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# On the impossibility of sustainable growth in a manufacturing based economy

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## ABSTRACT

This paper investigates a possibility of sustainable growth in a multi-output endogenous growth framework where the capital accumulation takes place mainly through the production of the dirty manufactured goods. It is shown that in a closed economy, economic growth is not environmentally sustainable, even under an optimal pollution tax unless the consumption elasticity of substitution between clean and dirty goods approaches infinity as in a small open economy which exports dirty goods. There exists a minimal threshold level of the ratio of clean to dirty capital that ensures sustainable growth in a closed economy.

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Sustainable growth; environmental Kuznets curve; elasticity of marginal utility; elasticity of substitution

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## 1. Introduction

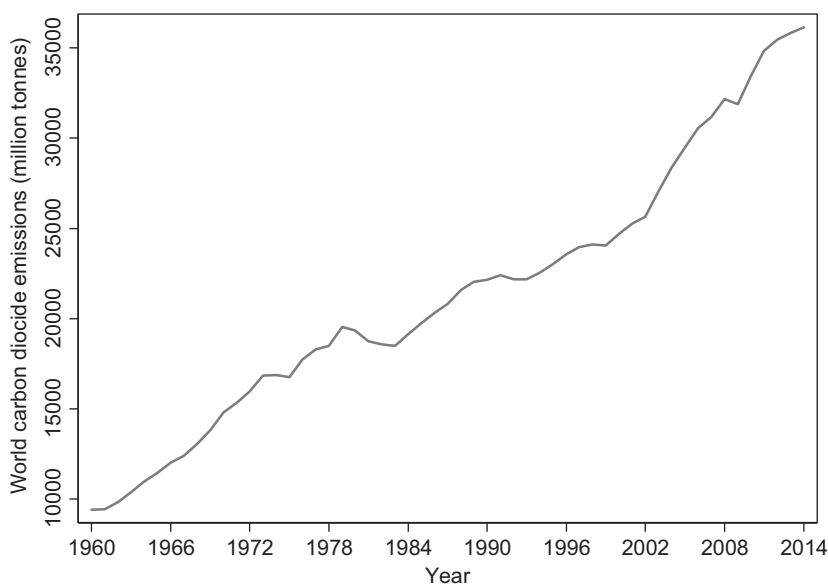
This paper examines the possibility of environmentally sustainable growth in a two-sector dynamic general equilibrium framework in which the capital accumulation takes place mainly in the form of dirty manufacturing capital. The paper is motivated by the empirical observation that, despite growing effort on abatement activities in major industrialized countries, the world CO<sub>2</sub> emissions have constantly been growing (Figure 1). The paper is motivated by the empirical observation that, despite growing effort on abatement activities in major industrialized countries, the world CO<sub>2</sub> emissions have constantly been growing.

Whether society will choose a path with sustained growth depends on how the tradeoff between consumption and pollution evolve as the economy becomes richer (Stokey, 1998). If the environmental costs become sufficiently high, society will not be willing to pay such costs and growth will cease. Michel and Rotillon (1995) show that the socially optimal growth rate is zero if dirty goods are produced with constant

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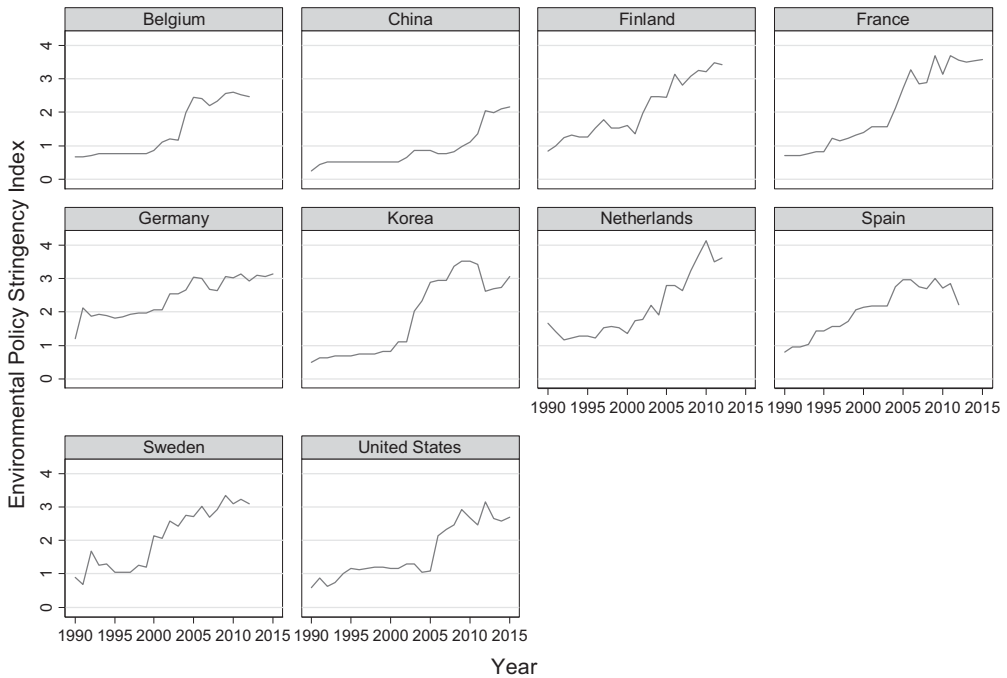
**Figure 1.** World carbon dioxide emissions.

