Environmental Policies and Production Deregulations:
The Macroeconomic Implications of Health Effects

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(February 2008)

Abstract. In this paper we introduce health effects in an endogenous growth model with environmental concerns and use it to study the long-run behavior of an economy responding to environmental policies and production deregulations. A particular emphasis is to analyze the role of the health effect stemming from environmental quality improvements in terms of the effects of both policies above on employment, growth, and environmental quality. By characterizing the balanced-growth-path equilibrium, we show that in somewhat departing from the common conclusion in the environmental literature, the government by implementing an ambitious environmental policy (either emission taxation or expansionary public abatement) may reap a triple-dividend in terms of a better environmental quality, a higher growth rate and a higher level of employment. It is also interesting to point out that due to the health effect, aggregate consumption could be *crowded in* (rather than crowded out) by the fiscal expansion in public abatement. In view of the recent trend in the deregulation of the goods market in the OECD countries, this study cautions us in a way that differs from the common notion: in the presence of the health effect, production deregulation may not necessarily be a good strategy in enhancing employment and economic growth.

Keywords: Health effects; environmental tax; public abatement; production deregulations
JEL Classification: H21; H23; I18; J22

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1. Introduction

Ever since Lucas's (1988) seminal article, it has been widely believed in the literature that human capital is one of the most important engines of growth. Most of the existing literature on this issue stresses the importance of investment in human capital in the form of education but ignores the role of improvements in health in affecting economic growth.[1] However, as indicated by van Zon and Muysken (2001) that "total health costs in Western economies are roughly 8-9% of GDP, whereas expenditures on education account for another 6-7%. … one should not forget that health is also a very important factor in economic growth." Recently, Cuddington, et al. (1994) pointed out that an epidemic disease has a significant impact on the rate of growth by affecting people's health. The World Development Report 1993 stresses that improvements in health in developing countries are potentially important in boosting productivity and growth. Somewhat surprisingly, Knowles and Owen's (1995) empirical study suggests a stronger and more robust relationship between income per capita and health capital than between income per capita and educational human capital.

This paper aims to present an *endogenous growth* model with the endogenous labor-leisure-health care decision and, accordingly, analyze the role of health in terms of the effects of environmental policies and production deregulations on both macroeconomic and environmental performance. The basic idea is that given the so-called health effect, pollution will affect the household's labor-leisure-health care decision (with a particular emphasis on labor supply) through the health impacts. As a result, it is conceivable that the health effect will play an important role in terms of affecting the efficacy of a government's policies.

Schwartz and Repetto (2000) provided much evidence to point out that decreasing levels of major air pollutants result in a better labor productivity.[2] Most of the empirical literature on this issue has focused on work loss days (WLD), restricted activity days (RAD), and sick-leaves (SL).[3] These studies unequivocally support a significant connection between air pollution and reduced labor supply. To be more specific, there exists a statistically significant relationship between total suspended particles and both WLD and RAD in Health Interview Survey (HIS) data (Ostro, 1983 and Hausman, et al., 1984), fine particles (defined by that $PM_{2.5^-}$ particulate matter with an aerodynamic diameter of less than 2.5 μm) and WLDs for working labor force in HIS data (Ostro, 1987), fine particles and RAD in HIS data (Ostro and Rothschild, 1989), and sulphur dioxide (SO_2) and WLD in Dutch data (Zuidema and Nentjes, 1997), air pollution (particulate matter (PM_{10}),

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[1] Ever since Schultz (1961) and Mushkin (1962), economists have long conceived that, in addition to education, human capital can also be accumulated through improvements in health. However, Muysken, et al. (2003) point out that the second component of human capital – health – has been largely ignored in the growth literature.

[2] See Ostro (1994) and Zuidema and Nentjes (1997) for an excellent survey of evidence regarding the health impacts.

[3] A restricted activity day is defined as a day where the individual alters her/his normal activity, without necessarily being absent from work.

nitrogen dioxide (NO_2) and SO_2) and sick-leaves in Oslo data (Hansen and Selte, 2000).

Although it has long been conceived that health by its nature has important implications for labor supply, economic models that could offer insight into this question are still lacking. In particular, as claimed by Muysken, et al. (2003), “the link between health and growth has hardly been researched in the theoretical literature of endogenous growth.” To focus on endogenous growth models with environmental concerns, Mohtadi (1996) introduces the health effect by simply incorporating environmental quality into the households’ utility function, thereby reflecting their amenity to improvements in health. By contrast, Gradus and Smulders (1993), van Ewijk and van Wijnbergen (1995) and Smulders and Gradus (1996) argue that environmental quality provides public non-extractive productive services (i.e. the production externalities of the environment) due to the assumption that a clean environment can improve workers’ health and hence their productivity.[4] Since these studies confine their analyses to a framework where labor is assumed to be inelastic and fixed exogenously, the implications of health on labor, as noted above, are not dealt with appropriately. Instead, this paper is seriously concerned with the use of the household’s available time in regard to leisure, labor, and health care. It enables us to more adequately graph the health effect by making us more aware of the household’s reallocation of time in response to the pollution damage caused by firms.

Our modeling with regard to the endogeneity of time allocation shares some features with Grossman (1972a) and more recently Schwartz and Repetto (2000) and Williams (2003) who have distinct contributions in the health-related literature. Grossman (1972b) set out to construct an empirically testable model of the demand for the commodity “good health.” By developing *static models*, Schwartz and Repetto (2000) and Williams (2003) shed light on the interactions with the health effects of pollution and derived the second-best environmental taxes. Their studies were obviously *partial equilibrium* analyses that may not provide us with a complete picture in relation to health effects in a *macro-economy*. By contrast, our study is a *general equilibrium* analysis and the framework we adopt is a dynamic optimizing macro model with market imperfections.

van Zon and Muysken (2001) were one of a few exceptions that addressed the role of health in affecting economic growth via a general analysis. Based on Lucas’s (1988) model, they internalized the impact of health on longevity and elegantly showed that a slowdown in growth can be explained by a preference for health that is positively influenced by an aging population. Unlike

[4] A large body of literature on modeling the linkage between growth and the environment has accumulated in recent years. A common conclusion in these studies is that, if environmental quality gives rise to a positive externality in relation to private production, an ambitious environmental policy will usually stimulate economic growth. Basically, as elucidated by Alfsen, et al. (1992), Ballard and Medema (1993), Brendemoen and Vennemo (1994) and van Ewijk and van Wijnbergen (1995), environmental pollution lowers both the productivity of labor by harming the public’s health and the productivity of physical capital by depreciating the productive equipment. As a result, they hence incorporated aggregate environmental quality as an input into the production process to capture these productive services of the environment.

them, however, this paper attempts to re-examine the effects of environmental policies (including emission tax and public abatement) on the demand for health, employment, growth, and environmental quality in the presence of health effects. A particular emphasis is that the efficacy of production deregulation is also analyzed in a growing economy with environmental concerns due to the fact that regulatory reform by adjusting market competition policies has emerged as an important trend in both OECD and non-OECD countries (see OECD, 2002). Form the environmental perspective, this issue is also important since according to the report of Velthuijsen and Worrell (1999, pp.188-190), the energy (resource) markets often riddled with market imperfections and environmental concern has accelerated the current policy trends towards deregulation. In this study, we will thus provide preliminary answers to the following questions: What happens to economic growth, employment, and environmental quality under the deregulatory policy? What is the role of the health effect in answering the above question?

