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Koichi Futagami* and Yasuhiro Nakamoto†

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Abstract

We examine the effects of environmental policies such as a subsidy for reforestation and an export-income tax in a small open economy with a renewable resource. In the small economy, the harvested renewable resources are exported to acquire foreign assets and consumers can invest in the natural resource to preserve it. In the setup, we show how the environmental policies affect the natural resource and the domestic economy.

Key words: Renewable resources; The effects of environmental policies.

JEL classification: F41; H21; Q28.

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1 Introduction

Some low-income nations are facing a shortage of natural resources such as forestry, fish and wildlife stocks. Governments in most countries have become more aware of such threats and the risk of natural resources depletion. However, there are no stylized policies for preserving natural resources because government policies affect not only natural resources but also other economic variables such as consumption and investment. In this paper, we examine the effects of environmental policies on renewable resources and on the domestic economy by using a small open economy model.

The sustainability of major renewable resource stocks is a significant issue in many countries, especially developing countries. For instance, there have been widely publicized claims that forests in countries such as Indonesia, Malaysia and the Philippines have been harvested rapidly, with deforestation shifting from the temperate zone to the tropics following World War II. Other renewable resources, including fish and wildlife stocks, are also under threat in many developing countries.

In these developing countries, most of the harvested resources are exported to acquire foreign assets, which enable these countries to achieve rapid growth of their economies. Repetto and Gillis (1988) mentioned that, by 1970, between 7 and 10 percent of the total forest area in Indonesia was being utilized to acquire foreign assets, with the timber sector, specifically logs and plywood, providing a major source of foreign exchange. Indeed, between 1970 and 1979, gross foreign exchange earnings from the export of tropical hardwood grew from US $ 110 million to US $ 2.1 billion. Considering that gross domestic product in 1970 was about US $ 11 billion, the exports created by the deforestation were very valuable in Indonesia. In the Philippines, the share of exports represented by logs and lumber in GDP rose from about 9 percent in the late 1940s to about 15 percent by 1970. In 1970, 16.6 million hectares, or 55 percent of the country's land area, was made up of forests; however, between 1971 and 1980, forest lands decreased by 1.7 million hectares. The export of fish products in Iceland also contributed considerably to the nation's foreign currency earnings, with the contribution of the fishing industry's exports to GDP at around 17 percent in 1978 and 7 percent in 2007.[1]

In many developing countries, the overuse of natural resources is continuing, so that preservation of these resources is still required. While some developing countries have introduced short-term environmental policies, some of these environmental policies have generated unintended negative effects on the conservation of resources. Two such environmental policies are regeneration policies, such as reforestation policy, and a specific income tax for harvesters.[2] Repetto and Gillis (1988) focused on the income tax policy in relation to logging investments in Indonesia and noted that most timber companies had not paid income taxes at all from 1967 through to 1983. They concluded: *More effective income taxation would not have reduced the rate of exploitation of the tropical forest, but would have clearly raised the benefits of timber exploitation to the owner of the forest resource.* In addition, some researchers have examined the effects of reforestation. In Indonesia, from 1946 through to 1983, reforestation programs impacted on 2.3 million hectares of land. To examine the impacts of the subsidy on reforestation in Indonesia, Osgood (1994) made use of panel data on 20 regions in Indonesia from 1972 to 1988. Interestingly, she concluded that the reforestation subsidy encouraged further deforestation. In addition, Repetto and Gillis (1988) examined reforestation policies in Malaysia and the Philippines and found that 21,000 hectares were replanted between 1974 and 1981 in Malaysia, while more than 78,000 hectares had been reforested between 1976 and 1983 in the Philippines. Shen and Contreras-Hermosilla (1995) noted that, in India, during 1985–89, the total number of seedlings distributed under the farm forestry program was in the order of 1.4–2.0 billion a year, which was enough to plant 560,000–800,000 hectares.