Source: World Bank (2017).

returns to scale and investment consists of unconsumed dirty goods. Further, the authors show that in order to obtain a socially optimal positive growth rate, the economy needs to redirect some of its accumulated capital towards abatement activities. This redirection will impose a substantial social burden if the growth is driven primarily by the accumulation of dirty goods.

The burden of pollution abatement expenditure is evidenced in the increasing stringency of environmental policy. OECD (2017) defines the OECD Environmental Policy Stringency (EPS) as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior. Selected environmental policy instruments that are mainly related to climate and air pollution are scored and aggregated into single digit EPS index (Botta & Koźluk, 2014). The EPS index uses various instruments including government R&D expenditures for renewable energy technologies expressed as % of GDP, emission limit value for a given substance, the percentage of renewable energy to be procured, the tax rate for emissions of NO<sub>x</sub>.<sup>1</sup> The index ranges from 0 (not stringent) to 6 (highest degree of stringency). As can be seen in Figure 2, the EPS index of major exporting countries in the world indicates that the pollution abatement expenditure has, indeed, risen over time. Despite a growing effort on abatement activities from major exporting countries including China, pollution growth of the world economy has yet to show any signs of slowing down.

In any one-sector model of economic growth where pollution emission grows in proportion to output, the real return to capital declines as the environmental standard becomes strict. The only way to maintain the real return as the capital stock grows is to let pollution grow in proportion to capital which, in return, will increase the environmental costs. In the absence of sufficiently rapid exogenous technical progress, as