By characterizing the balanced-growth-path equilibrium, this paper shows that if the health represents a larger benefit from a higher emission tax rate, the government by implementing an ambitious environmental policy (either emission taxation or expansionary public abatement) may reap a triple-dividend in terms of a better environmental quality, a higher growth rate and a higher level of employment. Of importance, these beneficial effects will be reinforced by the health effect. As a result, aggregate consumption could be *crowded in* (rather than crowded out) by the fiscal expansions in public abatement. In addition, based on the recent trends in deregulation in good markets in OECD countries, this study gives us a caution that differs from the common notion: in the presence of the health effect the deregulation of production may not necessarily be a good strategy in enhancing employment and economic growth.

The remainder of this paper proceeds as follows. The analytical framework is outlined in Section 2. By characterizing the balanced-growth path equilibrium, Section 3 investigates the steady state effects of the emission tax, public abatement, and production deregulation. Section 4 then provides our concluding remarks.

2. The Model

The model consists of three types of agents: households, firms, and a government. The household derives utility from both consumption and leisure, but incurs disutility from the external damage in the form of aggregate pollution produced by firms. A particular emphasis is that the aggregate stock of pollution, denoted by S, will give rise to the so-called *health effect* in terms of governing the household's labor supply. To be more specific, pollution may cause the household to be sick and, consequently, reduce the time it has available for work (or leisure). The production side of the economy comprises two sectors: the intermediate goods sector and the final good sector.

The intermediate goods market is characterized by monopolistic competition, while the final good market is perfectly competitive. The intermediate good producers operate with a Cobb-Douglas technology that uses capital, labor, and emission (the extractive use of the environment) as factors of production. In the final good sector, the goods are homogeneous and produced from the set of intermediate goods. For simplicity, we assume that the final good firms do not generate pollution. For environmental management, the government considers two ecological policies: emission taxation and public abatement. To balance its budget, the government levies lump-sum and emission taxes to finance its expenditure on public abatement.

2.1. Firms

The basic production environment we consider is akin to Guo and Lansing (1999).

The final good market

There is a single final good in the economy, which can be consumed, accumulated as capital, and paid for as taxes. Following Dixit and Stiglitz (1977), the final good, *y*, is produced using a continuum of intermediate inputs y_i, $i \in [0,1]$. Specifically, the final good production technology is given by:

$$y = [\int_0^1 y_i^{1-\eta} di]^{1/(1-\eta)}; \ \eta \in [0,1), \tag{1}$$

Subject to (1), the profit maximization problem for the final good firm is expressed as:

$$\max_{y_i} \quad y - \int_0^1 p_i y_i di, \tag{2}$$

where p_i is the relative price of the *i*-th intermediate good and the final good is viewed as the numeraire. Thus, the first-order condition for this optimization problem allows us to derive the demand function for the *i*-th intermediate good:

$$p_i = y^{\eta} y_i^{-\eta}. \tag{3}$$

It is easy to learn from (3) that the price elasticity of demand for y_i is $-1/\eta$. The coefficient η measures the degree of monopoly of the intermediate good firms. If $\eta = 0$, intermediate goods are perfect substitutes in the production of the final good, implying that the intermediate goods sector is perfectly competitive. If $\eta > 0$, intermediate good firms face a downward-sloping demand curve that can be exploited to manipulate prices.

The intermediate goods market

Intermediate good producers operate in a monopolistic market. Each intermediate producer uses a symmetric technology as follows:

$$y_i = f(k_i, e_i, L_i) = Ak_i^{\alpha} e_i^{\beta} L_i^{\varepsilon}, \tag{4}$$

where A is a technology parameter, and k_i, L_i, and e_i are the capital, labor, and emission inputs employed by the *i*-th intermediate good producer, respectively. The parameters α, β and ε reflect the weights of the private capital, emissions, and labor on production, respectively. In order to ensure a positive but diminishing marginal productivity of capital, emissions, and labor, we assume that $0 < \alpha, \beta, \varepsilon < 1$.[5]

To produce output, an intermediate good firm will rent capital (at the rental rate r) and labor (at the wage rate w) from households and pay emission tax (at the rate τ_e) to the government for permission to emit pollution. Thus, given the demand function of the final good firms (3) and the production function (4), the optimization problem of the intermediate good producer *i* is to choose k_i, L_i, and e_i so as to maximize profits, π_i, i.e.:

$$\max \quad \pi_i = p_i y_i - rk_i - wL_i - \tau_e e_i, \tag{5}$$

$$\text{s.t.} \quad p_i = y^{\eta} y_i^{-\eta} \quad \text{and} \quad y_i = Ak_i^{\alpha} e_i^{\beta} L_i^{\varepsilon},$$

The corresponding first-order conditions yield the common *MR* = *MC* conditions as follows:

$$r = (1-\eta) y^{\eta} y_i^{-\eta} [\alpha A k_i^{\alpha-1} e_i^{\beta} L_i^{\varepsilon}] = (1-\eta)\alpha \frac{p_i y_i}{k_i}, \tag{6a}$$

$$w = (1-\eta) y^{\eta} y_i^{-\eta} [\varepsilon A k_i^{\alpha} e_i^{\beta} L_i^{\varepsilon-1}] = (1-\eta)\varepsilon \frac{p_i y_i}{L_i}, \tag{6b}$$

$$\tau_e = (1-\eta) y^{\eta} y_i^{-\eta} [\beta A k_i^{\alpha} e_i^{\beta-1} L_i^{\varepsilon}] = (1-\eta)\beta \frac{p_i y_i}{e_i}. \tag{6c}$$

Symmetric equilibrium

Our analysis is confined to a symmetric equilibrium under which $p_i = p$, $k_i = k$, $L_i = L$, $e_i = e$, $y_i = y$, and $\pi_i = \pi$, for all *i*. Accordingly, the production function can be restated as:

$$y = Ak^{\alpha} e^{\beta} L^{\varepsilon}. \tag{4a}$$

Moreover, due to the fact that the final good market is perfectly competitive, the free-entry equilibrium is pinned down by the zero-profit condition:

$$y - \int_0^1 p_i y_i di = 0, \tag{7}$$

implying that $p_i = p = 1$ in equilibrium.