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[1]See the homepage of the Icelandic Ministry of Fisheries and Agriculture's Icelandic Fisheries Information Centre at: http://www.fisheries.is/iceland/

[2]Further, Repetto and Gillis (1988) showed that a policy that bans the export of logs in Indonesia has not necessarily promoted better forest conservation. Shen and Contreras-Hermosilla (1995) mentioned that the logging ban in Thailand had a limited effect on reducing the rate of deforestation, and instead may have caused illegal trade to increase.

Repetto and Gillis (1988) and Shen and Contreras-Hermosilla (1995) concluded that the subsidized forestation policies provided little or no incentive to plant trees so that the reforestation policies aimed at regeneration have proved largely ineffective.

In the resource-dependent developing countries, environmental policies have a large impact not only on these countries' natural resource sectors but also on their whole economies. Hence, in this paper, we construct a dynamic general equilibrium model of a small open economy with a renewable resource. The small economy in our model has the following characteristics. The renewable resource is harvested to produce exportable commodities, which are exported to acquire the foreign assets. In addition, people can invest in the natural resource such as tree planting or fish replenishment to avoid its depletion. Under this set-up, our focus is to examine the dynamic impact of temporary environmental policy changes on the resource as well as on the domestic economy because environmental policies are temporarily performed in actual economies such as Indonesia and Malaysia. To shed light on effects of such temporary policy changes, we compare them with effects of permanent policy changes. Specifically, a government can use two policy instruments; a subsidy policy for reforestation and an income tax policy against the harvesters. Our main finding is the following: Permanent increases of these policy instruments can increase the level of the natural resource; instead, temporary increases of these policy instruments always decrease the level of the natural resource in the long run compared to its original level, although the level of the natural resource increases in the short run.

Our study is closely related to some of the existing investigations in the environmental dynamic models with renewable resources and the international macrodynamic models (e.g., Elíasson and Turnovsky, 2004., Fullerton and Kim, 2008 and Silva et al. 2013).[3] Many environmental studies incorporate renewable natural re-

[3]Concretely, Elíasson and Turnovsky (2004) construct an endogenous growth model with a renewable resource to examine the effects of an increase in the productivity of the harvest sector and the final output sector. Fullerton and Kim (2008) show that pollution tax revenues are not enough to pay for optimal public spending on abatement in the macrodynamic model with the renewable resource. Silva et al (2013) construct a more general equilibrium model with renewable

sources into macrodynamic models; however, these existing studies do not focus on the temporary effect of environmental policies in a small open economy. Furthermore, even if the temporary policies are conducted in their closed economies, the economy would go back to the original steady state after the policy variables return to its original levels. As a result, the temporary environmental policies are not harmful for the natural resource in the long run.

Alternatively, the structure of our model is the same as Sen and Turnovsky (1989), Turnovsky (1997) and Schubert and Turnovsky (2002) in the sense that when policy temporarily changes under the assumption of perfect foresight, the small open economy does not return to its original steady-state equilibrium after the policy variables returns to its original levels. This insight on public policies is completely different from the result of the closed macrodynamic models that the long-run equilibrium coincides with the original steady state under temporary policy changes. However, the existing studies do not include the natural resource sector in each model and furthermore, their attention is not to examine the temporary effects of environmental policies.

Finally, our motivation is closely related to that in Rondeau and Bulte (2007) in the point that both the studies cast some doubts about the usefulness of environmental protection policies. Rondeau and Bulte (2007) make use of a single-country partial equilibrium model with the interaction between habitat and open-access resource in Bulte and Horan (2003). They show that compensation schemes aimed at reducing hunting mortality can actually decrease the wildlife stock. This is because compensation distorts relative commodity prices, thereby being able to increase the returns to agriculture and encourage agricultural expansion. Instead, we use a dynamic macroeconomic model where the natural resource sector is newly introduced, especially, the harvested renewable resource is used to obtain the foreign assets. The essential cause that the environmental policies may be harmful for the natural resource lies in the implementation term of environmental policies in our model.

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and non-renewable resources to analyze the effects of the emission tax on the economy.

That is, the natural resource may be harmed by the temporary implementation of environmental policies, not the permanent one.

