de prendre en compte l'évolution de la technologie au cours du temps: le progrès technique peut ainsi permettre de réduire l'intensité polluante de la production. Un autre phénomène économique aurait aussi pu être ajouté dans la décomposition de la CKE: l'activité d'abattement. En effet, même si traditionnellement il n'apparaît pas, ce facteur joue un rôle important dans l'évolution de la qualité environnementale et est souvent pris en compte dans les récents travaux, qu'ils soient appliqués ou théoriques.

Les travaux de Grossman & Krueger (1993) ont été à l'origine d'un grand nombre d'études empiriques ayant pour but de tester la robustesse des résultats sus-mentionnés, et d'identifier la valeur seuil du revenu permettant d'expérimenter une croissance soutenable. (*cf.* Panayotou (2000) ou Levinson (2002) pour un état de l'art exhaustif de toutes les études menées). *In fine*, il semble que ce phénomène de courbe en U soit avéré pour bon nombre de polluants, à l'exception notable du CO_2 et de quelques autres polluants qui partagent la caractéristique d'être des polluants de type globaux et trans-frontières (Harbaugh *et al.* (2000), Holtz-Eakin & Selden (1995), Cole *et al.* (1997)).[2] Une autre conclusion émerge à la lecture de tous ces travaux: la valeur seuil du revenu, point de retournement dans la relation PIB *per capita*-pollution, dépend d'autres facteurs socio-économiques et varie au gré des politiques instaurées. Par exemple l'ouverture commerciale, la mise en place de politiques environnementales, le régime politique ou encore le degré de corruption dans l'économie sont autant de facteurs qui influencent la valeur seuil du revenu (Torras & Boyce (1998), Panayotou (2000)). En effet, le régime politique ou la qualité des institutions modèlent (au moins partiellement) les préférences environnementales, la demande de protection environnementale, l'acceptation des politiques vertes etc....Ainsi, même si la courbe en U existe, ces variables socio-économiques peuvent expliquer que le niveau de développement nécessaire à la croissance soutenable ne soit pas (encore) atteint par certaines économies.

Finalement, au delà du débat sur le niveau du revenu qui permet un changement de signe dans la relation croissance-environnement, la CKE atteste qu'une croissance de long terme n'est pas incompatible avec une amélioration de la qualité environnementale. A partir de cette observation, il est pertinent de chercher à identifier les conditions dans lesquelles cette relation émerge (ou pas) et de mettre en lumière les mécanismes économiques qui pourraient engendrer ce type de convergence non-monotone.

2. Les controverses sur le CO_2 ont souvent été justifiées par des comportements de passager clandestin. En effet, lorsque la pollution est trans-frontière, les incitations à lutter ou à réduire les émissions sont réduites: la source n'étant pas toujours clairement définie et le fait de pouvoir bénéficier des efforts des autres freinent les actions environnementales qui viseraient à dépolluer. Dans ce contexte, la phase de croissance associée à une amélioration des conditions environnementales émerge tardivement.

Les fondements théoriques

Parallèlement à ces nombreux articles empiriques, une littérature théorique s'est développée autour de l'existence de la CKE. Les théories dites traditionnelles de la croissance ont pendant longtemps négligé la présence d'externalités négatives liées à l'activité économique, sous forme de pollution. Puis, peu à peu s'est imposée l'idée que la dégradation environnementale était un produit dérivé de la croissance (de la production comme de la consommation) et qu'elle pouvait générer une perte d'utilité pour les agents économiques.[3] Certains modèles de croissance récents en intégrant une dimension environnementale proposent ainsi différents fondements théoriques à cette courbe en U et mettent en avant différents mécanismes qui conduisent, dans le long terme, à une croissance soutenable. En l'occurrence, une croissance compatible avec une réduction de la pollution peut être atteinte si la technologie est efficace et/ou si des efforts sont réalisés par les agents pour empêcher la dégradation environnementale.[4]

Une hypothèse commune à tous ces modèles est donc l'introduction dans la fonction d'utilité d'un nouvel argument représentant la pollution (c'est dans ce cas une perte d'utilité) ou la qualité environnementale (c'est dans ce cas un surcroît d'utilité). Les agents économiques arbitrent alors entre la consommation privée et un bien (mal) public. Typiquement, les agents comparent l'utilité marginale qu'ils retirent de la consommation de bien privé et le dommage marginal qu'ils subissent lorsque l'environnement se dégrade. Cet arbitrage conduit les autorités ou les entreprises à tenir compte des externalités négatives associées au phénomène de croissance et donc à modifier leurs comportements. Les poli-

3. Parallèlement, toute une littérature a émergé considérant la relation entre le phénomène de croissance et l'évolution des ressources naturelles (*cf.* Dasgupta & Heal (1979), Dasgupta (1982)).

4. La technologie peut être aussi bien une technologie de dépollution qu'une technologie de production moins intensive en pollution.

tiques environnementales mises en place se traduisent par des changements de technologie (Gradus & Smulders (1993), Bovenberg & Smulders (1995), Stokey (1998), Andreroni & Levinson (2001), Jones & Manuelli (2001) entre autres). Par exemple, lorsqu'une politique environnementale est mise en place par le gouvernement, les firmes sont incitées à produire plus proprement, et la croissance s'accompagne d'une réduction de la dégradation environnementale: elles peuvent alors soit directement dépolluer (technologies de bout de chaîne), soit réduire l'intensité polluante du processus de production.

Dans le but de maximiser leur utilité, les individus peuvent aussi investir eux mêmes en protection environnementale (Beltratti (1996), Jaeger (1998)). Dès lors, la réduction de la pollution passe par une allocation des ressources différentes et, en particulier, par l'attribution d'une plus grande part des ressources à la préservation environnementale. Par exemple, dans un cadre à générations imbriquées, John & Pecchenino (1994) reproduisent la courbe en U en modélisant les préférences des agents et leur choix en terme de maintenance environnementale tandis que le phénomène de croissance est incarné par l'accumulation de capital physique. La partie décroissante de la courbe en U émerge donc lorsque les individus n'investissent pas en maintenance, mais privilégient la consommation de bien privé à défaut du bien public, l'environnement. Au contraire, la partie croissante de la courbe est le fruit des efforts de maintenance supportés par les agents.

Dans cette thèse, nous présentons trois modèles théoriques dans lesquels l'évolution de la qualité environnementale est largement inspirée de l'article de John & Pecchenino (1994). Ainsi, dans le but de bien distinguer la contribution de cette thèse par rapport à cette littérature, nous en présentons brièvement les principales caractéristiques.

Un modèle de référence

Nous empruntons à John & Pecchenino (1994) leur définition de la qualité environnementale, en tant que bien composite incluant l'ensemble des aménités fournies par la nature. L'environnement apparaît comme une variable générale qui ne restreint pas l'analyse à quelques problématiques environnementales précises. En effet, la qualité environnementale doit être appréhendée comme un index incluant à la fois la qualité de l'air, de l'eau, des sols, mais aussi la gestion des ressources naturelles et halieutiques, de la biodiversité, des déchets, etc..Dans cette optique, nous ferons souvent référence dans cette thèse à des données empiriques récentes qui incarnent parfaitement cette idée de bien public multidimensionnel. Nous utiliserons, par exemple, l'indice de performance environnementale (IPE) qui est une pondération de 16 sous-indicateurs rassemblant les multiples aspects que peut recouvrir la qualité environnementale (cf. YCELP (2006)). Finalement, cette variable capture aussi bien les aménités locales que globales qu'offre l'environnement naturel. Le tableau 1 offre une synthèse des différents sous-indicateurs utilisés pour construire cet indicateur.

La qualité environnementale est un stock qui se dégrade sous l'effet de l'activité humaine, mais peut aussi être restauré grâce aux efforts de maintenance financés par la population. Plus précisément, les agents valorisent l'environnement et sont à même d'engager des dépenses qui permettent de préserver ou d'améliorer l'environnement futur. Ces dépenses de maintenance sont simplement le reflet de l'arbitrage entre consommation de bien privé et consommation de bien public, l'environnement. Par ailleurs, le processus de croissance incarné par l'accumulation de capital physique génère des externalités négatives, en particulier des flux de pollution. Dans ce modèle, l'environnement (E_t) évolue

Indice de Performance Environnementale						
Objectifs	Santé environnementale	Vitalité de l'écosystème				
Politique environnementale concernée	Santé environnementale	Air	Eau	Biodiversité et habitat	Ressources naturelles productives	Energie
Indicateurs	Mortalité infantile, pollution intérieure, eau potable, moyens d'assainissement, particules urbaines	Particules urbaines, qualité de l'ozone	Charge en nitrogène, consommation d'eau	Consommation d'eau, protection des espèces animales, protection de l'écosystème, exploitation forestière	Exploitation forestière, subventions agricoles, ressources halieutiques	Efficacité énergétique, énergies renouvelables, CO_2 par PIB

Table 1: Construction de l'IPE

selon l'équation suivante:

$$E_{t+1} = (1-\eta)E_t - \beta c_t + \sigma m_t$$

où $\eta \in (0,1)$ représente le taux de dépréciation de l'environnement. Ici, ce taux de dépréciation implique qu'en l'absence d'activité humaine, la qualité environnementale tend vers un niveau par convention égal à zéro[5]. Ici, la dégradation naturelle de l'environnement renvoie à l'absence d'entretient des aménités naturelles, comme par exemple les forêts, les parcs, etc...La dégradation environnementale (pollution, extraction de ressources, etc...) est représentée par le terme βc_t, c'est-à-dire résulte des flux de consommation. Enfin, σm_t reflète les mesures environnementales prises par les agents. Ces dépenses peuvent être interprétées comme des dépenses de dépollution, ou alors de préservation et entretien de l'environnement. De même que les flux de pollution ont un effet décalé sur le stock de qual-

5. Si le stock de pollution et non plus d'environnement avait été modélisé, alors le paramètre η aurait représenté un taux de régénération de la nature, ou un taux d'absorption naturel de la pollution.

ité environnementale, les efforts de maintenance jouent sur l'état futur de l'environnement. En effet, dans la réalité les différents écosystèmes naturels réagissent relativement lentement aux mesures et changements environnementaux.

La contribution principale des travaux de John & Pecchenino (1994) tient au fait que pour de faibles niveaux de développement (et donc de pollution), les agents privilégient leur consommation et n'investissent pas en maintenance. En conséquence, les premières phases de la croissance sont caractérisées par une dégradation de l'environnement naturel. Cependant, cette détérioration initiale, concomitante à une élévation du niveau de vie, génère une perte d'utilité importante qui se traduit par une hausse des incitations à investir en maintenance. John & Pecchenino (1994) montrent alors qu'à partir d'un certain niveau de revenu, la maintenance apparaît et contrebalance les effets négatifs associés aux flux de pollution. A partir de ce moment, le développement s'accompagne d'une amélioration des conditions environnementales. On retrouve bien la relation en U préalablement discutée.

Toutefois, une des principales faiblesses de ce modèle réside dans l'existence d'un unique agent représentatif, qui exclut à priori tout problème de coordination des agents notamment sur le financement d'un bien public. Ainsi, dans ce modèle, tout se passe comme s'il existait un gouvernement (représentant une seule génération vivante) et dont le but serait de fournir cet effort de maintenance. Alors, le prix de la maintenance serait fixé de telle sorte que l'effort de maintenance agrégé de tous les agents soit optimal, comme à l'équilibre de Lindahl. De manière équivalente, on peut penser que la maintenance est une taxe optimale prélevée sur le revenu des jeunes agents. Cette restriction sera levée dans le troisième chapitre de la thèse qui introduit une politique publique endogène avec des agents hétérogènes dans un modèle de vote à majorité simple.

Du capital humain vers l'environnement

En utilisant ce cadre comme référence, nous étudions dans cette thèse les impacts de la croissance sur l'environnement lorsque le moteur de la croissance est l'accumulation de capital humain, plutôt que physique. Nous montrons qu'il est possible de retrouver à la fois d'un point de vue dynamique une convergence non-monotone, comme la courbe de Kuznets environnementale, mais aussi dans une optique de plus long terme, une croissance soutenable. Néanmoins, ce résultat ne tient pas à l'existence de solutions en coin sur les choix environnementaux (maintenance), mais plutôt à l'existence d'interactions entre accumulation de capital humain et environnement.

Au delà de l'effet revenu déjà présent dans les modèles avec capital physique, nous montrons que lorsque le développement passe par l'acquisition de plus de connaissance, la croissance génère à travers d'autres canaux plus de préoccupations environnementales. En effet, nous considérons que le niveau de développement peut lui même affecter les choix réalisés par les agents en matière environnementale. Comme l'ont mis en lumière Mokyr (1993), Schultz (1993), Blackburn & Cipriani (2002), Chakraborty (2004) ou encore Cervellati & Sunde (2005), l'accumulation de capital humain se traduit aussi par une amélioration de la santé des agents économiques, un allongement de la durée de vie, une élévation du niveau des connaissances, une meilleur niveau d'éducation etc.... Or tous ces effets peuvent modifier les choix économiques et/ou politiques des agents en matière environnementale. Par exemple, une plus grande longévité permet aux agents de jouir de l'environnement naturel plus longtemps. Alors, dans la mesure où la qualité environnementale est valorisée, les agents sont incités à investir plus en maintenance: ils bénéficieront donc plus longtemps de leur investissement et le rendement de ces dépenses sera mécaniquement plus élevé. Autre exemple, si le consentement à payer des agents croît avec le niveau d'éducation comme l'ont démontré certains travaux empiriques (Goetz *et al.* (1998), Carlsson & Johansson-Stenman (2000), Brock & Taylor (2005)), alors la réussite et l'acceptation des politiques publiques en faveur de la préservation environnementale, peut être conditionnée par le niveau moyen d'éducation dans l'économie.

Finalement, même s'il génère des externalités négatives, le développement permet, à travers un effet revenu, de consacrer plus de ressources à la protection environnementale. Il devient alors indispensable de se développer pour pouvoir lutter contre la dégradation environnementale comme le soulignait Beckerman (1992): "*...finalement le meilleur -et probablement le seul- moyen d'avoir un environnement décent dans la plupart des pays est de devenir riche...*". De plus, comme nous l'avons mis en avant, la croissance qualitative peut aussi stimuler la demande de protection environnementale. Dès lors, il convient de s'interroger sur les conditions (environnementales ?) qui favorisent une croissance soutenable. De la même manière, il est pertinent d'analyser l'impact des externalités négatives générées par les premières phases de développement: peuvent-elles ralentir le processus de croissance? En effet, en plus du revenu ou du niveau de capital humain, les décisions des individus peuvent être dictées par l'environnement courant, passé ou encore par les anticipations qu'ils forment sur l'état futur de la qualité environnementale. C'est cette relation, allant de l'environnement vers le développement que nous décrivons par la suite.

De la sphère environnementale vers le développement

Dans cette deuxième partie, nous nous intéressons aux conséquences de la dégradation environnementale en terme de développement. En effet, la croissance et le développement économique bouleversent inexorablement l'environnement naturel. Parfois, la dégradation de la qualité environnementale occasionne une réduction sévère notamment du niveau de santé des agents, des ressources essentielles à la survie et au développement, etc.. L'environnement peut alors devenir un frein, si ce n'est un obstacle à la croissance. Dans ce cas, la croissance n'est plus le moteur de la préservation environnementale, mais, c'est bien l'environnement qui est le moteur du développement.

Quantifier l'impact de l'environnement sur la santé

Depuis quelques décennies déjà, le constat mis en lumière par de nombreuses institutions internationales notamment la Banque Mondiale (2001) et l'Organisation Mondiale de la Santé (2004; 2006) est sans appel: une détérioration de la qualité environnementale, qu'elle soit chronique ou aiguë, affecte le niveau de santé des agents. Chiffres à l'appui, l'Organisation Mondiale de la Santé (OMS) estimait dans son rapport en 2006 que 24% des maladies touchant la population mondiale étaientt attribués aux risques environnementaux[6]. Autre exemple, l'OMS recensait sur cette même année 3 millions de décès dus à la pollution atmosphérique. Bien sûr, la nature et l'amplitude des effets de la détérioration des conditions environnementales diffèrent selon l'économie considérée, et reposent sur d'autres facteurs socio-économiques. En effet, les dommages environnementaux sont multi-dimensionnels et englobent aussi bien la pollution atmosphérique, que la réduction des ressources naturelles (parfois vivrières), le changement climatique, la désertification et la déforestation, la dégradation de la qualité de l'eau (voire sa raréfaction), la diminution de la biodiversité, la pollution "indoor", les déchets, etc...Ainsi, toutes les économies, des plus pauvres aux plus riches, sont touchées par ce phénomène de dégradation des conditions environnementales. Toutefois, la répartition des risques et des dommages est

6. cf.Lambin (2008) qui reprend ces chiffres et fait un état des lieux complet et exhaustif des impacts de l'environnement sur la santé des êtres humains ou animaux.

assez inégalitaire: les populations les plus pauvres souffrent de manière disproportionnée de la détérioration des conditions environnementales, quelle soit lente ou rapide, locale ou globale. L'écart de revenu, d'accès au soins, d'efficacité du système de santé, de niveau d'éducation, la dépendance aux ressources naturelles, etc., sont autant de facteurs qui contribuent largement à expliquer cette plus grande vulnérabilité.

Parallèlement à ces observations générales, de nombreux travaux économétriques ont cherché à estimer et à mesurer précisément l'impact de l'environnement sur la santé, à tester la robustesse de ces effets (voir par exemple Lessenger *et al.* (1995), Fitzgerald *et al.* (1998), Pope (2000), Chay & Greenstone (2003) Dasgupta (2004), Evans & Smith (2005), Markandia (2006), Krupnick (2006)), tout en contrôlant pour l'ensemble des variables socio-économiques déjà mentionnées. En utilisant des données sur les consultations médicales et hospitalières, les soins pharmaceutiques, ou encore le nombre de jours passés en bonne santé perdus par an (Disabilities Adjusted Life Years), voire les décès, toutes ces études ont contribué à affirmer l'importance de ces dommages environnementaux sur la santé des individus. Pope (2000) présente plusieurs faits stylisés: par exemple, une augmentation aiguë de la pollution atmosphérique provoque une augmentation allant de 1 à 3% (selon les mesures de la pollution, le lieu etc...) du nombre recensé d'hospitalisations. De même, Soares & de Souza Porto (2009) montrent que 7% des cas d'empoisonnement recensés au Brésil sont attribués à l'usage de pesticides, qui nécessitent dans environ 80 % des cas des consultations médicales ou séjours hospitaliers. Enfin, plus indirectement, la qualité environnementale peut aussi influencer la productivité des agents ou le taux d'absentéisme des enfants à l'école (Romieu *et al.* (1992), Park *et al.* (2002), Mendell & Heath (2004)). Typiquement, dans l'étude économétrique de Currie *et al.* conduite au Texas (USA) en

2007, les résultats suggèrent qu'une journée supplémentaire pendant l'année où le niveau de monoxide de carbone serait supérieur aux standards environnementaux, conduirait à augmenter le taux d'absentéisme des enfants à l'école d'environ 9%.

La relation allant de l'environnement vers la santé des agents étant établie au niveau microéconomique, il est intéressant de comprendre ses conséquences à un niveau agrégé. En effet, s'il est avéré que l'environnement naturel détermine, au moins partiellement, le niveau de santé des agents, alors il participe de façon non négligeable au phénomène de développement. C'est dans cette optique et en se fondant sur ces données empiriques que nous étudions la relation causale qui existe entre la qualité environnementale et la croissance.

La santé: un facteur déterminant de la croissance

La santé des agents économiques et en particulier celle des enfants (qui sont, parmi la population, plus sensibles aux différents risques environnementaux) est un moteur capital de la croissance. Comme l'ont mis en lumière un certain nombre de travaux, des agents en mauvais état physique présentent des capacités cognitives plus faibles, des taux d'absentéisme plus élevés, des taux de fécondité plus bas, ou plus largement une plus faible productivité dans quelque activité que ce soit (Strauss & Thomas (1998), Kalemli-Ozcan *et al.* (2000), Bloom *et al.* (2001), Behrman & Rosenzweig (2004), Weil (2008)). Ainsi la santé pourrait expliquer, et cela dans une large mesure (autant peut-être que l'éducation), les différences observées en terme de développement à l'échelle mondiale. Par exemple, Weil (2008) estime, en données de panel, que 22.6 % de la variance du revenu par travailleur peut être expliquée par les écarts de niveaux de santé. De même, Behrman & Rosenzweig (2004) estiment que les différences de poids à la naissance entre les pays contribuaient à hauteur de 1,6% de la variance mondiale du revenu par tête.

A un niveau microéconomique, cet impact de la santé sur la productivité des agents a aussi été mis en avant. Comme le constate Strauss & Thomas (1998), une alimentation plus riche en protéine augmente significativement le salaire horaire, reflet d'une plus grande efficacité. De même, une alimentation plus saine et donc par conséquent une meilleure santé favorise nettement la réussite scolaire (donc facilite l'accumulation de capital humain), et les performances intellectuelles des enfants (Behrman & Rosenzweig (2004)). Dès lors, le rendement de l'investissement en éducation semble étroitement lié au niveau de santé des individus puisque le niveau de santé est typiquement positivement corrélé avec le salaire.

Ainsi, l'environnement par son effet sur la santé des agents influence le processus de croissance comme nous l'avons vu plus haut. Mais cette relation a aussi été analysée plus directement par quelques études qui font un lien direct entre les conséquences d'un environnement dégradé et la perte potentielle de croissance associée. Comme le montrent Maccini & Yang (2005), Bleakley (2003) ou encore Miguel & Kremer (2004) les conditions environnementales, parce qu'elles modifient considérablement le rendement de l'investissement en éducation, jouent un rôle important dans la formation de capital humain et donc sur le niveau de développement. Ainsi, la météorologie, et notamment la pluviométrie, s'avèrent être des facteurs déterminants du niveau de santé, et via cet effet sur la réussite scolaire, un moteur potentiel de croissance économique. De même, l'éradication d'un certain nombre de maladies comme la malaria qui sont associées à un environnement naturel très endommagé, a participé à stimuler vigoureusement le taux de scolarisation en Amérique du Sud. Dès lors, l'environnement favorise et accélère l'accumulation de capital humain et la croissance, à la fois d'un point de vue quantitatif mais aussi qualitatif. En d'autres termes, un individu en bonne santé physique pourra à la fois s'éduquer plus en faisant preuve de capacités cognitives plus développées mais aussi plus longtemps.

Comment la santé affecte le développement

Toutes ces études suggèrent qu'il existe un lien direct entre environnement et productivité. Cependant, des mécanismes plus indirects, en renforçant cet effet initial, peuvent intervenir. En effet, en modifiant à la fois les coûts et les rendements du capital humain, la santé des agents devient un déterminant central des décisions d'investissement en éducation. C'est l'argument proposé par Schultz (2002) qui montre que les décisions d'investissement en capital humain dépendent du niveau de santé des individus et que cela affecte, en retour, les salaires. En effet, investir en capital humain est coûteux, et la perspective du rendement est essentielle dans la prise de décision. Un état de santé relativement dégradé réduit l'efficacité des dépenses d'éducation puisque l'individu sera, à priori, plus absent à l'école, moins performant lors de l'apprentissage etc.... Dès lors, si le rendement potentiel des dépenses se réduit, les agents économiques sont alors tout simplement moins incités à investir en éducation. Là encore, l'accumulation de capital humain semble dépendre des conditions environnementales, à travers le niveau de santé des individus.

L'espérance de vie des individus, mesure pertinente du niveau de santé, influence également le processus de développement. Et, d'un point de vue théorique, c'est aussi un facteur déterminant dans la formation de capital humain.[7] Comme nous l'avons évoqué précédemment, l'éducation est un investissement coûteux (coût soit monétaire soit temporel) et les agents doivent arbitrer entre le coût privé de cet investissement et son rendement. Or, une plus grande longévité allonge la période pendant laquelle les agents économiques bénéfi-

7. Ici nous ne distinguerons pas l'espérance de vie de la longévité. Nous considérons que dans les deux cas la durée de vie est allongée.

cient de leur investissement en éducation de telle sorte que, mécaniquement, le rendement de l'investissement s'en trouve accru. Autrement dit, l'allongement de la durée de vie, en modifiant le taux d'escompte des agents (*i.e.,* leur préférence pour le présent) les incite à investir plus en capital humain pour bénéficier par exemple d'un plus haut revenu pendant plus longtemps. Ce mécanisme économique fait référence à l'effet Ben-Porath (1967), qui trouve en outre écho dans les données; on observe ainsi, à partir du dix-neuvième siècle, une relation croissante et monotone entre longévité, niveaux d'éducation et capital par tête (Hazan & Zoabi (2006)). De nombreux travaux, notamment Galor & Weil (2000), Boucekkine *et al.* (2003), Lagerlof (2003), Cervellati & Sunde (2005) ou encore Galor (2005), ont par ailleurs introduit et utilisé ce raisonnement économique pour expliquer le phénomène de transition d'un régime dit malthusien, vers un régime de croissance soutenue. Finalement, les conditions environnementales, parce qu'elles altèrent le taux de préférence pour le présent peuvent expliquer, dans une certaines mesure, le phénomène de croissance ainsi que les choix d'acquisition de capital humain. De plus, si l'environnement est aussi valorisé par les individus, mais soumis à ce taux d'escompte, alors l'environnement affecte les choix environnementaux des agents, et donc joue sur l'évolution même de la qualité environnementale.

De l'environnement vers le développement

Dans cette thèse, l'impact de l'environnement sur la santé, puis celui de la santé sur le développement sont simultanément considérés. Nous mettons en avant ces canaux de transmission de la qualité environnementale vers la croissance économique à travers l'accumulation de capital humain et nous montrons que les sphères économiques et environnementales sont étroitement liées. Des articles théoriques ont auparavant déjà abordé cette problématique en supposant aussi que la pollution endommage les capacités d'apprentissage des agents, ce qui, par conséquent, freine l'accumulation de capital humain, tout comme la croissance. C'est le cas de Gradus & Smulders (1993), où l'impact de la dégradation environnementale passe par un taux de dépréciation du capital humain plus important. Ils montrent alors qu'un consentement à payer pour dépolluer plus important peut favoriser le phénomène de croissance en augmentant, en retour, le rendement de l'investissement en capital humain. Dans le papier de van Ewijk & van Wijnbergen (1995), les flux de pollution réduisent eux l'efficacité des dépenses d'éducation mais aussi la productivité des travailleurs dans la fonction de production.[8] Dès lors, les auteurs s'intéressent à la croissance de long terme et montrent qu'une politique environnementale sévère, en internalisant les externalités négatives liées aux flux de pollution, peut permettre d'accroître le taux de croissance de l'économie. Une contribution majeure de notre thèse est de considérer que c'est la qualité environnementale, prise comme une variable de stock, qui affecte l'évolution du capital humain dans l'économie ainsi que les prises de décision en terme d'éducation. Si le moteur de la croissance reste le capital humain, la croissance n'est plus indissociable de l'évolution de la qualité environnementale.

Cette variable de stock peut aussi déterminer l'espérance de vie des agents, autre indicateur du niveau de santé. Comme nous l'avons présenté plus haut dans l'Introduction, l'espérance de vie représente, au delà du taux d'escompte, le poids que les agents accordent à l'environnement. Dans les modèles de croissance, cette variable clef influence les choix

8. Cette hypothèse selon laquelle la qualité environnementale, ou les flux de pollution, affectent directement la productivité des travailleurs est aussi utilisée dans les travaux de Williams III (2000), Williams III (2003). Toutefois, son approche se concentre sur les interactions fiscales existantes entre taxes environnementales et taxes sur le travail. Il traite ainsi des questions du double dividende qui s'éloignent du sujet qui nous concerne dans cette thèse.

économiques des agents et donc le phénomène de développement. Dans cette optique, notre démarche se rapproche de celle choisie par Pautrel (2006) ou encore Ballestra & Dottori (2009). En effet, dans ces deux articles, la longévité, déterminée par les conditions environnementales, est le moteur de l'accumulation de capital humain chez Pautrel (2006), et de capital physique chez Ballestra & Dottori (2009). Dans l'article de Pautrel (2006), lorsque l'espérance de vie croît, le stock de capital humain grandit car les générations se renouvellent moins souvent et donc favorise la croissance. Cependant, les choix d'investissement des agents en capital humain sont indépendants des conditions environnementales. Dans l'article de Ballestra & Dottori (2009), les agents ne valorisent pas l'environnement en tant que tel mais seulement la consommation: le bénéfice d'une amélioration de la qualité environnementale ne passe que par l'allongement de la durée de vie. Il n'y a pas d'arbitrage entre consommation de bien privé et consommation de bien public.

Cette réflexion nous a permis de mettre en exergue empiriquement et théoriquement les incidences d'une modification des conditions environnementales sur le développement. Ces conclusions mises en regard avec celles de la première partie de l'Introduction font apparaître une relation à double sens entre l'évolution de l'environnement naturel et le phénomène de croissance. En effet, le développement peut favoriser une amélioration des conditions environnementales, lorsqu'il génère un plus haut revenu, ou qu'il facilite l'émergence d'une conscience verte, etc... Mais le processus de développement est, dans une certaine mesure, conditionné par l'environnement. Dès lors, la sphère économique et environnementale ne sont plus dissociables et doivent être considérées simultanément. L'originalité et la contribution principale de cette thèse sont de considérer cette double causalité et ainsi d'aborder la question du développement et de l'environnement de manière plus complète.

Présentation de la thèse

L'objectif principal de cette thèse est donc de mettre en lumière le caractère équivoque de la relation existante entre la croissance d'une part et l'évolution de l'environnement naturel d'autre part. En effet, il apparaît désormais bien établi théoriquement et empiriquement que la croissance économique affecte, de façon non-monotone, la qualité environnementale. De même, nous avons montré dans quelle mesure ces impacts sur l'environnement peuvent influencer en retour le processus de développement, notamment à travers leurs effets sur la santé ou le niveau d'éducation des agents. Dès lors, dans cette thèse nous nous attacherons à prendre en compte simultanément ces interactions entre sphère économique et sphère environnementale. Le schéma ci-dessous illustre notre démarche.

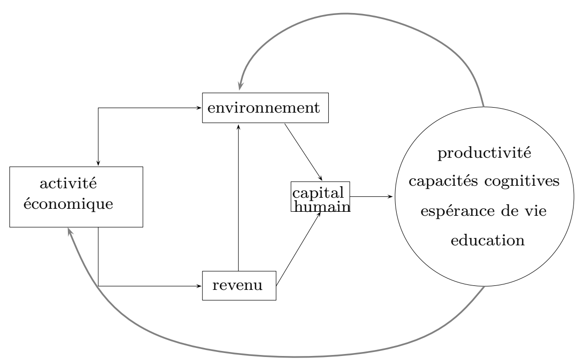


Figure 1: Interactions entre environnement et processus de croissance

Dans chacun des chapitres qui composent cette thèse, nous montrerons qu'il existe une complémentarité entre les choix en matière environnementale et les choix d'éducation, ou le niveau de santé des agents.

D'un point de vue théorique, cette complémentarité se traduit par l'évolution dynamique simultanée de deux variables économiques: le capital humain et la qualité environnementale. Cette détermination conjointe génère une propriété intéressante et pertinente au regard des observations empiriques, qu'est la multiplicité d'équilibres. Ainsi, les modèles que nous présentons dans chacun des chapitres, nous permettent d'illustrer et de justifier, au moins partiellement, la disparité des trajectoires de long terme suivies par les économies en termes de performance environnementale mais aussi de développement. Cette propriété nous conduit aussi à identifier, par des raisonnements économiques, les conditions dans lesquelles ce que nous avons défini comme des trappes à pauvreté environnementale émergent. Ces résultats théoriques font bien sûr écho à des situations réalistes selon les rapports internationaux de la Banque Mondiale (2001), de l'Organisation Mondiale de la Santé (2004; 2006), qui eux-mêmes font référence à ce concept économique de trappe environnementale et qui soulignent les inégalités en terme de développement. Bien sûr, la multiplicité d'équilibres conduit souvent à l'apparition de trappes à pauvreté dans la littérature économique (*cf.* pour une revue de la littérature Azariadis (1996)). Toutefois, ces trappes sont plus souvent expliquées par des facteurs technologiques, par le revenu, ou encore des facteurs comportementaux comme la fertilité, les évolutions culturelles, etc...Dans cette thèse, la trappe à pauvreté sera définie aussi par rapport aux conditions environnementales: elle associera donc un faible niveau de capital humain et une qualité environnementale fortement endommagée. Elle pourra aussi être caractérisée par une faible espérance de vie ou un niveau de santé relativement bas.