Under symmetric equilibrium, we rewrite (6a)-(6c) as follows:

[5] It worth noting that, to shed light on the health effect, the aggregate stock *S* in our model does not enter the production function to provide any non-extractive productive services.

$$r = (1-\eta)\alpha \frac{y}{k}, \quad (8a)$$

$$w = (1-\eta)\varepsilon \frac{y}{L}, \quad (8b)$$

$$\tau_e = (1-\eta)\beta \frac{y}{e}, \quad (8c)$$

Clearly, if $\eta > 0$, the factor prices *r*, *w* and τ_e are lower than the corresponding marginal products $\alpha y/k$, $\varepsilon y/L$, and $\beta y/e$. Intermediate firms may earn an economic profit if $\eta > 0$; we can calculate this as follows:

$$\pi = y - rk - wL - \tau_e e = [1-(1-\eta)(\alpha+\beta+\varepsilon)]y. \quad (9)$$

Equation (9) indicates that the higher the degree of monopoly η, the greater the profit share of national income that the firm will have. If $\eta \to 0$ (perfect competition), the intermediate good producer's $\pi \to [1-(\alpha+\beta+\varepsilon)]y$, implying that the firm's profits are possibly positive when the production function exhibits decreasing returns to scale in k, e, L (i.e. $\alpha+\beta+\varepsilon<1$) (the representative firm pays for these factors).

2.2. Ecological system

The pollution stock grows as the firms' emission use e_i increases, while it declines as the government's public abatement M increases. Thus, we assume that the pollution stock accumulates in the following manner:

$$\dot{S} = g\left(\frac{\int_0^1 e_i di}{M}\right) - \delta S; \qquad g' > 0 \text{ and } g'' < 0, \quad (10)$$

where an overdot denotes the rate of change with respect to time, $\delta \in (0,1]$ is a constant natural decay rate, and $g(\cdot)$ can be simply thought of as the production function of pollution. The extreme case where $\delta = 1$ implies that the emissions do not accumulate and the stock of pollution is just a function of the current emissions.

Under symmetric equilibrium $e_i = e$, the evolution of the pollution stock (10) can be further represented as:

$$\dot{S} = g\left(\frac{e}{M}\right) - \delta S. \quad (10a)$$

2.3. Households

The economy is populated by a unit measure of identical and infinitely-lived households. The representative household derives positive utility from both consumption *c* and leisure ℓ, but incurs disutility from the stock of environmental pollution, *S*. Accordingly, the representative household's discounted lifetime utility is given by:

$$\int_0^{\infty}[\Lambda_1 \ln c + \Lambda_2 \ln \ell - \Lambda_3 \ln S]e^{-\rho t}dt\,; \quad \Lambda_1, \Lambda_2, \Lambda_3 > 0\,, \tag{11}$$

where $\rho(>0)$ is the subjective rate of time preference, and Λ_1, Λ_2 and Λ_3 measure the impact of consumption, leisure and pollution on the households' satisfaction, respectively.

Each household is endowed with a constant unit of time *T*. To shed light on the health effect, we follow Williams (2003) and assume that pollution causes households to lose some time to sickness that will decrease the time they have available for work or leisure. By defining the fraction of time lost to sickness as $1-\sigma$, the representative household's available time is equal to $T-(1-\sigma)T=\sigma T$ where $0<\sigma<1$. The term σ can be thought of as the *effective ratio* of time available for the household's activities. Burtraw, et al. (1998) and USEPA (1996) both found that reducing sulfur dioxide emissions gives rise to a beneficial effect in the reduction of morbidity. In our model, morbidity can be simply measured in work-loss days -- the number of work days per year a worker misses that is attributed to pollution consumption. Thus it is reasonable to assume that the effective ratio of available time σ decreases with pollution *S*. In addition to this specification, we further assume that σ can also be raised by the household's health care investment by devoting *h* units of the time input to health care, like going to a gymnasium or engaging in a sport, as specified by Grossman (1972a). This specification allows the household to react endogenously to the change in the pollution stock (or the government's policies). Accordingly, we specify a general form of σ as follows:

$$\sigma=\sigma(S,h)\,,\ \ \sigma_S<0\,,\ \ \sigma_{SS}>0\,,\ \ \sigma_h>0\,,\ \ \sigma_{hh}<0\,. \tag{12}$$

In Grossman's (1972a) framework, consumers produce health commodities with inputs being the consumption of health goods and their own time. In this paper our purpose is to shed light on how pollution affects health and the effective ratio of available time and how an individual allocates his available time among labor supply and the health input in such a way that rewards him with a higher effective ratio of available time. Therefore, we downplay the role of consumers' inputs in terms of the consumption of medicines or health goods. This simplification will also allow us to place more attentions on the linkage between market imperfections and the health effect.

With the specification (12), the time constraint of the representative household is given by:

$$\sigma(S,h)T=\ell+L+h\,. \tag{13}$$

This implies that households divide their available time endowment σT between leisure ℓ, labor *L* and health care investment *h*.

In addition to the time constraint, the household is also constrained by its budget. Specifically, the household is bound by a flow budget constraint linking capital accumulation to any difference between its income (including rent, wages, profit and transfers) and expenditure (consumption) at each instant of time, that is:

$$\dot{k} = wL + rk + \pi - c + tr \,, \tag{14}$$

where $tr > 0$ (< 0) is a lump-sum transfer (lump-sum tax).

Following the common assumption in the relevant literature, and taking the stock of environmental pollution S as given, the household chooses c, ℓ and h so as to maximize the discounted sum of utility (11), subject to (12)-(14), and given the initial capital k_0. By substituting (12) and (13) into (14), we have the current-value Hamiltonian function:

$$H = \Lambda_1 \ln c + \Lambda_2 \ln \ell - \Lambda_3 \ln S + \lambda\{rk + \pi + w[\sigma(S,h)T - \ell - h] - c + tr\} \,,$$

where λ is the co-state variable which can be interpreted as the shadow value of the private capital stock measured in utility terms.

The optimal conditions necessary for this optimization problem are given by:

$$\frac{\Lambda_1}{c} = \lambda \,, \tag{15a}$$

$$\frac{\Lambda_2}{\ell} = w\lambda \,, \tag{15b}$$

$$\sigma_h(S,h) \cdot T = 1 \,, \tag{15c}$$

$$\frac{\dot{\lambda}}{\lambda} = \rho - r \,, \tag{15d}$$

together with (14) and the transversality condition $\lim_{t\to\infty} \lambda k e^{-\rho t} = 0$. Thus, by taking the log derivative of (15a) and combining it with (4a), (15d) and (8a), we further obtain the following Keynes-Ramsey rule:

$$\frac{\dot{c}}{c} = (1-\eta)\alpha A k^{\alpha-1} e^{\beta} L^{\varepsilon} - \rho \,. \tag{16}$$

2.4. The Government

In order to sustain an equilibrium with balanced growth, following Turnovsky (1995), we assume that the government sets its public abatement expenditure as a fixed fraction of output, that is

$$M = \phi y \,; \qquad 0 < \phi < 1 \,, \tag{17}$$

where parameter ϕ is the public abatement expenditure share.

The government is assumed to balance its budget at any instant of time. Thus, the government's budget constraint can thus be expressed as:

$$M + tr = \phi y + tr = \tau_e e \,. \tag{18}$$

To isolate the effect of the government's environmental policies, we further assume that the government balances its budget at any instant in time by adjusting the lump-sum transfer *tr*.