The remainder of the paper is organized as follows. In the next section, we present the model. Section 3 shows the existence and uniqueness of the steady state. Section 4 examines the effects of government policies on the economy. Section 5 gives discussion. Our conclusions are summarized in Section 6.

2 The basic framework

This section presents a small open economy model with a renewable resource. The population is constant over time and its size is normalized to be unity. This economy consists of firms and a government as well as households.

2.1 The evolution of the renewable resource

The economy is endowed with a stock of a renewable resource n_t, where t stands for time. We assume that the reproduction of the renewable natural resource is characterized according to $G(n_t)$. The reproduction function $G(n_t)$ has an inverted U-shape, with $G'' < 0$ and $G(0) = G(\bar{n}) = 0$, where $\bar{n}$ represents the *carrying capacity* of the natural resource.[4] This means that there is a level $\tilde{n}$ that satisfies $G'(\tilde{n}) = 0$. In other words, $\tilde{n}$ expresses the level of the renewable resource that provides the maximum sustained yield. If the level of the natural resource is below the level of $\tilde{n}$, then the marginal reproduction of the natural resource takes positive values, whereas if it exceeds $\tilde{n}$, the marginal reproduction of the natural resource takes negative values.[5] In addition, we assume that, as the level of the natural resource

[4]For example, in an economy with a renewable resource, Schaefer (1954), Bovenberg and Smulders (1996), Brander and Taylor (1998), Ayong Le Kama (2001), Wirl (2004), Elíasson and Turnovsky (2004), and López et al.(2007) made use of a reproduction function with a U-shape.

[5]Due to the concavity of $G(n_t)$, it is recognized that analysis of the stability is more complicated. For instance, see Fullerton and Kim (2008).

approaches infinity, the change rate of the natural resource is given by $G(\infty) = -\infty$.[6] The households can invest in reproduction of the natural resource.[7] Thus, we assume that the renewable resource held by a household evolves as follows:

$$\dot{n}_t = \Gamma(a_t) + G(n_t) - z_t, \tag{1}$$

where $\Gamma(\cdot)$ represents the investment function for the natural resource, a_t is the investment in the natural resource, and z_t is the harvested level of the natural resource for use as an input into production.[8] The investment function $\Gamma(a_t) : \Re_+ \to \Re_+$ is assumed to be twice continuously differentiable, strictly increasing, and strictly concave with respect to the investment a_t; furthermore, it satisfies the Inada conditions.[9]

2.2 The household and the firms

We describe the representative household's preference as follows. The household obtains utility from consumption and from the natural resource. In particular, we assume that the household becomes happier as the quantity of the natural resource

[6]Following a lot of existing papers (e.g., Brander and Taylor 1997, and Elíasson and Turnovsky 2004), the following reproduction function satisfies the assumption:

$$G(n_t) = \Delta \times n_t \left(1 - \frac{n_t}{\bar{n}}\right),$$

where Δ is the intrinsic rate of growth of the resource. We will make use of this reproduction function in numerical examples.

[7]As for the investment a_t, López et al. (2007) commented that investments in natural resources comprise tree planting, fish replenishment including aquaculture investments, protection or cleanup of ecosystems, soil protection including terracing drainage, and agricultural fallowing.

[8]Unlike our model, the harvest of the natural resource is carried out according to the Schaefer harvesting function in some papers (e.g., Brander and Taylor 1998a and 1998b).

[9]Some studies introduce the natural resource sector including the investment in the natural resource by households (e.g., Hoagland et al., 2003 and López et al., 2007). López et al. (2007) assume that households can invest in the natural resource as in the current setting. Hoagland et al (2003) consider a more complicated natural resource sector, that is, the investment in the natural resource by households indirectly increases the size of the natural fish stock through the expansion of the area devoted to aquaculture.