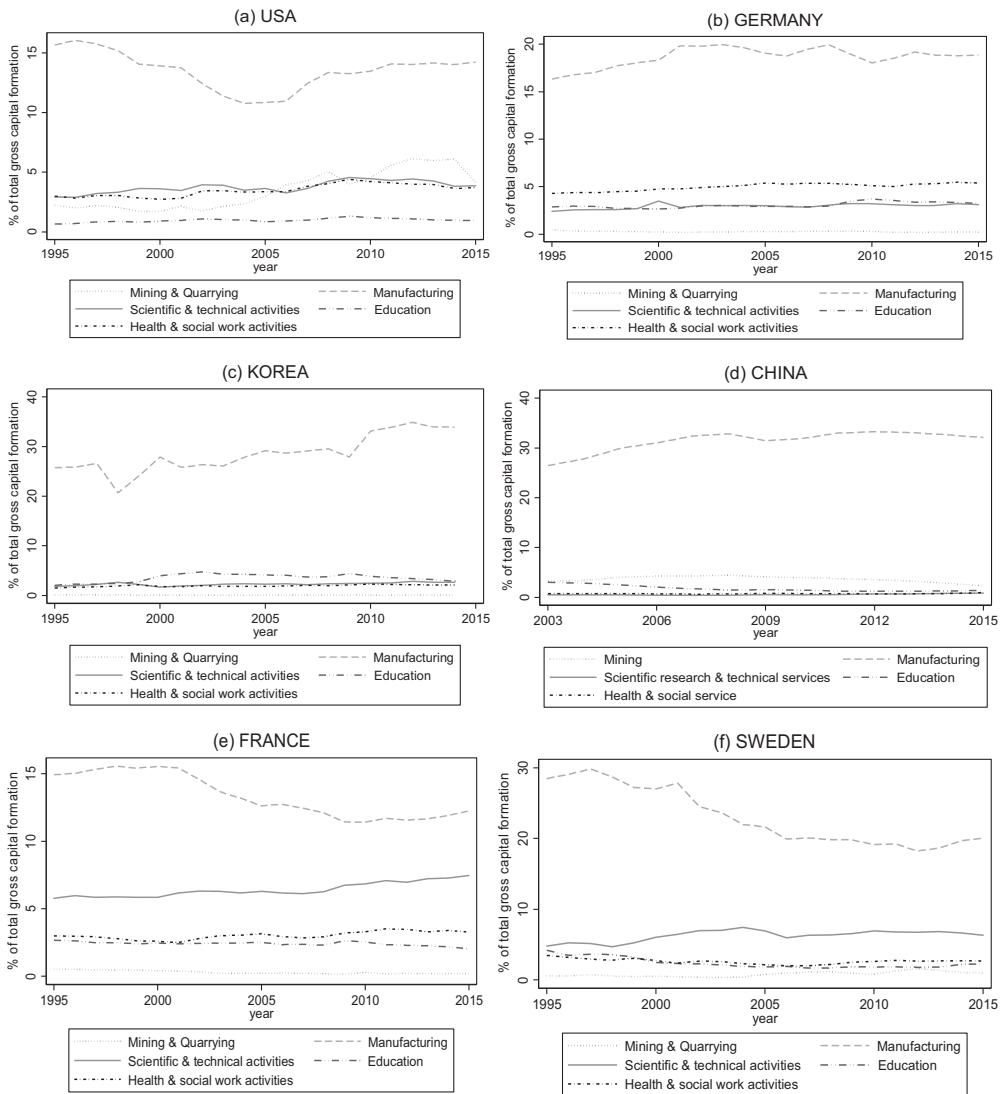
Graphs by Country

**Figure 2.** Environmental policy stringency index of major exporting countries.  
Source: OECD (2017).

postulated by Brock and Taylor (2010), sustainable growth seems hardly possible in the one-sector model of economic growth.

To explain the possibility of sustainable growth without relying on the presence of exogenous technical progress in the abatement activities, we examine the composition of capital, or the ratio of clean to dirty capital goods across industrialized countries in a two-good model of economic growth. As shown in Figure 3, pollution emission growth (as measured in terms of CO<sub>2</sub> emissions per capita) has recently declined in major industrialized nations such as the United States, Germany, France, and Netherlands. Meanwhile, the proportion of clean capital goods that consists of scientific research, health, and investment in education has increased over time. Conversely, in countries such as China and Korea, the ratio of dirty manufacturing to capital goods has increased persistently over time. Although the environmental stringency index has increased, carbon dioxide emissions per capita are continuing to increase in China and Korea (Figure 4).

Despite the evidence of growing world pollution emissions, theoretical models of economic growth have concluded that economic growth leads to policies and institutions that may make permanent economic growth compatible with a stable environment and also eventually with an improving environment (Acemoglu, Aghion, Bursztyn, & Hemous, 2012; Bovenberg & Smulders, 1995; Stokey, 1998). In particular, many growth models assume one final good sector (i.e., Acemoglu et al., 2012; Bovenberg & de Mooij, 1997; Bretschger & Smulders, 2007; Brock & Taylor, 2010; Stokey, 1998), and rely on both exogenous and endogenous technical progress to



**Figure 3.** Gross capital formation by activities major exporting countries (% of total).

Source: OECD (2017) and China Bureau of Statistics (2017).

achieve sustainable growth path. The output composition effect, as has often considered important by empirical analyses (i.e., Cole & Elliot, 2003; Grossman & Krueger, 1995) received little attention in the one sector model of economic growth.

To investigate the importance of the composition of capital, it is essential to introduce a two-final good sector model of economic growth. Recently, López and Yoon (2014a, 2014b, 2016) examined the possibility of sustainable growth in both open and closed economies using a two-sector endogenous growth model in which the capital accumulation occurs primarily through the clean capital, and the population consumes both clean and dirty goods (mostly manufactured goods). According to López and Yoon (2016), a Pigovian pollution tax induces changes in relative prices of dirty and clean consumption goods, which leads to a structural transformation of the