By substituting the government's budget constraint (18), the intermediate good producers' profits (9), and the optimization condition for intermediate producers (8a)-(8c) into the household's budget constraint (14), the economy-wide resource constraint for the economy is given by:

$$\dot{k} = (1-\phi)Ak^{\alpha}e^{\beta}L^{\varepsilon} - c\,. \tag{19}$$

3. The Steady-State Effects in the Balanced-Growth-Path Equilibrium

A *dynamic equilibrium* is defined as a tuple of paths $\{c, k, L, \ell, h, \sigma, e, S\}_{t=0}^{\infty}$ such that:

(i) the representative household maximizes its lifetime utility (11), subject to the time and budget constraints (13) and (14), i.e. the optimizing conditions (15a)-(15d) hold;

(ii) the representative final good firm maximizes its profits (2), i.e. the optimizing condition (3) holds and the zero-profit condition is met, i.e. (7) holds;

(iii) the intermediate goods firms maximizes their profits (5) and, accordingly, (8a)-(8c) hold under symmetric equilibrium.

(iv) the goods market clears, i.e. (19) is met;

(v) the evolution of the pollution stock (10a) and the flow government budget constraint (18) are met.

Let superscript '*' denote the stationary values of relevant variables. In line with Smulders and Gradus (1996), Bovenberg and Smulders (1996), Elbasha and Roe (1996), and Bovenberg and de Mooij (1997), a non-degenerate balanced-growth path (*BGP*) equilibrium requires that the growth rate of the pollution stock be zero $(\dot{S}/S)^{*} = 0$ along the *BGP* in an endogenous growth model with pollution. Thus, there exists a tuple of paths $\{c, k, L, \ell, h, \sigma, e, S\}_{t=0}^{\infty}$ such that the fraction of time devoted to leisure, work, and health care along the *BGP* equilibrium should be constant, i.e. $(\dot{\ell})^{*} = (\dot{L})^{*} = (\dot{h})^{*} = \dot{\sigma} = 0$. Given these conditions, it is easy to see from (4a), (16), (17) and (19) that in the *BGP* equilibrium the economy exhibits *common growth* in which consumption, capital, emission, output and public abatement expenditure all grow at a common rate, i.e.:

$$(\dot{c}/c)^{*} = (\dot{k}/k)^{*} = (\dot{e}/e)^{*} = (\dot{y}/y)^{*} = (\dot{M}/M)^{*}.$$

Besides, in order to ensure an endogenously determined and constant growth rate, the condition $\beta = 1-\alpha$ is imposed throughout the remainder of the paper.

We now are ready to characterize the *BGP* equilibrium. To solve the common balanced-growth rate, we define the transformed variable: $x = c/k$. Accordingly, by using (4a), (8b), (8c), (13) and (15a)-(15c) we can derive the following instantaneous relationships:

$$\ell = \ell(x, S, \tau_e, \eta)\,; \quad \ell_x > 0\,, \quad \ell_S \gtrless 0\,, \quad \ell_{\tau_e} > 0\,, \quad \ell_\eta > 0\,, \tag{20a}$$

$$L = L(x, S, \tau_e, \eta)\,; \quad L_x < 0\,, \quad L_S < 0\,, \quad L_{\tau_e} < 0\,, \quad L_\eta < 0\,, \tag{20b}$$

$$h = h(S)\,; \quad h_s \gtrless 0\,. \tag{20c}$$

The exact expressions of the comparative statics in (20a)-(20c) are relegated to Appendix A.

Given the instantaneous relationships in (20a)-(20c), it follows from (16) and (19) that the dynamic system in terms of the transformed variables x can be expressed as follows:

$$\frac{\dot{x}}{x} = \Gamma \Xi + x - \rho\,, \tag{21}$$

where $\Gamma = \alpha(1-\eta) - (1-\phi)$ and $\Xi = [(1-\eta)^{1-\alpha}(1-\alpha)^{1-\alpha}\tau_e^{\alpha-1} A L^{\varepsilon}]^{1/\alpha}$. To guarantee a positive consumption-capital ratio x in the *BGP* equilibrium, we must assume:

Condition P. $\rho > \Gamma[(1-\eta)^{1-\alpha}(1-\alpha)^{1-\alpha}\tau_e^{\alpha-1} A L^{\varepsilon}]^{1/\alpha}$**.**

Moreover, by substituting (4a), (8c) and (17) into (10a), we rewrite the evolution of the pollution stock as:

$$\dot{S} = g\left(\frac{(1-\eta)(1-\alpha)}{\phi\tau_e}\right) - \delta S\,, \tag{22}$$

Given (20a)-(20c), these two differential equations (21) and (22) constitute the dynamic system of our model and the dynamic system can be reduced to a 2×2 system in terms of the transformed variable *x* and pollution *S*. Accordingly, we can establish the following theorem to verify the existence and uniqueness of a non-degenerate *BGP* equilibrium:

Theorem 1. Under Condition P, there exists a unique balanced-growth equilibrium.

Proof. See Appendix B.

Substituting (20b) into (21) and (22), and then linearizing the resulting equations around the steady-state value, denoted by x^* and S^*, we have:

$$\begin{bmatrix} \dot{x} \\ \dot{S} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x - x^* \\ S - S^* \end{bmatrix} + \begin{bmatrix} a_{13} d\phi + a_{14} d\tau_e + a_{15} d\eta \\ a_{23} d\phi + a_{24} d\tau_e + a_{25} d\eta \end{bmatrix}. \tag{23}$$

The exact expressions of a_{zj} for $z = 1, 2$ and $j = 1, \cdots, 5$ are arranged in Appendix C. By defining μ_1 and μ_2 as the two characteristic roots of the dynamic system, (23) allows us to derive:

$$\mu_1 = a_{11} = -\delta < 0\,,$$

$$\mu_2 = a_{11} = \frac{\Omega x^* - \varepsilon \ell^* \Gamma \Xi}{\Omega} \gtrless 0 .$$

These relationships indicate that there exist two possible cases of dynamic stability: one of the cases is a *sink* (dynamic stability) that has both roots with positive real parts and the other one is a *saddle-path stability* that has one root with a negative real part and one with a positive real part. Since there is a jump variable x in this dynamic system, a sink will display local indeterminacy and the saddle-path stability will be locally determinate. For a meaningful analysis of the comparative statics, in what follows we will focus on the case of saddle-path stability (hence $\mu_1 \mu_2 = \Delta = -\delta(\Omega x^* - \varepsilon \ell^* \Gamma \Xi) / \Omega < 0$) which displays local determinacy.

Let γ^* be the common balanced growth rate of the economy. Thus, from (19) we have:

$$\gamma^* = (1-\phi)[(1-\eta)^{1-\alpha} (1-\alpha)^{1-\alpha} \tau_e^{\alpha-1} A(L^*)^{\varepsilon}]^{1/\alpha} - x^* . \tag{24}$$

According to (24), we establish the following proposition:

Proposition 1. *Under Theorem 1,*

(i) *in the absence of the health effect* ($\sigma = 1$ *and* $\sigma_S = 0$)*, in the BGP equilibrium the effects of the emission tax on the pollution stock, labor supply and the economic growth rate are given by:* $(\partial S^* / \partial \tau_e)\big|_{\sigma=1, \sigma_S=0} < 0$, $(\partial L^* / \partial \tau_e)\big|_{\sigma=1, \sigma_S=0} \gtrless 0$, *and* $(\partial \gamma^* / \partial \tau_e)\big|_{\sigma=1, \sigma_S=0} < 0$;

(ii) *in the presence of the health effect, in the BGP equilibrium, the effects of the emission tax on the pollution stock, labor supply and the economic growth rate are given by:* $\partial S^* / \partial \tau_e < 0$, $\partial L^* / \partial \tau_e \gtrless 0$, *and* $\partial \gamma^* / \partial \tau_e \gtrless 0$.