Cette thèse s'articule autour de trois chapitres, dont nous présentons brièvement les résultats principaux. Les deux premiers chapitres se concentrent davantage sur les interactions existantes entre santé et qualité environnementale tandis que le dernier analyse la complémentarité entre niveaux d'éducation et performance environnementale.

Environmental Health and Education: towards Sustainable Growth

Dans ce chapitre, nous analysons les interactions existantes entre la qualité de l'environnement, la santé des agents et le développement économique.

Nous présentons un modèle à générations imbriquées, où les agents économiques vivent trois périodes dont la première est consacrée à l'éducation. Nous supposons à l'instar de de la Croix & Doepke (2003) que l'évolution du stock de capital humain dans l'économie dépend à la fois des dépenses d' éducation faites par les parents pour leurs enfants, mais aussi du stock de capital humain déjà atteint qui se transmet de générations en générations. Par ailleurs, l'évolution de la qualité environnementale est similaire à celle proposée par John & Pecchenino (1994).

La contribution principale de ce modèle théorique est d'introduire une nouvelle variable dans l'équation d'accumulation du capital humain qui incarne l'efficacité des dépenses d'éducation. Cette variable, qui représente alors tout simplement la santé des agents durant leur enfance, est endogène et dépend de la qualité environnementale courante. D'autre part, l'évolution de la qualité environnementale est directement affectée par le niveau de développement à travers le niveau des dépenses de maintenance environnementale, mais aussi de la consommation polluante.

Finalement, dans ce modèle il existe une complémentarité entre dépenses d'éducation et qualité environnementale. Par exemple, si l'environnement est dégradé, les parents ont peu d'incitations (voire aucune) à investir dans l'éducation de leurs enfants, car le rendement de l'investissement est faible. En effet, un environnement pauvre induit, entre autres, une détérioration de la santé. En retour, moins de capital humain entraîne une réduction de la maintenance et donc agit aussi sur l'état futur de l'environnement. Cette complémentarité donne naissance à la co-détermination dynamique du capital humain et de la qualité environnementale à long terme. Sous certaines configurations paramétriques, des équilibres multiples apparaissent et notamment, une trappe à pauvreté environnementale émerge. Cette dernière sera caractérisée par un faible niveau de développement (capital humain) et un environnement détérioré. En revanche, une situation initiale favorable peut faire naître un cercle vertueux où l'économie peut atteindre un sentier de croissance continue et soutenable caractérisé par une augmentation continue du capital humain et de la qualité environnementale.

Les résultats de court terme, durant la phase de transition, sont aussi intéressants au regard de notre discussion précédente sur l'existence de la Courbe de Kuznets environnementale. En effet, les interactions dynamiques entre capital humain et environnement permettent de reproduire une convergence non-monotone, en forme de U, vers le sentier de croissance soutenue. Au début du processus de développement, la qualité environnementale est bonne et les agents investissent plus en éducation, donc la qualité environnementale se détériore, mais de moins en moins; lorsque l'économie atteint un niveau de revenu suffisant, alors les individus choisissent d'investir davantage en maintenance et le développement s'accompagne d'une amélioration de la qualité environnementale. Cependant, si les conditions environnementales sont défavorables, l'économie ne convergera pas vers un sentier de croissance continue, mais vers la trappe à pauvreté environnementale. Dans ce cas, les dommages environnementaux associés à la première phase de développement sont tels qu'ils empêchent l'économie de croître davantage et la détérioration environnementale se poursuit. Finalement, nous justifions l'existence de trajectoires divergentes en termes de performance environnementale et de développement.

Life Expectancy and the Environment

Dans ce chapitre, écrit en collaboration avec Fabio Mariani et Agustín Perez-Barahona[9], nous analysons les interactions existantes entre la qualité de l'environnement, l'espérance de vie des individus et le développement économique.

Ce chapitre s'appuie, par ailleurs, sur des observations empiriques qui mettent en exergue à la fois une corrélation positive entre espérance de vie et performance environnementale ainsi qu'une bi-modalité dans la distribution mondiale des performances environnementales. L'objectif de ce chapitre est, par conséquent, de reproduire ces deux faits stylisés.

Nous présentons un modèle à générations imbriquées où les agents vivent deux périodes, l'âge adulte et la vieillesse. Toutefois, la durée de la deuxième période de vie est conditionnée par l'espérance de vie des individus, qui dépend en particulier de la qualité environnementale subie à l'âge adulte. L'individu représentatif partage ainsi son revenu de première période entre maintenance et consommation, qui génère dans ce modèle des flux de pollution. De manière cohérente avec le premier chapitre, la loi dynamique qui guide l'évolution de la qualité environnementale au cours du temps est largement inspirée par les travaux de John & Pecchenino (1994).

Ce modèle met en évidence une double causalité, à la fois dans le long terme mais aussi durant la phase de transition, entre l'environnement et l'espérance de vie des agents. D'une part, une plus grande longévité incite les agents à investir en maintenance, car ils bénéficient plus longtemps de ce bien public; d'autre part, un environnement plus propre participe à accroître la longévité. Cette complémentarité se traduit à long terme par la présence d'équilibres multiples, et une trappe à pauvreté environnementale peut apparaître.

9. Fabio Mariani, IRES (Belgique), Paris 1; Agustín Perez-Barahona, INRA, Polytechique (France).

Toutefois, dans ce chapitre, si la trappe est toujours associée à un environnement dégradé, elle est aussi caractérisée par une faible espérance de vie.

Par la suite, nous analysons les implications de ce modèle en terme de Bien être. Il est alors possible d'identifier les sources d'externalité qui doivent être corrigées pour atteindre à l'état stationnaire (mais aussi de façon inter-temporelle) l'optimum social. Enfin, nous montrons que notre modèle est robuste à l'introduction d'une dynamique du capital humain. Dans cette extension, la corrélation positive entre environnement et espérance de vie est préservée, tout comme la propriété d'équilibres multiples. Néanmoins, la trappe environnementale est désormais aussi caractérisée par un faible niveau de capital humain.

Education and the Political Economy of Environmental Protection

Dans ce dernier chapitre, nous proposons un modèle d'économie politique qui, à travers les choix d'éducation, peut justifier les différences de performances environnementales entre les économies.

Dans ce modèle théorique, les agents vivent deux périodes. Ils partagent la première période de vie entre éducation et travail, tandis qu'ils consacrent leur deuxième période de vie à profiter de l'environnement. Les agents s'éduquent pendant un laps de temps irréductible permettant d'acquérir un niveau de compétence minimal: au terme de cette période, les individus entrent sur le marché du travail en tant que travailleurs "peu qualifiés". Toutefois, s'ils le souhaitent, les agents peuvent investir, toujours en terme de temps, en éducation supplémentaire, pour devenir par la suite des travailleurs "qualifiés". Le coût de cette éducation additionnelle est propre à chaque agent. Par conséquent, en fonction de ce coût et de l'utilité qu'ils retirent de l'acquisition de nouvelles connaissances, les agents choisissent de s'éduquer ou pas. La population est donc divisée en deux groupes de travailleurs: les travailleurs qualifiés et les travailleurs peu qualifiés. En accord avec les observations empiriques, les plus qualifiés sont aussi ceux qui présentent une espérance de vie plus grande. Or, une plus grande longévité permet de jouir plus longtemps de l'environnement: les individus sont donc incités à investir en capital humain s'ils veulent profiter de l'environnement.

Une fois que ces choix d'éducation sont faits, les individus votent sur une politique publique, et plus particulièrement sur le niveau de la taxe qui sera prélevée de manière forfaitaire sur leur revenu. Cette taxe finance exclusivement des dépenses de maintenance environnementale, qui sont donc désormais assurées par le gouvernement. En accord avec de nombreuses études empiriques, les agents plus éduqués ont un consentement à payer plus important pour préserver l'environnement. Dans notre modèle, les différences en terme de volonté à payer sont le fruit des choix d'éducation et passent par les différents niveaux d'espérance de vie, ce qui nous renvoie aux conclusions de notre deuxième chapitre. Par ailleurs, les préférences étant unimodales, le niveau de taxe effectivement appliqué dans l'économie dépend de la distribution des qualifications dans la population. Ainsi, si l'électeur médian est qualifié, la taxe prélevée sera plus importante. Ainsi, l'effort de maintenance mis en place par le gouvernement sera plus grand.

Le modèle met en exergue le rôle des anticipations, que forment les agents quant à l'état futur de l'environnement, sur les choix d'éducation et donc sur la politique environnementale effectivement menée. Sous l'hypothèse d'anticipations parfaites, il existe des équilibres multiples. Si les agents forment des anticipations optimistes alors ils sont incités à investir en capital humain: la taxe appliquée est alors relativement élevée, les dépenses de maintenance aussi et donc la qualité environnementale bonne. Au contraire, si les anticipations sont plutôt pessimistes, alors la majorité dans la population de travailleurs est peu qualifiée, les efforts de maintenance sont faibles et finalement la qualité environnementale endommagée. La convergence vers un équilibre dépend alors de la coordination des anticipations des agents quant à l'état futur de la qualité environnementale: on parle alors d'anticipations auto-réalisatrices.

Le rôle essentiel que jouent les anticipations des agents ouvre la voie à l'introduction de politiques publiques, dont le but serait de sélectionner le meilleur équilibre. Dans le modèle, nous proposons d'étudier les conséquences d'une politique qui subventionnerait l'éducation. Nous montrons ainsi que si l'économie est initialement prise dans la trappe environnementale, alors ce type de politique peut améliorer la performance environnementale d'une économie dans le long terme.

Chapter 1

Environmental health and Education: towards sustainable growth

1.1. Introduction

As underlined by the World Bank (2001) in its strategic report and by the UNDP (2008), the environment considerably affects health outcomes, due to traditional environmental hazards (lack of safe sanitation, indoor pollution, exposure to disease vector) but also through more modern environmental risks (transports, industry, agro-chemicals...). In addition, these reports point out that poor countries are more sensitive to both kind of environmental issues, so that good environmental conditions are often associated with higher levels of human capital while health risks exacerbate poverty.

According to these evidence and as a starting point of the motivation, our chapter relies on a wide empirical literature which emphasizes the damages imposed on agents' health status by a poor environment, like, for instance, Fitzgerald *et al.* (1998), Pope (2000), Bleakley (2003), Chay & Greenstone (2003), Dasgupta (2004), Evans & Smith (2005), WHO (2004, 2006), Currie & Schmieder (2008).[1] These papers also underline that the deterioration of the environment (including atmospheric pollution, water quality degradation, soils occupations, wastes, natural resources depletion etc.) reduce sharply and especially children health outcomes and that of elderly people.

When focusing on development issues, the impact of the environment on children's health is particularly interesting since the latter induces strong aggregate effects on human capital accumulation.[2] Indeed, it has been well established, for instance by Hansen & Selte (2000), Bloom *et al.* (2001), Schultz (2003), Chakraborty (2004), Weil (2008), that health outcomes contribute significantly to human capital-led growth: healthier agents are more productive, present lower levels of absenteeism and more cognitive capacities of learning, etc. Therefore, since environmental conditions influence dramatically children' health status, it plays a key role in the growth process. Such kind of causal mechanism can be, at least partially, illustrated by some empirical evidence like Romieu *et al.* (1992), Park *et al.* (2002), Mendell &

1. In particular, the decline of environmental conditions usually translate into health risks and diseases going from cardiopulmonary to respiratory symptoms (asthma, cough....), epidemiologic diseases, blood lead level, acute poisoning or even cancers among others (Murray & Lopez (1996), World Bank (2001)). Of course, all those effects differ in their magnitude, depending on the level of income, the health care system, the medicine technology...

2. In this chapter, we do not focus on the effects of the environment on individuals'life expectancy rather than on children'health since we want to capture a relationship between environmental quality, health and the choices of education. In addition, the linked between agents longevity and environmental conditions have been already tackled in other papers like Pautrel (2006), Ballestra & Dottori (2009), or even in the following chapters of the thesis.

Heath (2004), Currie *et al.* (2007), Ikefuji & Horii (2007). In those papers, the authors show that deteriorated environmental conditions reduce significantly children school attendance, even after controlling for many others socio-economic variables. Typically, this may have heavy consequences on school attainment and, further, on human capital accumulation.[3]

The major novelty of our article is therefore to propose a theoretical model in which harmful effects of pollution on human capital accumulation are introduced: it is assumed that the efficiency of education expenditure is directly affected by the environment, through its implications on children' health.

We present an overlapping generations model where altruistic parents invest in education for their offspring, while the effectiveness of this investment depends explicitly on the current state of the environment: we consider that children' health may be dramatically affected by a poor environmental quality, thus reducing sharply the efficiency of education expenditure. This causal link between the environment and health may be captured by, for instance, the level of school attendance as mentioned previously. In the end, the stock of human capital is affected by both the current state of the environment and the level of human capital inherited from the previous generation. In turn, the environment is influenced by human capital through pollution flows (generated by agents' consumption) and environmental maintenance (positively related to agents' income). Thus, in our model human cap-

3. The consequences of specific environmental issues could also be measured through a lot of indicators like for instance hospital admissions, medicine visits, or even DALY's data (which measure the Disability-Adjusted Life Year across various causes of illness or environmental risks).

ital and environmental quality dynamics are jointly determined. This may lead to multiple equilibria and an environmental poverty trap might occur if returns to education are too low. Indeed growth-induced environmental risks reduce health outcomes, thus diminishing the return to education: human capital accumulation is slackened and income becomes too low to trigger further investment in the environmental preservation. Environmental conditions are still deteriorating and the economy may fall into a vicious cycle which drives it, in the long-run, into the trap.

Along the transition path, our model is also consistent with empirical observations with regards to the existence of the Environmental Kuznets Curve (Grossman & Krueger (1995), Shafik (1994), Panayotou (1993)), hereafter EKC. Indeed, it turns out that only developed economies have experienced over time this U-shaped relationship between environmental quality and income; while developing countries seldom display this kind of dynamical pattern, meaning that those developing countries would be somewhat trapped on the decreasing part of the U. One major justification for this phenomena could be, as argued by Gangadharan & Valenzuela (2001), the negative effects of a damaged environment on agents' health. Our setting can account for non-ergodic dynamics that allow to replicate these two different trajectories and may explain why some economies can be caught into a trap, by emphasising the twofold relationship between environmental quality and human capital production.

Finally, this article is related to two main fields of the economic literature. First, it considers an OLG structure, where agents value the future environmental quality, both for self-interested and purely altruistic motives[4], and may invest in maintenance in order to improve it. This basic framework is in line with the seminal works of John & Pecchenino (1994), although in our set up, intergenerational externalities do not come from physical capital accumulation, but human capital dynamics, via consumption behaviour. Moreover, the growth process is driven by human capital accumulation and private choices of education affect the future state of the environment. Some others papers have already dealt with the impact of the environment on heath in growth models like Gradus & Smulders (1993) or van Ewijk & van Wijnbergen (1995). However, they consider that pollution flows as the crucial variable, whereas we choose, in a more general way, to take into account a stock of environmental quality. In addition, in those articles there is no room left for private expenditures of maintenance. Second, our contribution is linked to many papers dealing with educational choices and economic development (see for instance de la Croix & Doepke (2003), Chakraborty (2004), Galor & Moav (2002)). In those theoretical OLG models, altruistic parents invest in their children's education. However, educational choices are not related with a prospect of sustainable growth, from an environmental point of view. This literature also deals with multiple equilibria and poverty traps, associated with income, technology, fertility or even human capital (see Azariadis (1996), Blackburn & Cipriani (2002)). Here, the trap will be characterized in addition by a poor environmental quality.

The article is organized as follows: after this Introduction, Section 1.2 presents

4. See, for instance, Popp (2001) for further discussion on the various motives that may trigger environmental expenditure.

the basic framework and the structure of the model; Section 1.3 analyses microeconomic behaviours; Section 1.4 proposes the main dynamical results. Finally, Section 1.5 concludes.

1.2. The Model

In this section, we present the setup of the model and discuss the main assumptions.

1.2.1. Basic Framework

In this model, we consider an infinite-horizon economy where time is discrete, $t = 0, 1, 2, ..., \infty$ and we assume no demographic growth. The representative agent lives for three periods: childhood, adulthood and the old age. During childhood, agents do not derive any utility although they educate; during adulthood, agents supply their human capital to the market and all decisions are taken; finally, when old, agents benefit from the environment and care about the level of human capital reached by their offspring. Therefore, the representative agent born at date $t-1$ maximizes its lifetime utility, defined over consumption when adult (c_t), environmental quality when old (E_{t+1}) and the level of human capital attained by their children (h_{t+1}):

$$U_{t-1} = \ln c_t + \gamma(\ln E_{t+1} + \ln h_{t+1}), \tag{1.1}$$

where $\gamma > 0$ is a discount factor that determines the weight given to both future level of human capital and environmental quality. It is assumed that children are endowed with one unit of time, dedicated to education that is privately funded. Here, parents invest in the education of their children through a warm glove effect. In line with de la Croix & Doepke (2003), human capital evolves according to:

$$h_{t+1} = [\mu + v_t \Lambda_t]^{1-\theta} h_t^{\theta}. \tag{1.2}$$

The stock of human capital depends on two main elements: human capital inherited from parents, h_t, and v_t being the education expenditure. Notice that $0 < \theta < 1$ measures the relative importance of human capital transmission versus education expenditure in the production of human capital.[5] In this framework, education expenditure, v_t, could be regarded as the *potential* quantity of education provided by parents to their offspring while $v_t \Lambda_t$ embodies the *effective* quantity of education received by a child. Hence, $(1 - \Lambda_t) \in (0, 1]$ represents the fraction of education lost, due to illness, or the time spent at home instead of school etc. Broadly speaking Λ_t captures children' health outcomes and can be regarded as the effectiveness of education expenditure. Yet, the determinants of this variable will be deeply discussed later on (see section 1.2.2). Moreover, notice that agents are also endowed with "basic skills" ($\mu > 0$) that allow their human capital to be still positive, even if parents do not invest in education.

5. Let us underline that $(1 - \theta)$ is, in fact, an "adjusted" elasticity of human capital to education expenditure, since it includes not only education but innate ability (μ).

In this setting, we consider that agents value the amenities provided by the environment, in particular when old. Agents care about environmental quality and both the use and non-use values of these amenities are taken into account: for instance, individuals may be concerned by the neighbouring environment (like green spaces, forests, water and air quality), as well as by more global environmental issues (like global warming, natural resources, biodiversity etc.). Following John & Pecchenino (1994), the law of motion of environmental quality writes as:

$$E_{t+1} = (1-\eta)E_t - P_t + \sigma m_t, \tag{1.3}$$

where $0 < \eta < 1$ is the natural depreciation rate of the environment, P_t are pollution flows, m_t is environmental maintenance, while $\sigma > 0$ accounts for its efficiency. Let us underline that this maintenance represents all actions engaged by agents in order to preserve or improve the environment. Besides, equation (1.3) implies that, in order to improve future environmental quality, the effort of maintenance must be high enough to compensate for both natural depreciation and pollution flows, otherwise the environment deteriorates.

During adulthood, adults supply inelastically h_t units of human capital and earn $w_t h_t$, with w_t being the wage rate. Using (1.2), the labour income depends, at least partially, on the parental investment in education, but also on the efficiency of such expenditure at date $t-1$. In the end, we consider here that agents' productivity is not directly affected by environmental conditions, but, alternatively that the supply of human capital depends on the environment: the labour income indirectly relies on the environment suffered during childhood. Income can be used for three alternative purposes: consumption, education investment and environmental maintenance. Hence, the budget constraint when adult writes as:

$$w_t h_t = c_t + m_t + v_t. \tag{1.4}$$

One good is produced in the economy and the production technology requires only one input, human capital. The production function can be expressed as: $Y_t = \omega h_t$, where ω is an index of productivity. As the production function exhibits constant returns to scale, it follows directly that the wage rate is given by the average productivity of human capital: $w_t = \omega$. In addition, we consider that pollution flows derive from consumption[6]:

$$P_t = \beta c_t, \tag{1.5}$$

where $\beta \in [0, 1]$ represents the cleanness degree of consumption. Here, a high value of β induces that consuming implies more pressure on the environment. Otherwise said, even when quantitatively consumption is low, its harmful impact on the environment can be heavy, including for instance polluting emissions, wastes, or even natural resources depletion, etc..Moreover, in this set-up, consumption represents an intergenerational externality. Indeed, adults' consumption deteriorates the future state of the environment suffered by the next generation when adult and the following generation when young, while this effect is not taken into account by agents when

6. We could have alternatively assumed that pollution arises from production, but results are qualitatively unchanged.

maximising their lifetime utility.

1.2.2. Efficiency of Education Expenditure

Let us now consider Λ_t, the efficiency of education expenditure, as a function of environmental quality, such that: $\Lambda_t \equiv \Lambda(E_t)$, where $\Lambda(\cdot)$ is increasing and concave and takes it values on the interval $[0, \lambda]$, with $\lambda \leq 1$.

This assumption can be justified by a wide empirical economic literature dealing with the effects of environmental quality on human health. As mentioned in Introduction, it has been often highlighted that children' health can be harshly affected by deteriorated environmental conditions (Pope (2000), Chay & Greenstone (2003), Evans & Smith (2005), Bleakley (2003), Dasgupta (2004), Currie & Schmieder (2008)). This may have, for instance, a direct outcome on the level of school attendance, so that when environmental quality is damaged, the level of absenteeism at school is higher. Yet, it is well established that health plays a crucial role in human capital production: healthier agents display better cognitive capacities, more willingness to learn, less absenteeism etc. (see, for instance, Weil (2008), Grossman & Kaestner (1997)). Hence, everything goes as if the environment determines education expenditure effectiveness, through its impacts on children's health. Environmental quality becomes then a key factor for human capital production.

In order to obtain closed-form solutions, we assume that the effect of the environment on children' health is described by:

$$\Lambda(E_t) = \frac{\lambda E_t}{(1 + E_t)}, \tag{1.6}$$

where $\Lambda(\cdot)$ is increasing and concave in environmental quality and $\lim_{E_t \to \infty} \Lambda(E_t) = \lambda$. As environmental quality improves, children spend more and more time at school and present better cognitive capacities; nevertheless, it is supposed that this efficiency of educational spending is strictly bounded and smaller than one. Indeed, children health status depends on other factors, beyond environmental quality, which could explain why children may be absent of school. In particular, λ accounts for the health care effectiveness, the medicine technology or the access to health care services, meaning that if it is low, an improvement in environmental quality translates into a small enhancement of children' health.

Notice that through this function $\Lambda(\cdot)$, a two-way causality between human capital and environmental quality occurs. On the one hand, the environment affects the productivity of education when young, and determines, in the end, the labour income earned when adult: a poor environment reduces education efficiency when young, and ceteris paribus, the level of human capital reached when adult.[7] On the other hand, human capital, through the choices of consumption and maintenance, influences the evolution of environmental quality. This twofold relationship will be established formally in the following section which presents the optimal microeco-

7. Here the environment suffered when young does not affect workers' productivity, rather than the quality of the workforce. We could have assumed that the current environmental quality affects directly adults' productivity as it can be modeled in Williams III (2003), but this would heavily complicate the model, although the main mechanisms would be reinforced.

nomic choices of agents.

1.3. Microeconomic Choices

In this section, we derive and discuss the optimal microeconomic choices from the maximisation of the Utility function (1.1) under the constraints (1.2), (1.3), (1.4) and (1.5). Solving the maximization program yields the following First Order Condition (FOC) on education expenditure:

$$\gamma(1-\theta)\Lambda(E_t)c_t \leq [\mu + v_t\Lambda(E_t)], \text{ an equality holds if } v_t > 0. \tag{1.7}$$

We also obtain the FOC on maintenance:

$$\gamma\sigma c_t \leq E_{t+1}, \text{ an equality holds if } m_t > 0. \tag{1.8}$$

Notice that the presence of a minimal level of human capital, μ implies that it may be optimal for parents not to invest in education for their children. Symmetrically, if environmental quality is sufficiently high, agents have no incentive to engage in environmental maintenance. Hence, the optimisation problem may induce the existence of corner solutions with respect to educational spending and maintenance. Hereafter, superscript $i = \{S, U\}$ and $j = \{C, D\}$ will denote respectively the *Schooled* solution when children are educated ($v_t > 0$) and the *Unschooled* one ($v_t = 0$), when it is optimal for parents not to invest in education. Symmetrically, we define the *Clean* solution when agents invest in maintenance or the *Dirty* one when no environmental preservation is engaged.

In order to describe clearly the dynamics of our model, the plan (E_t, h_t) has been divided into four regions. As a result of utility maximization, the corner solution for education occurs if, according to equation (1.7):

$$h_t < \frac{\mu[\sigma(1+\gamma)+\beta]}{\gamma(1-\theta)\sigma\omega\Lambda(E_t)} - \frac{\gamma(1-\eta)}{\omega\sigma} \equiv \Phi(E_t), \tag{1.9}$$

where $\Phi(E_t)$ being a downward sloping curve, meaning that the level of human capital required to invest in education reduces with environmental quality. Similarly, according to equation (1.8), the corner solution for maintenance occurs if:

$$h_t < \frac{(1-\eta)[1+\gamma(1-\theta)]E_t}{\omega(\gamma\sigma+\beta)} - \frac{\mu}{\omega\Lambda(E_t)} \equiv \Psi(E_t), \tag{1.10}$$

where $\Psi(E_t)$ is increasing and concave in environmental quality. It could also be the case that agents do not invest neither in education nor in maintenance: according to both equation (1.7) and (1.8), this would happen if both the following inequalities hold:

$$h_t < \frac{\mu}{\gamma(1-\theta)\omega\Lambda(E_t)} \equiv \phi(E_t) \tag{1.11}$$

and

$$h_t < \frac{(1-\eta)E_t}{\omega(\gamma\sigma+\beta)} \equiv \psi(E_t), \tag{1.12}$$

where $\phi(E_t)$ is a downward sloping curve while $\psi(E_t)$ is increasing and linear. These boundary conditions (1.9)-(1.12) divide the state space (E_t, h_t) into four sets, $\mathcal{S}^{i,j}$, as depicted in Figure 1.1:

$$\mathcal{S}^{S,C} = \left\{(h_t, E_t) \in \mathbb{R}^2_+ : h_t > \Phi(E_t) \,\text{and}\, h_t > \Psi(E_t)\right\},$$
$$\mathcal{S}^{U,C} = \left\{(h_t, E_t) \in \mathbb{R}^2_+ : \psi(E_t) < h_t < \Phi(E_t)\right\},$$
$$\mathcal{S}^{S,D} = \left\{(h_t, E_t) \in \mathbb{R}^2_+ : \phi(E_t < h_t < \Psi(E_t))\right\}, \tag{1.13}$$
$$\mathcal{S}^{U,D} = \left\{(h_t, E_t) \in \mathbb{R}^2_+ : (E_t, h_t) \notin \mathcal{S}^{S,C} \cup \mathcal{S}^{U,C} \cup \mathcal{S}^{S,D}\right\}.$$

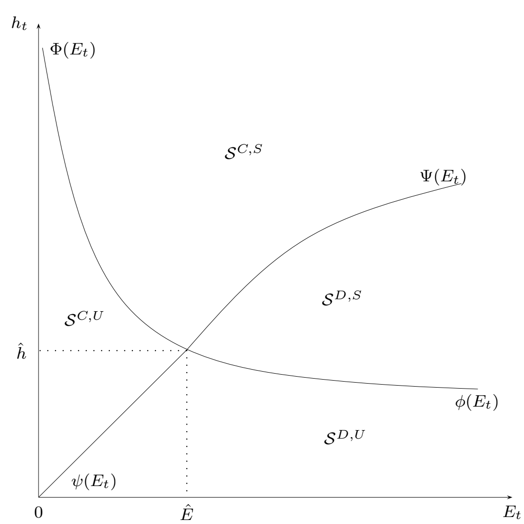


Figure 1.1. *Plan*

To summarize, for very low levels of development (human capital) agents will not invest neither in education, nor in maintenance, because income is too low. If the environment deteriorates, agents do not educate their children, as the return to education is depleted, but might invest in maintenance. Alternatively, if environmental conditions improve, agents will only start to invest in education, not in maintenance. Finally, an interior solution appears for high enough levels of human capital and as soon as environmental quality reaches intermediate values; parents invest in both education and environmental preservation.

1.3.1. *Education Expenditure*

Taking into account (1.7) and (1.8), we derive the optimal choice of education expenditure, when $m_t = 0$ and when $m_t > 0$:

$$v_t = \begin{cases} \frac{\gamma(1-\theta)\Lambda(E_t)\omega h_t - \mu}{\Lambda(E_t)[1+\gamma(1-\theta)]} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,D} \\ \frac{\gamma(1-\theta)\Lambda(E_t)[(1-\eta)E_t + \sigma\omega h_t] - \mu[\sigma(1+\gamma)+\beta]}{\Lambda(E_t)[\sigma(1+\gamma(2-\theta))+\beta]} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \tag{1.14}$$

In both configurations, a clean environment boosts education expenditure. In fact, when environmental conditions improve, the return on the investment in human capital rises, thus encouraging parents to engage in educational spending. In addition, in the interior regime, a substitution effect arises: if less maintenance is needed, *ceteris paribus*, parents will be able to educate more their offspring.

1.3.2. *Maintenance*

Similarly, substituting (1.14) into (1.8) yields the expression for optimal maintenance, when $v_t = 0$ and when $v_t > 0$:

$$m_t = \begin{cases} \frac{\omega h_t(\gamma\sigma+\beta) - (1-\eta)E_t}{\sigma(1+\gamma)+\beta} & \text{for } (E_t, h_t) \in \mathcal{S}^{U,C} \\ \frac{(\gamma\sigma+\beta)[\Lambda(E_t)\omega h_t + \mu] - \Lambda(E_t)(1-\eta)(1+\gamma(1-\theta))E_t}{\Lambda(E_t)[\sigma(1+\gamma(2-\theta))+\beta]} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \tag{1.15}$$

The above expression reproduces the standard results found in the literature (see for instance John & Pecchenino (1994); Ono (2002)), according to which both pollution flows and income have a positive impact on environmental actions, while improved environmental conditions tend to reduce maintenance. However, in the interior regime, introducing human capital accumulation reinforces the second effect: for a clean environment, agents are more prone to invest in education since investment in human capital is more efficient. Then, a substitution effect arises thus reducing green expenditure. This additional effect vanishes obviously when parents do not invest in education.

1.4. Dynamics

Substituting optimal choices into the dynamic equations describing the evolution of human capital (1.2) and environmental quality (1.3) yields a bi-dimensional dynamical system that illustrates the co-evolution of h_t and E_t:

$$\begin{cases} h_{t+1} = [\mu + v(E_t, h_t)\Lambda(E_t)]^{1-\theta} h_t^{\theta} \\ E_{t+1} = (1-\eta)E_t - P(E_t, h_t) + \sigma m(E_t, h_t), \end{cases} \tag{1.16}$$

with given initial conditions (E_0, h_0). Here the functions $v(E_t, h_t)$, $m(E_t, h_t)$ and $P(E_t, h_t)$ describe respectively the optimal choices of education and maintenance, and the resulting level of pollution, derived from optimal choices of consumption (see equation (1.5)). In order to assess the dynamic properties of the setting, we draw a phase diagram that depicts the overall dynamics. To do this, we start by presenting separately the human capital stationary locus (hh locus) and that of the environment (EE locus).