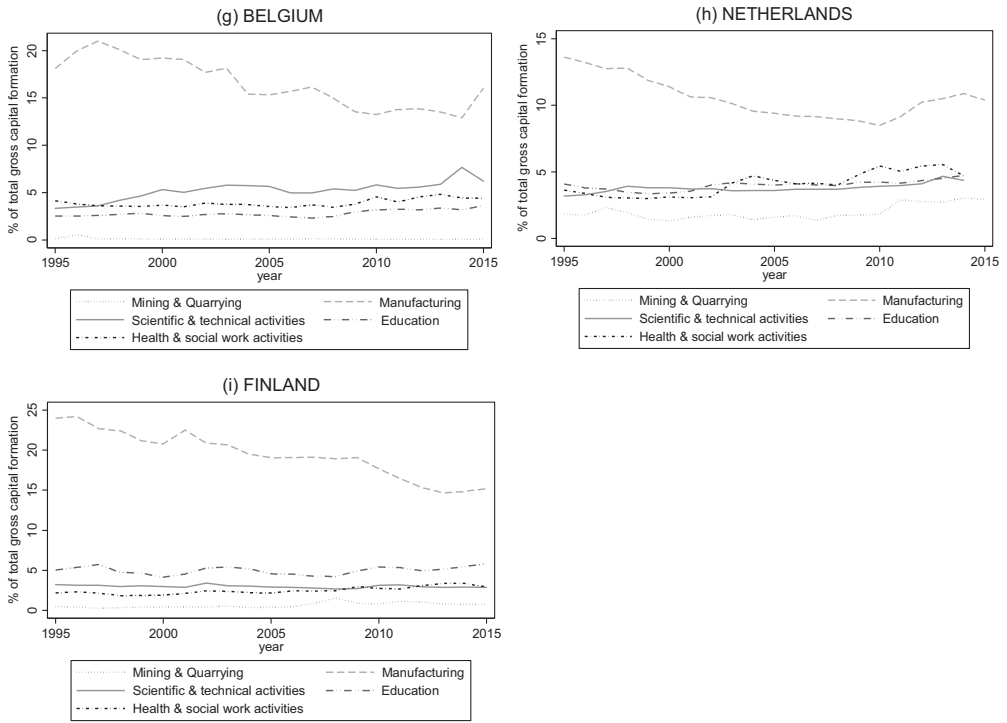


Figure 3. Continued

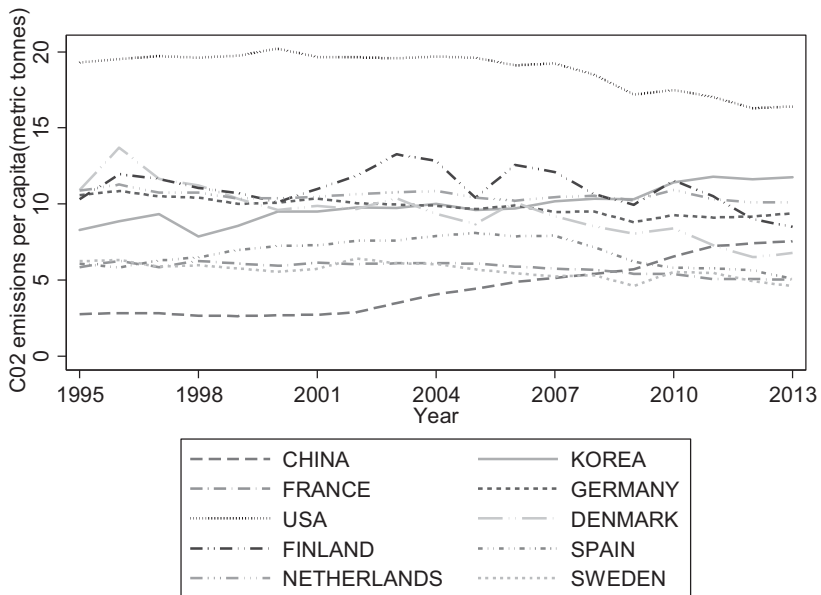


Figure 4. Carbon dioxide emissions per capita of major exporting countries. Source: World Bank (2017).

economy. Sustainable growth is possible, even in the absence of flexible substitution between pollution input and clean capital. As long as the dirty good is used as a consumption good only, sustainable growth is possible. However, they did not explicitly examine the feasibility of sustainable growth when the economy uses pollution intensive dirty good as a primary source of investment that leads to economic growth.

This paper attempts to complement López and Yoon (2016) by showing that the positive result on the feasibility of sustainable growth would no longer be valid if the investment good consisted only of a dirty good. If the capital accumulation takes place mainly in the dirty industry, the return to the capital declines fast enough to remove incentives for accumulating capital in a closed economy as the environmental stringency increases over time. This paper shows that, as long as the investment consists of dirty goods, positive, sustainable growth becomes unattainable under a Pigovian pollution tax, even if the clean good industry is characterized by the model with positive spill-over effects. The impossibility of sustainable growth when the capital consists only of the dirty good holds for any finite level of consumption elasticity of substitution between clean and dirty consumption goods, and technical elasticity of substitution between capital and pollution inputs. The impossibility also holds for any level of elasticity of marginal utility of income (inverse of the intertemporal elasticity of substitution). The impossibility result implies that the clean capital, such as human and knowledge capital, plays a key role in sustainable growth.