Proof. See Appendix D.

As shown in Proposition 1, the health effect plays a crucial role in terms of affecting the effects of environmental taxation. Proposition 1(i) conveys a common conclusion in the environmental literature whereby environmental taxation proves beneficial to environmental quality at the cost of decreasing labor supply and retarding economic growth (see the studies of Ligthart and van der Ploeg, 1994, and Huang and Cai, 1994, who analyze the growth effect in the *AK* model). Intuitively, the emission tax gives rise to a distortionary effect in terms of raising the price of the extractive use of the environment that discourages the intermediate firms from the use of emissions. As a result, the pollution stock S falls. On the other hand, the decrease in the emission input lowers the marginal productivity of private capital and labor. This leads households to reduce their labor supply and investment and, accordingly, the balanced-growth rate falls.

However, as shown in Proposition 1(ii), if the health represents a larger benefit due to a higher emission tax rate (i.e. σ_S is negative and its effect is substantially large), the government by imposing an emission tax may reap a triple-dividend in terms of a better environmental quality, a higher growth rate and a higher level of employment. When the health effect is seriously taken into account, a rise in the environmental tax rate will not only decrease pollution, but will also increase the time that the household has available for work. Thus, the households will tend to increase their labor supply, and this will increase the marginal productivity of capital due to labor and capital being technical complements in production. Given that the emission tax has a productive function, thereby facilitating firms' production, the balanced-growth rate may be enhanced accordingly. Once the health effect is large enough, an ambitious emission tax policy will stimulate (rather than retard) the long-run growth rate.

It is also interesting to examine the effects of expansionary expenses on public abatement in the presence of the health effect to which we now turn.

Proposition2. *Under Theorem 1, in the BGP equilibrium an increase in public abatement has the following effects:* $\partial L^* / \partial \phi > 0$, $\partial \gamma^* / \partial \phi > 0$, and $\partial S^* / \partial \phi < 0$. *It is worth noting that these beneficial effects will be reinforced by the health effect.*

Proof. See Appendix E.

Proposition 2 indicates that an increase in the share of public abatement expenditure will lower the pollution stock and will increase both labor supply and the steady-state growth rate. The intuition is straightforward. Given the government budget constraint, an increase in public abatement expenditure will reduce the amount of resources available to the private sector through an increase in a lump-sum tax. The decrease in after-tax income will lead the household to decrease its consumption and leisure (by assuming that both consumption and leisure are normal goods), implying that the amount of labor supply increases. This gives rise to a favorable impact on the marginal product of capital and in turn enhances economic growth. An interesting result is that when the health effect represents a reward (a better health situation, due to $dS^* / d\phi < 0$ and $\sigma_S < 0$) from an increase in the public abatement, these beneficial effects from increasing ϕ on employment and economic growth will become stronger. By virtue of the productive health effect, public abatement will become more favorable to the economy's performance.

In light of the role of the environmental production externality (or so-called public non-extractive productive services), Bovenberg and Smulders (1995, 1996), Smulders and Gradus (1996), and Byrne (1997) argue that an ambitious environmental policy can stimulate economic growth as long as the environmental quality gives rise to a positive externality in regard to private production.[6] In departing

[6] Some empirical studies, such as Alfsen, et al. (1992), Ballard and Medema (1993), Brendemoen and Vennemo (1994)

from their argument, we show that emission taxation can increase the growth-enhancing dividend provided that the health effect is taken into account.

One point is particularly worth noting. In Appendix E we also observe that the government expenditure on public abatement has an ambiguous effect on the consumption-capital ratio, i.e.:

$$\frac{dx^*}{d\phi} = \frac{\Xi[\delta\Omega - (1-\eta)(1-\alpha)\varepsilon\phi^{-2}\tau_e^{-1}\Gamma T\sigma_S g']x^*}{\Delta\Omega} \gtrless 0 .$$

This result is in contrast to that in the standard neoclassical approach whereby an increase in government purchases, financed by a lump-sum tax, has a negative wealth effect which will reduce aggregate consumption (see, for instance, Aiyagari, et al., 1992). Thus, private consumption is crowded out by public expenditures. However, this outcome is obviously inconsistent with the empirical evidence examined by Fatás and Mihov (2001) and Blanchard and Perotti (2002), whereby the expansion in the government expenditure leads to significant increases in consumption. In this paper we show that, in response to fiscal expansion in relation to public abatement, the health effect will generate a productive function that stimulates labor supply and in turn consumption. As a result, aggregate consumption could be *crowded in* by the fiscal expansions in public abatement. This result somewhat casts doubt on the argument of Oueslati (2002), whereby there is a crowding out effect caused by the increase in abatement expenses, which negatively affects private consumption.

Nickell (1999) and Blanchard and Giavazzi (2003) point out that production regulations are often blamed for the poor macroeconomic performance of Europe over the last 30 years. When these regulations are removed, both output and productivity growth will increase. Based on this and similar arguments, regulatory reforms that focus on adjusting market competition policies have emerged as an important trend in both OECD and non-OECD countries (see OECD, 2002). In what follows, we will attempt to answer the following questions: Is deregulation in the goods market always beneficial for an economy? What happens to the quality of the environment under the deregulatory policy? What is the role of the health effect in answering the above two questions?

In line with Blanchard and Giavazzi (2003), deregulation can be defined as a policy that lowers the firm's markup η in our analytical framework. Accordingly, we then have:

Proposition 3. *Under Theorem 1,*

(i) in the absence of the health effect, in the BGP equilibrium, the effects of deregulations in the intermediate goods market on the pollution stock, labor supply and the economic growth rate are given by: $(\partial S^*/\partial\eta)\big|_{\sigma=1, \sigma_S=0} < 0$, $(\partial L^*/\partial\eta)\big|_{\sigma=1, \sigma_S=0} < 0$, *and* $(\partial\gamma^*/\partial\eta)\big|_{\sigma=1, \sigma_S=0} < 0$;

and van Ewijk and van Wijnbergen (1995), point out that environmental pollution lowers both the productivity of labor by harming the public's health and the productivity of physical capital by depreciating the productive equipment. As a result, the economy-wide quality of the environment can be thought of as a non-extractive productive service that affects firms' production.

(ii) *in the presence of the health effect, in the BGP equilibrium, the effects of deregulations in the intermediate goods market are given by:* $\partial S^* / \partial \eta < 0$, $\partial L^* / \partial \eta \gtrless 0$ *and* $\partial \gamma^* / \partial \eta \gtrless 0$.

Proof. See Appendix F.