1.4.1. The hh Locus

Let us first define the stationary locus of human capital: $hh \equiv \{(E_t, h_t) : h_{t+1} = h_t\}$. The level of human capital in the steady-state is crucially affected by the region it belongs to. It is possible to state that, as illustrated in Figure 1.2:

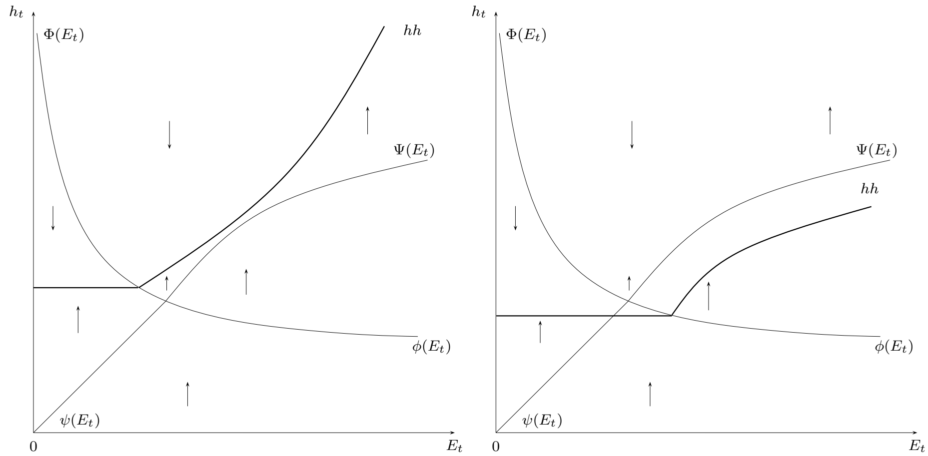
Lemma 1 *Human capital is constant when it equals:*

$$hh(E_t) = \begin{cases} \mu & \text{for } (E_t, h_t) \in \mathcal{S}^{U,C} \\ \frac{\gamma(1-\theta)\mu}{1+\gamma(1-\theta)(1-\Lambda(E_t)\omega)} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,D} \\ \frac{\gamma(1-\theta)[\sigma\mu+(1-\eta)\Lambda(E_t)E_t]}{[\sigma(1+\gamma(2-\theta)-(1-\theta)\Lambda(E_t)\omega)+\beta]} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \tag{1.17}$$

For any given value of environmental quality, human capital converges towards this stationary locus, hh.

Proof. See Appendix A ■

As it is shown in Appendix A, the hh locus is split into two distinct parts. For a too poor environmental quality, agents do not invest in education and therefore the stock of human capital does not vary over time: it is pinned down to the exogenous level of basic skills and the stock of human capital is only passed on to future generations. Further increases in environmental quality lead parents to invest in education for their offspring, since the return to the investment in human capital



(a) hh locus enters the interior regime (b) hh locus enters a dirty area

Figure 1.2. *The hh locus enters the interior regime*

becomes higher. The hh locus enters the schooled areas and increases with environmental quality. Let us underline that the shape of the hh locus in these areas crucially depends on the behaviour with respect to environmental maintenance. Figure 1.2a depicts the case where the hh locus enters the interior regime. In that case, the property of convexity can be explained by the positive effect of environmental quality on the choice of education: when environmental quality raises, there is less need of maintenance, thus more resources are available for education. Nevertheless, it could be the case that, following an improvement in environmental quality, the hh locus enters the schooled but dirty area (see Figure 1.2b). Then, the enhancing effect of environmental quality disappears so as the property of convexity: the hh locus becomes concave in the environment. Notice also, that under specific parametric conditions, the hh locus may go through both areas.

1.4.2. The EE Locus

The stationary locus of the environment is defined as $EE \equiv \{(E_t, h_t) : E_{t+1} = E_t\}$ as depicted in Figure 1.3. Environmental quality is at the steady-state when the positive effect of maintenance is fully offset by the negative effect of both pollution flows and the natural depreciation of the environment. Therefore, it is possible to claim that:

Lemma 2 *Environmental quality is constant when:*

$$EE(E_t) = \begin{cases} \frac{-\beta - \eta[1+\gamma(1-\theta)]\Lambda(E_t)E_t}{\beta\Lambda(E_t)\omega} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,D} \\ \frac{E_t[\sigma(1+\gamma\eta)+\beta]}{\gamma\sigma^2\omega} & \text{for } (E_t, h_t) \in \mathcal{S}^{U,C} \\ \frac{E_t[\sigma(1+\gamma(1+\eta-\theta))+\beta]}{\gamma\sigma^2\omega} - \frac{\mu}{\Lambda(E_t)\omega} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \quad (1.18)$$

Moreover, for any given level of human capital, environmental quality converges towards this stationary locus, EE.

Proof. See Appendix B ∎

It is worth noticing that when $m_t = 0$, the EE locus is negative, which is inconsistent with the explicit form of the utility function (see equation (1.1)). Then, in the zero maintenance areas, we can only state that environmental quality always deteriorates. However, as soon as $m_t > 0$, and as illustrated in Figure 1.3, the stationary locus of the environment is globally increasing in h_t. This means that a higher level of human capital allows for a cleaner stationary environmental quality. This property stems from the fact that an increase in the income translates into more

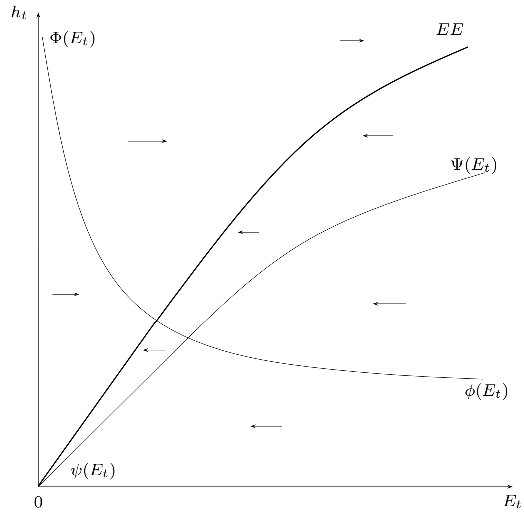


Figure 1.3. *The EE locus*

maintenance, despite an increasing consumption. More specifically, this relationship is first linear (in the unschooled regime) and becomes concave (in the interior regime), because the efficiency of education expenditure is it-self concave with respect to environmental quality.

1.4.3. Global Dynamics

This section presents the main dynamical results of the model. We study long-run dynamic implications of our model and characterize the steady-states, defined as the point where hh and EE intersect. It is then possible to claim that:

Proposition 1 *Under proper conditions, the joint dynamics of human capital and environmental quality described by (1.16) may either (i) be featured by a continuous growth path; or (ii) exhibit only one stable steady-state, or (iii) exhibit two steady-states, the first one, namely the environmental trap being stable, the second is not.*

Hence, depending on initial conditions, the economy falls into the environmental development trap or follows a continuous and sustainable growth path.

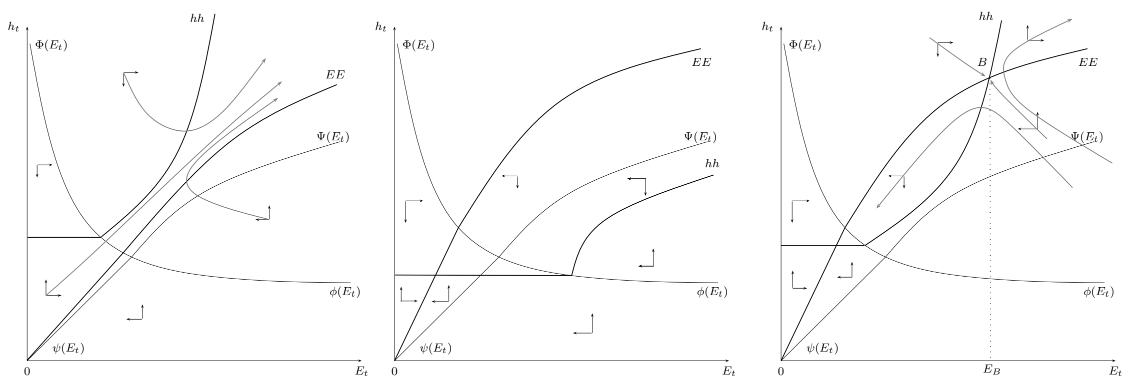
Proof. See Appendix C ■

The situation (i) to (iii) are depicted in Figure 1.4 below. In Figure 1.4a, whatever initial conditions, the economy follows a continuous and sustainable development path, where both human capital and environmental quality improve over time. Intuitively, this case is likely to occur when, for instance, μ, the level of basic skills, λ, the health care effectiveness, or even ω the labour productivity are high enough. All these parameters contribute to raise the stock of human capital, no matters the level of education expenditure. Similarly, for very high degree of maintenance efficiency, the configuration (i) of Proposition 1 may occur, as the stationary locus of environmental quality is shifted downward.

In case (ii) of Proposition 1, again, no matter initial conditions, the economy converges towards the unique, low and stable equilibrium. Obviously, this situation is less favourable compared to the previous case: the economy is caught in a situation where human capital equals the level of basic skills (since parents do not invest in education for their offspring) and environmental quality is fairly damaged.

Finally, in the configuration depicted in Figure 1.4c, initial conditions are crucial. For low initial environmental quality and/or human capital (below the saddle path), the economy will end up with the low equilibrium. When environmental quality is strongly damaged, agents invest less in education (or do not invest at all), because returns to this investment is sharply reduced. Then, the dynamics of human capital are slackened and the total income perceived by agents diminishes. Thus, although pollution flows are few, households are not able to invest enough in maintenance, and the environment does not improve enough to trigger further additional education expenditure. As environmental quality deteriorates, incentives to invest in human capital decrease: the economy is caught in a vicious cycle that drives it to the low equilibrium. This stable equilibrium, namely the environmental development trap, will be therefore characterized by a low level of development and deteriorated environmental conditions. These mechanisms are consistent with empirical evidence, and in particular with the existence of low human development traps (see UNDP (2008)). In compliance with our conclusions, this report underlines the fact that deteriorated environmental conditions may harm further economic development, through its interactions with health.

Alternatively, relatively clean initial environmental conditions or high enough level of development (above the saddle path) allow for reaching a self-sustained development path: good initial environmental conditions boost the investment in education that allows for an increased income, which, in turn, stimulates environmental maintenance. Thus, as human capital accumulates environmental quality improves: this virtuous cycle drives the economy to develop in a green and sustainable way. In the presence of multiple equilibria, it is worth noticing that the low equilibrium may belong either to the unschooled area or to the interior regime. In particular, a higher effectiveness of maintenance σ or a greener consumption (low β) would, at least, move to the right the low equilibrium. Consequently, the low equilibrium would exhibit higher human capital and better environmental conditions.



(a) Sustainable growth path (b) Environmental trap (c) Multiple equilibria

Figure 1.4. *Global Dynamics*

1.4.4. Environmental Kuznets Curve

As already mentioned, in specific configurations of parameters, some economies might be caught, in the long-run, into an environmental development trap, whose features are supported by empirical evidence. On the transition path, the model provides also interesting results, in particular when dealing with the Environmental Kuznets Curve.

As described by Grossman & Krueger (1995) among others, during early stages of the development process, as long as the economy grows, it might simultaneously deteriorates its environmental conditions; then, if the economy reaches a sufficiently high level of income, the population starts to care about the environment, thus allowing to develop and improve environmental quality. However, this U-shaped pattern is not experienced by all economies and, in particular, the less developed countries usually do not reach the sufficient level of income that would allow them to develop as well as improve the environment.[8] Among the various reasons that may justify this observation, Gangadharan & Valenzuela (2001), the World Bank (2001) or even the UNDP (2008) underline the negative impact of a damaged environment on health during early stages of development: the benefit from the growth process might be offset by the harmful effect of bad environmental conditions on human health, through many different channels: diseases, mal nourishment, etc....

Our theoretical framework allows us to replicate these results along the transition path. One major contribution of this chapter is also to be able to reproduce such kind of U-shaped pattern, by introducing human capital accumulation issues, without referring to corner solution on maintenance, as it can be the case in John & Pecchenino (1994). In the interior regime, the economy may converge non monotonously towards the sustainable development path. Nevertheless, if initial environmental conditions are poor and human capital is low (the system stands below the saddle path, see figure 1.4c), the economy might be caught in an environmental poverty trap. In both cases, the first phase of development is associated with a deterioration of the environment. This fall in environmental quality affects negatively children's health and return to investment in human capital sharply diminishes. However, if the level of human capital is high enough, the deterioration of the environment reduces as income raises. When the level of income is sufficiently high, the economy develops and harmful pollution flows are offset by efforts of maintenance. The relationship between development and environmental quality reverses and the economy reaches

8. The existing debate around the existence of the EKC is even wider, as conclusions often differ according the nature of pollution. However, here we restrict our discussion to global comparisons.

the increasing part of the U-shaped curve. On the contrary, the economy may never reach the "threshold level of income" that would enable to develop and improve environmental conditions. Then, the vicious cycle exposed previously drives the economy to the trap. In that case, environmental quality always deteriorates: these economy would be probably located on the decreasing part of the U-shaped curve.

1.4.5. Escaping the Environmental Poverty Trap

Among all the situations presented above, the environmental trap is the less favourable in terms of welfare. Otherwise said, agents' utility is lower, in the long run, compared to the opportunity of a sustainable and continuous development path. Then, it seems reasonable to asses the different possibilities to escape from such equilibrium. In this section, we tackle this issue by considering two alternative tools: first an environmental policy, second a public policy in favour of the economic development.

Let us consider the impact of a cleaner consumption, on the environmental trap. A smaller value of the parameter β may, at least, increase the value of the low equilibrium, when the latter belongs to unschooled regime. Although the stationary locus of human capital is independent of β, the stationary environmental quality is crucially affected by the cleanness degree of consumption. In addition, it could be the case that the trap shifts from the unschooled regime to the schooled one, if β becomes small enough. If consumption is less pollution intensive, then harmful pressure of human capital on the environment reduces: the EE locus, as depicted on Figure 1.4c, shifts downward. In the interior regime, this consumption-induced pollution also alters the stationary locus of human capital: a dirty consumption reduces incentives to invest in education through a substitution effect with maintenance. Then, the hh locus moves up. In all likelihood, combining these two effects enables to escape from the trap. Yet, an environmental policy that would aim at reducing the consumption-induced pollution (thus correcting the intergenerational externality of consumption) could be considered.

The same goal could be reached by means of a public policy that would promote the development process. Yet, when focusing on developing economies, it seems more relevant to pay attention to the productivity of low-skilled agents, embodied by μ in our model, rather than the wage rate, ω. Indeed, as already mentioned, the parameter μ, the level of basic knowledge, may also favour the emergence of a unique continuous growth path since it raises the human capital stationary locus. However, a crowding-out effect exists, thus reducing the interior regime area. In fact, despite the positive long-run effect, an increase in μ discourages the effort of education at a microeconomic level. Consequently, the required level of human capital to engage education expenditure is higher. Finally, there might exist a range of values of μ for which the economy can escape from the trap. Otherwise said, a large increase of the level of basic skills, derived for instance from a educational public policy, can exhibit pernicious effects. However, we could wonder about the resulting impact of a subsidy that would lower the cost of private education. In particular, this issue could be assessed in comparison with the outcome of a environmental policy as suggested above.

1.5. Conclusion

In this chapter we have analyse the interplay between health, human capital and the environment, as well as the resulting dynamic implications. The model hinges upon a simple mechanism which highlights a two-way causality between human capital accumulation and sustainable development. Human capital dynamics crucially depends on current environmental conditions, through children'health, while the dynamics of the environment is, in turn, affected by human capital, through pollution and maintenance. The joint dynamics of these variables is determined and may imply the existence of multiple development regimes. In particular, our results are consistent with the empirical evidences on the existence of the EKC. In addition, non-ergodicity allows us to identify an environmental poverty trap, characterized by a low level of development and bad environmental conditions. Possible strategies to escape the trap, as well as factors affecting the risk to be caught in such a trap, have been discussed.

Finally, our model can be extended along the following directions: (i) investigating the outcome of suitable public policy; (ii) introducing some demographic issues; (iii) providing a deeper analysis of the central planner solution.

1.6. Appendices

A. Proof of Lemma 1

The stationary value of human capital is described by the equation: $h_{t+1} = h_t$. From (1.16), this relation can be rewritten as:

$$h_t = \mu + v(E_t, h_t)\Lambda(E_t) \tag{A.1}$$

Plugging optimal choices into this expression yields equation (1.17).

Let us now characterize this stationary locus of human capital. When $v_t = 0$, the hh locus is a constant equal to the level of basic skills, $\mu > 0$. When $(E_t, h_t) \in \mathcal{S}^{S,D}$, the hh locus exhibits the following properties, according to the assumptions with respect to $\Lambda(E_t)$:

$$\frac{\partial hh(E_t)}{\partial E_t} = \frac{\gamma^2\mu(1-\theta)^2\Lambda'(E_t)\omega}{[1+\gamma(1-\theta)(1-\Lambda(E_t)\omega)]^2} \tag{A.2}$$

Using (1.6), then, it easy to check that $\partial^2 h^S_{hh}/\partial E^2 < 0$. When $(E_t, h_t) \in \mathcal{S}^{S,C}$, the hh locus exhibits the following properties:

$$\frac{\partial hh(E_t)}{\partial E_t} = \gamma(1-\theta)\left\{\frac{(1-\eta)[\Lambda'(E_t)E_t + \Lambda(E_t)]}{g(E_t)} - \frac{[\sigma\mu + (1-\eta)\Lambda(E_t)E_t]g'(E_t)}{g(E_t)^2}\right\}, \tag{A.3}$$

with $g(E_t) \equiv [\sigma(1+\gamma(\eta-\theta) - (1-\theta)\Lambda(E_t)\omega) + \beta] > 0$ and where $g'(E_t) < 0$ and $g''(E_t) < 0$. Again using (1.6), and in order to determine the sign of the second derivative, let us assume that:

$$\partial^2 hh(E_t)/\partial E_t^2 = A'(E_t) - B'(E_t), \tag{A.4}$$

where$A(E_t) \equiv \frac{(1-\eta)[\frac{\lambda E_t}{(1+E_t)^2}+\frac{\lambda E_t}{1+E_t}]}{g(E_t)}$ and $B(E_t) \equiv \frac{[\sigma\mu+(1-\eta)\frac{\lambda E_t^2}{1+E_t}]g'(E_t)}{g(E_t)^2}$. Let us first consider the derivative of $A(E_t)$ and assume that $u \equiv (1-\eta)\lambda[\frac{E_t}{(1+E_t)^2} + \frac{E_t}{1+E_t}]$. Since $u' = \frac{(1-\eta)2\lambda}{(1+E_t)^3}$ and $g'(E_t) < 0$, then it follows obviously that $A'(E_t) > 0$. Second, let us study the properties of $B(E_t)$. Let us assume that $\kappa \equiv [\sigma\mu + (1-\eta)\frac{\lambda E_t^2}{1+E_t}]g'(E_t)$. The derivative of κ w.r.t. E_t equals:

$$\kappa' = \left[(1-\eta)g'(E_t)\left\{\frac{2\lambda E_t}{1+E_t} - \frac{\lambda E_t^2}{(1+E_t)^2}\right\}\right] - g''(E_t)\left\{\sigma\mu + (1-\eta)\frac{\lambda E_t^2}{1+E_t}\right\} \tag{A.5}$$

Provided that $g''(E_t) > 0$ and that $\left\{\frac{2\lambda E_t}{1+E_t} - \frac{\lambda E_t^2}{(1+E_t)^2}\right\} > 0$, then it follows that $\kappa' < 0$. Finally, we deduce that $B'(E_t) < 0$. Using (A.4), we can claim that the hh locus is convex when $(E_t, h_t) \in \mathcal{S}^{S,C}$.

We prove then the stability of the hh locus. Let define $\triangle h_t = h_{t+1} - h_t$.

For $(E_t, h_t)c \in \mathcal{S}^{U,C}$, $h_{t+1} = \mu$, human capital equals its stationary value.

For $(E_t, h_t) \in \mathcal{S}^{S,D}$, $\triangle h_t = h_t^\theta \left\{\frac{\gamma(1-\theta)\omega h_t \lambda E_t - \mu(1+E_t)}{\lambda E_t[1+\gamma(1-\theta)]}\right\}^{1-\theta} - h_t$.

For $(E_t, h_t) \in \mathcal{S}^{S,C}$, $\triangle h_t = h_t^\theta \left\{\frac{\gamma(1-\theta)[(1+E_t)\sigma\mu + \lambda(1-\eta)E_t^2 + \lambda\sigma\omega h_t E_t]}{(1+E_t)[\sigma(1+\gamma(2-\theta))+\beta]}\right\}^{1-\theta} - h_t$. Consequently, we verify that for $hh(E_t) > (<) h_t$, $\triangle h_t > (<) 0$, both for $(E_t, h_t) \in \mathcal{S}^{S,D}$ and $(E_t, h_t) \in \mathcal{S}^{S,C}$. Hence, the value of h_t converges towards $hh(E_t)$.

B. Proof of Lemma 2

First of all, let us characterize the stationary locus of environmental quality, described by equation (1.18). In the zero maintenance area, the EE locus is negative, which is inconsistent with our framework, see equation (1.1). However, the first derivative of the function is negative, which implies that for $(E_t, h_t) \in \mathcal{S}^{S,D}$ and $(E_t, h_t) \in \mathcal{S}^{U,D}$, environmental quality decreases over time. In the clean but unschooled area, and using the properties of the function $\Lambda(E_t)$, we can easily see that $\lim_{E\to 0} EE(E_t) = 0$, $\partial EE(E_t)/\partial E_t > 0$ and $\partial^2 EE(E_t)/\partial E_t^2 = 0$. Finally, for $(E_t, h_t) \in \mathcal{S}^{S,C}$, $\partial EE(E_t)/\partial E_t > 0$ and $\partial^2 EE(E_t)/\partial E_t^2 < 0$.

Let focus on the stability properties of this locus and let define $\triangle E_t = E_{t+1} - E_t$. For $(E_t, h_t) \in \mathcal{S}^{U,C}$, $\triangle E_t = \frac{\gamma\sigma[(1-\eta)E_t + \sigma\omega h_t]}{\sigma(1+\gamma)+\beta} - E_t$. It is easy to verify that for $EE(E_t) < (>)h_t$, $\triangle E_t > (<)0$. For $(E_t, h_t) \in \mathcal{S}^{S,C}$, $\triangle E_t = \left\{\frac{\gamma\sigma^2[\mu(1+E_t)+\lambda\omega h_t E_t \gamma\sigma^2] + (1-\eta)\lambda E_t^2 \gamma\sigma}{[\sigma(1+\gamma(2-\theta))+\beta]\lambda E_t}\right\} - E_t$. We can then show that for $EE(E_t) < (>)h_t$, $\triangle E_t > (<)0$. Then, for $(E_t, h_t) \in \mathcal{S}^{U,C}$ and $(E_t, h_t) \in \mathcal{S}^{S,C}$ the value of E_t converges to its stationary value described by $EE(E_t)$.

C. Proof of Proposition 1

The EE locus consists in an increasing line in $\mathcal{S}^{U,C}$ and then becomes concave in $\mathcal{S}^{S,C}$. The hh locus consists in an horizontal line in $\mathcal{S}^{U,C}$ and then may become either concave in $\mathcal{S}^{S,D}$ or convex in $\mathcal{S}^{S,C}$. Three different configurations may occur: (i) If for $(E_t, h_t) \in \mathcal{S}^{U,C}$ the two loci do not intersect, meaning that $hh > EE$. Then, it implies obviously, that following an increase in E_t, the hh locus enters the interior regime and becomes convex. In the interior regime, under specific parametric conditions, it could be the case that $hh > EE$ always. There is no steady-state, the economy follows a sustainable and continuous growth path, where both human capital and environmental quality improve.

(ii) If for $(E_t, h_t) \in \mathcal{S}^{U,C}$ the two loci intersects once, but if the hh locus very low, then the further increases in environmental quality drive the hh locus falls into the zero maintenance area. Here, the EE locus i not defined, so that in the end, only equilibrium exists in $\mathcal{S}^{U,C}$. No matter initial conditions, th economy converges towards this equilibrium.

(iii) If for $(E_t, h_t) \in \mathcal{S}^{U,C}$ the two loci intersect, but the hh locus displays intermediary values, then further increases drives it to the interior regime. As the EE locus is concave, the two loci cross once. Given the properties of both loci, this equilibrium in $\mathcal{S}^{U,C}$ is unstable and is associated with a saddle path. If for $(E_t, h_t) \in \mathcal{S}^{U,C}$ the two loci do not intersect, but the hh locus displays intermediary values, then further increases drives it to the interior regime. Again as the EE locus is concave and starts below the hh locus in the interior regime, the the two loci cross twice in $\mathcal{S}^{S,C}$. Given the properties of each locus, the first intersection defines a stable stead-state, while the second one is not.

Chapter 2

Life expectancy and the environment[1]

2.1. Introduction

Environmental care betrays some concern for the future, be it one's own or that of forthcoming generations. Yet, the way people value future is crucially affected, among others, by their life expectancy: a higher longevity makes people more sympathetic to future generations and/or their future selves. Therefore, if someone expects to live longer, she should be willing to invest more in environmental quality.

Of course, the causal link between life expectancy and environmental quality may also go the other way around. Several studies in medicine and epidemiology, like Elo & Preston (1992), Pope (2000), Pope *et al.* (2004) and Evans & Smith (2005), show that environmental quality is a very important factor affecting health and morbid-

1. This chapter is a joint work with Fabio Mariani and Agustin Perez-Barahona.

ity: air and water pollution, depletion of natural resources, soils deterioration and the like, are all capable of increasing human mortality (thus reducing longevity). As pointed out by Galor & Moav (2007), these extrinsic risks of mortality may have long-lasting effects on human genes and could explain the composition of the contemporary population. Nevertheless, beyond all these risks, the environment specifically provides a source of well-being that may support a higher life expectancy. As underlined by Lambin (2008), the amenities provided by the nature, at home as well in the workplace, contribute to a better physiological and psychological equilibrium: the presence of domestic animals, the ambiant environment, the neighbourhood, the proximity to countryside, etc...

Consequently, it should not come as a surprise that, as we will show extensively later on, life expectancy is positively correlated across countries with environmental quality. In addition, the data suggest the existence of "convergence clubs" in terms of both environmental performance and longevity, with countries being concentrated around two levels of environmental quality and life expectancy, respectively.

This chapter provides a theoretical framework that allows us to reproduce the stylized facts highlighted above. To do that, we model explicitly the two-way causality between the environment and longevity, which generates a positive dynamic correlation between the two variables. This kind of interaction, which is central to our analysis, might in turn also justify the existence of an environmental poverty trap, characterized by both bad environmental conditions and short life expectancy. Moreover, we are able to identify inter-generational externalities, and study how they might be corrected by policy intervention.

In the benchmark version of our model, we consider overlapping generations of three-period lived agents, who get utility from consumption and environmental quality. During adulthood, when all relevant decisions are taken, they can work and allocate their income between consumption and investment in environmental maintenance: consumption involves deterioration of the future quality of the environment (through pollution and/or resource depletion), while maintenance helps to improve it. A key ingredient of our setting is that survival until the last period is probabilistic, and depends on the inherited quality of the environment. In turn, this survival probability affects the weight of future environmental quality in the agents' utility function. The idea that agents take utility from the future state of the environment is compatible with both self-interest and altruism towards future generations.

It can be shown that optimal choices depend crucially on life expectancy: a higher probability to be alive in the third period boosts investment in the environment and reduces consumption (the latter translating into less environmental deterioration). Since longevity is in turn affected by environmental conditions, the resulting two-sided feedback produces a positive correlation between the two variables, both at the steady-state and along the transition path.

Depending on the shape of the survival probability function, our model can also allow for multiple equilibria and may explain the existence of poverty traps: initial conditions do matter and a given economy may be caught in a high-mortality/poor-environment trap. In particular, we build an example based on a convex-concave function linking environmental quality and life expectancy, which is backed up by some well-established scientific literature (see Cakmak *et al.* (1999) and Scheffer *et al.* (2001)). Possible strategies to escape from the trap will be also identified and discussed.

After analyzing the welfare and policy implications of our benchmark model, we introduce human capital accumulation so as to deal with endogenous income dynamics. Parents can use their income to also educate their children, while survival probabilities are affected by both environmental quality and education. Considering human capital led growth, we are able to see that the positive dynamic correlation between life expectancy and the environment still holds, and extends to income in the long-run. However, we also find that short-run deviations, which allow the environment to worsen as income increases, are possible. Under proper conditions, we may eventually end up with multiple development regimes, where the low-life-expectancy/poor-environment trap is now characterized by low human capital as well.

Our model is primarily related to those papers that have analyzed environmental issues in a dynamic OLG framework. Among them, John & Pecchenino (1994) deal with environmental maintenance as an inter-generational problem, but life expectancy is assumed to be exogenous and plays no role in their model. The idea of explaining environmental care with an uncertain lifetime is instead present in Ono & Maeda (2001), although in their model environmental quality does not affect longevity. On the contrary, Jouvet *et al.* (2007) consider the impact of environmental quality on mortality, but neglect completely the role of life expectancy in defining environmental choices and leave no room for maintenance. Our model is also somewhat related to Jouvet *et al.* (2000), who use inter-generational altruism to explain environmental choices.

Let us also point out that, although environmental poverty traps have been already studied by John & Pecchenino (1994) and Ikefuji & Horii (2007), these papers overlook the role of life expectancy, which in contrast we consider as being a crucial factor behind the existence of multiple equilibria. In this respect, our chapter is related to Blackburn & Cipriani (2002), or Chakraborty (2004), Chakraborty & Das (2005) in which life expectancy is regarded as a possible cause of underdevelopment traps (although not linked to the environment).

The remainder of the chapter is organized as follows. Section 2.2 presents some stylized facts on environmental quality and life expectancy that provide the motivation of our study. Section 2.3 introduces and solves the basic model, discussing its dynamic properties and welfare implications. An extended version of the model, allowing for human capital accumulation, is analyzed in Section 2.4. Section 2.5 concludes.

2.2. Stylized facts

Here we want to present the stylized facts that motivate our analysis and will be matched by the main results of our theoretical model.

As a proxy for environmental quality, we use a newly available indicator: the Environmental Performance Index (henceforth EPI). This synthetic indicator (YCELP (2006)) takes into account both "environmental health", as defined by child mortality, indoor air pollution, drinking water, adequate sanitation and urban particulates, and "ecosystem vitality", which includes factors like air quality, water and productive natural resources, biodiversity and sustainable energy. In the end, the EPI is computed as a weighted average of 16 sub-indicators, each one converted to a proximity-to-target measure with a theoretical range of 0 to 100. Therefore, the EPI itself can ideally take values in the 0-100 range and, clearly enough, reducing pollution or preserving natural resources may both contribute to improve environmental quality. Using the EPI allows us to avoid a myopic view of environmental quality, according to which environmental degradation can be traced back only to industrial activity and pollution. In fact, poor environmental quality can also be explained by factors like mismanagement of natural resources, deforestation, overgrazing, unsanitary practices, etc.[2] Since child mortality is, obviously, strongly correlated with life expectancy, in the rest of the chapter we employ an amended version of the original EPI, which is obtained removing the child mortality factor.[3]

Life expectancy is measured using "life expectancy at birth" (2005), from UN (2007) data. Data on environmental quality and life expectancy are simultaneously

2. Countries with a comparable EPI level may exhibit very different sub-indicators scores. Take for instance United States, Russia and Brazil, that are ranked 28, 32 and 34 respectively, with an EPI ranging from 78.5 to 77. The United States rank very high in environmental health, but very low in the management of natural resources. Russia displays excellent resource indicators, while failing to achieve decent scores in sustainable energy. Finally, Brazil does well in water quality, but is characterized by extremely low biodiversity indicators. See YCELP (2006) for further examples.

3. Child mortality accounted for 10.5% of the total EPI.

available for a sample of 132 countries; they allow us to observe a couple of stylized facts.

Across countries, environmental quality is positively correlated with life expectancy.