## 2. The basic framework and analysis

We consider an economy that produces two goods: one clean, and one dirty. The production of a dirty good generates pollution, while the production of a clean good involves no pollution. Let  $k$  denote the physical capital, which is distributed between the clean and dirty industries. Let  $k_d$  denote the amount of capital employed in the dirty sector, and let  $x$  denote pollution emissions. Following López (1994) and Copeland and Taylor (2005), we regard pollution as a factor of production. Let  $F(k_d, x)$  represents the production technology of the dirty good. Assuming a constant elasticity of substitution (CES) function,

$$y_d = F(k_d, x) = \left[ \alpha k_d^{-\frac{1-\omega}{\omega}} + (1-\alpha)x^{-\frac{1-\omega}{\omega}} \right]^{-\frac{\omega}{1-\omega}}, \quad (1)$$

where  $\omega > 0$  represents the elasticity of substitution between capital and pollution, and  $0 < \alpha < 1$  is a fixed parameter. The dirty sector produces both new capital and final consumption goods.

The output of the clean good is assumed to depend only on the capital input and is governed by the linear technology,

$$y_c = A(k - k_d). \quad (2)$$

The clean sector produces only the final consumption goods. For expositional convenience, we normalize the price of the clean good to unity ( $p_c = 1$ ). Assuming that the government reimburses tax receipt in a lump-sum way, we note that the income of the representative consumer consists of revenue from clean good and dirty good industry,

$$A(k - k_d) + pF(k_d, x).$$

We assume that consumers derive utility from consumption of the clean good ( $c_c$ ) and dirty good ( $c_d$ ) and disutility out of pollution ( $x$ ), and that the utility function is separable in consumption goods and pollution. Let's denote consumer's utility function as  $U(c_c, c_d, x) = u(c_c, c_d) - v(x)$  where  $u(c_c, c_d)$  is increasing, strictly concave homothetic function of the consumption of the clean good and dirty good. Let  $c \equiv c_c + pc_d$  denote the total consumption expenditure in units of the clean good. The consumer combines  $c_c$  and  $c_d$  to minimize expenditure for a given level of utility,  $u$ . Thanks to homotheticity of the utility function, the total minimized consumption expenditure can be represented by the expenditure function for some parameter  $\rho$ ,

$$c \equiv e(1, p; u) = e(1, p)u^\rho = \text{Min}_{c_c, c_d} \{c_c + pc_d : u(c_c, c_d) = u\}.$$

where  $e(1, p)$  denote the unit expenditure function. Let  $c_c(1, p; u)$  and  $c_d(1, p; u)$  denote the solutions to the expenditure minimization decision. It follows from the duality properties of the expenditure function that  $c_c(1, p; u) + pc_d(1, p; u) = e_1(1, p; u) + pe_2(1, p; u) = e(1, p; u)$  where a subscript number reflects the first derivative with respect to the corresponding argument in functions of more than one variable. Let  $\dot{k} = \frac{dk}{dt} = I - \delta k$ , where  $I$  and  $\delta$  are the investment and depreciation rate respectively. Since the gross capital accumulation,  $\dot{k} + \delta k$ , is equal to net savings (income less consumption), the economy's budget constraint can be written as,

$$\dot{k} = F(k_d, x) + \frac{1}{p} [A(k - k_d) - e(1, p; u)] - \delta k. \tag{3}$$

Let  $\rho = \frac{1}{1-a}$  where  $a$  measures the elasticity of marginal utility of income. The consumer's indirect utility function can be written as

$$u = \frac{1}{1-a} \left( \frac{c}{e(1, p)} \right)^{1-a},$$

where the unit expenditure function  $e(1, p)$  can be regarded as the cost-of-living index.<sup>2</sup> The parameter  $a$  is the elasticity of marginal utility (*EMU*) and  $u(c, p)$  is assumed to be increasing and strictly concave in  $c$ . If  $a < 1$  we adopt a positive utility scale such that  $0 < u < \infty$ , while we scale the utility index to  $-\infty < u < 0$  when  $a > 1$ .