increases. For instance, we suppose that people feel happier when the number of fish in own sea increases or when the number of trees in own forests and mountains increases. In addition, the used preference follows Economides and Philippopoulos (2008). In this economy, there are two final goods: one is produced by physical capital and labor according to the neoclassical production function per capita, $f(k)$, where k stands for the capital stock per capita; the other is produced by harvesting the natural resource according to the production function $h(z_t)$. The production function $h(\cdot)$ is strictly increasing, twice differentiable, and concave with respect to the harvested natural resource; furthermore, it satisfies the Inada conditions. We assume that all of the goods produced by the harvested renewable resource are exported. That is, the household does not consume the goods produced by the harvested natural resource.[10] Then, the preference of the household is expressed as follows:

$$U[0] = \int_0^\infty [u(c_t) + v(n_t)]e^{-\rho t}dt, \tag{2}$$

where $u(\cdot)$ and $v(\cdot)$ represent the instantaneous utility functions of private consumption c_t and the natural resource n_t, respectively, and ρ is the fixed rate of time preference. The instantaneous utility functions, $u(\cdot)$ and $v(\cdot)$, are twice continuously differentiable, strictly increasing, and strictly concave in terms of c_t, and n_t, respectively. In addition, these functions satisfy the Inada conditions.

In the small open economy, the world interest rate, r, is assumed to be constant. As profit maximization of the firms ensures that $r = f'(k)$, the domestic capital stock takes a constant value, k, and the wage rate also becomes constant, $w = f(k) - kf'(k)$.

By making use of the goods produced by the capital stock, the household has the option of either consuming the goods or investing in reproduction of the natural

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[10]When the household consumes the export commodities, the preference is written as follows:

$$U[0] = \int_0^\infty [u(c_t) + v(n_t) + \omega(\text{export goods})]e^{-\rho t}dt,$$

where $\omega(\cdot)$ represents the utility function of export goods consumption. Because the relative price of consumption commodities is exogenously given in a small open economy, this generalization does not change the essence of main finding obtained in this model.

resource. Then, the accumulation of the foreign asset, b_t is expressed as follows:

$$\dot{b}_t = rb_t + f(k) + (1 - \tau^y)ph(z_t) - c_t - (1 - \tau^a)a_t - Z, \tag{3}$$

where Z is the lump-sum transfer. Moreover, p shows the relative price of the exported good, measured by the price of the consumption good, which is exogenously given because of the set-up in the small open economy.

In the accumulation equation for the foreign asset (3), we consider two types of environmental policies. First, τ^a represents the constant rate of the investment subsidy. An increase in τ^a implies that the relative price of the investment in the natural resource decreases, which would further stimulate the investment. As the level of the natural resource is improved, the investment subsidy policy would be regarded as a regeneration policy such as a reforestation policy. Second, τ^y shows the constant income tax rate imposed only on the exportable income. It is likely to be one of the environmental protection policies targeting forest-based industry (or fisheries) because, when the rate of the export-income tax increases, the level of the harvested natural resource would decrease, which could protect the natural resource.[11]

Finally, the government is assumed to keep the following balanced budget:

$$Z = \tau^a a_t - \tau^y ph(z_t). \tag{4}$$

Note that when $Z > 0$, the government imposes a lump-sum tax, whereas when $Z < 0$, the government makes transfers.

The representative household maximizes its lifelong utility (2) subject to the evolution of the renewable resource (1) and the budget constraint (3). To solve the maximization problem, we constitute the current value Hamiltonian as follows:

$$H \equiv u(c_t) + v(n_t) + q_t \left\{ rb_t + f(k) + (1 - \tau^y)ph(z_t) - c_t - (1 - \tau^a)a_t - Z \right\} + \eta_t \left\{ \Gamma(a_t) + G(n_t) - z_t \right\}, \tag{5}$$

[11] Because we assume a small open economy, the result is the same even if the income tax is imposed not only on the export income but also on the rest of the income.

where η_t is the shadow value for the natural resource associated with (1) and q_t is the shadow value for the foreign assets associated with (3).