As reported in Figure 2.1, for our cross-section of 132 countries there is strong evidence supporting the idea that longevity and environmental quality are linked; in particular, the correlation coefficient is equal to 0.66 and statistically significant at the 1% level. The graph below is compatible with the hypothesis of a two-way causality between the two variables.

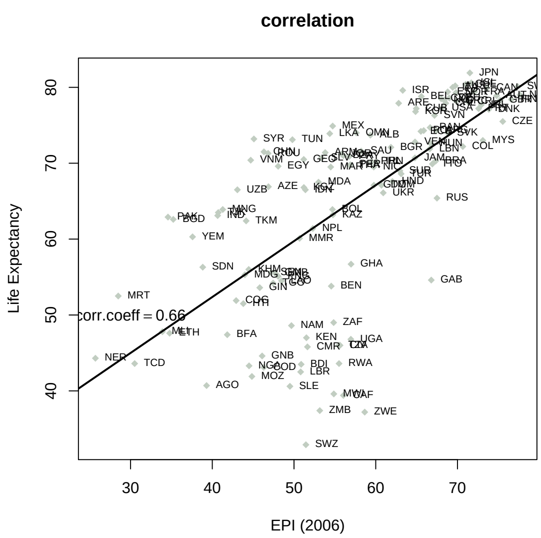


Figure 2.1: Environmental quality and life expectancy
Sources: YCELP (2006), UN (2007)

In addition, a second kind of stylized fact is particularly interesting.

Environmental quality and life expectancy are bimodally distributed across countries.

Therefore, the data suggest the possibility of an environmental poverty trap, characterized also by short life expectancy. This concept points to the existence of "convergence clubs" in terms of environmental performance and longevity: countries are concentrated around two levels of the EPI and life expectancy. In fact Figure 2.2, depicting histograms and kernel density estimates (with optimal bandwidth), displays bimodal distributions of both variables across countries.[4]

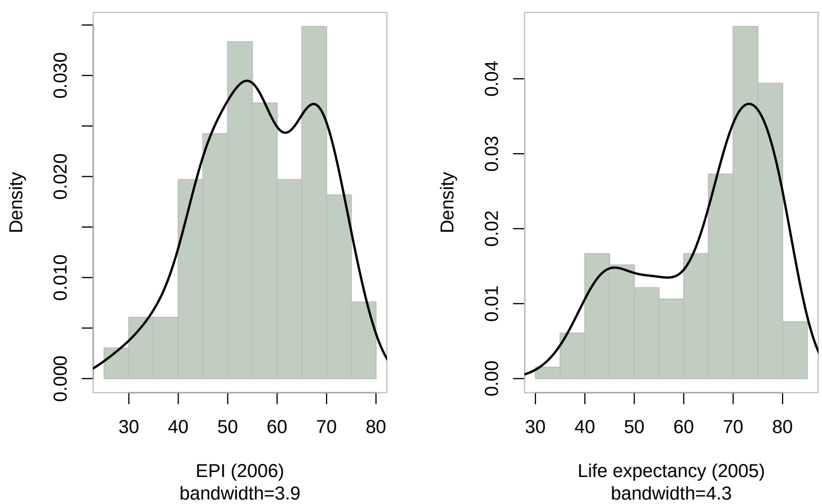


Figure 2.2: Bimodal distribution of environmental quality and life expectancy
Sources: YCELP (2006), UN (2007)

We believe that this double bimodality can be interpreted as a trap, since there is a high degree of overlap in the lower modes of the two distributions represented

4. In both cases, the null hypothesis of unimodality is rejected by the Hartigan's *dip* test, which measures the maximum difference, over all sample points, between the empirical distribution function, and the unimodal distribution function that minimizes the maximum difference. Accordingly, we calculate the *dip* test statistic (d). For our EPI data, the computed value of d is 0.0385. As it can be inferred from Hartigan & Hartigan (1985), in the case of our sample size (132 observations), the null hypothesis of unimodality is rejected because $d > 0.0370$ (at the 5% significance level). The same applies to life expectancy: on the basis of our data, since $d = 0.036$, the Hartigan's dip test allows us to reject the null hypothesis of unimodality at the 10% significance level.

in Figure 2.2. For instance, out of the 48 countries in the lower mode of the life expectancy distribution (less than 58 years), only one shows up in the upper mode of the EPI distribution (EPI score larger than 62). Moreover, if we divide both distributions into two groups of equal size, we find that (i) out of 66 countries with a EPI index lower than the median value (56.04), 54 also belong to the group characterized by a life expectancy below the median (69.5), and (ii) out of the 66 countries with lower-than-median life expectancy, 55 also exhibit a below-the-median value of the EPI.

Among "trapped" economies we find, together with African countries, the vast majority of ex-USSR republics. The low life expectancy in Africa has often been related to mismanagement of environmental resources, pollution and anthropogenic climate change (see, among others, Patz *et al.* (2005)). The argument for a pollution-driven mortality resurgence has also been put forward by McMichael *et al.* (2004) and, in the case of ex-USSR, by Feachem (1994) and Jedrychowski (1995).

2.3. The benchmark model

We start by setting up a simple model where agents allocate their income between current consumption and environmental maintenance. Consumption, generating pollution and/or increasing pressure on natural resources, involves some degradation of environmental quality. No growth mechanism is considered.

2.3.1. *Structure of the model*

We consider an infinite-horizon economy that is populated by overlapping generations of agents living for three periods: childhood, adulthood, and old age. Time is discrete and indexed by $t = 0, 1, 2, ..., \infty$. All decisions are taken in the adult period of life. Individuals live safely through the first two periods, while survival to the third period is subject to uncertainty. We assume no population growth. Furthermore, agents are considered to be identical within each generation, whose size is normalized to one (in the first two periods). In order to get closed-form solution, we consider the following preferences:

$$U_t(c_t, E_{t+1}) = \ln c_t + \pi_t \gamma \ln E_{t+1}. \tag{2.1}$$

People care about adult consumption (c_t) and environmental quality when old (E_{t+1}); $\gamma > 0$ represents the weight agents give to the future environment (green preferences), while π_t denotes the survival probability, which is taken as given since it depends on inherited environmental quality. Here, for the sake of simplicity, we abstract from time discounting so that the subjective preference for the future is entirely determined by $\pi_t \gamma$. Notice also that, in our framework, an increase (decrease) in the survival probability translates into a higher (lower) life expectancy, so that hereafter we will use the two concepts interchangeably.

Let us underline that E_t may encompass both environmental conditions (quality of water, air and soils, etc.) and resources availability (biodiversity, forestry, fisheries, etc.).[5] Broadly speaking, E_t can be seen as an index of the amenity (use and non-use) value of the environment.

Adult individuals face the following budget constraint:

$$w_t = c_t + m_t; \tag{2.2}$$

they allocate their income (w_t) between consumption and environmental maintenance (m_t). In this benchmark version of our model, income is assumed to be exogenous.[6] Environmental maintenance summarizes all the actions that agents can take in order to preserve and improve environmental conditions.

Following John and Pecchenino (1994), the law of motion of environmental quality is given by the following expression:

$$E_{t+1} = (1 - \eta)E_t + \sigma m_t - \beta c_t - \lambda Q_t, \tag{2.3}$$

with $\beta, \sigma, \lambda > 0$ and $0 < \eta < 1$.

The parameter η is the natural rate of deterioration of the environment, σ represents the effectiveness of maintenance, whereas β accounts for the degradation of the environment, or pollution, due to each unit of consumption. The above formulation also allows for the possibility of exogenous external effects on the environment: $\lambda Q_t > 0$ (< 0) represents the total impact of a harmful (beneficial) activity.[7]

5. All these issues are taken into account by the EPI, that we have consistently used as a proxy of environmental quality in Figures 2.1and 2.2.

6. This assumption will be relaxed in Section 2.4, where we allow for human capital accumulation and consequent income dynamics.

7. Natural disasters or episodes of acute pollution, like oil slicks or the Chernobyl accident, can be typical

Notice that a reduction in c_t has a double effect on the environment: it directly affects environmental quality through β (alleviating the pressure on natural resources and/or reducing pollution), and frees resources for maintenance (relaxing the budget constraint). Moreover, equation (2.3) implies that agents cannot, through their actions, modify the current state of the environment E_t: the latter is thus inherited, depending only on the past generation's choices.[8]

2.3.2. Optimal choices

Taking as given w_t, E_t and π_t, agents choose c_t and m_t so as to maximize $U_t(c_t, E_{t+1})$ subject to (2.2), (2.3), $c_t > 0$, $m_t > 0$ and $E_t > 0$. With a general utility function, the optimality condition writes as:

$$\frac{\partial U_t}{\partial c_t} = (\beta + \sigma)\frac{\partial U_t}{\partial E_{t+1}}. \tag{2.4}$$

Using equation (2.1), optimal choices are then given by:

$$m_t = \frac{\lambda Q_t - (1-\eta)E_t + [\beta + \gamma(\beta+\sigma)\pi_t]w_t}{(\beta+\sigma)(1+\gamma\pi_t)}, \tag{2.5}$$

and

$$c_t = \frac{(1-\eta)E_t + \sigma w_t - \lambda Q_t}{(\beta+\sigma)(1+\gamma\pi_t)}. \tag{2.6}$$

examples of $Q_t > 0$, while the implementation of an international agreement that promotes a worldwide reduction of pollutants (*i.e.* the Kyoto Protocol) or the preservation of the Amazonian forest could be regarded as a negative Q_t in our model.

8. Therefore, our results would not change if we introduce current environmental quality E_t in the utility function.

Notice that here, given that agents are identical and the population is normalized to one, aggregate variables are completely equivalent to individual ones. Therefore, all variables in our model can be also easily interpreted as "country" variables.

From (2.5) and (2.6), we can observe that both consumption and environmental maintenance are positively affected by income: richer economies are more likely to invest in environmental care. In addition, current environmental quality has a positive effect on consumption, but a negative one on maintenance: investments in maintenance are less needed if the inherited environment is less degraded. These two results have already been established by John & Pecchenino (1994).

The novelty of our model is that we can identify a specific effect of life expectancy (as determined by the survival probability π_t) on environmental maintenance. As it can be easily seen from the following derivative

$$\frac{\partial m_t}{\partial \pi_t} = \frac{\gamma[(1-\eta)E_t + \sigma w_t - \lambda Q_t]}{(\beta+\sigma)(1+\gamma\pi_t)^2}, \tag{2.7}$$

which is positive for interior solutions, a higher survival probability induces more maintenance, since it raises stronger concerns for the future state of the environment. This paves the way for a positive correlation between longevity and environmental quality, along the transition path.

In addition, a relatively larger value of Q_t requires more investment in maintenance. Notice that the term $(1-\eta)E_t - \lambda Q_t$ represents the net effect of past and external environmental conditions on optimal choices.

2.3.3. Dynamics

Once we substitute (2.5) and (2.6) into (2.3), we get the following dynamic difference equation, describing the evolution of environmental quality over time:

$$E_{t+1} = \frac{\gamma \pi_t}{1 + \gamma \pi_t} [(1 - \eta) E_t + \sigma w_t - \lambda Q_t]. \tag{2.8}$$

So far we have considered π_t as exogenous, although we have pointed out that life expectancy may depend on (bequeathed) environmental quality. Now, we introduce explicitly a function $\pi_t = \pi(E_t)$, such that $\partial \pi(E_t)/\partial E_t > 0$, $\lim_{E_t \to 0} \pi(E_t) = \underline{\pi}$ and $\lim_{E_t \to \infty} \pi(E_t) = \overline{\pi}$, with $0 < \underline{\pi} < \overline{\pi} < 1$. This formulation is consistent with a large body of medical and epidemiological literature showing strong and clear effects of environmental conditions on adult mortality, like for instance Elo & Preston (1992), Pope *et al.* (1995), 2004, Pope (2000) and Evans & Smith (2005). Such effects are obtained after controlling for income and other socio-economic factors. The shape of $\pi(E_t)$ may reflect "technological" factors affecting the transformation of environmental quality into survival probability such as, for instance, medicine effectiveness.

Let us underline that agents cannot improve their own survival probability by investing in maintenance. This is consistent with equation (2.3), where current environmental choices (especially m_t) affect the future state of the environment. Any investment in maintenance will be rewarded, in terms of environmental quality and life expectancy, only in the future period. This introduces inter-generational externalities, whose consequences will be addressed in Subsection 2.3.6.

The dynamics of our model are now given by:

$$E_{t+1} = \frac{\gamma\pi(E_t)}{1+\gamma\pi(E_t)}[(1-\eta)E_t + \sigma w_t - \lambda Q_t] \equiv \phi(E_t), \tag{2.9}$$

where, for the sake of simplicity, w_t and Q_t are assumed to be not only exogenous but also constant, so that $w_t = w$ and $Q_t = Q$.

This kind of dynamics results from the two-sided feedback between life expectancy and the environment, described by $m_t = m(\pi_t)$ and $\pi_t = \pi(E_t)$, respectively. In this framework, a steady-state equilibrium is defined as a fixed point E^* such that $\phi(E^*) = E^*$, which is stable (unstable) if $\phi'(E^*) < 1$ (> 1).

Depending on the shape of the transition function $\phi(E_t)$, we may have different scenarios. Figure 2.3 shows that we have only one stable steady-state as long as $\phi(\cdot)$ is concave for all possible values of E_t. From equation (2.9) we can infer that the steady-state value of environmental quality E^* (and consequently life expectancy π^*) is positively affected by income w (through the effectiveness of maintenance, σ) and preferences for the environment (γ), while it is negatively influenced by the external effect λQ and the natural rate of deterioration η.

Non-ergodicity and multiple steady-states may instead occur if $\phi(\cdot)$ displays one or more inflection points, being for instance first convex and then concave. In this case, depending on initial conditions, an economy may end up with either high or low environmental quality: E_H^* and E_L^*, respectively (see Figure 2.3).

A transition function $\phi(E_t)$ compatible with the existence of multiple equilibria

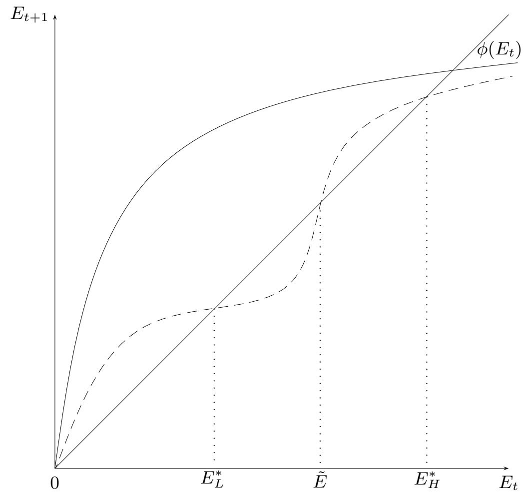


Figure 2.3: Dynamics

might be generated by a variety of functional forms describing the survival probability $\pi(E_t)$. In particular, a step-function approximation of a convex-concave $\pi(E_t)$ is convenient to get analytical results.[9] In this case, a substantial improvement in the survival probability can be achieved only after a given environmental threshold is attained. This is consistent with the idea that environmental degradation may affect ecosystems, or human health, following a convex-concave relationship. Dasgupta & Mäler (2003) explain that nature's non-convexities are frequently the manifestation of feedback effects, which might in turn imply the existence of ecological thresholds and multiple equilibria. Threshold-effects, non-smooth dynamics and regime shifts in ecosystems are indeed commonly assumed in natural sciences, as pointed out by Scheffer *et al.* (2001).[10]

9. Notice that, however, the existence of multiple equilibria is not constrained by assuming a convex-concave $\pi(E_t)$. Multiplicity of steady-state is also compatible, for instance, with a concave $\pi(E_t)$ of the type $\pi(E_t) = \min\{\underline{\pi} + AE_t^{\upsilon}, \overline{\pi}\}$, with $A > 0$ and $0 < \upsilon \leq 1$. We are thankful to an anonymous referee for pointing out this possibility.

10. See also Baland & Platteau (1996), who state that, in the case of natural resources involving ecological processes, there might well be threshold levels of exploitation beyond which the whole system moves in

2.3.4. An analytical illustration

The possibility of multiple equilibria implies the existence of an environmental poverty trap. To give an analytical illustration of such a case, we introduce now the following specific functional form relating the survival probability to inherited environmental conditions:

$$\pi(E_t) = \begin{cases} \underline{\pi} & \text{if } E_t < \tilde{E} \\ \overline{\pi} & \text{if } E_t \geq \tilde{E} \end{cases}, \tag{2.10}$$

where $\overline{\pi} > \underline{\pi}$, and $\tilde{E}$ is an exogenous threshold value of environmental quality, above (below) which the value of the survival probability is high (low). The value of $\tilde{E}$ may depend on factors such as medicine effectiveness, health care quality, etc. For instance, a low $\tilde{E}$ can be explained by a very efficient medical technology that makes long life expectancy possible even in a deteriorated environment. A high $\tilde{E}$ might instead represent the case of a developing country, where health services are so poorly performing that mortality remains high even under pretty good environmental conditions.

Given equation (12.10), the transition function $\phi(E_t)$ becomes:

$$\phi(E_t) = \begin{cases} \frac{\gamma\underline{\pi}}{1+\gamma\underline{\pi}}[(1-\eta)E_t + \sigma w - \lambda Q] & \text{if } E_t < \tilde{E} \\ \frac{\gamma\overline{\pi}}{1+\gamma\overline{\pi}}[(1-\eta)E_t + \sigma w - \lambda Q] & \text{if } E_t \geq \tilde{E} \end{cases}. \tag{2.11}$$

a discontinuous way from one equilibrium to another. The existence of a threshold effect in the relation between air-pollution and mortality has been also detected, for instance, by Cakmak *et al.* (1999).

We can then claim the following:

Proposition 2 *If the following condition holds:*

$$\frac{\gamma\underline{\pi}}{1+\gamma\eta\underline{\pi}} < \frac{\tilde{E}}{\sigma w - \lambda Q} < \frac{\gamma\overline{\pi}}{1+\gamma\eta\overline{\pi}},$$

then the dynamic equation (2.11) admits two stable steady-states E_L^* and E_H^*, such that $E_L^* < \tilde{E} < E_H^*$.

Proof. Provided that it exists, any steady-state is stable since $\phi'(E_t) < 1$, $\forall E_t > 0$. Multiplicity arises if $[\gamma\underline{\pi}/(1+\gamma\eta\underline{\pi})](\sigma w - \lambda Q) < \tilde{E} < [\gamma\overline{\pi}/(1+\gamma\eta\overline{\pi})](\sigma w - \lambda Q)$, which yields the condition above. ■

In particular, we have that:

$$E_L^* = \frac{\gamma\underline{\pi}}{(1+\gamma\eta\underline{\pi})}(\sigma w - \lambda Q) \text{ and } E_H^* = \frac{\gamma\overline{\pi}}{(1+\gamma\eta\overline{\pi})}(\sigma w - \lambda Q). \qquad (2.12)$$

As shown by Figure 2.4, the threshold value $\tilde{E}$ identifies a poverty trap: an economy starting between 0 and $\tilde{E}$ will reach the equilibrium point A, which is a steady-state characterized by both low environmental quality (E_L^*) and short life expectancy (pinned down to $\underline{\pi}$). In fact, a lower survival probability induces agents to substitute environmental maintenance with consumption. However, if initial conditions are such that $e_0 \geq \tilde{E}$, the economy will end up in the higher steady-state B, where longer life expectancy ($\overline{\pi}$) is associated with a healthier environment (E_H^*).

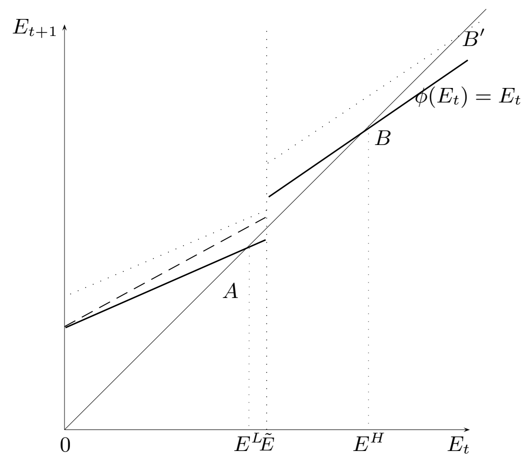


Figure 2.4: Environmental poverty trap

2.3.5. In and out of the trap

The very existence of an environmental trap implies that some countries (or regions) may experience, over time, both environmental degradation and decay in life expectancy. Cross-section data would suggest that the latter is much less common than the former. Environmental degradation might not imply lower longevity because economic growth (neglected until now in our analysis) can harm the environment, but also generate additional income to increase (or preserve) longevity. However, there is also evidence of countries where environmental degradation is associated with a reduction in life expectancy. For instance, McMichael *et al.* (2004) identify 40 countries that experienced a decrease in longevity between 1990 and 2001.[11] They also suggest that the resulting World divergence in terms of life expectancy might be explained by "(the growing) health risks consequent on large-scale

11. Most of them are African or ex-Soviet countries. Losses in longevity are sometimes severe, going up to 15-18 years, and "in several West African countries, (they) are not obviously attributable to HIV/AIDS".

environmental changes caused by human pressure". We can also mention the case - particularly cherished by economists - of Easter Island, which serves as a good example of a closed system where insufficient environmental care (or better, too much pressure on natural resources) ultimately led to a dramatic reduction of the local population (see Diamond (2005), or de la Croix & Dottori (2008)).

Let us now go back to our formal framework and assume that our economy is initially trapped in the low steady-state (A, in Figure 2.4) characterized by $(E_L^*, \underline{\pi})$. We can identify three different ways of escaping this trap: (i) a large enough permanent reduction in the threshold value $\tilde{E}$, (ii) a parallel shift-up of the function $\phi(E_t)$, and (iii) an increase of the slope of $\phi(E_t)$. The first one, as already seen, might correspond to improvements in medicine.[12] The second may be induced by a permanent income expansion and/or reduction of harmful external effects.[13]. The third one may be instead explained by a permanent rise of $\underline{\pi}$ that, similar to a reduction of $\tilde{E}$, can be traced back to technological progress in medical sciences, etc. Whatever the case, E_L^* would be associated with a greater concern about the future, implying more maintenance, less consumption, and finally convergence to the high (and now unique) steady-state B defined by $(E_H^*, \overline{\pi})$.

Intuitively, all the above channels may work in the opposite direction: a reduction in w and/or an increase in Q may lead to the elimination of the high steady-state

12. In de la Croix & Sommacal (2009)), advances in medicine, through a longer life expectancy, promote capital accumulation and growth. In our setting, they induce a different kind of investment, *i.e.* environmental maintenance.

13. A possible real world example of a smaller Q could be the implementation of international agreements, such as the Kyoto Protocol. Notice that even a temporary reduction in Q can help leaving the trap. In this case, however, escaping from the trap does not imply the elimination of the lower steady-state.

and an economy, which would have otherwise ended up there, can be thrown back in the poverty trap. Even temporary shocks (such as natural disasters or episodes of acute pollution) may be sufficient to fall in the trap. This raises a concern about the environmental awareness of countries. Neglecting environmental care and a bad management of natural resources may make countries vulnerable to even temporary events with serious long-lasting consequences for human development. Furthermore, some countries might find themselves trapped if they meet environmental constraints when life expectancy is still low. This could be the case of those African countries that display a low life expectancy, but are already very polluted.

2.3.6. Welfare analysis

In our model, agents are outlived by the consequences of their environmental choices and are not able to internalize the external effects of these choices on future generations. It would then be interesting to compare such a decentralized equilibrium with a "green" golden rule allocation, as defined by Chichilnisky *et al.* (1995). This means solving the model from the point of view of a social planner, whose objective is to maximize aggregate utility at the steady-state. The case of a full-fledged forward-looking planner, who also cares about generations along the transition path and thus develops an optimal inter-temporal plan, will be analyzed in Appendix A.

As in John & Pecchenino (1994), we then look for the optimal steady-state combination of consumption and environmental quality that maximizes $U(c, E)$, subject to:

$$\eta E = \sigma w - (\beta + \sigma)c - \lambda Q, \tag{2.13}$$

which summarizes the budget and the environmental constraints, at the steady-state.

The resulting optimality condition is given by:

$$\frac{\partial U}{\partial c} = \frac{\beta + \sigma}{\eta} \left(\frac{\partial U}{\partial E} + \frac{\partial U}{\partial \pi} \frac{\partial \pi}{\partial E} \right). \tag{2.14}$$

Comparing (2.14) with (2.4) at the steady-state, we can see immediately that the golden rule allocation does not coincide with the decentralized equilibrium, since (i) $\eta < 1$, and (ii) $\partial\pi/\partial E \neq 0$. In fact, as soon as there are intergenerational externalities linked to environmental quality (as an argument of the utility function and as a factor affecting life expectancy), individual agents consume more (and invest less in maintenance) than it would be socially optimal. We can then claim the following:

Proposition 3 *At the steady-state, a decentralized equilibrium involves lower environmental quality than the green golden rule allocation.*

The "distance" between the decentralized and the golden rule values of E is inversely related to η, while it is increasing in $\|\partial\pi/\partial E\|$. At the limit, as η tends to 1 and $\partial\pi/\partial E$ tends to 0, the effect of environmental care on the future state of the environment and life expectancy vanishes, thus eliminating inter-generational externalities. Therefore, the decentralized solution approaches the golden rule allocation.

In order to achieve an optimal allocation in the decentralized economy, environmental policies can be implemented. Consider for instance a tax levied on consumption, so that its price becomes $(1+\tau)$ (instead of 1): given the structure of our model, this boils down to taxing pollution. Tax receipts will be then transferred in a lump-sum way to agents.[14] If this is the case, decentralized agents define their optimal choices according to:

$$\frac{\partial U}{\partial c} = [\beta + (1+\tau)\sigma]\frac{\partial U}{\partial E}. \tag{2.15}$$

Equating (2.14) and (2.15), we can deduce the tax rate that realizes the optimal allocation:

$$\tau^* = \frac{(\beta+\sigma)}{\eta\sigma}\left[(1-\eta) + \frac{\frac{\partial U}{\partial \pi}\frac{\partial \pi}{\partial E}}{\frac{\partial U}{\partial E}}\right]. \tag{2.16}$$

It can be noticed that the smaller the size of external effects, the lower the environmental tax. In addition, τ^* depends positively on β (which magnifies, through the pollution term in (2.3), the intergenerational externality), and negatively on σ (which, defining the effectiveness of maintenance, reduces the size of negative external effects).

In order to get some further insight, we specify the utility function as in (2.1) and the survival probability π as in (2.10), so that $\partial\pi/\partial E = 0$.[15] We can accordingly determine the following "golden" value for environmental quality:

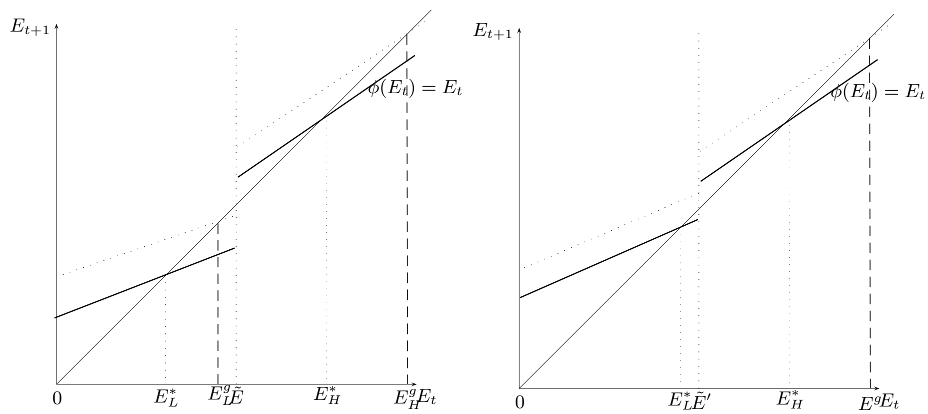
$$E^g = \frac{\gamma\pi}{(1+\gamma\pi)\eta}(\sigma w - \lambda Q), \tag{2.17}$$

14. Our analysis would hold qualitatively unaffected, if taxes were used to subsidize maintenance.

15. Therefore, one of the two externalities disappears and the tax rate in (2.16) simplifies into $\tau^* = (1-\eta)(\beta+\sigma)/(\eta\sigma)$.

which can be compared to the case of a decentralized economy producing multiple equilibria (as defined by E_L^* and E_H^* in (2.12)).

Let us now describe the dynamics of the model, under the social planner and in the private case, respectively. In Figure 2.5, we draw as a solid line the transition function for the decentralized economy, while the dotted line represents the dynamic evolution of E under the social planner hypothesis.



(a) (b)

Figure 2.5. The green golden rule

Depending on the value of $\tilde{E}$, we may have two different scenarios. If $\tilde{E}$ is sufficiently larger than E_L^*, as in Figure 2.5a, then there will also be two golden rule allocations, each one superior to the corresponding competitive equilibrium. If instead $\tilde{E}$ is close enough to E_L^* ($\tilde{E}'$ in Figure 2.5b), then there exists a unique green golden rule allocation; in this case we may say that the social planner eliminates the lower steady-state, thus driving the economy out of the trap.[16]

16. Whether the social planner circumvents the poverty trap depends crucially on the shape of the $\pi(\cdot)$ function. Suppose to have, for instance, a low $\underline{\pi}$ and/or a high $\tilde{E}$ in (2.10): in this case, although the planner's optimality condition (2.14) implies less consumption and more maintenance (with respect to the decentralized economy), this does not necessarily translate into a higher survival probability ($\overline{\pi}$), at the steady-state.

2.4. Introducing human capital accumulation

In the basic version of our model, income was completely exogenous in every period and we did not allow for any growth mechanism. In this Section, we aim at overcoming this limitation by introducing human capital accumulation through education. We want to capture three rather simple ideas: (i) environmental preservation subtracts some resources not only from consumption but also from investment, (ii) income growth, relaxing the budget constraint, makes more maintenance possible, and (iii) growth might itself involve some pollution.[17] A complementary analysis, with investment concerning physical capital instead of human capital, will be developed in Appendix B.

2.4.1. Structure of the model

Agents maximize the following utility function:

$$U_t(c_t, h_{t+1}, E_{t+1}) = \ln c_t + \pi_t(\alpha \ln h_{t+1} + \gamma \ln E_{t+1}), \tag{2.18}$$

where, with respect to (2.1), we have introduced explicitly inter-generational altruism. Parents care about the human capital level attained by their children (h_{t+1}), and the importance attached to this term is measured by $\alpha \in (0, 1)$. Intergenerational altruism is eventually magnified (reduced) by a higher (lower) π_t: the

17. Ikefuji & Horii (2007) also have a model with poverty-environment traps related to human capital. However, life expectancy plays no role in their framework. Moreover, since they do not allow for maintenance, they are not able to consider a trade-off between investment and environmental preservation. Finally, in their model higher human capital necessarily implies lower pollution, thus neglecting that growth itself is potentially polluting.

success (or failure) of their children will affect relatively more those parents who will live long enough to witness it. Once more, for the sake of simplicity, we neglect inter-temporal discounting, so that the preference for the future is completely defined by the survival probability. As it was in the basic model, an increased survival probability implies also that agents put more value on future environmental quality.

The production of a homogeneous good takes place according to the following function:

$$y_t = wh_t, \tag{2.19}$$

where w, which we assume to stay constant over time, is both an index of productivity and the wage rate; h_t is also aggregate human capital, once we normalize to one the population of our economy. As before, fertility is exogenous, constant and such that there is no population growth.

The budget constraint writes as:

$$wh_t = c_t + m_t + v_t. \tag{2.20}$$

Agents are paid w for each unit of human capital. Available income may be employed for three alternative purposes: current consumption (c_t), environmental maintenance (m_t) and educational investment (v_t). More precisely, v_t denotes the total amount of education bought by parents for their children, assuming that education is privately funded.