The consumer's underlying preferences are described by a CES utility function, so that the unit expenditure function is given as

$$e(1, p) = [\gamma_c + \gamma_d p^{1-\sigma}]^{\frac{1}{1-\sigma}},$$

where  $\sigma > 0$  is the elasticity of substitution between the dirty good and clean good, and  $\gamma_c > 0$  and  $\gamma_d > 0$  are fixed parameters. The optimal level of  $c$  is determined by the inter-temporal optimization, as detailed below. We assume that the environmental damage is separable from consumption in the welfare function, and can be represented as  $v(x) = \frac{x^{1+\eta}}{1+\eta}$ , where  $\eta > 0$  is a fixed parameter. Then the consumer's instantaneous welfare is:



$$U \equiv \frac{1}{1-a} \left( \frac{c}{e(1,p)} \right)^{1-a} - \frac{x^{1+\eta}}{1+\eta}.$$

We assume a fixed discount rate,  $\rho$ . If the government optimally regulates pollution, the economy behaves “as if” it maximizes the present discounted value of welfare,

$$\max_{c,x} \int_0^\infty \left\{ \frac{1}{1-a} \left( \frac{c}{e(1,p)} \right)^{1-a} - \frac{x^{1+\eta}}{1+\eta} \right\} \exp(-\rho t) dt,$$

subject to the budget constraint Equation (3), and the initial condition  $k = k_0$ .

It is now necessary to define what we mean by “sustainable economic growth.”

**Definition 1:** We say that sustainable growth is possible if, at some point along the growth process, the competitive economy is able to continue growing indefinitely while pollution emissions permanently decline.

Therefore, sustainability requires that there exists a finite time,  $T \geq 0$ , such that at any time  $t > T$ ,  $\hat{x} < 0$ . It implies also that  $\lim_{t \rightarrow \infty} \hat{x} \leq 0$ .

Let  $\lambda$  denote the shadow value of the capital input. Then the above optimization implies the following current-value Hamiltonian with  $c = e(1, p; u)$

$$H = \frac{1}{1-a} \left( \frac{c}{e(1,p)} \right)^{1-a} - \frac{x^{1+\eta}}{1+\eta} + \lambda \left[ F(k_d, x) + \frac{1}{p} [A(k - k_d) - e(1, p; u)] - \delta k \right],$$

The following first-order conditions are necessary:

$$1 - \frac{\lambda}{p} e(1, p; u) [(1-a)u]^{\frac{a}{1-a}} = 0, \tag{4}$$

$$pF_1 \left( \frac{k_d}{x} \right) = A, \tag{5}$$

$$\lambda F_2 \left( \frac{k_d}{x} \right) = v'(x), \tag{6}$$

$$\hat{\lambda} = \rho + \delta - \frac{A}{p}, \tag{7}$$

$$\dot{k} = F(k_d, x) + \frac{1}{p} [A(k - k_d) - e(1, p; u)] - \delta k, \tag{8}$$

$$\lim_{t \rightarrow \infty} \lambda k(t) e^{-\rho t} = 0. \tag{9}$$

Define  $M(p) = \frac{A}{p} - \rho - \delta$ . Then from (7),  $\widehat{\lambda} \geq 0$  if  $M(p) \leq 0$ . That is, the price of the dirty output is assumed to remain below  $\frac{A}{\rho + \delta}$  to ensure positive shadow value of capital. From Equation (6), the optimal pollution tax is equal to the marginal rate of substitution between the pollution and consumption expenditure. That is,  $\tau \equiv v_1(x)/\lambda$ .

Let's first examine the possibility of sustainable growth in the small open economy where the price of the dirty good is fixed exogenously in the world market, and the consumption elasticity of substitution becomes infinity at the world price of the dirty good. From Equation (5), the factor ratio,  $\frac{k_d}{x}$  is fixed as well. If  $v(x) = \frac{x^{1+\eta}}{1+\eta}$ , Equation (6) implies that  $\widehat{x} = \frac{\widehat{\lambda}}{\eta} = \frac{1}{\eta}(\rho + \delta - \frac{A}{p})$ . As long as the world price of the dirty good remains below  $\frac{A}{\rho + \delta}$ , the pollution emission declines monotonically over time.

**Proposition 1:** In a small open economy where the dirty good is freely traded in the world market, the optimal pollution tax induces monotonically decreasing pollution emission along the positive growth path.