The first order conditions are:[12]

$$u'(c_t) = q_t, \tag{6a}$$

$$(1-\tau^y)q_t p h'(z_t) = \eta_t, \tag{6b}$$

$$\Gamma'(a_t)\eta_t = (1-\tau^a)q_t, \tag{6c}$$

$$r - \rho = -\frac{\dot{q}_t}{q_t}, \tag{6d}$$

$$\frac{v'(n_t)}{\eta_t} + G'(n_t) - \rho = -\frac{\dot{\eta}_t}{\eta_t}. \tag{6e}$$

Finally, the transversality conditions for the foreign asset and the natural resource are:

$$\lim_{t\to\infty} q_t b_t e^{-\rho t} = 0, \quad \text{and} \quad \lim_{t\to\infty} \eta_t n_t e^{-\rho t} = 0. \tag{6f}$$

2.3 Equilibrium dynamics

This subsection characterizes the equilibrium paths. Let us define a competitive equilibrium as follows.

Definition. *A competitive equilibrium is a sequence of allocation,* $\{c_t, b_t, n_t, z_t, a_t, k_t\}_{t=0}^{\infty}$*, such that, given the initial conditions* b_0*,* k_0*, and* n_0*, and a set of prices* $\{w,\ r,\ p\}$*, the representative household's utility is maximized, the firm's profits are maximized, the governmental budget constraint is balanced every time, and all markets are cleared.*

[12] A considerable number of existing papers assume that private agents do not take the motion of natural resources into account when optimizing their choices. Instead, to focus on the temporary impact of the environmental policies, we assume that there is no environmental externality; however, we confirmed that the main result in Proposition 2 is not changed even if the reproduction of the renewable resource, $G(n_t)$ is used for the externality and is not internalized.

We now turn to deriving the dynamic equations of this economy. First, from equations (6a) and (6d), we obtain:[13]

$$\frac{\dot{c}_t}{c_t} = -\frac{u'(c_t)}{c_t u''(c_t)}(r - \rho). \tag{7}$$

Assuming that $r = \rho$ in the small open economy, the level of consumption is constant over time. Hereafter, we omit the subscript t from consumption, and denote the constant level of consumption by $\bar{c}$.

Next, solving (6c) for η_t and substituting (6a) into it, we obtain the shadow price for the natural resource:

$$\eta_t = \frac{(1 - \tau^a) u'(\bar{c})}{\Gamma'(a_t)}. \tag{8}$$

Differentiating (8) with respect to time and substituting this equation into (6e), we obtain:

$$\frac{\dot{a}_t}{a_t} = -\frac{\Gamma'(a_t)}{a_t \Gamma''(a_t)} \left(r - G'(n_t) - \frac{v'(n_t)\Gamma'(a_t)}{(1 - \tau^a)\, u'(\bar{c})} \right) \equiv F(n_t, a_t, c_t, \tau^a), \tag{9}$$

where we note that $r = \rho$.

From equations (6b) and (6c), we obtain:

$$p h'(z_t) = \frac{1 - \tau^a}{(1 - \tau^y)\Gamma'(a_t)}. \tag{10}$$

Solving (10) for the harvested resource z_t yields:

$$z_t = z(a_t, \tau^a, \tau^y), \tag{11a}$$

where the derivatives are given by:

$$\frac{\partial z_t}{\partial a_t} = -\frac{\Gamma''(a_t) h'(z_t)}{\Gamma'(a_t) h''(z_t)} < 0, \quad \frac{\partial z_t}{\partial \tau^a} = -\frac{h'(z_t)}{(1 - \tau^a) h''(z_t)} > 0, \text{ and } \frac{\partial z_t}{\partial \tau^y} = \frac{h'(z_t)}{(1 - \tau^y) h''(z_t)} < 0.$$

Furthermore, because the functions $h(z_t)$ and $\Gamma(a_t)$ satisfy the Inada conditions, $z(a_t, \tau^a, \tau^y)$ has the following characteristics:

$$\lim_{a_t \to 0} z(a_t, \tau^a, \tau^y) = \infty, \quad \text{and} \quad \lim_{a_t \to \infty} z(a_t, \tau^a, \tau^y) = 0. \tag{11b}$$

[13]The additive separability of utility function is critical for the movement of consumption; therefore, in Section 5 we make use of the non-separable utility function so that the level of consumption is not constant over time.