Education is pursued by parents because it can be transformed into future human capital according to the following function:

$$h_{t+1} = \delta h_t^{\theta} (\mu + v_t)^{1-\theta}, \tag{2.21}$$

where, depending on $\theta \in (0, 1)$, "nature" (parental human capital h_t) complements "nurture" (v_t) in the accumulation of productive skills. Notice that $\delta > 0$ accounts for total factor productivity in education, while the parameter $\mu > 0$ prevents human capital from being zero even if parents do not invest in education, as in (de la Croix & Doepke, 2003, 2004).

Agents engage in maintenance because it helps to improve future environmental quality, according to:

$$E_{t+1} = (1 - \eta)E_t + \sigma m_t - \beta c_t - \psi y_t. \tag{2.22}$$

This formulation reproduces (2.3), with two exceptions: we have now added a factor accounting for growth-induced pollution (through the coefficient $\psi > 0$), while the term representing external effects has been removed for ease of presentation. Since here, differently from the benchmark model, we have introduced explicitly a production function, it seems reasonable to consider that such production can also, to some extent, affect environmental conditions. Therefore, we have now two potential sources of pollution: consumption and production. As in the real world, both consumers and firms are susceptible to degrading the environment. We assume for the moment $\psi < \sigma$, thus implying that the environmental benefit produced by one unit of maintenance is larger than the environmental damage caused by one unit of production. This looks sensible, since maintenance is completely dedicated to improving the environment, while production generates pollution only as a "by-product".

2.4.2. Optimal choices

Maximizing (2.18) subject to (2.20), (2.21), (2.22), $c_t > 0$, $m_t > 0$, $E_t > 0$ and $h_t > 0$, leads to the following optimal choices:

$$\begin{aligned} m_t &= \frac{\sigma[\beta+\gamma(\beta+\sigma)\pi_t](\mu+wh_t)}{\sigma(\beta+\sigma)\left\{1+[\alpha(1-\theta)+\gamma]\pi_t\right\}} \\ &+ \frac{[\sigma+(\beta+\sigma)\alpha(1-\theta)]\psi wh_t-(1-\eta)[\sigma+\alpha(1-\theta)(\beta+\sigma)\pi_t]E_t}{\sigma(\beta+\sigma)\left\{1+[\alpha(1-\theta)+\gamma]\pi_t\right\}}, \end{aligned} \tag{2.23}$$

$$v_t = \frac{\left\{\alpha(1-\theta)[(1-\eta)E_t+(\sigma-\psi)wh_t]-\gamma\mu\sigma\right\}\pi_t-\mu\sigma}{\sigma\left\{1+[\alpha(1-\theta)+\gamma]\pi_t\right\}}, \tag{2.24}$$

and

$$c_t = \frac{(1-\eta)E_t+\mu\sigma+(\sigma-\psi)wh_t}{(\beta+\sigma)\left\{1+[\alpha(1-\theta)+\gamma]\pi_t\right\}}. \tag{2.25}$$

First of all, it is interesting to compare (2.23) with (2.5): the negative association between maintenance and current environmental quality still holds, as well as the positive effect of income, which is now related to current human capital. All other things being equal, human capital accumulation makes more income available for environmental care. Of course, investment in maintenance is negatively affected by α, reflecting the relative substitutability between future human capital and future environmental quality in the utility function. Finally, the positive effect of life expectancy on environmental maintenance is confirmed, provided that:

$$\gamma\sigma > \alpha(1-\theta)\beta, \tag{2.26}$$

as it can be inferred from:

$$\frac{\partial m_t}{\partial \pi_t} = \frac{[\gamma\sigma - \alpha(1-\theta)\beta][(1-\eta)E_t + \mu\sigma + (\sigma - \psi)wh_t)]}{\sigma(\beta+\sigma)\left\{1 + [\alpha(1-\theta)+\gamma]\pi_t\right\}^2}. \tag{2.27}$$

Condition (2.26), which we assume to hold henceforth, requires that the preference for environmental quality and the effectiveness of maintenance (γ and σ, respectively) must be strong enough to compensate for the weight attached to education (both in the utility function, through α, and in human capital formation, through $(1-\theta)$), and the detrimental effect of consumption on the environment (β).

Parental investment in education depends positively on both human capital (because of the traditional income effect and the inter-generational externality in education) and current environmental quality. If the latter is good enough, requiring a smaller investment in maintenance, it frees resources that can be allocated to education. Moreover, as expected, longer life expectancy induces a stronger investment in human capital. [18] In fact, provided that $\psi < \sigma$, the following derivative is always

18. This result, that we obtain for parentally-funded education, is quite common in the literature, although it may be motivated by different reasons. For instance, Galor (2005) p. 231, claims that "... the rise in the expected length of the productive life may have increased the potential rate of return to investments in children's human capital, and thus could have induced an increase in human capital formation ...". The positive effect of life expectancy on human capital accumulation can be also generalized to self-funded education: since Ben Porath (1967), it has been well established that the expectation of a longer productive life induces agents to invest more in their own human capital.

positive:

$$\frac{\partial v_t}{\partial \pi_t} = \frac{\alpha(1-\theta)[(1-\eta)E_t + \mu\sigma + (\sigma-\psi)wh_t)]}{\sigma\left\{1+[\alpha(1-\theta)+\gamma]\pi_t\right\}^2}. \tag{2.28}$$

Based on equations (2.27) and (2.28), a positive correlation between life expectancy and both environmental quality and human capital arises, along the transition path.

2.4.3. Dynamics

By replacing (2.23)-(2.25) into (2.21) and (2.22), we get the following non-linear system of two difference equations, which describes the dynamics of our economy:

$$h_{t+1} = \delta h_t^{\theta}\left(\frac{\alpha(1-\theta)[(1-\eta)E_t + \mu\sigma + (\sigma-\psi)wh_t)]\pi_t}{\sigma\left\{1+[\alpha(1-\theta)+\gamma]\pi_t\right\}}\right)^{1-\theta} \equiv \xi(h_t, E_t), \tag{2.29}$$

$$E_{t+1} = \frac{\gamma[(1-\eta)E_t + \mu\sigma + (\sigma-\psi)wh_t)]\pi_t}{1+[\alpha(1-\theta)+\gamma]\pi_t} \equiv \zeta(h_t, E_t). \tag{2.30}$$

In this set-up, a steady-state equilibrium is defined as a fixed point (h^*, E^*) such that $\xi(h^*, E^*) = h^*$ and $\zeta(h^*, E^*) = E^*$. To build an analytical example, we assume, similar to Section 2.3, the following functional form for the survival probability:

$$\pi_t(h_t, E_t) = \begin{cases} \underline{\pi} & \text{if } E_t + \kappa h_t < J \\ \overline{\pi} & \text{if } E_t + \kappa h_t \geq J \end{cases}, \tag{2.31}$$

with $\kappa, J > 0$. This formulation captures the substitutability (accounted for by κ) between human capital and environmental quality in increasing life expectancy. Notice also that J is an exogenous threshold value. In Section 2.3, we have explained how environmental conditions could improve longevity. However, now we also assume that each agent's probability of survival is positively related to her own human capital. Such a mechanism has already been exploited, for instance, by Blackburn & Cipriani (2002), Boucekkine *et al.* (2002), de la Croix & Licandro (2007), in theoretical models linking growth and demographic dynamics. Apart from an obvious income effect, the positive influence of human capital on longevity may be justified by the fact that better educated people have access to better information about health and are less likely to take up unhealthy behavior (such as smoking, becoming overweight, etc.) This is also consistent with the findings of several empirical studies like, for instance, Lleras-Muney (2005). Alternatively, in our model, human capital could also be interpreted as a health capital as in Chakraborty & Das (2005) or even Ballestra & Dottori (2009). In that case, agents would use their income for two alternative purposes: health expenditures or environmental maintenance. Health expenditures would have a direct impact on survival probability, while environmental would have an indirect effect.

Equation (2.31) paves the way to the existence of multiple steady-states, *i.e.* multiple solutions to the system composed by (2.29) and (2.30). After defining the two loci $HH \equiv \{(h_t, E_t) : h_{t+1} = h_t\}$ and $EE \equiv \{(h_t, E_t) : E_{t+1} = E_t\}$, we can claim the following:

Proposition 4 *Provided that (i) $\psi < \sigma$, (ii) proper conditions on the threshold value J hold, and (iii) the slope of HH is larger than the slope of EE, then there* *exist two stable steady-states A and B such that* $0 < h_A^* < h_B^*$ *and* $0 < E_A^* < E_B^*$.

Proof. See Appendix C ■

In particular, the high equilibrium is characterized by:

$$E_B^* = \frac{\gamma\mu\sigma^2\overline{\pi}}{\sigma + \left\{\gamma\eta\sigma + [\sigma - \delta^{\frac{1}{1-\theta}}(\sigma-\psi)w]\alpha(1-\theta)\right\}\overline{\pi}}, \tag{2.32}$$

and

$$h_B^* = \frac{\alpha(1-\theta)\delta^{\frac{1}{1-\theta}}\mu\sigma^2\overline{\pi}}{\sigma + \left\{\gamma\eta\sigma + [\sigma - \delta^{\frac{1}{1-\theta}}(\sigma-\psi)w]\alpha(1-\theta)\right\}\overline{\pi}}, \tag{2.33}$$

while, to obtain the low equilibrium (h_A^*, E_A^*), we just need to replace $\overline{\pi}$ with $\underline{\pi}$ in the above expressions. Notice that $w\delta^{1/(1-\theta)} < \sigma/(\sigma-\psi)$ is a sufficient condition for both steady-state values to be strictly positive.

It can be shown that the steady-state values of both environmental quality and human capital are positively affected by π and w, provided that $\psi < \sigma$. Concerning the other parameters, it is interesting to underline that E^* depends positively on θ: the more important is nature (with respect to nurture) in human capital formation, the more parents will be likely to invest in maintenance (rather than in education). Obviously, α and γ also influence positively the long-run levels of both human capital and environmental care. All these findings do not depend on the multiplicity of equilibria, and would apply to the case of a unique steady-state as well.

Let us now give a quick description of the behavior of our dynamical system. An economy starting from low (high) enough environmental quality and parental human capital, so that $E_0 + \kappa h_0 < J$ $(\geq J)$, will end-up in the steady-state equilibrium A

(B), which is characterized by both low (high) environmental quality and human capital and short (longer) life expectancy. Such a situation is represented by the phase diagram in Figure 2.6.

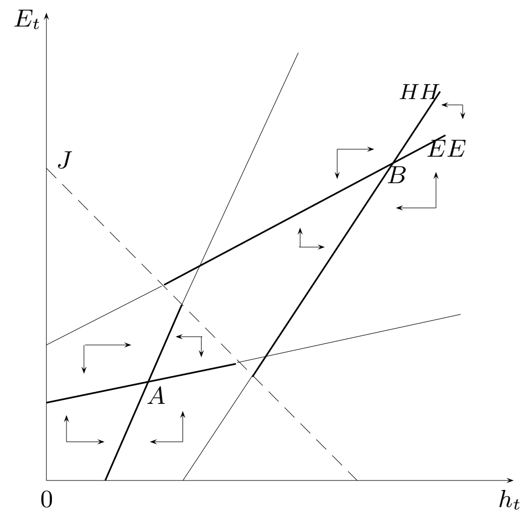


Figure 2.6: Phase diagram

The causal relationship linking the survival probability to both environmental quality and human capital implies the possibility of a country being stuck in a poverty trap, as in the benchmark model, and the underlying mechanism is quite similar. However, the trap is now characterized by three elements, namely low levels of: (i) environmental quality, (ii) life expectancy, and (iii) human capital.[19] By consequence, differently from Section 2.3, an economy initially trapped in the inferior steady-state can get out of it also through exogenous factors or policies that are related to human capital. We may think of, amongst others, the introduction of public schooling or educational subsidies, or an exogenous increase in the produc-

19. This result is consistent with stylized facts, which suggest a bimodal distribution of human capital as well. Data are available upon request.

tivity of the schooling system (δ). In Figure 2.6, the latter would correspond to a repositioning of the EE and HH loci, such that (h_0, E_0) may fall in the basin of attraction of B instead of A.

Finally, we would emphasize that the dynamics represented in the above diagram are also consistent with the so-called environmental Kuznets curve (Grossman & Krueger (1995)). An economy starting with low human capital and a fairly good environmental quality, will first experience a deterioration of environmental conditions as it develops, but will then see its environment improving for further stages of growth.

2.4.4. Welfare analysis

Here we want to find the green golden rule allocation and compare it with the equilibrium of the decentralized economy, where agents do not internalize the effects of their actions on the welfare of following generations. We will proceed as we did in Section 2.3, by solving, at the steady-state, the problem of a social planner who treats all generations symmetrically and strives to maximize aggregate utility.

Therefore, we look for the optimal steady-state combination of consumption, environmental quality and human capital that maximizes:

$$U(c, E, h) = \ln c + \pi(E)(\alpha \ln h + \gamma \ln E), \tag{2.34}$$

subject to:

$$wh = c + m + v, \tag{2.35}$$

$$\eta E = \sigma m - \beta c - \psi w h, \tag{2.36}$$

and

$$h = \delta h^{\theta}(v + \mu)^{1-\theta}.] \tag{2.37}$$

Notice that (2.35) and (2.36) are, respectively, the budget and the environmental constraints at the steady-state, while (2.37) is the stationary production function for human capital.

Eliminating m and v, and solving for c, we obtain:

$$c = \frac{-\eta E + \mu\sigma + [(\sigma - \psi)w - \sigma\delta^{\frac{1}{\theta-1}}]h}{\beta + \sigma}. \tag{2.38}$$

After replacing c in the utility function, we can solve the system made of the two first-order conditions $\partial U/\partial E = 0$ and $\partial U/\partial h = 0$ to obtain:

$$E^{g} = \frac{\alpha\mu\sigma\pi}{\eta[1 + (\alpha + \gamma)\pi]} \tag{2.39}$$

and

$$h^{g} = \frac{\alpha\mu\sigma\pi}{[\sigma\delta^{\frac{1}{\theta-1}} - (\sigma - \psi)w][1 + (\alpha + \gamma)\pi]}, \tag{2.40}$$

where, consistently with our analytical example, π can be either $\underline{\pi}$ or $\overline{\pi}$. We are ensured that this solution represents a maximum since: $\partial^2 U/\partial E^2 < 0$ and $\partial^2 U/\partial h^2 < 0$. After comparing E^{g} with E^{*}, we can claim the following:

Proposition 5 *At the steady-state, for sufficiently low values of η, the decentralized* *equilibrium involves lower environmental quality than the green golden rule allocation. Moreover, under proper conditions, the social planner solution may imply the elimination of the environmental trap.*

In particular, we need $\eta < \hat{\eta}$, where:

$$\hat{\eta} \equiv \frac{\sigma + [\sigma - \delta^{\frac{1}{1-\theta}}(\sigma - \psi)w]\alpha(1-\theta)\pi}{\sigma(1+\alpha\pi)}. \tag{2.41}$$

Provided that the conditions mentioned in Proposition 3 hold, $\hat{\eta}$ is positive. In addition, for α tending to 0, $\hat{\eta}$ tends to 1, thus reproducing the case analyzed in Section 2.3. This is not surprising, since α represents the weight of human capital in the utility function.

Moreover, depending on how close the decentralized low steady-state is to J, there is the possibility that the golden rule allocation is unique. In other words, a social planner who internalizes inter-generational externalities might be able to drive the economy out of the trap.

Finally, let us point out that the socially optimal allocation can be decentralized by means of suitable tax/subsidy policies of the kind we have studied in Section 2.3. The main findings (in terms, for instance, of optimal environmental taxation) would not be different from the benchmark model. However, since further sources of externalities (related to human capital) are now present, additional instruments would be needed.

2.5. Conclusions

In this chapter we have studied the interplay between life expectancy and the environment, and the resulting dynamic implications. The basic mechanism, upon which our theoretical model is built, is very simple. On the one hand, environmental quality depends on life expectancy, since agents who expect to live longer have a stronger concern for the future and therefore invest more in environmental care. On the other hand, longevity is affected by environmental conditions. By modeling environmental quality as an asset that can be accumulated over time, we have shown that life expectancy and environmental dynamics can be jointly determined. Eventually, multiple equilibria may arise, defining an environmental kind of poverty trap characterized by both low life expectancy and poor environmental performance. Both the correlation between environment and longevity, and possible non-ergodic dynamics, are consistent with stylized facts.

Our model is also robust to the introduction of a very simple growth mechanism via human capital accumulation. If education depends on life expectancy, and survival probabilities are affected by both environmental quality and human capital, we show that the positive dynamic correlation between longevity and environmental quality is preserved, and extends to income (in the long-run).

Moreover, our welfare analysis suggests that decentralized equilibria are inefficient. Agents do not internalize the effects of their choices on future generations. A social planner who takes these inter-generational externalities into account might achieve a superior equilibrium. We also show that the optimal allocation can be decentralized by means of appropriate environmental policies.

Finally, as interesting extensions and possible directions for further research, we would suggest: (i) to introduce heterogeneity among agents, moving from a representative agent set-up to a political economy model, where environmental choices are determined through voting; (ii) to enhance the demographic part of the model, allowing for endogenous fertility and relating environmental quality to demographic factors other than longevity (population density, for instance); (iii) to explore alternative policy options suitable for restoring optimality.

2.6. Appendices

A. Optimality of the dynamics

Let us now consider a full-fledged, forward-looking social planner, who seeks to maximize a social welfare function including all generations (both at the steady-state and along the transition path). The Lagrangian for this problem is:

$$\mathcal{L} = \nu^{-1}U_{-1} + \sum_{t=0}^{\infty} \nu^t \left\{ U_t(c_t, E_{t+1}) + \lambda_{t+1}[(1-\eta)E_t + \sigma w - (\sigma+\beta)c_t - E_{t+1}] \right\}, \tag{A.1}$$

where λ_{t+1} is the Lagrangian multiplier, corresponding to the shadow price of environmental quality and $\nu \in (0,1)$ accounts for inter-temporal discounting. From the two f.o.c.'s ($\partial\mathcal{L}/\partial c_t = 0$ and $\partial\mathcal{L}/\partial E_{t+1} = 0$), we obtain the following optimality condition:

$$\frac{\partial U_t}{\partial c_t} = (\beta + \sigma)\left[\frac{\partial U_t}{\partial E_{t+1}} + \nu\frac{\partial U_{t+1}}{\partial \pi_{t+1}}\frac{\partial \pi_{t+1}}{\partial E_{t+1}} + \nu\lambda_{t+2}(1-\eta)\right]. \tag{A.2}$$

Comparing the above expression with (2.4), we see that for the decentralized equilibrium to be socially optimal, we would need:

$$\frac{\partial U_{t+1}}{\partial \pi_{t+1}}\frac{\partial \pi_{t+1}}{\partial E_{t+1}} + \lambda_{t+2}(1-\eta) = 0, \tag{A.3}$$

which never holds, unless $\partial\pi_{t+1}/\partial E_{t+1} = 0$ and $\eta = 1$. Equation (A.3) allows us to identify two different inter-generational externalities, both related to m_t. The first term accounts for the effect of maintenance on the survival probability of future generations; the second one is due to the direct effect of maintenance on future environmental quality.

As in Section 2.3, inefficiencies can be corrected by means of environmental taxes. Since both externalities are related to the same source (maintenance), it turns out that one policy instrument is sufficient to achieve optimality. If τ_t is the tax rate on consumption at time t, decentralized agents allocate their resources according to:

$$\frac{\partial U_t}{\partial c_t} = [\beta + (1+\tau_t)\sigma]\frac{\partial U_t}{\partial E_{t+1}}. \tag{A.4}$$

Therefore, by equating (A.2) and (A.4), and solving for τ_t, we get the optimal tax trajectory:

$$\tau_t^* = \frac{\nu(\beta+\sigma)\left[\frac{\partial U_{t+1}}{\partial \pi_{t+1}}\frac{\partial \pi_{t+1}}{\partial E_{t+1}} + \lambda_{t+2}(1-\eta)\right]}{\sigma\frac{\partial U_t}{\partial E_{t+1}}}. \tag{A.5}$$

It can be easily checked that the intensity of taxation depends on the size of the inter-generational external effects, $\partial\pi_{t+1}/\partial E_{t+1}$ and $(1-\eta)$, respectively. Concerning the other parameters, it should be noticed that a higher ν, implying a greater concern for future generations, requires the tax rate to be heavier, while the effect of β and σ is as in Subsection 2.3.6.

B. Physical capital

Here, we want to show that our benchmark model is robust to the introduction of physical capital. Since the latter is built on savings, the optimization problem of our representative agent needs to be modified. The utility function is now:

$$U_t(c_t, c_{t+1}, E_{t+1}) = \ln c_t + \pi_t(\rho \ln c_{t+1} + \gamma \ln E_{t+1}), \tag{B.1}$$

where $\rho \in (0,1)$, which might be eventually set equal to $(1-\gamma)$, measures the preference for future consumption. The first-period budget constraint becomes:

$$w_t = c_t + m_t + s_t, \tag{B.2}$$

so that we explicitly introduce savings (s_t) in our analysis. Savings will be used to finance future consumption, according to:

$$c_{t+1} = \frac{s_t R_{t+1}}{\pi_t}, \tag{B.3}$$

where R_{t+1} denotes the interest factor at time $t+1$. As pointed out by Chakraborty (2004), the above expression is also consistent with the assumption of a perfect annuity market, and takes into account that agents are not sure to survive to their third period of life. In fact, they are perfectly aware that only with a probability π_t, they will be able to enjoy their current savings as future consumption.

To determine the factor prices w_t and R_{t+1}, we can introduce a neo-classical production function that, in per-capita terms, can be simply written as $y_t = f(k_t)$.

Investment is made out of savings; the law of motion for the stock of physical capital writes as:

$$k_{t+1} = (1-\iota)k_t + s_t, \tag{B.4}$$

where $\iota \in (0,1]$ is the depreciation rate of capital.

The dynamics of environmental quality are described by:

$$E_{t+1} = (1-\eta)E_t + \sigma m_t - \beta c_t - \epsilon k_t, \tag{B.5}$$

with $\epsilon > 0$. With respect to equation (2.3), we have added the ϵk_t term to take into account that also the use of capital in production, and not only consumption, is potentially polluting.

In this economy, individual agents select m_t and s_t (and implicitly define an optimal inter-temporal consumption plan), so as to maximize $U_t(c_t, c_{t+1}, E_{t+1})$ subject to (B.2), (B.3) and (B.5). Their optimizing behavior implies, in general terms:

$$\frac{\partial U_t}{\partial c_{t+1}} = \frac{\sigma \pi_t}{R_{t+1}} \frac{\partial U_t}{\partial E_{t+1}}, \tag{B.6}$$

along with (2.4). If we take the logarithmic utility function (B.1) and use (B.3), we obtain:

$$\gamma \sigma s_t = \rho E_{t+1}. \tag{B.7}$$

Abstracting from corner solutions, optimal choices are thus given by:

$$m_t = \frac{[\epsilon k_t - (1-\eta)E_t][\sigma + \rho(\beta+\sigma)\pi_t] + \sigma[\beta + \gamma(\beta+\sigma)\pi_t]w_t}{\sigma(\beta+\sigma)[1+(\rho+\gamma)\pi_t]}, \tag{B.8}$$

$$s_t = \frac{\rho \pi_t [(1-\eta)E_t - \epsilon k_t + \sigma w_t]}{\sigma + (\rho+\gamma)\sigma \pi_t}, \tag{B.9}$$

and

$$c_t = \frac{(1-\eta)E_t - \epsilon k_t + \sigma w_t}{(\beta+\sigma)[1+(\rho+\gamma)\pi_t]}. \tag{B.10}$$

It can be noticed that investments in environmental care m_t depend positively on the existing stock of physical capital, through two different channels: the first one is related to more pollution (ϵk_t) requiring more maintenance, while the second one accounts for a straightforward income effect (since $w_t = w(k_t)$). Conversely, investment in physical capital (savings) is an increasing function of environmental quality, due to a substitution effect: a healthier environment needs less maintenance, thus freeing resources for alternative purposes.

In the long-run, this kind of interplay translates into a positive correlation between the stationary values of capital and environmental quality. In fact, combining (B.4) and (B.7), we obtain $\gamma\iota\sigma k^* = \rho E^*$. It is then clear that, for instance, as soon as multiple equilibria become possible (depending on the shape of $\pi(E_t)$), the corresponding poverty trap will be characterized by low levels of life expectancy and both environmental quality and physical capital.

Once we replace optimal choices (B.8), (B.9) and (B.10) into (B.4) and (B.5), and consider that $w_t = f(k_t) - k_t f'(k_t)$, we can compute the steady-state values for environmental quality and physical capital. Take for instance a Cobb-Douglas production function, such that $y_t = Bk_t^{\chi}$ (with $\chi \in (0, 1)$ and $B > 0$), and assume a survival probability function as in (2.10). The steady-state level(s) of physical capital would then be given by:

$$k^* = \left\{ \frac{B\rho\sigma(1-\chi)\pi}{\iota\sigma + [\epsilon\rho + \iota\sigma(\gamma\eta + \rho)]\pi} \right\}^{\frac{1}{1-\chi}}. \tag{B.11}$$

The stationary value(s) for environmental quality can be accordingly determined, using $E^* = (\gamma\iota\sigma/\rho)k^*$.

C. *Proof of Proposition 4*

The proof is organized as follows. We will first characterize the two loci HH and EE, and then analyze the existence, multiplicity and stability of the steady-states. Let us now recall the definitions of the two loci: $HH \equiv \{(h_t, E_t) : h_{t+1} = h_t\}$ and

$EE \equiv \{(h_t, E_t) : E_{t+1} = E_t\}$.

C.1. Locus HH

From equation (2.29) we get that $h_{t+1} - h_t = \xi(h_t, E_t) - h_t$, where π_t is given by equation (2.31). Therefore, the locus HH writes as:

$$E_t = -\frac{\sigma\mu}{1-\eta} + \frac{\sigma\left\{1 + [\alpha(1-\theta)+\gamma]\pi_t\right\} - \alpha(1-\theta)(\sigma-\psi)w\pi_t\delta^{\frac{1}{1-\theta}}}{\alpha(1-\theta)(1-\eta)\pi_t\delta^{\frac{1}{1-\theta}}}h_t, \qquad \text{(C.1)}$$

where $\pi_t = \underline{\pi}$ $(= \overline{\pi})$ for $E_t + \kappa h_t < J$ $(\geq J)$. As we can see in Figure 2.6, locus HH is a discontinuous function divided into two parts (both straight lines) by $E_t = J - \kappa h_t$. Its intersection with the y-axis is given by $E_{t_{HH}}\mid_{h_t=0} = -\sigma\mu/(1-\mu) < 0$, while its slope can be expressed as:

$$\frac{\partial E_t}{\partial h_t} = \frac{\sigma\left\{1 + [\alpha(1-\theta)+\gamma]\pi_t\right\} - \alpha(1-\theta)(\sigma-\psi)w\pi_t\delta^{\frac{1}{1-\theta}}}{\alpha(1-\theta)(1-\eta)\pi_t\delta^{\frac{1}{1-\theta}}} \equiv s_h(\pi_t), \qquad \text{(C.2)}$$

where $\pi_t = \underline{\pi}$ $(= \overline{\pi})$ for $E_t + \kappa h_t < J$ $(\geq J)$. Indeed, as it is clear from the above equation, for s_h to be positive, we just need to have a positive numerator. Moreover, one can also verify that $\partial s_h(\pi)/\partial\pi < 0$. This implies that the first portion of the locus HH (given by $s_h(\underline{\pi})$) is steeper than the second one ($s_h(\overline{\pi})$), as depicted in Figure 2.6.

C.2. Locus EE

Equation (2.30) yields $E_{t+1} - E_t = \zeta(h_t, E_t) - E_t$, where π_t is given by equation (2.31). Therefore, the locus EE can be written as:

$$E_t = -\frac{\gamma\sigma\mu\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta)+\gamma]\pi_t\}} - \frac{\gamma(\sigma-\psi)w\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta)+\gamma]\pi_t\}}h_t, \tag{C.3}$$

where $\pi_t = \underline{\pi}$ $(= \overline{\pi})$ for $E_t + \kappa h_t < J$ $(\geq J)$. Like HH, the locus EE is also a discontinuous function divided in two different parts (once more straight lines) by $E_t = J - \kappa h_t$. Moreover:

$$E_{t_{EE}} \mid_{h_t=0} = -\frac{\gamma\sigma\mu\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta)+\gamma]\pi_t\}},$$

while the slope of EE is given by:

$$\frac{\partial E_t}{\partial h_t} = -\frac{\gamma(\sigma-\psi)w\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta)+\gamma]\pi_t\}} \equiv s_E(\pi_t), \tag{C.4}$$

where, as usual, $\pi_t = \underline{\pi}$ $(= \overline{\pi})$ for $E_t + \kappa h_t < J$ $(\geq J)$. One can easily observe that the denominator of the previous equation is strictly negative. Therefore, $E_{t_{EE}} \mid_{h_t=0} > 0$ and, provided that $\sigma > \psi$, $s_E > 0$. Moreover, since $\partial(E_{t_{EE}} \mid_{h_t=0})/\partial\pi > 0$, the y-intercept corresponding to $\pi_t = \overline{\pi}$ is larger than the one defined by $\pi_t = \underline{\pi}$. Finally, we also have $\partial s_E(\pi)/\partial\pi > 0$, for $\sigma > \psi$. Consequently, the slope of the first portion of the locus EE (given by $s_E(\underline{\pi})$) is smaller than the slope of the second part $(s_E(\overline{\pi}))$, as represented in Figure 2.6.

C.3. Existence, multiplicity and stability of steady-states

Provided that $s_h > s_E$ and $\sigma > \psi$, there exist two points $A \equiv (h_A, E_A) = EE(\underline{\pi}) \cap HH(\underline{\pi})$ and $B \equiv (h_B, E_B) = EE(\overline{\pi}) \cap HH(\overline{\pi})$, such that $0 < h_A < h_B$ and $0 < E_A < E_B$. A and B are both steady-states if $e_A + \kappa h_A < J < E_B + \kappa h_B$. Figure 2.6 provides a straightforward illustration of this condition: the dashed line $E_t + \kappa h_t = J$ should lie between A and B.

Let us now study the stability of A and B. Consider first the locus HH, and take a point $(\overline{h}, \overline{E}) \in HH$. For a fixed $E_t = \overline{E}$, and using (C.1), the dynamics of h_t are described by:

$$\begin{aligned} h_{t+1} &= \delta {h_t}^{\theta} \left\{ \frac{\sigma\left\{1 + [\alpha(1-\theta) + \gamma]\pi_t\right\} - \alpha(1-\theta)(\sigma-\psi)w\pi_t\delta^{\frac{1}{1-\theta}}}{\sigma\left\{1 + [\alpha(1-\theta) + \gamma]\pi_t\right\}\delta^{\frac{1}{1-\theta}}}\overline{h} \right\} \qquad \text{(C.5)} \\ &+ \delta {h_t}^{\theta} \left\{ \frac{\alpha(1-\theta)(\sigma-\psi)w\pi_t}{\sigma\left\{1 + [\alpha(1-\theta) + \gamma]\pi_t\right\}} h_t \right\}^{1-\theta}, \end{aligned}$$

where $\pi_t = \underline{\pi}$ $(= \overline{\pi})$ for $E_t + \kappa h_t < J$ $(\geq J)$. If $s_h > s_E$, then the numerator of equation (C.2) is positive, since $s_E > 0$. Consequently, we can verify that, for $h_t > \overline{h}$ $(< \overline{h})$, $\Delta h_t < 0$ (> 0). Hence, h_t decreases (increases). Similarly, let us now consider a point $(\overline{h}, \overline{e}) \in EE$. For a fixed $h_t = \overline{h}$, and taking (C.3), the dynamics of E_t are given by the following expression:

$$\Delta E_t = \frac{\gamma(1-\eta)\pi_t - \left\{1 + [\alpha(1-\theta) + \gamma]\pi_t\right\}}{1 + [\alpha(1-\theta) + \gamma]\pi_t}(E_t - \overline{E}), \qquad \text{(C.6)}$$

where $\pi_t = \underline{\pi}$ $(= \overline{\pi})$ for $E_t + \kappa h_t < J$ $(\geq J)$. Since the numerator is negative, it is clear that, for $E_t > \overline{E}$ ($< \overline{E}$), $\Delta E_t < 0$ (> 0). Hence, E_t decreases (increases).