In a small open economy, the dirty sector shrinks over time and the increasing share of consumption and investment demands for the dirty good is met by imports. The country will eventually specialize in the production of clean goods. The economy becomes cleaner exclusively through the output composition effect in an open economy. As long as the world price of the dirty good is constant, the ratio of capital to pollution is fixed and there is no technique effect of pollution reduction. The resulting unilateral export of pollution simply increases global pollution growth.

Let us now consider the sustainable growth of a closed economy, or a world economy as a whole. In addition to the equilibrium conditions arising from the first order conditions that are derived from the open economy, the market clearing conditions that determine the equilibrium level of the relative price must be considered explicitly. Using Roy's identity, the consumer demand for the dirty good is  $c_d = \frac{\gamma_d p^{-\sigma} c}{\gamma_c + \gamma_d p^{1-\sigma}}$ . Defining the share of the dirty good in the consumption expenditure as  $s(p) \equiv \frac{p c_d}{p c_d + c}$ , and the share of capital in the output value of the dirty good as  $S_k \equiv \frac{k_d F_1(k_d, x)}{F(k_d, x)}$ , the CES specifications imply that,  $s(p) = \frac{\gamma_d}{\gamma_c p^{\sigma-1} + \gamma_d}$ ;  $S_k = \alpha \left[ (1 - \alpha) \left( \frac{k_d}{x} \right)^{\frac{1-\alpha}{\alpha}} + \alpha \right]^{-1}$ .<sup>3</sup>

Using Roy's identity, the demand for clean good is given as  $c_c = \frac{e_1(1, p)}{e(1, p)} c$  and the market clearing condition for the clean good implies that  $A(k - k_d) = \frac{e_1(1, p)}{e(1, p)} c$ .

It follows that

$$A(k - k_d) = e_1(1, p) [(1 - a)u]^{1-a}. \tag{10}$$

Using the property of CES expenditure function, it is easy to derive

$$\widehat{e}_1(1, p) = \sigma s(p) \widehat{p}, \tag{11}$$

where  $\widehat{e}_1$  and  $\widehat{p}$  denote a proportional change of each variable respectively. Let  $k_c = k - k_d$ . Then by differentiating both sides of Equation (10) logarithmically, we

have after some algebraic manipulation,

$$\widehat{k}_c = \left( \sigma s(p) + \frac{1-s(p)}{a} \right) \widehat{p} + \frac{M(p)}{a}. \tag{12}$$

From [Equations \(5-7\)](#), we can derive the equations for proportional changes of the endogenous variables as follows.

$$\widehat{p} - \frac{1-S_K}{\omega} \left( \widehat{\frac{k_d}{x}} \right) = 0, \tag{13}$$

$$\frac{S_K}{\omega} \left( \widehat{\frac{k_d}{x}} \right) + \widehat{p} - \eta \widehat{x} = M(p). \tag{14}$$

Furthermore, from the definition, we have

$$\widehat{k}_c = - \left( \frac{k_d}{k_c} \right) \widehat{k}_d + \left( \frac{k}{k_c} \right) \widehat{k}. \tag{15}$$

We now express  $\widehat{k}$  as a function of  $k$  and exogenous technology and preference parameters.

Let  $V(k)$  denote the maximized value of the constrained optimization. Then from the principle of optimality, we have

$$\rho V(k) = u - v(x) + V'(k) \left[ F(k_d, x) + \frac{1}{p} [A(k - k_d) - e(1, p; u)] - \delta k \right], \tag{16}$$

where  $V'(k)$  denotes first derivatives of  $V$  with respect to  $k$ .

By differentiating [Equation \(16\)](#) with respect to  $k$ , we have

$$\widehat{k} = - \frac{M(p)V'(k)}{kV''(k)} = b(k)M(p), \tag{17}$$

where  $b(k) > 0$  and  $V''(k)$  denotes second derivatives of  $V$  with respect to  $k$ .  $b(k)$  can be interpreted as an inverse of the elasticity of marginal value of the capital. Inserting this relationship into the [Equation \(15\)](#) we have

$$- \left( \frac{k_d}{k_c} \right) \widehat{k}_d - \left( \sigma s + \frac{1-s}{a} \right) \widehat{p} = \frac{M(p)}{a} - \frac{k}{k_c} b(k)M(p). \tag{18}$$

Then the system of [Equations \(13\) \(14\) and \(18\)](#) solves for  $\widehat{k}_d, \widehat{p}$  and  $\widehat{x}$  as follows.