Proposition 3(i) conveys a common notion that deregulation can be accompanied by a growth-enhancing effect ($\partial \gamma^* / \partial \eta < 0$) at the cost of increased pollution ($\partial S^* / \partial \eta < 0$), if the role of the health effect is entirely downplayed. The reason for this is that a more competitive market not only motivates households to consume more but it leads firms to produce more. This, on the one hand, is beneficial for economic growth, but, on the other hand, is harmful to the environmental quality. Second, when the health effect is taken into account, it will become a crucial factor in terms of governing the macroeconomic effects of deregulations, i.e. $\partial L^* / \partial \eta \gtrless 0$ and $\partial \gamma^* / \partial \eta \gtrless 0$. Since deregulations in the intermediate goods market will result in a larger pollution stock, this may cause the household to fall sick and, consequently, reduce its labor supply. This additional effect will thus lead the balanced-growth rate to fall. Therefore, in the presence of the health effect from pollution, a deregulatory policy (lowering η) will have an ambiguous effect on employment and economic growth.

Nickell (1999) and Gersbach (2000) argue that deregulation in the goods market will improve productivity and, as a result, generate a favorable effect on employment and output. However, when we take the environmental issue into account with a particular emphasis on the health effect, the question concerning "whether deregulation is always beneficial for an economy" becomes a contentious issue that deserves more careful investigation. In an endogenous growth setting with environmental concerns, Proposition 3 gives us a cautionary answer: in the presence of the health effect deregulation may not necessarily be a good strategy in enhancing employment and economic growth.[7]

4. Concluding Remarks

By developing an endogenous growth model with environmental concerns, we have studied in this paper the long-run behaviors of an economy responding to environmental policies and production deregulations. A particular emphasis has been to analyze the role of the so-called health effect in the efficacy of both policies above.

[7] Cohen and Saint-Paul (1997), Blanchard (1998), and Amable and Gatti (2002) cast doubt on the employment-enhancing (or the output-enhancing) effect of deregulations.

By characterizing the *BGP* equilibrium, several interesting results emerge from our analysis. In departing from the common conclusion in the environmental literature whereby environmental policies prove beneficial to environmental quality at the cost of decreasing labor supply and retarding economic growth), the government by imposing an emission tax (or increasing abatement expenses) may reap a triple-dividend in terms of a better environmental quality, a higher growth rate and a higher level of employment. The key reason is that by the virtue of the health effect, there exists a reward (better health) from implementing these environmental policies that stimulates labor supply and hence economic growth. It is also important to emphasize that due to the health effect, aggregate consumption could be *crowded in* (rather than crowded out) by the fiscal expansion in relation to public abatement. In addition, in an endogenous growth model with an emphasis on the health effect, our study has given us a cautionary policy implication: deregulation may not necessarily be a good strategy in enhancing employment and economic growth.

Appendix A (*The derivations concerning the comparative statics in (20a)-(20c)*)

Using (4a), (8b), (8c), (13) and (15a)-(15c) we have:

$$\Lambda_2 x = \Lambda_1 \varepsilon \ell [(1-\eta)(1-\alpha)^{1-\alpha} \tau_e^{\alpha-1} A L^{\varepsilon-\alpha}]^{1/\alpha}, \quad (A1)$$

$$\sigma_h(S,h)T = 1, \quad (A2)$$

$$\sigma(S,h)T = \ell + h + L. \quad (A3)$$

Accordingly, it is easy to derive the following comparative statics by totally differentiating (A1)-(A3):

$$\frac{\partial \ell}{\partial x} = \ell_x = \frac{\alpha \ell L}{x\Omega} > 0, \qquad \frac{\partial L}{\partial S} = L_S = \frac{\alpha \sigma_S L T}{\Omega} < 0,$$

$$\frac{\partial \ell}{\partial S} = \ell_S = \frac{(\alpha-\varepsilon)\ell T \sigma_S}{\Omega} \gtrless 0; \quad if\ \alpha \lessgtr \varepsilon, \qquad \frac{\partial L}{\partial \tau_e} = L_{\tau_e} = \frac{-(1-\alpha)\ell L}{\tau_e \Omega} < 0,$$

$$\frac{\partial \ell}{\partial \tau_e} = \ell_{\tau_e} = \frac{\alpha \ell L}{\Omega} > 0, \qquad \frac{\partial L}{\partial \eta} = L_\eta = \frac{-\ell L}{(1-\eta)\Omega} < 0,$$

$$\frac{\partial \ell}{\partial \eta} = \ell_\eta = \frac{\ell L}{(1-\eta)\Omega} > 0 \qquad \frac{\partial h}{\partial S} = h_S = \frac{-\sigma_{hS}}{\sigma_{hh}} \gtrless 0; \quad if\ \sigma_{hS} \gtrless 0,$$

$$\frac{\partial L}{\partial x} = L_x = \frac{-\alpha \ell L}{x\Omega} < 0, \qquad \Omega = \alpha L + (\alpha-\varepsilon)\ell > 0.$$

The above information leads to the instantaneous relationships reported in (20a)-(20c).

Appendix B (*The proof of Theorem 1*)

From (23), we can derive the slopes of $\dot{S}=0$ and $\dot{x}=0$, respectively:

$$\left.\frac{\partial S}{\partial x}\right|_{\dot{S}=0} = -\frac{a_{21}}{a_{22}} = 0,$$

$$\left.\frac{\partial S}{\partial x}\right|_{\dot{x}=0} = -\frac{a_{11}}{a_{12}} = -\frac{\Omega x^* - \varepsilon \Gamma [(1-\eta)^{1-\alpha}(1-\alpha)^{1-\alpha} \tau_e^{\alpha-1} A \ell^* L^{\varepsilon}]^{1/\alpha}}{\varepsilon \Gamma T \sigma_S x^* [(1-\eta)^{1-\alpha}(1-\alpha)^{1-\alpha} \tau_e^{\alpha-1} A L^{\varepsilon}]^{1/\alpha}} \gtrless 0,$$

implying that the $\dot{S}=0$ locus is horizontal and the $\dot{x}=0$ locus could be either downward sloping or upward sloping. Due to the ambiguity of the slope of $\dot{x}=0$, there are three distinct cases in the *BGP* equilibrium that are sketched by Figures 1a-1c, respectively. Consider first the case where $\Gamma = \alpha(1-\eta) - (1-\phi) < 0$. Given this condition, it is easy to see that the $\dot{x}=0$ locus is monotonically downward sloping. Moreover, (21) tells us that x and S exhibit a one-by-one relationship and satisfy the following relationship:

$$S \to 0 \ \Rightarrow \ \sigma \to 1 \ \Rightarrow \ L \to L_{\max} \ \Rightarrow \ x \to \rho,$$

$$S \to \infty \ \Rightarrow \ \sigma \to 0 \ \Rightarrow \ L \to 0 \ \Rightarrow \ x \to \Theta = \rho - \Gamma[(1-\eta)^{1-\alpha}(1-\alpha)^{1-\alpha} \tau_e^{\alpha-1} A L_{\max}^{\varepsilon}]^{1/\alpha},$$

where $L_{\max}$ is denoted as the corresponding value determined by $\sigma \to 1$, i.e. the largest amount of the household's available time (it is plausible to assume that $L_{\max}$ is equal to the total endowment *T*). Thus, the transferred variable *x* is plausibly restricted at $x^* \in [\rho, \Theta]$. Therefore, by applying the fixed point theorem, the *BGP* equilibrium (x^*, S^*) exists and is unique, as shown in Figure 1a.