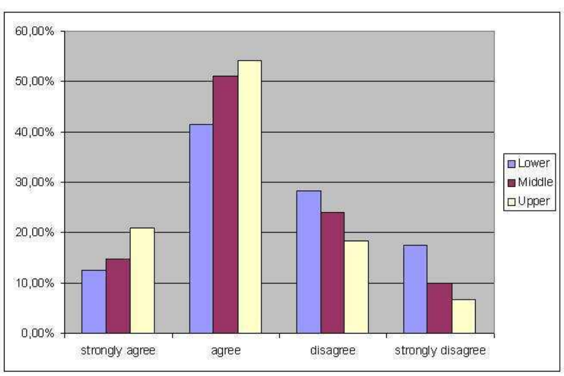
Chapter 3

Education and the Political Economy of Environmental Protection

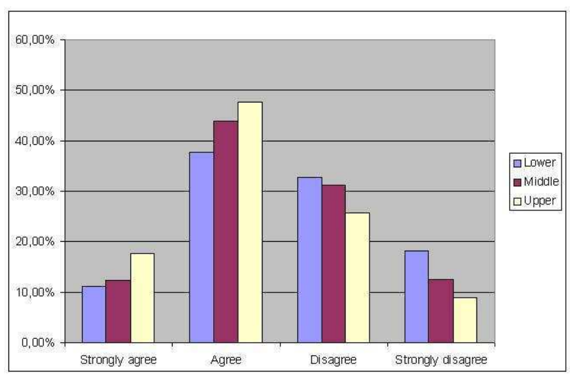
3.1. Introduction

What can explain or justify the world distribution of environmental performances? The traditional answer emphasizes the key role played by technology or industrial structure to explain these long-term discrepancies. More recently, another channel has been put forward: agents'preferences with regards to the environment. In particular, those preferences are often associated with a rising income and may help to achieve better environmental conditions. Yet, the relationship linking the two variables is controversial. Because high-income agents may protect themselves against environmental hazards, they might be discouraged to support a public policy in favour of environmental protection. Besides, it has also been highlighted that the societies that are highly dependent on natural resources, exhibit a strong concern for the environment. We can think, for instance, about the Indian "tribus" around the Amazon or poor economies where natural endowment is a crucial factor for further development. Then, the relationship between green awareness and income is not straightforward and needs to be more deeply investigated. In this chapter, we propose some micro-foundations that rely on the choices of education and life expectancy. Since agents who invest in human capital benefit longer from the environment, they are also more likely to contribute for environmental preservation. In turn, for similar reasons, a clean environment is an incentive to educate. This complementarity may lead to multiple equilibria that account for the observed heterogeneity in environmental performances.

The role played by education in the emergence of a green consciousness can be empirically backed-up. For instance in a study conducted in the USA, Goetz *et al.* (1998) show that even after controlling for income, age and others socio-economic factors, environmental quality was higher in the States where the proportion of agents who have a high school degree is large. Graduate schooled agents are certainly more aware of environmental risks and outcomes, more sensitive to green campaigning and prevention, are likely to adopt "sustainable" behaviours, etc... Broadly speaking, higher human capital allows individuals to perceive the costs and the benefits of achieving better environmental conditions (see also Carlsson & Johansson-Stenman (2000), Kahn (2002), Brock & Taylor (2005), Fredriksson *et al.* (2005), Farzin & Bond (2006)). This positive relationship may also be captured through the analysis of the green vote. In this respect, Thalmann (2004) and Bornstein & Lanz (2008) show, using the data from a Swiss referendum on green taxes, that the acceptance and approval of green taxes is higher among educated agents. Finally, this evidence can also be illustrated thanks to the World Value Survey data.[1] In particular, we can observe that, in OECD countries, highly educated individuals tend to be more favorable to environmental preservation and may more easily accept the potentiel corresponding fiscal pressure. For instance, at the positive statements "*would give a part of my income for the environment*"(see Figure 3.1a, or "*increase in taxes if used to prevent environmental pollution*" below) (see Figure 3.1b), the proportion of upper educated individuals who *strongly agree* or *agree* amounts to around 65 %; on the contrary, the share of lower educated agents who are definitely opposed to additional environmental expenditures may amount to 45% in the first case, and around 35% in the second case.



(a) "*..give a part of income..*"



(b) "*..increase in tax..*"

Figure 3.1. World Value Survey data dealing with environmental actions

1. The World Value Survey consists in a study dealing with "*values and cultural changes in societies all over the world*". The data are available on the following web site: http://www.worldvaluessurvey.org/. Individuals are asked to answer a wide range of assertions concerning their own cultural values. Reported answers are ranged from "*strongly agree*" to "*strongly disagree*".

At an aggregate level, these findings imply that environmental quality may crucially depend on the distribution of skills within the population. A country where the share of highly educated agents is large, is more likely to engage itself in environmental protection or more prone to accept a heavier environmental fiscal pressure. The development of human capital may be regarded as a complementary (if not alternative) means of achieving environmental goals, in addition of the more classic instruments, like for instance command-and-control regulations,... Some empirical data may support these conclusions, such that more educated economies display better environmental performance. Indeed, using data from the Center for International Development (CID (2000)) on the secondary school enrolment in 2000 and the Environmental Index Performance (YCELP (2006)), we can observe a positive correlation, as shown in Figure 3.2, between the two variables.[2] The present chapter aims at capturing this phenomena through a model of political economy.

In this chapter, we consider a continuum of two-period lived agents who get utility from consumption and environmental quality. During adulthood, when all relevant decisions are taken, they share their time endowment between education and work. Once agents have acquired basic skills, they may directly supply *unskilled* labour to the market. Alternatively, they can choose to provide *skilled* labour by investing in additional human capital. In addition, we consider that educated workers also exhibit a higher life expectancy. The key ingredient of our setting is that life ex-

2. The EPI index was built as a synthetic index of environmental performance. It includes various factors, going from "environmental health" (indoor pollution, drinking water, adequate sanitation and urban particulates) to "ecosystems vitality" (air quality, water and productive natural resources, biodiversity). Data are available on-line at http://epi.yale.edu.

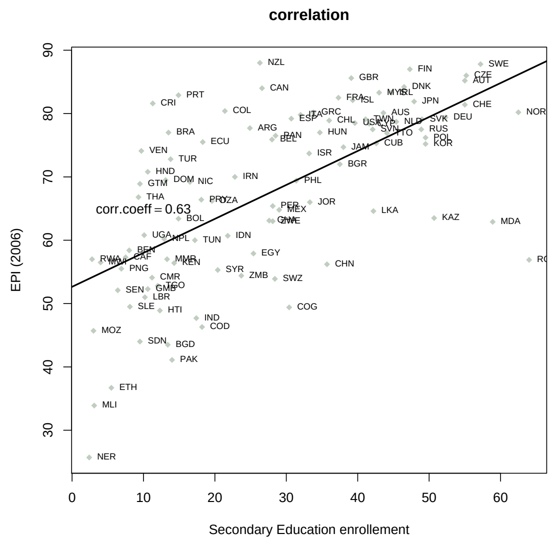


Figure 3.2: Correlation between second school enrollment and environmental performance

pectancy determines the marginal utility of the environment: agents who expect to live longer exhibit stronger concern for the environment since they will benefit more from it. Consequently, choices of education depend ultimately on agents' expectations with respect to future environmental quality. When individuals anticipate deteriorated environmental conditions at next date, they have few incentives to invest in additional human capital and the proportion of *unskilled* workers within the population increases. Conversely, when they forecast a clean future environmental quality, they are likely to bear an extra cost of education, to benefit longer from the environment when old.

Once occupational choices are made, agents vote on the level of the poll tax, which is exclusively used to finance public environmental maintenance. It is shown that optimal willingness-to-pay for the environment depends crucially on education and so on longevity: a higher life expectancy increases the level of the preferred tax, by raising stronger concern for the environment, while it reduces private consumption. This result may be backed up by compelling evidence, like Goetz *et al.* (1998), Carlsson & Johansson-Stenman (2000), Brock & Taylor (2005), that highlight the important role played by both socio-demographic and economic factors, including the level of education or health status, in explaining the positive correlation between the level of education and the public support for environmental protection.

We consider a simple majority voting mechanism so that the political outcome depends on the current distribution of traits within the population. Hence, if the majority within the economy is *unskilled*, the implemented environmental tax is the lower one, and conversely. In turn, as previously exposed, the median voter's feature is it-self affected by expected future environmental quality. This dynamic interaction between the economic and political decisions of individuals may generate multiple equilibria and indeterminacy. In particular, we show that agents' expectations regarding future environmental quality may be self-fulfilling as the public policy is endogenous. Hence, the coordination on one outcome allows for multiple equilibrium paths with different long-run consequences in terms of environmental quality and development. On the one hand, if expectations are coordinated on thinking the future environmental quality to be good , there is a room for an equilibrium path that self-confirms these anticipations: in the long-run, the economy is driven towards a high equilibrium characterized by both good environmental quality and a more highly educated population. On the other hand, if expectations are more pessimistic, then *skilled* workers are a minority. The resulting effort of maintenance provided publicly is smaller and confirms initial predictions: the economy may be caught in a trap featured by a poor environment and a majority of *unskilled* workers.

Finally, the crucial role played by agents'expectations paves the way for public intervention in order to select the higher equilibrium. Since in our model, agents vote on environmental policy, the authorities are not capable of making a commitment on the future environmental quality. However, the government may aim at encouraging education in order to favour the emergence of optimistic forecasts. Accordingly, we assess the dynamic consequences of a public policy whose goal is to stimulate the investment in human capital in order to escape from the trap. Among many available instruments, we choose to model the impact of a reduction in the fixed cost of education. Public policy is still endogenous, but tax is now used for two alternative purposes: education and environmental maintenance. We show that if initially the economy is trapped, public policy may be first detrimental to the environment to switch the trajectory, while in a second step it allows the economy to reach a better overall situation: an improved environment and a majority of *skilled* workers. We also underline that the policy design optimally varies over time. In fact, public policy in favour of education has to be temporary; after a while, tax benefits must again be entirely devoted to environmental protection.

Our chapter is related to those articles that have analysed environmental issues in dynamic OLG framework. In particular, we refers to the setting proposed by John & Pecchenino (1994) or Ono (2002) to describe the evolution of environmental quality over time. A link can also be established with the paper of Ikefuji & Horii (2007) who identify a poor-environment trap associated with a low level of human capital or the one by Mariani *et al.* (2009) where the trap is also characterized by a lower life expectancy. However, our analysis contrasts with those papers as we consider the effort of maintenance being provided publicly, as a consequence of a political equilibrium. On the contrary, Jouvet *et al.* (2008) consider the trade-off between private and public environmental spending, although agents differ, in their framework, in their behaviour with respect to bequest.

This article is also built on recent models of expectation-driven multiplicity like Saint Paul & Verdier (1997), Bisin & Verdier (2000) or Hauk & Saez-Marti (2002), although we concentrate on more environmental dynamical issues, rather than the mechanism of preference transmission. Nevertheless, as in these papers we investigate the opportunities of public intervention in order to select a unique equilibrium. In this respect, our chapter may also be related to the article of Glomm & Ravikumar (1995) who study the dynamic implications of equilibrium selection.

The remainder of the chapter is organised as follows. In Section 3.2, we introduce the model and analyse the dynamic behaviours of the economy. Policy implications are discussed in Section 3.4 and Section 3.5 concludes.

3.2. The model

3.2.1. The basic framework

Let us consider an overlapping generations model where individuals live for two periods. Time is discrete, $t = 0, 1, ... + \infty$ and at any date t, there is a continuum of agents of mass 1 being born. Accordingly, no population growth is considered. Lifespan utility of an agent i, at date t, writes as:

$$U_t^i = c_t^i + \pi_t^i E_{t+1} \tag{3.1}$$

It is defined over private consumption (c_t) during the first period of life and environmental quality (E_{t+1}) when old. In our setting, agents could have valued the environment during their first period of life; however, as we will see below, their choices with respect to environmental conditions do not affect the current environment so that the results hold unchanged.

Utility derived from the second period of life is discounted by a factor $\pi_t^i \in (0, 1]$ which accounts for life expectancy.[3] Since only environmental quality is discounted, life expectancy can also be regarded as the weight given by agents to main environmental concerns so that, it could be interpreted as the level of green preferences. It is worth noticing that here, the discount factor is endogenous since we consider that life expectancy of an individual i crucially depends on educational choices.

3. Throughout the chapter, we interchangeably use the terms "life expectancy" and "longevity" since both concepts exhibit similar properties. It can be either a probability of surviving to old age or the length of the second period of life, thus being included in the interval $(0, 1]$. In either case, the benefit drawn from the environment is discounted by a time-length factor.

More specifically, we argue that longevity is widely explained by the level of education (without focusing on the feedback effect of life expectancy on education investment it-self): more educated agents adopt healthier behaviours, have more information about risks, etc...Because education and income are positively linked, more educated agents, who often exhibit higher income, may also have better access to health services, adequate living conditions, etc. (see, for instance, Barro & Sala-i Martin (1995), Chakraborty (2004), de la Croix & Licandro (2007) or Lleras-Muney (2005)).

3.2.1.1. Education

During the first period of life, each agent is endowed with one unit of time, which can be shared among education and work. All individuals spend a fixed period of time at school, $\lambda \in (0, 1)$, in order to acquire basic skills. Once they get this primary knowledge, they can directly supply *unskilled* labour to the market. However, they may also become *skilled*, through acquisition of additional human capital. Since individuals rather than their parents decide about their education, the choice of acquiring human capital implies a trade-off: human capital allows for a higher wage while it requires a loss in the valuable time, z. Let us suppose that this time cost is distributed uniformly within the population on the range $[0, 1]$. As in Cervellati & Sunde (2005), this parameter z may be interpreted as innate abilities in terms of learning capacities. However, in our model, individual abilities affect the cost of education rather than its return. Consequently, a high z (equivalent to lower abilities) implies that the time spent educating is longer and the remaining time working on the market, shorter. Then, the labour income (y_t^i) for both types of existing workers, during the first period of life, is given by:

$$\begin{cases} y_t^s = (1-\lambda-z)w_t^s \\ y_t^u = (1-\lambda)w_t^u, \end{cases} \tag{3.2}$$

where $i = \{s, u\}$, for *skilled* workers and *unskilled* ones, respectively. If two types of workers co-exist within the population, we can also define two distinct levels of life expectancy corresponding to the educational choices. Therefore, we denote π^i, the life expectancy of a worker i, where $0 < \pi^u < \pi^s \leq 1$, according to empirical evidence mentioned in the Introduction.

3.2.1.2. Environmental quality

Agents use their labour income to consume but are also subjected to a poll tax ($\tau_t > 0$).[4] Since environmental quality is mostly a public good and costs required to abate pollution are very high, individuals or groups within the population are unable to effectively provide them. Then, we assume that this tax is levied by the government in order to alleviate pollution, to improve or, at least, to preserve environmental quality. Accordingly, in our framework, we consider a political equilibrium where agents take an active part in the decision-making process concerning

4. Of course, it could be the case that the tax is proportional to the wage; however, as we will see later, in that case, the choice regarding extra education would depend on both expectations with respect to future environmental quality, but also predictions about the future tax rate. Moreover, the preferred tax rate it-self would depend on wages, and so would be distributed within the population of educated agents. Finally, this would heavily complicate the analysis.

the design of the environmental policy, by voting on the level of such a tax. Consequently, the effective tax which is implemented will depend on the distribution of skills among the population.

Finally, all decisions are taken during the first period of life and the budget constraint writes as:

$$y_t^i - \tau_t = c_t^i \tag{3.3}$$

This tax, used by the government considerably affects the evolution of environmental quality over time. In fact, in line with the seminal work of John & Pecchenino (1994), we express the law of motion of environmental quality as:

$$E_{t+1} = (1-\eta)E_t - P_t + \sigma g(\tau_t) \tag{3.4}$$

where $0 < \eta < 1$ is the natural depreciation rate of the environment, P_t, harmful pollution flows, $g(\tau_t)$, the environmental maintenance provided by the authorities and $\sigma > 0$, the efficiency of such environmental expenditure on the environment. Let us underline that here, agents value the environment that may encompass environmental conditions (going from air quality to quality of water, soils etc.) as well as resources availability (like, for instance, biodiversity, forestry, fisheries and so on..). Broadly speaking, this variable $E_t \geq 0$ is multidimensional and can be regarded as an indicator of all amenities provided by nature.

Furthermore, it is worth noticing that in our set-up, maintenance outcome (as well as pollution flows) account only for the next period so that adults' choices with respect to the environment can not directly affect current environmental conditions. Indeed, the natural environment and most kinds of ecosystems react slowly to pollution flows or environmental measures so that environmental changes are postponed and often occur after a long period.

3.2.1.3. Production

In the end, one good is produced (and privately consumed) thanks to labour. Both kinds of workforce are perfectly substitute, so that:

$$Y_t = A^s H_t + A_t^u L_t, \tag{3.5}$$

where H_t represents the aggregate *skilled* workforce (so called human capital) and L_t the aggregate *unskilled* labour available in the economy. [5] Then, A^i stands for the productivity level of each labour force. We assume that $A^s > A^u$ since we want to capture the greater capacity of educated agents to adopt and apply a given technology, to learn additional knowledge: it is less "costly" to adapt to advanced technologies being already educated (for further discussion see, among others, Fershtman *et al.* (1996), Caselli (1999), Galor & Moav (2000)). Finally, for ease of presentation, we assume constant productivity and do not consider any growth process.

Besides, so as the market is competitive and labour forces exhibit constant returns

5. This perfect substitutability between *skilled* and *unskilled* labour types is very restrictive and may be discussed. However, allowing for the complementarity would heavily complicate the model, although the reasoning with respect to the choices of education is preserved.

to scale, each input is paid to its marginal productivity. Therefore, a skill premium exists for educated workers, which involves a positive wage gap between both kinds of occupations. From (3.5), wage rates are deduced:

$$\begin{cases} w^s = A^s \\ w^u = A^u \end{cases} \tag{3.6}$$

Finally, we consider that pollution flows in the economy arise from the production process such that:

$$P_t = \beta Y_t, \tag{3.7}$$

with $0 < \beta \leq 1$, which reveals the cleanness degree of production.[6] The higher β, the dirtier the production. Here, we neglect the fact that pollution intensity may differ from one kind of labour to an other, like Ikefuji & Horii (2007) do, but we consider a whole production-induced pollution. In this respect, it could be quite similar to assume that pollution is associated with consumption flows in the economy. We could have considered that *unskilled* labour was more polluting, similar to Ikefuji & Horii (2007). More specifically, we would have endogeneized the parameter β, so that it evolves positively with the share of *unskilled* workforce within the economy: $\beta(\frac{L}{H})$ and $\beta'(\cdot) > 0$. In that case, our results would have been reinforced. Indeed, a large proportion of *unskilled* workers would induce a heavier pressure on the environment as well as the lower level of environmental protection: the deterioration of the environment would probably accelerate.

6. We consider here a linear relationship between pollution flows and production for the sake of simplicity.

3.2.2. Microeconomic choices

In this section, we present the microeconomic choices of agents. On the one hand, we show that educational choices hinge on utilities comparison; on the other hand, the effort of maintenance is derived from a simple majority voting mechanism. Then, using the dynamic complementarity between choices of education and the demand for environmental protection allows us to study the global dynamics of the environment in Section 3.3.

In order to clearly present our analysis, we consider a specific timing during the first period of life: at first, agents choose whether to educate or not, and in a second step, they vote, according to their skills, on the level of the tax.

3.2.2.1. Educational choices

An individual i with a time cost equal to z is indifferent between educate himself or not, if, for a given tax,

$$U_t^s = U_t^u \Leftrightarrow [(1-\lambda-z)w^s - \tau_t] + \pi^s E_{t+1} = [(1-\lambda)w^u - \tau_t] + \pi^u E_{t+1} \qquad (3.8)$$

Using (3.6), a threshold value on z, is deduced from the above equality:

$$\tilde{z}_t = \frac{(1-\lambda)(A^s - A^u) + [\pi^s - \pi^u]E_{t+1}^a}{A^s} \equiv \tilde{z}(E_{t+1}^a), \qquad (3.9)$$

with E_{t+1}^a, the expected future state of the environment. Since agents derive utility from the environment during their second period of life, they have to anticipate future environmental conditions when they decide about their additional education. The uncertainty that leads agents to form expectations with regards to the environment, lies in the fact that choices of education will have an impact on both the effort of maintenance and the pollution flows. The static comparison of utility (see equation (3.8)) implies that for any distributed $z \leq \tilde{z}(E^a_{t+1})$, agents choose to acquire additional knowledge; conversely, if $z > \tilde{z}(E^a_{t+1})$, individuals do not invest in further education and provide *unskilled* labour force. Obviously, if $\tilde{z}(E^a_{t+1})$ is very high that is for $E^a_{t+1} \geq \hat{E} \equiv \frac{\lambda(A^s - A^u) + A^u}{[\pi^s - \pi^u]}$, everybody educates (*i.e.* the proportion of highly educated agents equals unity); the production is only ensured thanks to type-s workers. When $E^a_{t+1} = 0$, there is still a positive share of agents that spend time educating, $\tilde{z}(E^a_{t+1}) = \frac{(1-\lambda)(A^s - A^u)}{A^s}$[7].

Not surprisingly, this threshold value $\tilde{z}(E^a_{t+1})$ depends on two main factors. The first one, quite usual, is the income effect: a rise in the wage gap between *skilled* and *unskilled* activities spurs the extra investment in human capital, while λ, the fixed cost of primary education tends to discourage it. The second factor is represented by agents' expectations regarding the future state of the environment. Individuals are prone to suffer a higher cost of education if they anticipate improved future environmental conditions. In fact, an expected good environmental quality fosters education, because, in that case, agents hope to benefit longer from the environment

7. More precisely, it becomes impossible to solve the model in an analytical way. For instance, considering a Cobb-Douglas production function (such that the two labour types are complement) would prevent from computing a threshold value on z. Nevertheless, using such production function and we are able to state that there exists a unique value of z, which also depends positively on expectations with respect to environmental quality and which determines when agents decide to invest in human capital or not. (see Appendix F)

when old. This positive effect holds all the more so as the longevity gap is large between the two types of workforce. Figure 3.3 depicts the relationship between $\tilde{z}(E^a_{t+1})$ and the future state of the environment.

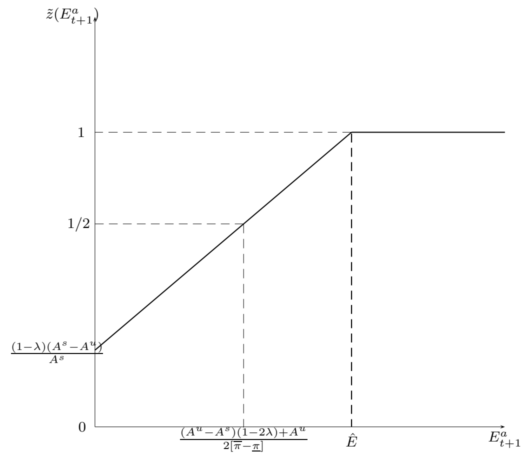


Figure 3.3: share of *skilled* agents within the population

Finally, let us notice that the global impact of the *skilled* workers' productivity (A^s) is not clear cut. In particular, despite the positive income effect, it turns out that education is costly, with zA^s measuring the individual cost of acquiring human capital (see equation (3.2)). Yet, when agents educate they receive a fixed gain derived from the environment, altered by a longevity effect. Then, the relative gain of being *skilled* ($[\pi^s - \pi^u]E^a_{t+1}/A_s$) falls with A^s. In fact, the net utility derived from the environment is cut down by the global cost of education.

Provided that z is uniformly distributed within the population, the aggregate labour supplies of both types of workers, at date t, are given by:

$$H_t = \int_0^{\tilde{z}_t} dz = \tilde{z}(E^a_{t+1}) \tag{3.10}$$

and

$$L_t = \int_{\tilde{z}_t}^{1} dz = (1 - \tilde{z}(E^a_{t+1})) \tag{3.11}$$

Here, $\tilde{z}(E^a_{t+1})$ is exactly the proportion within the population that does educate.

Furthermore, using equations (3.10) and (3.11), the production in the economy can be rewritten as:

$$Y_t = \begin{cases} \tilde{z}(E^a_{t+1})(A^s - A^u) + A^u & \text{if } 0 < E^a_{t+1} < \hat{E} \\ A^s & \text{if } E^a_{t+1} \geq \hat{E} \end{cases} \tag{3.12}$$

When all workers are *skilled*, the production is fully determined by the productivity level of highly educated workers; when both types of workers co-exist, the share of *skilled* individuals in the economy boosts production.

In the end, using equation (3.7) and (3.12), it follows that pollution flows in the economy (P_t) may be expressed as:

$$P(E^a_{t+1}) = \begin{cases} \beta[\tilde{z}(E^a_{t+1})(A^s - A^u) + A^u] & \text{if } 0 < E^a_{t+1} < \hat{E} \\ \beta A^s & \text{if } E^a_{t+1} \geq \hat{E} \end{cases} \tag{3.13}$$

Since a rise in the proportion of highly educated workers stimulates both production (3.12) and pollution (3.13), a feedback effect of expectations on environmental quality arises: optimistic predictions trigger extra investment in education, which in turn, by increasing the share of *skilled* workers, induces more pollution and so more pressure on the environment. Finally, the net impact of agents' expectations on the evolution of the environment will crucially depend on the effort of maintenance provided by the government and on the adopted tax within the society.

3.2.2.2. Political equilibrium

As mentioned before, the poll tax is exclusively used to provide environmental maintenance expenditure (this could also be a direct reduction of pollution). The government's budget is balanced, so that:

$$\tilde{z}_t \tau_t + (1 - \tilde{z}_t)\tau_t = \tau_t, \tag{3.14}$$

the sum of the contributions finances the global effort of maintenance. The environmental protection provided by the authorities writes as:

$$g(\tau_t) = \tau_t^{\theta}, \tag{3.15}$$

with $\theta \in (0, 1]$, which could embody the efficiency of the maintenance technology (*cf.* Ballestra & Dottori (2009)). Here, tax revenue translates into maintenance, but we consider that this maintenance technology exhibits decreasing marginal returns: as tax receipts rise, the marginal efficiency of abatement reduces. It is more easy to abate pollution at the beginning of the cleaning process, but as the receipt grows, it becomes more tricky. Alternatively, this parameter θ could be regarded as the efficiency of government institutions, meaning that a low value of θ induces a larger wasted part of tax receipts. Tax revenue may be partly dissipated in collection costs; otherwise said, marginal collection costs increase in the tax, due, for instance, to the existence of bureaucratic inefficiencies (Saint Paul & Verdier (1997), Lightart & Ploeg (1999)). In the end, both interpretations of θ imply that utility is concave in environmental maintenance and so satisfies usual properties: individuals face a trade-off between private consumption and future environmental quality (consumption of a public good).

Once they have decided about their education, agents aim at maximising their lifetime utility under equations (3.3), (3.4) and (3.15) in order to determine their optimal willingness-to-pay for environmental preservation. From the First Order Condition (FOC), we obtain the optimal poll tax for both types of workers in a decentralized equilibrium:

$$\tau^i = (\sigma \pi^i \theta)^{\frac{1}{1-\theta}} \tag{3.16}$$

It is worth noticing that this optimal willingness-to-pay for the environment is constant over time and is fully determined by the level of education through life expectancy, which might differ according to the type of agent. Provided that $\pi^s > \pi^u$, it follows obviously that $\tau^s > \tau^u$ and environmental quality is indeed a normal good. Hence, high-income agents are more prone to pay for environmental protection.

Our result is thus consistent with widespread empirical evidence such that higher income or/and higher level of education raise stronger concern for the environment (Goetz *et al.* (1998), Carlsson & Johansson-Stenman (2000), Brock & Taylor (2005)). To some extent, this result may also be related to a theoretical literature that adresses the determinants of green consciousness, relying on the evolution of agents'income.

Finally, because the weight paid to environmental quality depends on agents' life expectancy, agents are merely capable of contributing more, if they expect to benefit longer from the environment, and conversely. As in Chapter 2, life expectancy becomes a major determinant of environmental performance.

In the end, such kind of microeconomic behaviours shape environmental quality at a macroeconomic level. Indeed, as individuals exhibit single-peaked preferences with respect to the environment, the theorem of the median voter holds. Therefore, the political outcome depends on the median voter's feature, be it *skilled* or *unskilled*, and writes as:

$$\begin{cases} \tau = \tau^u \text{ if } E^a_{t+1} < \tilde{E} \\ \tau = \tau^s \text{ if } E^a_{t+1} \geq \tilde{E} \end{cases} \tag{3.17}$$

with

$$\tilde{E} \equiv \frac{A^u - A^s(1-2\lambda) + A^u}{2[\pi^s - \pi^u]}, \tag{3.18}$$

where $\tilde{E}$ is defined as the level of E^a_{t+1} such that $\tilde{z}(E^a_{t+1}) = 1/2$.

The poll tax effectively chosen is crucially affected by agents'expectations with respect to environmental quality. If E^a_{t+1} is low, less agents invest in education and the share of *unskilled* workers is greater than half ($\tilde{z}(E^a_{t+1}) < 1/2$). Consequently, the effort of environmental preservation provided in the economy is mitigated. The oppposite is true if E^a_{t+1} is high. Agents are prone to suffer a higher extra cost of education: the share of *skilled* workers rises, the median voter becomes *skilled*

($\tilde{z}(E^a_{t+1}) \geq 1/2$).[8] Accordingly, the demand for environmental protection raises so as the tax.

3.3. Dynamics

Substituting (3.7)-(3.17) into the law of motion of environmental quality, we obtain a system that describes the global dynamical behaviour of the economy. Depending on the median voter's feature, we can characterize the dynamics of the economy. In particular, when the median voter is *unskilled*, we define $E_{t+1} \equiv \psi_u(E_t, E^a_{t+1})$ so that

$$\psi_u(E_t, E^a_{t+1}) = (1-\eta)E_t - P(E^a_{t+1}) + \sigma\tau^{u^\theta}, \tag{3.19}$$

with $P(E^a_{t+1})$ defined in (3.7). Pollution flows may vary according to E^a_{t+1}, since the expected value of th environment the population of *skilled* workers within the economy and therefore the pollution level. Alternatively, when the median voter is *skilled*, we define $E_{t+1} \equiv \psi_s(E_t, E^a_{t+1})$ such that

$$\psi_s(E_t, E^a_{t+1}) = \begin{cases} (1-\eta)E_t - P(E^a_{t+1}) + \sigma\tau^{s^\theta} & \text{if } E^a_{t+1} < \hat{E} \\ (1-\eta)E_t - \beta A^s + \sigma\tau^{s^\theta} & \text{if } E^a_{t+1} \geq \hat{E}. \end{cases} \tag{3.20}$$

8. Notice that here, there exists a usual problem when $\tilde{z}(E^a_{t+1}) = 1/2$ to determine which group wins the elections. In order to avoid this, and for the sake of simplicity, we simply assume that when $\tilde{z}(E^a_{t+1}) = 1/2$, the winner majority is *skilled*.

Finally, the global dynamics can be summarized by:

$$E_{t+1} = \begin{cases} \psi_u(E_t, E^a_{t+1}) & \text{if } E^a_{t+1} < \tilde{E} \\ \psi_s(E_t, E^a_{t+1}) & \text{if } E^a_{t+1} \geq \tilde{E} \end{cases} \tag{3.21}$$

The dynamics are dramatically influenced by expectations agents have about the future environment. These anticipations determine the share of *skilled* workers within the population and accordingly the type of the median voter. Hence, the evolution of environmental quality over time relies on individuals' anticipations. Using equation (3.21), we can argue that the median voter is *skilled* only for fairly high values of E^a_{t+1}. If initially agents anticipate good future environmental conditions, they choose to educate, since they expect to benefit longer from the environment. As the proportion of type-s workers increases, the median voter is likely to be *skilled*. Consequently, the government implements a heavier tax and the receipts devoted to environmental preservation are larger. Symmetric reasoning could apply when dealing with pessimistic expectations, that is when $E^a_{t+1} < \tilde{E}$.