$$\begin{pmatrix} -\frac{k_d}{k_c} & -\left(\sigma s + \frac{1-s}{a}\right) & 0 \\ \frac{S_K}{\omega} & 1 & -\left(\eta + \frac{S_K}{\omega}\right) \\ -\frac{1-S_K}{\omega} & 1 & \frac{1-S_k}{\omega} \end{pmatrix} \begin{pmatrix} \widehat{k}_d \\ \widehat{p} \\ \widehat{x} \end{pmatrix} = \begin{pmatrix} \frac{M(p)}{a} - \frac{k}{k_c} b(k)M(p) \\ M(p) \\ 0 \end{pmatrix}. \tag{19}$$

The determinant of the above system of equations is defined as,

$$|W| = -\frac{k_d}{k_c} \left( \frac{1}{\omega} + \eta \right) - \eta \left( \sigma s + \frac{1-s}{a} \right) \frac{1-S_K}{\omega} < 0. \tag{20}$$

The solution for  $\widehat{p}$  is given as

$$\widehat{p} = \frac{-\left(\frac{k_d}{k_c}\right)M(p)\frac{1-S_K}{\omega} + \frac{1-S_K}{\omega}\eta M(p)\left(\frac{1}{a} - \frac{k}{k_c}b(k)\right)}{|W|}, \tag{21}$$

while for the pollution level,

$$\widehat{x} = \frac{\frac{M(p)}{\omega} \left( \frac{1}{a} - \frac{k}{k_c} b(k) \right) + M(p) \left[ \frac{k_d}{k_c} + \frac{1-S_K}{\omega} \left( \sigma s + \frac{1-s}{a} \right) \right]}{|W|}. \tag{22}$$

If the economy is sustainable, the growth rate of the economy remains positive with eventually declining pollution growth. For the economy to grow, we must have  $M(p) > 0$ . Since  $|W| < 0$  from Equation (20), the numerator of Equation (22) should be eventually positive if the pollution emission declines. Since the second term of the numerator is always negative, the first term is necessarily positive for sustainable growth. That is,  $\left(\frac{1}{a} - \frac{k}{k_c}b(k)\right) > 0$ .

It follows that the second term of the numerator of the Equation (21) is positive if the economy continues to grow with declining pollution growth. The first term of the numerator is also positive as long as  $M(p) < 0$ . The first term of the numerator converges to zero as the dirty sector diminishes with ever diminishing  $(k_d/k_c)$ . In fact, when  $\widehat{p} < 0$ , we have from the Equation (13) that  $\widehat{\left(\frac{k_d}{x}\right)} < 0$ , and the production of dirty good decreases over time. It follows that the consumption growth turns negative. We now state the following proposition.

**Proposition 2:** In the manufacturing-based closed economy, the sustainable growth is not feasible for any finite value of  $\sigma$ .

If  $\sigma = \infty$ , the clean good and dirty good are perfect substitutes and can be used interchangeably at a fixed ratio as in a small open economy where the relative price between the clean good and dirty good is fixed in the world economy regardless of the level of domestic consumption of two goods. The sustainable growth is trivially feasible.

If the capital accumulation takes place mainly in the dirty industry, the positive economic growth path is not compatible with declining pollution growth. That is, the proportion of clean capital should not vanish over time to ensure sustainable growth. Since it is well known that the sustainable growth is possible when the capital consists of clean good only, there should exist a positive minimal level in the ratio of clean to dirty capital that assures sustainable growth.

**Corollary 1 to Proposition 2.** There exists a positive threshold level of the ratio of clean to dirty capital to achieve sustainable growth.

### 3. Concluding comments

The purpose of this study was to contribute to the literature of environment and development. Motivated by the experiences of Asian exporting countries such as China and Korea, we have explored the role of clean capital and the existence of a positive minimal level of the proportion of a clean capital in sustainable growth. Although a full characterization of such threshold level requires a serious further research in the future, our result suggests that the environmental policy that does not induce a systematic decrease in the composition of dirty capital is likely to raise the burden of compliance cost over time.

### Notes

1. See Botta and Koźluk (2014) for the complete list of instruments used in EPS index.
2. The scale parameter  $\frac{1}{(1-a)}$  is multiplied in an innocuous manner to facilitate calculation.
3. For Cobb-Douglas utility and production function case where  $\sigma = 1$  and  $\omega = 1$ ,  $s(p) = \frac{\gamma_d}{\gamma_c + \gamma_d}$  and  $S_k = \alpha$  so that both the share of the dirty good in the consumption expenditure and the share of capital in the output value of the dirty good become a constant value.

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No potential conflict of interest was reported by the authors.

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