By contrast, if $\Gamma > 0$, the slope of $\dot{x} = 0$ may be either positive or negative, as indicated in Figures 1b and 1c, respectively. However, in contrast to the previous case, the stationary value of *x* should satisfy $x^* \in [\Theta, \rho]$. Thus, the fixed point theorem ensures that the *BGP* equilibrium exists and is unique, provided that the (sufficient) condition $\rho > \Gamma[(1-\eta)^{1-\alpha}(1-\alpha)^{1-\alpha}\tau_e^{\alpha-1}AT^{\varepsilon}]^{1/\alpha}$ holds true. □

Appendix C (*The derivations concerning* a_{zj} *reported in (23)*)

Substituting (20b) into (21) and (22), and then linearizing the resulting equations around the steady-state equilibrium, we have:

$$\begin{bmatrix} \dot{x} \\ \dot{S} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x - x^* \\ S - S^* \end{bmatrix} + \begin{bmatrix} a_{13}d\phi + a_{14}d\tau_e + a_{15}d\eta \\ a_{23}d\phi + a_{24}d\tau_e + a_{25}d\eta \end{bmatrix}, \tag{C1}$$

where

$$a_{11} = \frac{\Omega x^* - \varepsilon\ell^*\Gamma\Xi}{\Omega} > 0,$$

$$a_{12} = \frac{x^*\varepsilon\Gamma T\Xi\sigma_S}{\Omega} \gtrless 0,$$

$$a_{13} = \Xi x^* > 0,$$

$$a_{14} = \frac{-\Gamma\Xi(\ell^* + L^*)(1-\alpha)x^*}{\tau_e\Omega} \gtrless 0,$$

$$a_{15} = \frac{-\Xi[\Gamma(\ell^* + L^*) + \Omega(1-\phi)]x^*}{(1-\eta)\Omega} \gtrless 0,$$

$$a_{21} = 0,$$

$$a_{22} = -\delta < 0,$$

$$a_{23} = \frac{-(1-\eta)(1-\alpha)g'}{\phi^2\tau} < 0,$$

$$a_{24} = \frac{-(1-\eta)(1-\alpha)g'}{\phi\tau_e^2} < 0,$$

$$a_{25} = \frac{-(1-\alpha)g'}{\phi\tau_e} < 0.$$

Appendix D (*The proof of Proposition 1*)

Equation (23) with $\dot{x} = \dot{S} = 0$ immediately yields the impact of emission taxation on the consumption-capital ratio and the pollution stock as given by:

$$\frac{\partial x^*}{\partial \tau_e} = \frac{-\Gamma\Xi(1-\alpha)[\delta\tau_e(\ell^* + L^*) + \varepsilon(1-\eta)\phi^{-1}T\sigma_S g']x^*}{\tau_e^2\Delta\Omega} \gtrless 0, \tag{D1}$$

$$\frac{\partial S^*}{\partial \tau_e} = \frac{-(1-\eta)(1-\alpha)g'}{\tau_e^2\delta\phi} < 0. \tag{D2}$$

By using (20b), (D1) and (D2), we can further derive the employment effect of emission tax:

$$\frac{\partial L^*}{\partial \tau_e} = \frac{(1-\alpha)L^*\{[\delta\,\ell^* + \alpha(1-\eta)\phi^{-1}\tau_e^{-1}T\sigma_S g']x^* + \delta\Gamma\Xi\ell^*\}}{\tau_e\Delta\Omega} \gtrless 0\,. \tag{D3}$$

From (24) and (D1)-(D3), the growth effect of emission taxation is given by:

$$\frac{\partial \gamma^*}{\partial \tau_e} = \frac{\alpha\delta\,\Xi\,x^*(1-\eta)(1-\alpha)[\tau_e\delta(\ell^* + L^*) + \varepsilon(1-\eta)\phi^{-1}T\sigma_S g']}{\tau_e^2\Delta\Omega} \gtrless 0\,. \tag{D4}$$

In addition, when the health effect is absent (i.e. $\sigma = 1$ and $\sigma_S = 0$), (D1)-(D4) will reduce to:

$$\left.\frac{\partial x^*}{\partial \tau_e}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{-\Gamma\Xi\delta(1-\alpha)(\ell^* + L^*)\,x^*}{\tau_e\Delta\Omega} \gtrless 0\,,$$

$$\left.\frac{\partial S^*}{\partial \tau_e}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{-(1-\eta)(1-\alpha)g'}{\tau_e^2\delta\phi} < 0\,,$$

$$\left.\frac{\partial L^*}{\partial \tau_e}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{(1-\alpha)\delta\,\ell^* L^*[x^* + \Gamma\,\Xi]}{\tau_e\Delta\Omega} \gtrless 0\,,$$

$$\left.\frac{\partial \gamma^*}{\partial \tau_e}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{\alpha\delta\,\Xi x^*\delta(1-\eta)(1-\alpha)(\ell^* + L^*)}{\tau_e\Delta\Omega} < 0\,.$$

□

Appendix E (*The proof of Proposition 2*)

Equation (23) with $\dot{x} = \dot{S} = 0$ immediately yields the impact of the government abatement expenditure share on the consumption-capital ratio and the pollution stock as given by:

$$\frac{\partial x^*}{\partial \phi} = \frac{\Xi[\delta\Omega - (1-\eta)(1-\alpha)\varepsilon\phi^{-2}\tau_e^{-1}\Gamma T\sigma_S g']x^*}{\Delta\Omega} \gtrless 0\,, \tag{E1}$$

$$\frac{\partial S^*}{\partial \phi} = \frac{(1-\eta)(1-\alpha)(\Omega x^* - \varepsilon\,\Gamma\Xi\ell^*)g'}{\tau_e\phi^2\Delta\Omega} < 0\,. \tag{E2}$$

Using (20b), (E1)and (E2), the impact of public abatement expenditure on the labor supply is given by:

$$\frac{\partial L^*}{\partial \phi} = \frac{\alpha L^*[(1-\eta)(1-\alpha)\phi^{-2}\tau_e^{-1}T\sigma_S g'x^* - \delta\Xi\ell^*]}{\Delta\Omega} > 0\,. \tag{E3}$$

From (24), (E1) and (E3), we have the growth effect of public abatement expenditure:

$$\frac{\partial \gamma^*}{\partial \phi} = \frac{\alpha\varepsilon\Xi(1-\eta)[(1-\eta)(1-\alpha)\phi^{-2}\tau_e^{-1}T\sigma_S g'x^* - \delta\Xi\ell^*]}{\Delta\Omega} > 0\,. \tag{E4}$$