However, even if the effect of the tax is clear cut, the distribution of skills within the population might display ambiguous effects. Because pollution flows grow with the share of highly educated workers in the economy, agents'expectations may translate into more pressure on the environment (see equation (3.7)). Yet, those anticipations become beneficial to environmental quality, only through a "cliquet" effect, that is when the economy shifts from one regime to another. In that case, optimistic predictions also implies a larger effort of maintenance, so that environmental quality improves.

3.3.1. Perfect foresight dynamics

In order to solve the dynamics, we assume that agents perfectly anticipate future environmental conditions, thus inducing that $E^a_{t+1} = E_{t+1}$. Under this assumption, the perfect foresight dynamics of the economy is obtained by solving the system (3.21) for $E^a_{t+1} = E_{t+1}$. Hence, a one-dimensional dynamical system describes the evolution of environmental quality over time:

$$E_{t+1} = \begin{cases} \Psi_u(E_t) & \text{if } E_{t+1} < \tilde{E} \\ \Psi_s(E_t) & \text{if } E_{t+1} \geq \tilde{E}, \end{cases} \tag{3.22}$$

with:

$$\Psi_u(E_t) = \frac{A^s[(1-\eta)E_t + \sigma {\tau^u}^\theta] - \beta(1-\lambda)({A^s}^2 + {A^u}^2) + \beta A^u A^s(1-2\lambda)}{A^s + \beta(A^s - A^u)(\pi^s - \pi^u)} \tag{3.23}$$

and

$$\Psi_s(E_t) = \begin{cases} \frac{A^s[(1-\eta)E_t + \sigma {\tau^s}^\theta] - \beta(1-\lambda)({A^s}^2 + {A^u}^2) + \beta A^u A^s(1-2\lambda)}{A^s + \beta(A^s - A^u)(\pi^s - \pi^u)} & \text{if } E_{t+1} < \hat{E} \\ (1-\eta)E_t - \beta A^s + \sigma {\tau^s}^\theta & \text{if } E_{t+1} \geq \hat{E} \end{cases} \tag{3.24}$$

The global perfect foresight dynamics (equation (3.22)) are in two parts differing by the median voter's feature. We start by analyzing separately the two trajectories and then we study the global dynamics.

More specifically we can prove that each part of the dynamics, $\Psi_u(E_t)$ or $\Psi_s(E_t)$, taken separately, admits only one globally stable steady-state, E^u and E^s, characterized by a low and a high environmental quality, respectively (see Appendix A). Here, a steady-state is defined as a fixed point E^i with $i = \{s, u\}$ such that: $\Psi_i(E_t) = E_t$. In particular, using equations (3.23) and (3.24), for $0 < E_{t+1} < \hat{E}$, we will have that:

$$E^u = \frac{A^s[\sigma \tau^{u^\theta}] - \beta[(1-\lambda)(A^{s^2} + A^{u^2}) - A^s A^u (1-2\lambda)]}{\beta(A^s - A^u)(\pi^s - \pi^u) + \eta A^s} \tag{3.25}$$

$$E^s = \frac{A^s[\sigma \tau^{s^\theta}] - \beta[(1-\lambda)(A^{s^2} + A^{u^2}) - A^s A^u (1-2\lambda)]}{\beta(A^s - A^u)(\pi^s - \pi^u) + \eta A^s}, \tag{3.26}$$

where $E^s > E^u$, since $\tau^s > \tau^u$. The sole difference between the two stationary values stands in the level of the tax.[9]

Given that properties, let us now study the global dynamics of the economy. In particular, it is described by the trajectory $\Psi_u(E_t)$ if the expected environmental quality is damaged, while it is characterized by $\Psi_s(E_t)$, if expectations are much more optimistic. Here, we assume that when two trajectories exist in $t + 1$, the economy follows the one prevailing at date t. Hereafter, this property refers to the concept of stationary expectations.[10] In order to describe clearly the global dynamics, we also define the threshold values on environmental quality that determine the area of existence of each trajectory. We denote by $\overline{E}$, the value of E such that $\Psi_u(\overline{E}) = \tilde{E}$: beyond $\overline{E}$, $\Psi_u(E_t)$ does not exist anymore, or otherwise said the majority is no longer

9. It is worth noticing that for $E_{t+1} \geq \hat{E}$, $E^s = \frac{\sigma \tau^{s^\theta} - \beta A^s}{\eta}$. However, we choose to report in the text the solutions depicted in Figure 3.4.

10. This assumption is made for ease of presentation and in order to give the main insights of the model. It will be relaxed in Subsection 3.3.2, where we present a more general case.

unskilled. Similarly, we define $\underline{E}$ such that $\Psi_s(\overline{E}) = \tilde{E}$. Since, in turn, the median voter's feature depends on expected future environmental conditions, we can claim that:

Proposition 6 *Let assume that agents have perfect foresight expectations, then*

(i) E_t *always converges towards* E^u*, if* $\underline{E} > E^s$*;*

(ii) E_t *always converges towards* E^s*, if* $\overline{E} < E^u$*;*

(iii) when $\underline{E} < E^u < E^s < \overline{E}$*, there always exist stationary expectations such that:*

- *if* $E_0 < \tilde{E}$*,* $E_{t+1} = \Psi_u(E_t)$ *and* E_t *converges towards* E^u
- *if* $E_0 \geq \tilde{E}$*,* $E_{t+1} = \Psi_s(E_t)$ *and* E_t *converges towards* E^s

Proof. See Appendix B ■

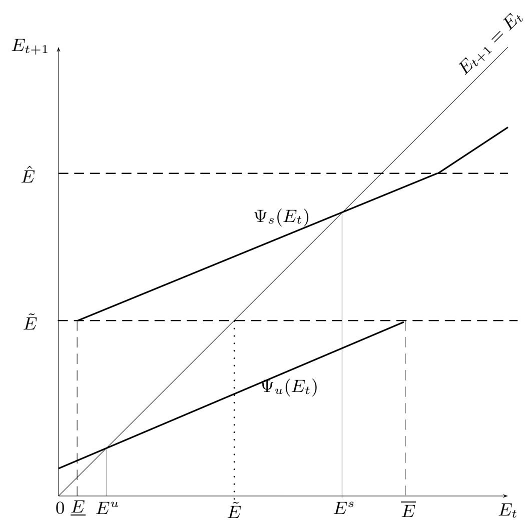


Figure 3.4: Multiple equilibria, case (iii) of Proposition 6

Part *(i)* of Proposition 6 is likely to arise when the value of $\tilde{E}$ is very high, thus implying that the majority may hardly be *skilled*. For instance, if primary education is already very costly, agents will have less incentives to invest in further education. Similarly, a very dirty production technology might prevent the high equilibrium to exist. In that case, no matter initial conditions, the economy converges towards the low, unique and globally stable equilibrium, E^u. Conversely, part *(ii)* might occur if the longevity gap is large. A high efficiency degree of maintenance expenditure compared to β may also favour the achievement of the high equilibrium, E^s.

Part *(iii)* of Proposition 6 is depicted in Figure 3.4. When the two steady-states co-exist, then, depending on initial conditions, the economy may converge towards either E^u or E^s. If initially, environmental quality is somewhat low (for $E_0 < \tilde{E}$), majority is *unskilled* so as the median voter. Under the assumption of stationary expectations, anticipations are and remain quite pessimistic, and incentives to educate drop. Then, the tax which is implemented is lower and the economy converges towards E^u, following the trajectory described by the function $\Psi_u(E_t)$. The resulting stationary value of environmental quality is low and the share of *unskilled* workers within the population is large. In that case, we can say the economy is caught in an environmental trap featured by a damaged environmental quality and a low level of development. Conversely, if initially the environment is clean (for $E_0 \geq \tilde{E}$), the median voter is *skilled*. Stationary expectations are optimistic and incentives to invest in extra education are boosted. The level of maintenance provided publicly is higher and the economy reaches E^s, a stationary value characterized by improved environmental conditions and a more educated population. In our framework, an increase in the proportion of *skilled* workers does not imply necessarily a heavier pressure on the environment. In fact, it also induces a rise in the environmental maintenance provided by the public authorities. Yet, as discussed above, this latter effect overcomes the former and so environmental quality at the high steady-state is well improved compared to the trap.

In our framework, the presence of multiple equilibria directly stems from the complementarity between incentives to invest in human capital and the willingness-to-pay for environmental protection, through the longevity effect. These multiple equilibria, linking environmental quality and level of education, can be backed up by some empirical evidence, which show that more educated economies are likely to exhibit better environmental conditions (see, for instance, Magnani (2000), Bimonte (2002), Fredriksson *et al.* (2005), Farzin & Bond (2006)). As shown previously, this positive relationship may be micro-founded. In particular, a higher level of education may in it-self trigger stronger concern for the environment (Goetz *et al.* (1998), Carlsson & Johansson-Stenman (2000), Brock & Taylor (2005)), thus encouraging the emergence of a green consciousness. At an aggregate level, this green concern of skilled individuals has more chance to translate into improved environmental quality through the greater ability of educated agents to influence political decisions *via*, for instance, lobbying groups, non-governmental organizations, ecological political groups, etc....

3.3.2. Indeterminacy and self-fulfilling equilibria

In this section, we relax the assumption of stationary expectations. In particular, we show that expectations might be self-fulfilling and might determine the long-run political outcome. In fact, there exist some values of E_t such that E_{t+1} is undetermined. Then, as in Bisin & Verdier (2000) or Hauk & Saez-Marti (2002), we focus on the case where the two stationary values of the environment belong to this indeterminacy area; finally, we study the dynamic implications of agents' coordination on a particular outcome regarding future environmental quality. We can then state that:

Proposition 7 *Expectations might be self-fulfilling since two different values of* E_{t+1} *are compatible with a unique value of* E_t*,* $\forall E_t \in [\underline{E}, \overline{E}]$*.*

Proof. See Appendix C ■

Interestingly, our model exhibits self-fulfilling expectations as claimed in Proposition 7. This implies that when, initially, the distribution of abilities within population is relatively balanced, the role of anticipations and their coordination on a particular issue become a key ingredient for the determination of long-run environmental evolutions.

Consider, for instance, a situation where initially agents of type-u are a majority and $E_t \in [\underline{E}, \overline{E}]$. If all of them are pessimistic and thus expecting that future environmental quality will remain damaged, the share of *unskilled* workers remains majority. The resulting effort of maintenance is thus small and self-confirms initial predictions. Consequently, if agents coordinate on this same pessimistic belief all along the dynamical process, the environment converges towards E^u. Conversely, starting from the same situation, that is a majority of *unskilled* workers within the population but if agents coordinate on a more optimistic anticipation, the stationary value of environmental quality may be improved. In fact, agents are more likely to invest in additional education for them-selves: type-s workers may become a majority and the tax equals τ^s, thus increasing mechanically the effort of maintenance. Again, expectations are realised while environmental quality reached by the economy is better. Moreover, *unskilled* workers turn out to be minority.

Proposition 6 states that the stationary values of the environment are stable under stationary expectations while Proposition 7 defines an indeterminacy area, in which expectations may be self-confirmed. Then, it turns out that these stationary values may be destabilized following a change in expectations. The Corollary below summarizes this result:

Corollary 1 *When E^s and $E^u \in [\underline{E}, \overline{E}]$, one economy that would have converged towards one of both equilibria under the assumption of stationary expectations, might rather reach the other steady-state thanks to a change in expectations.*

In the configuration depicted in Figure 3.4, the low equilibrium E^u belongs to the indeterminacy area $[\underline{E}; \overline{E}]$. Consequently, one economy initially trapped in E^u might jump onto the optimistic trajectory $\Psi_s(E_t)$ and converge towards E^s by means of change in expectations. In this case, switching from pessimistic anticipations to more optimistic ones allows the economy to escape from the initial poor-environment trap. Notice that this mechanism works also in the opposite way, so that an economy initially located in E^u might, in the end, be pushed towards the low equilibrium, if anticipations become suddenly pessimistic.

In our setting, the change in agents'expectations is a possible way, among others, to switch the trajectories followed by one economy. As pointed out by some other theoretical papers like Glomm & Ravikumar (1995), Bisin & Verdier (2000) or Hauk & Saez-Marti (2002), these multiple equilibria arise due to failures in the expectations coordination. Then, the implementation of public policies or the authorities commitment might be a solution that enables to correct these inefficiencies. Otherwise said, the success of any environmental policy, which aims at reducing environmental deterioration, could be realised, at least partially, if authorities are able to coordinate agents' beliefs on quite optimistic expectations with respect to the environment it-self. However, it is worth noticing that here, the government can not commit it-self with respect to the effort of maintenance since agents do decide on the prevailing level of maintenance provided publicly: the authorities can not announce any environmental policy in advance neither shape the median voter's ability. Expectations can not be influenced directly by the government. Nevertheless, in order to select one specific equilibrium and to ensure the achievement of its environmental goal, the government may choose to modify the cost of education. Indeed, education is a crucial factor that influencing agents green preferences.

In the following section, we emphasize the role played by a public policy on the opportunity of switching the equilibria. However, let us underline that, the selection of one specific equilibrium is not a trivial choice. In fact, the welfare analysis leads to ambiguous results due to the existence of heterogeneous agents: it is then tricky to rank both equilibria. On the one hand, the high equilibrium E^s always seems to be preferred by *skilled* workers: first, the implemented tax is exactly the one they vote for; second, environmental quality is higher. However, even if *unskilled* individuals benefit from a better environmental quality in E^s, they have to pay an undesirable and heavier tax τ^s. Then, the high equilibrium might not be optimal for *unskilled* workers. A governmental policy that would aim at reaching E^s and escaping the trap, might not be Pareto-optimal, if the taxation effect dominates the green benefits. Nonetheless, since the level of development is also higher in E^s, we will consider such an objective and assess the instrument to achieve it.

3.4. Policy implications

As mentioned above, an improved environmental quality and a higher level of development are reached, at the steady-state, if agents exhibit optimistic expectations, thus being more likely to educate. Accordingly, in order to step out from the poor-environment trap, the government may aim at encouraging agents to invest in additional human capital. Since the government is not capable of coordinating agents'beliefs, we consider stationary expectations and study the opportunities of achieving a better environmental performance, starting from the low equilibrium

E^u.

Consistently with our previous results, we consider, among the various available instruments, that the government reduces the fixed cost of education (λ) in order to boost the share of highly educated workers within the population. Here, as education is time consuming, the decrease of λ includes all improvements made in order to ameliorate the "learning technology": a better access to school, an increase in the size of teaching profession, more schools, and the like.

The starting point in time of our analysis is date T and the economy is pinned-down to E^u, the environmental trap such that $E^u < \overline{E}$. From that moment, the government announces that tax benefits are used for two alternative purposes: environmental maintenance and education. More precisely, the authorities decide to devote a share $\alpha \in (0, 1)$ of public receipt to environmental maintenance, while the remaining amount of tax $(1 - \alpha)$ are invested in education.

Because of the timing in the decision process, at date T, the share of both *skilled* and *unskilled* agents within the population is unaffected. Even if the public policy in favour of education is announced, unless the government contracts a debt, he can not fund the reduction in the fixed cost of education. As long as the public policy takes place, the government uses the receipts from the tax to finance the "subsidy" to education. Every thing goes as if the "educational" side of the policy is funded by the previous generation. This implies necessarily that the young generation at date T only suffer from the "green" side of the public policy. Agents' behaviour is instantaneously altered when dealing with the optimal poll tax and therefore, the environmental quality law of motion evolves from date $T+1$. Let us underline that the public policy is still endogenous, although agents do not vote on the distribution of the tax benefits among the two purposes: they only choose the level of the tax, taken as given the share devoted to environmental efforts.

In order to assess the potential consequences of such kind of endogenous public policy, we first describe the changes that occur during the transition phase at date T; then, we expose the resulting dynamics of the economy when the policy is fully implemented, from date $T+1$.

3.4.1. Transition phase

The governmental action has a direct effect on the future environmental quality, which enters the utility function of agents born at date T. Differently from (3.4), environmental quality now evolves according to:

$$E_{T+1} = (1-\eta)E_T - P_T + \sigma(\alpha\tau^p)^\theta, \tag{3.27}$$

where τ^p is the implemented tax, noted with superscript p that stands for *policy*. Provided that initially the economy is located in E^u, the value of P_T is given.

Since the level of technology is given and constant over time, agents maximise (3.1), under (3.2), (3.6) and (3.27) in order to determine the amended optimal poll tax. Notice that the design of the policy (α) is taken as given when agents determine their optimal willingness-to-pay. It yields for an individual of type-i:

$$\tau^{p,i} = (\sigma\pi^i\theta\alpha^\theta)^{\frac{1}{1-\theta}}. \tag{3.28}$$

This result captures the positive and one-way relationship between the share of tax revenue dedicated to environmental expenditure and the level of the tax: an increase in α fosters the investment in environmental maintenance. Otherwise said, since extra education is not triggered by any altruistic motive, a larger share of receipt devoted to education does not provide any additional gain of utility, but only a smaller incentive to invest in maintenance. Finally, compared to the benchmark model (that is when α equals unity), for both types of agents, the willingness-to-pay for improving environmental conditions is smaller, since $\alpha < 1$.

Under the assumption of stationary expectations, and because we only consider E^u as a starting point of the analysis, the dynamics are described by the following equation:

$$E_{T+1} = \Omega_u(E_T) \tag{3.29}$$

where $\Omega_u(E_T)$ is the "transitional" value of environmental quality. In fact, this dynamics is slightly amended compared to the benchmark model. Formally, using (3.9), (3.7), (3.27) and (3.28), it yields for $0 < E_{T+1} < \tilde{E}$:

$$\Omega_u(E_T) = \frac{A^s[(1-\eta)E_T + \sigma(\alpha\tau^{p,u})^\theta] - \beta(1-\lambda)(A^{s^2} + A^{u^2}) + \beta A^u A^s(1-2\lambda)}{A^s + \beta(A^s - A^u)(\pi^s - \pi^u)} \tag{3.30}$$

The economy jumps from E^u onto $\Omega_u(E_T)$. During this period, date T, the majority is *unskilled* and the environmental quality evolves taking into account the new willingness-to-pay. At next date, we can state that:

Lemma 3 *Starting from E^u, if the government implements a public policy in favour of education at date T, environmental quality deteriorates at date $T+1$.*

Proof. The slope of $\Omega_u(E_T)$ is identical to the one of $\Psi_u(E_t)$, $\forall\, E_t$ and $t = 0, ..T.. + \infty$. However, $\Omega_u(0) < \Psi_u(0)$. Thus, $\Omega_u(E_T)$ crosses the 45° line before E^u. ■

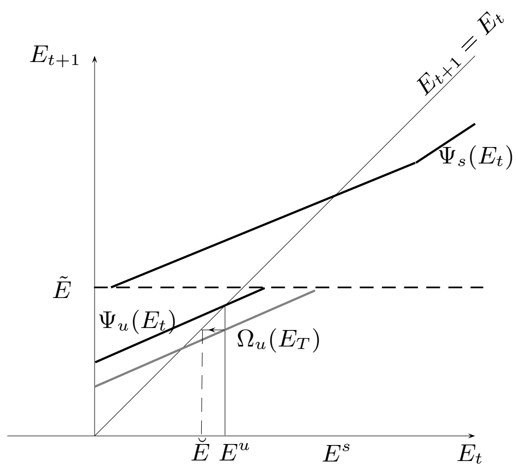


Figure 3.5: First phase of transition

As depicted in Figure 3.5, starting from the low equilibrium E^u, at date $T+1$, the economy ends up in $\breve{E}(\alpha)$, defined such that $\Omega_u(E^u) = \breve{E}(\alpha)$. This level of environmental quality crucially depends on the distribution of tax benefits. In fact, in the benchmark model, the whole revenue collected by the government is devoted to environmental maintenance. As soon as the public policy is implemented, the aggregate level of maintenance provided by the authorities is reduced. Obviously, since pollution flows are constant, environmental quality deteriorates compared to the initial situation. However, the larger the share granted to environmental protection, the less deteriorated the environment.

3.4.2. Long-run dynamics

Equation (3.27) describing the law of motion of the environment holds as soon as the public policy is implemented. However, from now on, the generation born at date $T+1$ benefits from the subsidy to education (ν_t) and so the proportion of *skilled* and *unskilled* workers in the economy might change.

3.4.2.1. Educational choices

Taking into account this fall into the cost of primary education, the budget constraint for both types of agents is now given by the following system:

$$\begin{cases} y^s_{T+1} = [1-(1-\nu_{T+1})\lambda - z]w^s \\ y^u_{T+1} = [1-(1-\nu_{T+1})\lambda]w^u, \end{cases} \tag{3.31}$$

where $\nu_t \in [0,1]$. The government's budget constraint is still balanced (see equation (3.14)); however a share $(1-\alpha)$ of these receipts are now devoted to education. The reduction in the fixed cost of education is financed by the previous generation. Once the level of the tax has been determined, the subsidy to education is deduced:

$$\nu = \begin{cases} [(1-\alpha)\tau^{p,u}]^{\kappa} & \text{if } E_T < \tilde{E} \\ \\ [(1-\alpha)\tau^{p,s}]^{\kappa} & \text{if } E_T \geq \tilde{E}, \end{cases} \tag{3.32}$$

where $\kappa \in [0, 1]$. Consistently with the benchmark model, we consider that κ reveals the efficiency of the learning technology: investing in schooling facilities exhibits decreasing marginal returns, meaning that initial tax benefits are more productive. Moreover, this parameter could capture the effectiveness of the tax collection, as previously. A higher value of κ would then imply that tax revenue are slightly dissipated in collection costs.

The investment in education is still shaped by the comparison of indirect utilities but now, using (3.1), (3.6) and (3.31), the threshold value on the private cost of education, z, writes as:

$$\tilde{z}^p_{T+1} = \frac{(A^s - A^u)[1 - (1-\nu)\lambda] + (\pi^s - \pi^u)E^a_{T+2}}{A^s} \equiv \tilde{z}^p(E^a_{T+2}) \tag{3.33}$$

Obviously, the positive effect of optimistic agents' expectations is preserved; in addition, the higher the subsidy, the greater the threshold education cost. This implies mechanically that agents with a higher individual education cost, who would have been *unskilled* in the basic model, may now invest in extra education. As previously, $\tilde{z}^p(E^a_{T+2})$ accounts for the share of *skilled* workers within the economy, so that if $E^a_{T+2} \geq \hat{E}^p \equiv \frac{A^u-(A^s-A^u)\lambda(1-\nu)}{(\pi^s-\pi^u)}$, $\tilde{z}^p(E^a_{T+2})$ equals unity. As we focus on a specific configuration, that is E^u as starting point, we can directly deduce the value of ν and the resulting threshold value on $\tilde{z}^p(E^a_{T+2})$. Indeed, at the previous date the majority was still *unskilled*, and so the poll tax was equal to $\tau^{p,u}$.[11]

This threshold value depends ambiguously on the parameter α, which captures the design of the policy. Let us recall that individuals care about the environment so that α positively influences agents willingness-to-pay for environmental protection . Then, on the one side, a higher value of α involves larger tax receipts, which may, in turn, trigger the investment in additional education and increase the share of *skilled* agents in the economy. On the other side, this also implies a smaller share of tax benefits dedicated to education, and so α also influences the decision of extra investment, but in the opposite way.

3.4.2.2. Political outcome

Similarly to our benchmark model and in order to determine their own optimal poll tax, agents maximise their utility (3.1), under (3.27) and (3.31). Solving this program yields the result already exposed in equation (3.28). Then, anticipations with respect to future environmental quality shape the long-run dynamic implications of the model. To determine which tax prevails in the economy, we proceed as

11. Notice that now the threshold value on z at date $T+1$ may take two different values according to the tax prevailing at date T. As we focus on a specific case, we do not present the alternative value of $\tilde{z}^p(E^a_{T+2})$ when the tax equals $\tau^{p,s}$ at date T.

in subsection 3.2.2.2. Hence, we can state that:

$$\begin{cases} \tau = \tau^{p,u} \text{ if } E^a_{T+2} < \tilde{E}^p(\alpha) \\ \tau = \tau^{p,s} \text{ if } E^a_{T+2} \geq \tilde{E}^p(\alpha) \end{cases} \tag{3.34}$$

where

$$\tilde{E}^p(\alpha) \equiv \frac{A^s - 2(A^s - A^u)[1 - (1 - [(1-\alpha)\tau^{p,u}]^\kappa)\lambda]}{2(\pi^s - \pi^u)} \tag{3.35}$$

Notice that $\tilde{E}^p(\alpha) \leq \tilde{E}$. The central point here is that, as shown by the following derivative, the threshold $\tilde{E}^p(\alpha)$ depends in a non-monotonic way of α:

$$\frac{\partial \tilde{E}^p(\alpha)}{\partial \alpha} = \frac{(\alpha - \theta)\kappa\lambda(A^s - A^u)[(1-\alpha)\tau^{p,u}]^\kappa}{(1-\alpha)(1-\theta)\alpha A^s(\pi^s - \pi^u)} \tag{3.36}$$

In particular, the impact of α is twofold such that $\tilde{E}^p(\alpha)$ is described by a U-shape, according to the values of α. Starting from large values of α, a fall in the parameter induces high returns on the educational public policy. Incentives to invest in human capital rise, and predictions have to be slightly optimistic to ensure a majority of *skilled* workers. As soon as α is small enough, then receipts reduces sharply. For very low values of the parameter, tax receipts are small, while the return on the environmental effort is very high. Agents have less incentives to educate, expectations have to be very optimistic (*i.e.*, E^a_{T+2} very high) to allow the majority to become *skilled*.

Since the goal pursued by the government is to step out from the trap, the threshold value $\tilde{E}^p(\alpha)$ should be as small as possible: this would ensure a *skilled* majority. Yet, this threshold is U-shaped following changes in α. Then, there might exist a range of intermediate values of the parameter α, such that $\tilde{E}^p(\alpha)$ is small enough and allows optimistic expectations to be self-confirmed. Therefore, this paves the way for an eventual optimal allocation of the public receipt among education and environmental maintenance.

Once again, starting from date $T+1$ and depending on the median voter's feature, we are able to characterize the dynamics of the economy. When the median voter is *unskilled*, we define $E_{T+2} \equiv \phi_u(E_{T+1}, E^a_{T+2})$ and formally, using (3.7), (3.27) and (3.34), we obtain:

$$\phi_u(E_{T+1}, E^a_{T+2}) = (1-\eta)E_{T+1} - P(E^a_{T+2}) + \sigma(\alpha\tau^{p,u})^\theta. \tag{3.37}$$

When the median voter is highly educated, we have $E_{T+2} \equiv \phi_s(E_{T+1}, E^a_{T+2})$ such that

$$\phi_s(E_{T+1}, E^a_{T+2}) = \begin{cases} (1-\eta)E_{T+1} - P(E^a_{T+2}) + \sigma(\alpha\tau^{p,s})^\theta & \text{if } E^a_{T+2} < \hat{E}^p \\ (1-\eta)E_{T+1} - \beta A^s + \sigma(\alpha\tau^{p,s})^\theta & \text{if } E^a_{T+2} \geq \hat{E}^p. \end{cases} \tag{3.38}$$

Finally, the global dynamics can be summarized by the following system:

$$E_{T+2} = \begin{cases} \phi_u(E_{T+1}, E^a_{T+2}) & \text{if } E^a_{T+2} < \tilde{E}^p(\alpha) \\ \phi_s(E_{T+1}, E^a_{T+2}) & \text{if } E^a_{T+2} \geq \tilde{E}^p(\alpha) \end{cases} \tag{3.39}$$

As before, we consider rational expectations implying that $E^a_{T+2} = E_{T+2}$. Then, we can characterize a perfect foresight dynamics by solving (3.37) and (3.38), for $E^a_{T+2} = E_{T+2}$. This assumption allows us to obtain a one dimensional dynamical system, that describes the evolution of environmental quality from date $T+1$ (see Appendix D):

$$E_{T+2} = \begin{cases} \Phi_u(E_{T+1}) & \text{if } E_{T+2} < \tilde{E}^p(\alpha) \\ \Phi_s(E_{T+1}) & \text{if } E_{T+2} \geq \tilde{E}^p(\alpha) \end{cases} \tag{3.40}$$

Similarly to the benchmark model, we can claim that, under proper conditions, each dynamic trajectory, $\Phi_u(E_T)$ or $\Phi_s(E_T)$ taken separately, admits only one globally stable steady-state, $E^{p,u}$ and $E^{p,s}$, characterized by a low and a high environmental quality, respectively. Moreover, when E_t belongs to the interval $[\underline{E}^p, \overline{E}^p]$, there exists an area of indeterminacy: in that case, expectations might be self-fulfilling.[12]

In particular, we have:

$$E^{p,u} = \frac{\sigma A^s(\alpha\tau^{p,u})^\theta + A^s A^u \beta(1-2\lambda) - \beta(1-\lambda)(A^{s^2} + A^{u^2}) - \beta\lambda(A^s - A^u)^2[(1-\alpha)\tau^{p,u}]^\kappa}{\beta(A^s - A^u)(\pi^s - \pi^u) + \eta A^s} \tag{3.41}$$

and

$$E^{p,s} = \frac{\sigma A^s(\alpha\tau^{p,s})^\theta + A^s A^u \beta(1-2\lambda) - \beta(1-\lambda)(A^{s^2} + A^{u^2}) - \beta\lambda(A^s - A^u)^2[(1-\alpha)\tau^{p,s}]^\kappa}{\beta(A^s - A^u)(\pi^s - \pi^u) + \eta A^s} \tag{3.42}$$

Notice that $E^{p,u} < E^u$ and $E^{p,s} < E^s$, since $\tau^{i^\theta} > (\alpha\tau^{p,i})^\theta$. Introducing this public policy that aims at stimulating investment in additional education lowers the stationary values of environmental quality. However, this kind of public policy may become very useful, under specific parameter configuration, when the objective of the government is to escape from the low equilibrium, E^u.

12. The two threshold values are defined respectively such as: $\Phi^s(\underline{E}^p) = \tilde{E}^p(\alpha)$ and $\Phi^u(\overline{E}^p) = \tilde{E}^p(\alpha)$.

3.4.3. Out of the trap

Let us remind that when $\alpha = 1$, then $\overline{E}^p = \overline{E}$ and $E^u = \breve{E}$. Yet, starting from a situation where $\overline{E} > E^u$ and the economy is stuck in the environmental trap, the objective of this section is to determine the parametric conditions on α, such that the economy escape from the trap. A sufficient condition to achieve this goal is written as: $E_{T+2} = \breve{E}(\alpha) > \overline{E}^p(\alpha)$. Indeed, in that case, at date $T+2$, the majority of workers choose to invest in human capital and the economy converges towards the high equilibrium $E^{p,s}$. In other words, the majority can only be *skilled* and so more prone to engage maintenance expenditure. The parameter α seems to be a relevant and available instrument to achieve this target: the share of public receipt devoted to environmental maintenance, and consequently to education, plays a crucial role by determining the median voter's feature.

Depending on the situation at date $T+1$, we can claim that, as shown in Figure 3.6:

Proposition 8 *Starting from E^u and under proper conditions, there exist two thresholds α_1 and α_2 with $0 < \alpha_1 < \alpha_2 < 1$, such that for $\alpha \in [\alpha_1, \alpha_2]$, $\overline{E}^p(\alpha) < \breve{E}(\alpha)$. Then, the economy jumps onto the optimistic trajectory described by $\Phi_s(E_{T+1})$ and, in the long-run, the economy reaches the high equilibrium, $E^{p,s}$.*

Proof. See Appendix E ■

There exists a set of values of α, in particular for $\alpha \in [\alpha_1, \alpha_2]$, so that the economy jumps onto the optimistic trajectory, which is unique. Therefore, the economy may

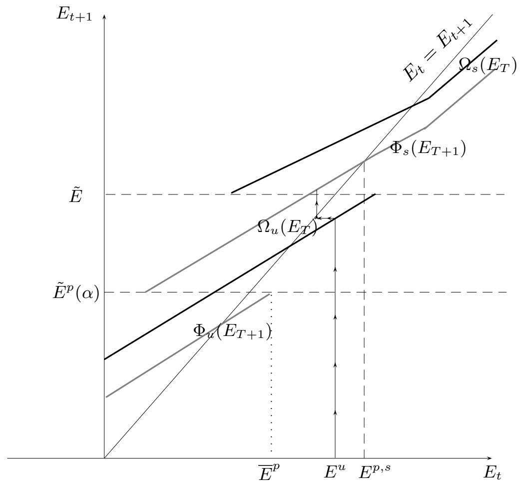


Figure 3.6: Policy

attain, in the long-run, the stable stationary value $E^{p,s}$. Indeed, starting from E^u, at date T, environmental quality deteriorates and the economy ends up in $\breve{E}(\alpha)$, since incentives to expand in environmental protection drop. Then, from $T+1$, the public policy affects agents' educational choices; a new dynamics arise. For intermediary values of α, $\overline{E}^p(\alpha)$ sharply falls while incentives to invest in education are boosted. In particular, if $\alpha \in [\alpha_1, \alpha_2]$, $\breve{E}(\alpha)$ does no longer belong to the indeterminacy area. As depicted in Figure 3.6, from date $T+2$, the economy follows directly the trajectory of $\Phi_s(E_{T+1})$. In that case, the majority within the population is *skilled* and so exhibits a higher willingness-to-pay. The public policy succeeds in coordinating agents'expectations and the economy escapes from the trap. Let us now study in detail under which conditions on the design of the public policy, this configuration may occur.

The opportunity of switching from the pessimistic trajectory to the optimistic one relies on the comparison between $\breve{E}(\alpha)$, that is the situation of the economy at date $T+1$, and $\overline{E}^p(\alpha)$. In particular, if $\breve{E}(\alpha) > \overline{E}^p(\alpha)$, the majority of workers within the population is *skilled* at date $T+2$ and environmental quality evolves according to the optimistic trajectory, $\Phi_s(E_{T+1})$. Indeed, similarly to the threshold value $\tilde{E}^p(\alpha)$, the relationship between $\overline{E}^p(\alpha)$ and α is U-shaped. Moreover, $\breve{E}(\alpha)$ is monotonously increasing in the parameter α. Figure 3.7 describes the situation where the two thresholds α_1 and α_2 exist.

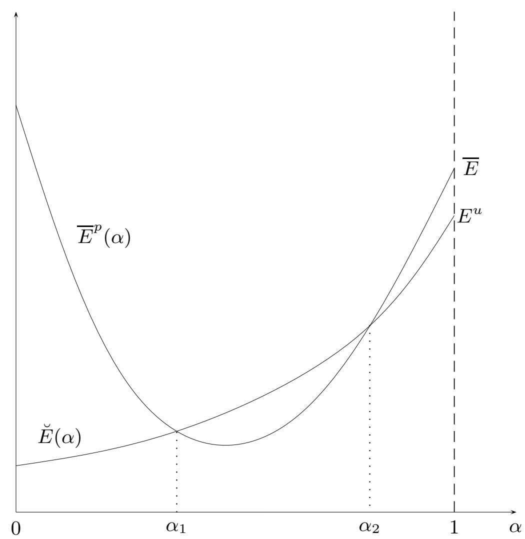


Figure 3.7: Policy design

In the situation depicted in Figure 3.7, when $\alpha = 1$, the economy is trapped in the low equilibrium ($\overline{E} > E^u$). Let us now consider that a share of the public receipts are devoted to education ($\alpha < 1$). As shown previously, the economy reaches $\breve{E}(\alpha)$, characterized by a damaged environmental quality. This decrease in α, if small enough, also reduces $\overline{E}^p(\alpha)$ sharply, as the public educational spending are very efficient. In the case where $\alpha \in [\alpha_1, \alpha_2]$, the later effect dominates the former: investment in human capital is high enough to ensure a majority of *skilled* workers. Finally, when α becomes too small, the public receipts diminish while educational spending are less efficient. This implies that $\overline{E}^p(\alpha)$ goes up as $\breve{E}(\alpha)$ is still decreasing.

Let us notice that from a strict environmental point of view, it could be in the interest of the government to choose the highest value of α, among the range of available values, that is α_2. In fact, as soon as $\alpha \in [\alpha_1, \alpha_2]$, the economy is capable of escaping the trap, and converges towards the higher stationary value of the environment, $E^{s,p}$. However, this steady-state depends positively on the parameter α, since it represents the share of public receipts devoted to public environmental maintenance. Then, in order to reach the highest stationary value of environmental quality, the authorities should implement a policy characterized by α_2.

Even if the public policy is still endogenous, the authorities may intervene in order to stimulate education. Starting from a low environmental quality, the economy may experience a non-monotonous convergence towards the high equilibrium. Following the implementation of the public policy, at first environmental quality deteriorates but then, if the policy design is balanced, the environment may improve and the proportion of highly educated agents within the society increases. However, as mentioned above, the stationary values of environmental quality when the policy is implemented are lower compared to the benchmark case, that is when education is not "subsided". Therefore, it may be the interest of the government to implement a temporary policy, in order to reach ultimately the highest equilibrium E^s.

Corollary 2 *Starting from E^u, a temporary public policy in favour of education* *may allow the economy to achieve the highest steady-state* $E^s > E^{p,s}$*, and so have long-lasting consequences.*

Once the economy reaches the optimistic trajectory $\Phi_s(E_{T+1})$, then it seems possible to return on the initial optimistic trajectory, described by $\Psi_s(E_{t+1})$, in order to attain the highest equilibrium, E^s. In fact, it is optimal at some specific point in time to stop the public policy and to devote all resources to environmental maintenance ($\alpha = 1$). Obviously, the economy attains a higher stationary value, since incentives to contribute for environmental maintenance are stronger, and the share of highly educated agents is larger.

The main message of this kind of policy is that educating the population may be a mean to improve in the long-run the overall situation, including environmental quality. The optimal dynamic design of the policy evolves overtime: it is in the interest of the government to transfer to education a share of resources initially devoted to environmental maintenance, and then, in a second to stop the educational spending in order to focus again on the environmental issue. This kind of conclusion may be related with some experimental studies dealing with the education, the information about environmental risks, or environmental protection. (see, for instance, Jalan & Somanathan (2008))

3.5. Conclusion

In this chapter we have studied the interaction between the political and economic decisions of agents. Agents decide whether to invest in additional human capital or not, according to their expectations regarding future environmental quality. Two types of workers co-exist within the population, some of them being *skilled*, the others *unskilled*. Once, their occupational choices are made, they vote for a poll tax that will be used to finance environmental protection and the level of the effective implemented tax depends finally on the median voter's feature. First, under the hypothesis of rational and constant expectations, the model may provide multiplicity of equilibria. Then, we show that agent's expectations may be self-fulfilling when public policy is endogeneised: for instance, if agents coordinate on optimistic expectations with regards to the future environment, they are likely to invest in additional education, display a higher willingness-to-pay for environmental protection, and the economy reaches in the long-run, the higher equilibrium, and conversely. This property of indeterminacy paves the way for a public policy implementation, in order to coordinate anticipations on one specific outcome. Finally, the level of education and environmental quality are positively correlated in the long-run.

Our model also proposes to investigate the opportunities of a public intervention in order to select a higher equilibrium. In this respect, we model the dynamic implications of a subsidy to education. We show that under specific conditions on the policy's design, reducing the fixed cost of education may allow for reaching the high equilibrium.

Finally, as interesting extensions for further research, we would suggest (i) to explore alternative public policies suitable for the selection of one outcome, (ii) to introduce other policy options that would allow for coordinating agent's expectations and (iii) to enhance the realistic dimension of the model, by endogeneising, for instance, technological progress.

3.6. Appendices

A. *Appendix A*

The dynamic system is described by equation (3.22) and explicitly by both (3.23) and (3.24). Let us now determine the conditions of *existence* and *stability* of the steady-states, E^u and E^s. $\Psi_u(E_t)$ is increasing and piecewise linear in E_t. The slope of the function belongs to the range $[0, 1]$. It follows that the solution of the equation $E_t = \Psi_u(E_t)$ is unique and globally stable. We denote this steady-state E^u. Hence, when $E_t > \Psi_u(E_t)$ $(<)$, environmental quality deteriorates (improves).

Similarly, $\Psi_s(E_t)$ is increasing and piecewise linear in E_t. The slope of the function belongs to the range $[0, 1]$. It follows that the solution of the equation $E_t = \Psi_s(E_t)$ is unique and globally stable. We denote this steady-state E^s. Hence, when $E_t > \Psi_s(E_t)$ $(<)$, environmental quality deteriorates (improves).

B. *Proof of proposition 6*

Let us determine under which conditions *multiplicity* may arise.

In order to determine the area of existence of each dynamics, we need to define two threshold values on E_t. First, $\Psi_u(E_t)$ exists for all $E_{t+1} < \tilde{E}$. Then, we define

$\overline{E}$ such that $\Psi_u(E_t) = \tilde{E}$. It follows that:

$$\overline{E} = \frac{\beta(A^s + A^u) + (A^u - A^s)(1 - 2\lambda) + A^u - 2\sigma {\tau^u}^\theta}{2(1-\eta)(\pi^s - \pi^u)} \tag{B.1}$$

Then, Ψ_u exists for all $E_t < \overline{E}$. Similarly, $\Psi_s(E_t)$ exists for all $E_{t+1} \geq \tilde{E}$. Then, we define $\underline{E}$ such that $\Psi_s(E_t) = \tilde{E}$. Using equation (B.1) and substituting τ^u by τ^s yields the value of $\underline{E}$. Obviously, since $\tau^s > \tau^u$, then $\overline{E} > \underline{E}$. Finally, Ψ_s exists for all $E_t > \underline{E}$.

(i) $\overline{E} > \underline{E} > E^s > E^u$.

For $E_t > \overline{E}$, the unique perfect foresight is described by $\Psi_s(E_t)$. Since, for $E_t > E^s$, environmental quality deteriorates, ultimately it becomes lower than $\overline{E}$. For $E_t \in [\overline{E}, \underline{E}]$, there exist two trajectories compatible with perfect expectations: $E_{t+1} = \Psi_u(E_t)$ or $E_{t+1} = \Psi_s(E_t)$. Since, $E_t > E^s > E^u$, environmental quality deteriorates, whatever the trajectory and becomes ultimately lower than $\overline{E}$. For $E_t < \overline{E}$, the unique perfect foresight path is described by $E_{t+1} = \Psi_u(E_t)$. Hence, the economy converges towards E^u.

(ii) $E^s > E^u > \overline{E} > \underline{E}$.

For $E_t < \underline{E}$, the unique perfect foresight is described by $\Psi_u(E_t)$. Since, for $E_t < E^u$, environmental quality improves, ultimately it becomes larger than $\underline{E}$. For $E_t \in [\overline{E}, \underline{E}]$, there exist two trajectories compatible with perfect expectations: $E_{t+1} = \Psi_u(E_t)$ or $E_{t+1} = \Psi_s(E_t)$. Since, $E_t < E^s < E^u$, environmental quality improves, whatever the trajectory and becomes ultimately larger than $\overline{E}$. For $E_t > \overline{E}$, the unique perfect foresight path is described by $E_{t+1} = \Psi_s(E_t)$. Hence, the economy converges towards E^s.

(iii)$\overline{E} > E^s > E^u > \underline{E}$

For any $E_0 < \tilde{E}$, $\Psi_u(E_t)$ describes the dynamics of the economy: the equilibrium reached is E^u. Conversely, for any $E_0 \geq \tilde{E}$, the dynamics of the economy is described by $\Psi_s(E_t)$ and the equilibrium attained is E^s.

C. *Proof of Proposition 7*

Both $\Psi_s(E_t)$ and $\Psi_u(E_t)$ are monotonically increasing in E_t (see Appendix A). Hence, for $E_t \in [\overline{E}, \underline{E}]$, $\Psi_s(E_t) \geq \Psi_s(\underline{E}) = \tilde{E}$ and $\Psi_u(E_t) \leq \Psi_u(\overline{E}) = \tilde{E}$. Consequently, if agents expect that the median voter will be *skilled* in $t+1$: $E_{t+1} = \Psi_u(E_t) \leq \tilde{E}$ and the median voter is effectively *skilled*. In a similar way, if agents expect that the median voter will be unskilled, $E_{t+1} = \Psi_s(E_t) \geq \tilde{E}$, and expectations are then self-confirmed.

D. *Dynamic implications of the public policy*

The dynamics are described by equation (3.40). Let us now determine the conditions of *existence* and *stability* of the steady-states, $E^{p,u}$ and $E^{p,s}$. $\Phi_u(E_{T+1})$ is increasing and piecewise linear in E_T. The slope of the function belongs to the range $[0, 1]$. It follows that the solution of the equation $E_{T+2} = \Phi_u(E_T)$ is unique and globally stable. We denote this steady-state $E^{p,u}$. Hence, when $E_T > \Phi_u(E_T)$ ($<$), environmental quality deteriorates (improves).

Similarly, $\Phi_s(E_T)$ is increasing and piecewise linear in E_T. The slope of the function belongs to the range $[0,1]$. It follows that the solution of the equation $E_{T+2} = \Psi_s(E_{T+1})$ is unique and globally stable. We denote this steady-state $E^{p,s}$. Hence, when $E_T > \Psi_s(E_T)$ $(<)$, environmental quality deteriorates (improves).

Let us determine under which conditions *multiplicity* may arise.

We define two threshold values on E_T. First, $\Phi_u(E_{T+1})$ exists for all $E_{T+2} < \tilde{E}^p$. We determine define $\overline{E}^p$ such that $\Phi_u(E_{T+1}) = \tilde{E}^p$. It follows that:

$$\overline{E}^p = \frac{\beta(A^s + A^u) + (A^u - A^s)(1-2\lambda) - 2\sigma(\alpha\tau^{p,u})^\theta(\pi^s - \pi^u) - 2\lambda(A^s - A^u)[(1-\alpha)\tau^{p,u}]^\kappa}{2(1-\eta)(\pi^s - \pi^u)} \tag{D.1}$$

Then, the dynamics is described by $E_{T+2} = \Phi_u$ for all $E_t < \overline{E}^p$. Similarly, $\Phi_s(E_{T+1})$ holds for all $E_{T+2} \geq \tilde{E}^p$. Then, we define $\underline{E}^p$ such that $\Phi_s(E_{T+1}) = \tilde{E}^p$. Using equation (D.1) and substituting $\tau^{p,u}$ by $\tau^{p,s}$ yields the value of $\underline{E}^p$. Obviously, since $\tau^{p,s} > \tau^{p,u}$, then $\overline{E}^p > \underline{E}^p$. Finally, $\Phi_s(E_{T+1})$ holds for $E_t > \underline{E}^p$.

Once these two thresholds are defined, the dynamics exhibit the same properties as the one described in Appendix B. Then, if we consider that expectations are no longer stationary, we can define an area of indeterminacy, if $E^{p,s}$ and $E^{p,u}$ belong to $[\underline{E}^p, \overline{E}^p]$.

E. *Proof of Proposition 8*

In this appendix we aim at showing that for some values of α, it could be the case that $\breve{E}(\alpha) > \overline{E}^p(\alpha)$, thus implying that the implemented policy allows from escaping the low equilibrium.

First, let us study the properties of $\breve{E}(\alpha)$.

$$\breve{E}(\alpha) = \frac{\beta A^s A^u (1-2\lambda) - \beta(1-\lambda)(A^{s^2} + A^{u^2}) + A^s(1-\eta)E^u + A^s \sigma(\alpha \tau^{p,u})^\theta}{A^s + \beta(A^s - A^u)(\pi^s - \pi^u)} \tag{E.1}$$

$$\breve{E}(0) = \frac{\beta A^s A^u (1-2\lambda) - \beta(1-\lambda)(A^{s^2} + A^{u^2}) + A^s(1-\eta)E^u}{A^s + \beta(A^s - A^u)(\pi^s - \pi^u)} \tag{E.2}$$

$$\breve{E}(1) = \frac{\beta A^s A^u (1-2\lambda) - \beta(1-\lambda)(A^{s^2} + A^{u^2}) + A^s(1-\eta)E^u + A^s \sigma(\tau^{p,u})^\theta}{A^s + \beta(A^s - A^u)(\pi^s - \pi^u)}, \tag{E.3}$$

with $\breve{E}(1) > \breve{E}(0)$. Moreover $\breve{E}(\alpha)$ is increasing and monotonous over the range $\alpha \in [0, 1]$.

Second, let us analyse the properties of $\overline{E}^p(\alpha)$ and then study the impact of the parameter α on this threshold value.

$$\overline{E}^p(0) = \frac{\beta(A^s + A^u) + (1-2\lambda)(A^u - A^s)}{2(1-\eta)(\pi^s - \pi^u) + A^u} \tag{E.4}$$

and

$$\overline{E}^p(1) = \frac{\beta(A^s + A^u) + (1-2\lambda)(A^u - A^s) - 2\sigma(\pi^s - \pi^u)(\tau^{p,u})^\theta}{2(1-\eta)(\pi^s - \pi^u) + A^u}, \tag{E.5}$$

with $\overline{E}^p(0) > \overline{E}^p(1)$.

$$\frac{\partial \overline{E}^p}{\partial \alpha} = \frac{[-\sigma(\pi^s - \pi^u)(1-\alpha)\theta(\alpha\tau^{p,u})^\theta + \lambda(A^s - A^u)\kappa(\alpha - \theta)[(1-\alpha)\tau^{p,u}]^\kappa]}{(1-\eta)\alpha(\pi^s - \pi^u)(1-\theta)(1-\alpha)} \tag{E.6}$$

The sign of $\frac{\partial \overline{E}^p}{\partial \alpha}$ depends on the value of α. Let us define $g(\alpha) = \alpha^{\frac{(1-\kappa)\theta}{1-\theta}}\sigma(\pi^s - \pi^u)\theta(\sigma\pi^u\theta)^{\frac{\theta-\kappa}{1-\theta}}$ and $f(\alpha) = \lambda(A^s - A^u)\kappa(\alpha-\theta)(1-\alpha)^{\kappa-1}$. Then,

$$sign\left\{\frac{\partial \overline{E}^p}{\partial \alpha}\right\} = sign\left\{g(\alpha) - f(\alpha)\right\} \tag{E.7}$$

Studying the properties of each function, we can define α^* such that: $f(\alpha) > g(\alpha)$ $(<)$, for $\alpha > \alpha^*$ $(<)$.

Indeed, $g(0) = 0$, $g'(\alpha) > 0$ and $\lim g(\alpha)_{\alpha\to 1} = \sigma(\pi^s - \pi^u)\theta(\sigma\pi^u\theta)^{\frac{\theta-\kappa}{1-\theta}}$ is finite. Moreover, $f(0) < 0$, and $\lim f(\alpha)_{\alpha\to 1} = +\infty$. The sign of $f'(\alpha)$ is positive for $0 < \alpha < 1$ if $\frac{1-\theta(1-\kappa)}{\kappa} < 1$. Yet, this conditions is always satisfied since $\kappa < 1$. Then, $f'(\alpha) > 0$. Finally, $g(\alpha)$ and $f(\alpha)$ cross only once and we define α^* such that: $f(\alpha^*) = g(\alpha^*)$.

We can deduce that if $\alpha > \alpha^*$ $(<)$, then $\frac{\partial \overline{E}^p}{\partial \alpha} > 0$ $(<)$. Hence the thresholds $\overline{E}^p(\alpha)$ draws a u-shaped pattern.

Finally, $\breve{E}(\alpha)$ and $\overline{E}^p(\alpha)$ may cross twice of the slope of $\breve{E}(\alpha)$ is lower than the slop of $\overline{E}^p(\alpha)$ for $\alpha = 1$. We have shown that $\partial\breve{E}(\alpha)/\partial\alpha|_{\alpha=1}$ is finite while $\partial\overline{E}^p(\alpha)/\partial\alpha|_{\alpha=1}$ is infinite. Then we can claim that:

$$\left.\frac{\partial \breve{E}(\alpha)}{\partial \alpha}\right|_{\alpha=1} < \left.\frac{\partial \overline{E}^p(\alpha)}{\partial \alpha}\right|_{\alpha=1} \tag{E.8}$$

Then, if the distance between $\overline{E}^p(1)$ and $\breve{E}(1)$ is not too large, the two functions may cross twice, thus defining two threshold values, α_1 and α_2, with $\alpha_1 < \alpha_2$. In that case, $\overline{E}^p(\alpha) < \breve{E}(\alpha)$ for $\alpha \in (\alpha_1, \alpha_2)$. In that case only, the policy will be efficient and allows the economy to jump directly on the optimistic trajectory, $\Phi_s(E_{T+2})$. On the contrary, if the distance between $\overline{E}^p(1)$ and $\breve{E}(1)$ is too large, then the two functions do not cross, and the policy is never efficient.

F. *Substitutability vs Complementarity*

In this section, we want to prove that under a more standard production function our results hold. In particular, let consider the following production function, so that *skilled* and *unskilled* labour forces are no longer substitutable, but complement:

$$Y_t = (A^s H_t)^\alpha (A^u L_t)^{1-\alpha}, \tag{E.1}$$

with $\alpha \in [0,1]$. Since the labour market is perfectly competitive, wages equal the marginal productivity of each type of workforce:

$$\begin{cases} w^s = \dfrac{\alpha Y_t}{H_t} \\ w^u = \dfrac{\alpha Y_t}{L_t} \end{cases} \tag{E.2}$$

Then, substituting the equations above into (3.9), we obtain the following expression:

$$\tilde{z} = \frac{(1-\lambda)(\alpha L_t - (1-\alpha)H_t)}{\alpha L_t} + \chi(\frac{H_t}{L_t})^{1-\alpha}, \tag{E.3}$$

with $\chi \equiv \frac{(\pi^s - \pi^u)E^a_{t+1}}{\alpha A}$ and $A \equiv A^{s^\alpha} A^{u^{(1-\alpha)}}$.

Using (3.10) and (3.11) into the equation above, and the threshold value $\tilde{z}$ is the solution of the following equation:

$$A(z) = B(z), \tag{E.4}$$

with $A(z) = z\alpha(1-z) - (1-\lambda)(\alpha - z)$ and $B(z) = \chi z^{1-\alpha}(1-z)^{\alpha}\alpha$.

Let us now study the properties of $A(z)$: $A(0) < 0$ and $A(1) = (1-\lambda)(1-\alpha)$

$$\frac{\partial A(z)}{\partial z} = \alpha(1-2z) + (1-\lambda), \tag{E.5}$$

with

$$\left.\frac{\partial A(z)}{\partial z}\right|_{z=0} = \alpha + 1 - \lambda \text{ and } \left.\frac{\partial A(z)}{\partial z}\right|_{z\to 1} = -\alpha + 1 - \lambda \tag{E.6}$$

and

$$\frac{\partial^2 A(z)}{\partial z^2} = -\alpha z \tag{E.7}$$

$A(z)$ reaches a maximum for $z = 1/2 + (1-\lambda)/\alpha$. Let us now study the properties of $B(z)$: $B(0) = 0$ and $B(1) = 0$. In addition,

$$\frac{\partial B(z)}{\partial z} = \chi\alpha z^{-\alpha}(1-z)^{\alpha-1}[1 - z - \alpha] \tag{E.8}$$

with

$$\left.\frac{\partial B(z)}{\partial z}\right|_{z\to 0} = +\infty \text{ and } \left.\frac{\partial B(z)}{\partial z}\right|_{z\to 1} = -\infty \tag{E.9}$$

and

$$\frac{\partial^2 B(z)}{\partial z^2} = -\alpha\chi z^{-\alpha-1}(1-z)^{\alpha-2}(1-\alpha)(\alpha + 2z) \tag{E.10}$$

$B(z)$ reaches a maximum value for $z = 1 - \alpha$.

Given that properties, we can deduce that $A(z)$ and $B(z)$ cross only once for $z \in (0, 1)$. Moreover, this threshold value increases with χ, and so with agents expectations with respect to environmental conditions. Similarly to our case where the two labour types are substitute, in that case there exists a unique value of z such that above this threshold agents do not invest in human capital.

Conclusion

Cette thèse a pour objet principal l'analyse des interactions existantes entre le processus de développement et l'environnement. Elle s'appuie par ailleurs sur de riches observations empiriques qui décrivent l'impact que peut avoir la croissance sur la qualité environnementale mais aussi qui mettent en lumière le rôle important joué par l'environnement naturel lors du processus de croissance. En effet, le phénomène de croissance génère des externalités négatives, dont l'exemple le plus emblématique est peut être la pollution atmosphérique. Toutefois, toute la littérature à la fois théorique mais aussi appliquée qui s'est développée autour de cette problématique met en avant une relation non-monotone entre l'évolution du revenu et celle de l'environnement: ainsi, les premières phases du développement sont caractérisées par une dégradation de la qualité environnementale, tandis qu'à partir d'un certain niveau du revenu, le phénomène de croissance s'accompagne d'une amélioration des conditions environnementales. Ce phénomène fait référence à la courbe de Kuznets environnementale. Il peut s'expliquer par un certain nombre de mécanismes économiques, et parmi eux, la réduction directe de la pollution est non-négligeable. Par ailleurs, nous tenons compte dans cette thèse des impacts que peut avoir l'environnement sur le processus de développement, notamment à travers la santé des agents ou leurs choix d'éducation. En effet, la santé ou l'éducation sont des facteurs déterminants de la croissance dans la mesure où des agents en bon état physique présentent des capacités cognitives plus importantes, une meilleure productivité etc..

Ainsi, nous introduisons une double causalité entre l'évolution de la sphère environnementale et les choix économiques des agents: en particulier, nous montrons comment le capital humain, en plus de l'effet revenu standard influence l'évolution de l'environnement au cours du temps, et comment ce dernier peut à son tour, favoriser (ou pas) le phénomène de développement. Cette double causalité conduit à la co-détermination dynamique de ces deux variables dynamiques et à long terme les modèles que nous présentons offre une possibilité d'équilibres multiples. Parmi ces équilibres, nous identifions une trappe à pauvreté environnementale qui est associée à un environnement dégradé et un faible niveau de développement. Finalement, nous proposons des mécanismes économiques qui justifient l'existence de différentes performances environnementales au niveau agrégé dans le long-terme, reflet de la situation observée dans la réalité.

Dans le premier chapitre, nous explorons la relation existante entre la santé des individus et leur choix en terme d'éducation mais aussi en matière environnementale. Nous montrons qu'il existe une complémentarité entre ces deux sphères. En effet, nous supposons que la productivité des dépenses d'éducation, faites par les parents dans ce modèle à G.I., dépend de la qualité environnementale courante.

Par ailleurs, l'environnement est affecté par les flux de pollution émanant de la consommation des agents, mais peut être amélioré grâce à des dépenses de maintenance environnementale, supportées financièrement par les agents économiques. Dès lors l'environnement et le développement évoluent simultanément et interagissent. Par exemple, les individus n'investissent en éducation que lorsque l'environnement est relativement propre. Le rendement de l'investissement augmente et le stock de capital humain dans l'économie croît. Cela offre en retour aux agents un plus haut revenu et plus de possibilités d'investir en maintenance environnementale. Les conditions environnementales s'améliorent etc.. Nous montrons que sous certaines conditions le modèle génère des équilibres multiples: l'équilibre bas est une trappe environnementale caractérisée par un environnement dégradé et un faible niveau de développement. Par ailleurs, le modèle permet de reproduire le phénomène de courbe en U mais justifie aussi, à travers cette complémentarité, le fait que certaines économies n'expérimentent pas un tel processus de développement.

Dans le deuxième chapitre, nous analysons les interactions entre espérance de vie et qualité environnementale. Toujours dans un modèle à G.I., nous montrons qu'une plus grande espérance de vie encourage les dépenses de maintenance environnementale, puisque les agents peuvent jouir plus longtemps de l'environnement. Par ailleurs, en s'appuyant sur des observations empiriques, nous supposons que l'espérance de vie est déterminée, au moins partiellement, par les conditions environnementales. Dès lors, à long terme, et pendant la phase de transition, nous montrons qu'il existe une corrélation positive entre qualité environnementale et espérance de vie. Le modèle peut aussi dans certains cas générer des équilibres multiples qui illustrent la bi-modalité dans la distribution à la fois de l'espérance de vie mais aussi des performances environnementales au niveau macroéconomique. Après avoir identifier dans l'équilibre décentralisé les sources d'externalité inter-générationnelle, nous résolvons le programme du planificateur social, à l'état stationnaire mais aussi de façon inter-temporelle. Nous en déduisons les outils de politique économique capables de restaurer l'optimalité à l'équilibre privé. Finalement, nous montrons que ce modèle est robuste à l'introduction du capital humain.

Dans le troisième et dernier chapitre de la thèse, nous présentons un modèle d'économie politique qui justifie, au niveau agrégé, les différences de performance environnementale par les choix d'éducation des agents économiques. Les individus choisissent d'acquérir du capital humain (ou pas), selon les anticipations qu'ils forment quant à l'état futur de l'environnement, et en fonction du coût supplémentaire qu'ils doivent supporter s'ils s'éduquent. Il y a donc deux catégories d'agents dans l'économie, avec chacun un niveau d'espérance de vie qui leur est propre: les agents les plus éduqués dans cette économie, vivent aussi plus vieux, et peuvent donc jouir plus longtemps de l'environnement. L'espérance de vie joue encore une fois un rôle clef et incite les agents à investir davantage en capital humain. Les agents votent par ailleurs sur le niveau d'une taxe dont l'usage exclusif est la maintenance environnementale fournie par les autorités. L'effort de maintenance effectivement réalisé dépend donc des anticipations des agents. En effet, si les anticipations sont relativement optimistes, les individus ont tendance à s'éduquer davantage, la majorité des agents est donc qualifiée. Comme les agents plus qualifiés ont un consentement à payer plus important pour l'environnement, la taxe effectivement instaurée est plus forte et l'effort public de maintenance s'en trouve accrut. Sous l'hypothèse d'anticipations parfaites, le modèle génère des équilibres multiples, reflet de la situation observée au niveau macroéconomique. Par ailleurs, dans certains cas, ces anticipations donnent lieu à une propriété d'indétermination. Dans ce cas, on dit que les anticipations sont auto-réalisatrices. Cette conclusion place au cœur des mécanismes économiques, la coordination des anticipations. Ceci ouvre la voie à la mise en place d'une politique publique qui viserait à coordonner les anticipations dans le but d'atteindre à long-terme une situation plus favorable en termes de qualité environnementale et de développement. Nous montrons qu'une politique en faveur de l'éducation peut permettre à une économie de sortir de la trappe et donc d'achever un objectif environnemental. Encore une fois, les choix d'éducation et la performance environnementale sont étroitement liés, comme dans le premier chapitre.

Une dimension toutefois n'a pas été traitée dans le cadre de cette thèse, c'est l'impact démographique d'une amélioration de la santé des agents sur l'environnement. En effet, un des mécanismes au coeur des modèles théoriques que nous proposons passe par l'impact de la longévité des agents sur les choix environnementaux. Nous montrons que l'allongement de la durée de vie encourage les individus à investir plus en faveur de la préservation environnementale, dans le but de jouir plus longtemps de l'environnement. Sans même considérer les facteurs économiques ou environnementaux qui favorisent une plus grande espérance de vie, cet effet peut aussi se traduire par une pression supplémentaire sur l'environnement. En effet, lorsque les générations vivent plus longtemps, alors elles génèrent plus de pression sur l'environnement, puisqu'elles continuent à consommer et/ou à produire. Cela engendre plus d'externalités négatives, implique de prélever plus de ressources naturelles etc..; Dès lors, une dimension, commune à trois articles présentés au cours de cette thèse, qui ajoutée pourrait enrichir notre analyse serait de prendre en compte l'évolution et la structure démographique des générations.

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