If the labor supply is exogenous, i.e. $\varepsilon = \Lambda_2 = 0$, (E1)-(E4) can be reduced to:

$$\left.\frac{\partial x^*}{\partial \phi}\right|_{\varepsilon=\Lambda_2=0} = \frac{\Xi\,\delta x^*}{\Delta} < 0\,,$$

$$\left.\frac{\partial S^*}{\partial \phi}\right|_{\varepsilon=\Lambda_2=0} = \frac{(1-\eta)(1-\alpha)x^* g'}{\tau_e \phi^2 \Delta} < 0\,,$$

$$\left.\frac{\partial L^*}{\partial \phi}\right|_{\varepsilon=\Lambda_2=0} = \frac{\alpha L^*[(1-\eta)(1-\alpha)\phi^{-2}\tau_e^{-1} T\sigma_S g' x^* - \delta \Xi \ell^*]}{\Delta\Omega} > 0\,,$$

$$\left.\frac{\partial \gamma^*}{\partial \phi}\right|_{\varepsilon=\Lambda_2=0} = 0\,. \qquad \square$$

Appendix F (*The proof of Proposition 3*)

Equation (23) with $\dot{x} = \dot{S} = 0$ immediately yields the effect of deregulations in the intermediate goods market on the consumption-capital ratio and the pollution stock as given by:

$$\frac{\partial x^*}{\partial \eta} = \frac{-\Xi\{\delta[\Gamma(\ell^* + L^*) + \Omega(1-\phi)] + \varepsilon \Gamma T(1-\eta)(1-\alpha)\phi^{-1}\tau_e^{-1}\sigma_S g'\}x^*}{(1-\eta)\Delta\Omega} \gtrless 0\,, \tag{F1}$$

$$\frac{\partial S^*}{\partial \eta} = \frac{-(1-\alpha)g'}{\tau_e \phi \delta} < 0\,. \tag{F2}$$

Using (20b), (24), and (F1)-(F3), the impacts of a deregulatory policy on employment and growth are given by:

$$\frac{\partial L^*}{\partial \eta} = \frac{L^*\{\alpha(1-\alpha)\phi^{-1}\tau_e^{-1} T\sigma_S g' x^* + \delta \ell^*[(1-\eta)^{-1}x^* + \alpha\Xi]\}}{\Delta\Omega} \gtrless 0\,, \tag{F3}$$

$$\frac{\partial \gamma^*}{\partial \eta} = \frac{\Xi\{\delta\varepsilon\ell^*(1-\phi)(1-\eta)^{-1}\Xi(\alpha\Gamma + 1 - \phi) + \alpha^2 x^*[\delta(\ell^* + L^*) + (1-\eta)(1-\alpha)\phi^{-1}\tau_e^{-1}\varepsilon T\sigma_s g']\}}{\alpha\Delta\Omega} \gtrless 0\,. \tag{F4}$$

In addition, in the absence of the health effect (i.e. $\sigma = 1$ and $\sigma_S = 0$), (F1)-(F4) reduce to:

$$\left.\frac{\partial x^*}{\partial \eta}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{-\Xi\delta[\Gamma(\ell^* + L^*) + \Omega(1-\phi)]x^*}{(1-\eta)\Delta\Omega} \gtrless 0\,,$$

$$\left.\frac{\partial S^*}{\partial \eta}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{-(1-\alpha)g'}{\tau_e \phi \delta} < 0\,,$$

$$\left.\frac{\partial L^*}{\partial \eta}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{L^* \delta \ell^*[(1-\eta)^{-1}x^* + \alpha\Xi]\}}{\Delta\Omega} < 0\,,$$

$$\left.\frac{\partial \gamma^*}{\partial \eta}\right|_{\substack{\sigma=1\\ \sigma_S=0}} = \frac{\Xi\{\delta\varepsilon\ell^*(1-\phi)(1-\eta)^{-1}\Xi(\alpha\Gamma + 1 - \phi) + \alpha^2 x^* \delta(\ell^* + L^*)\}}{\alpha\Delta\Omega} < 0\,. \qquad \square$$

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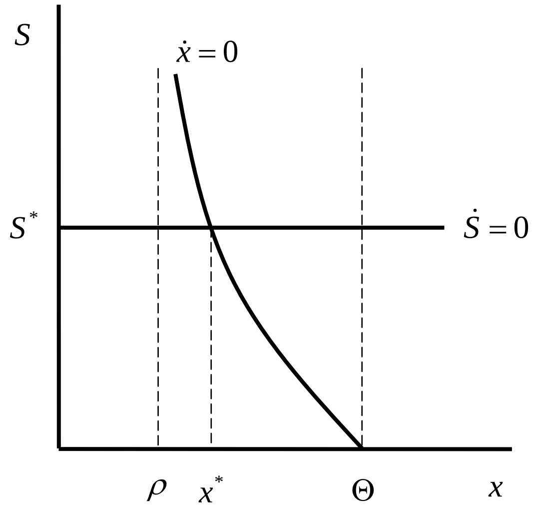

Figure 1a The $\Gamma < 0$ case.

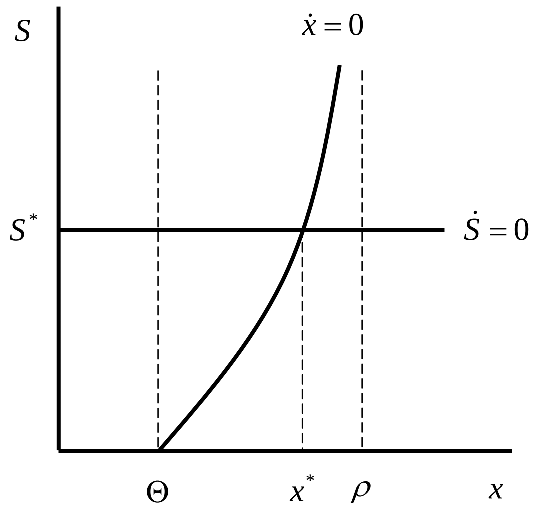

Figure 1b The $\Gamma > 0$ case with $a_{11} > 0$ and $(\partial S / \partial x)\big|_{\dot{x}=0} > 0$.

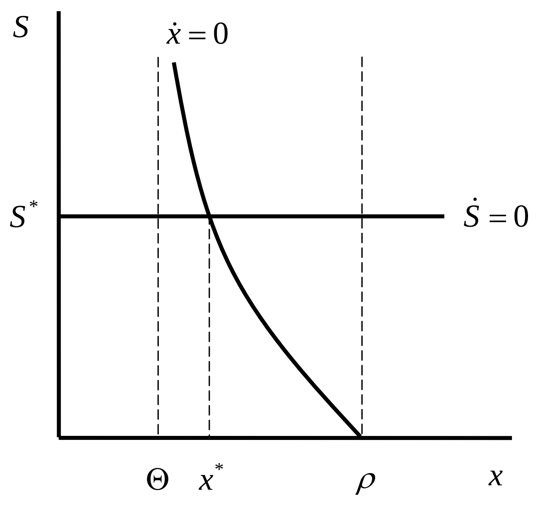

Figure 1c The $\Gamma > 0$ case with $a_{11} < 0$ and $(\partial S / \partial x)\big|_{\dot{x}=0} < 0$.