Substituting equation (11a) into the evolution of the natural resource (1), we obtain the dynamic equation of the natural resource as follows:

$$\dot{n}_t = \Gamma(a_t) + G(n_t) - z(a_t, \tau^a, \tau^y) \equiv H(n_t, a_t, \tau^a, \tau^y). \tag{12}$$

Equations (9) and (12) constitute the dynamic system for (a_t, n_t) of the small open economy, given a steady-state level of consumption and the rates of the investment subsidy and the export-income tax.

3 Steady-state equilibrium

This section analyzes the existence and the stability of the steady-state equilibrium.[14] With the rate of time preference and the interest rate both being exogenously given constants in the small open economy, we require $r = \rho$ for our system to have a finite interior steady-state value for the marginal utility of consumption. Under the assumption, the level of consumption is constant over time as seen in (7).

Let us assume that an asterisk indicates the steady-state levels of the variables. Taking account of $F(n^*, a^*, \bar{c}, \tau^a) = 0$ and $H(n^*, a^*, \tau^a, \tau^y) = 0$ in the steady state, given consumption and the environmental policies we draw the phase diagram.

At first, we consider the shape of the $\dot{a}_t = 0$ locus. In this case, the slope of the $\dot{a}_t = 0$ locus is:

$$\left.\frac{da_t}{dn_t}\right|_{\dot{a}_t=0} = -\frac{F_n}{F_a}(< 0), \tag{13}$$

where the respective derivatives are:[15]

$$F_n = \frac{\Gamma'(a^*)}{\Gamma''(a^*)}\left(G''(n^*) + \frac{v''(n^*)(r - G'(n^*))}{v'(n^*)}\right)(> 0), \quad F_a = r - G'(n^*)(> 0).$$

In addition, as the level of the natural resource approaches infinity (zero), the level

[14] As Fullerton and Kim (2008) point out, stability analysis of the steady state is complicated due to the concavity of the reproduction function $G(n_t)$.

[15] As shown later, it always holds that $r > G'$ in the steady state.

of the investment in the natural resource approaches zero (infinity).[16] As depicted in Figure 1, $\dot{a}_t > (<)0$ in region above (under) the $\dot{a}_t = 0$ locus.

[Figure 1 around here]

Next, making use of $H(n^*, a^*, \tau^a, \tau^y) = 0$, we can depict the $\dot{n}_t = 0$ locus as the U-shaped curve in Figure 1. This is because, by totally differentiating (23*b*), given $\bar{c}^*$, τ^a, and τ^y, we obtain:

$$\left.\frac{da_t}{dn_t}\right|_{\dot{n}_t=0} = \frac{H_n}{H_a}. \tag{14}$$

where

$$H_n = G'(n^*), \quad H_a = \Gamma'(a^*) - \frac{\partial z(\cdot)}{\partial a}(> 0).$$

That is, it can be shown that the $\dot{n}_t = 0$ locus has the negative (positive) slope if $G'(n^*) < (>)0$. Furthermore, because $G(0) = 0$ as the level of the natural resource approaches zero, the level of the investment in the natural resource approaches a finite level, which satisfies $z(a^*, \tau^a, \tau^y) = \Gamma(a^*)$. Instead, because $G(\infty) = -\infty$ as the level of the natural resource goes to infinity, the level of the investment in the natural resource approaches infinity. It can be confirmed that $\dot{n}_t > (<)0$ in the region above (under) the $\dot{n}_t = 0$ locus.

Linearization of the dynamic equations (9) and (12) around the steady state yields:

$$\begin{pmatrix} \dot{a}_t \\ \dot{n}_t \end{pmatrix} = \begin{pmatrix} F_a & F_n \\ H_a & H_n \end{pmatrix} \begin{pmatrix} a_t - a^* \\ n_t - n^* \end{pmatrix} \equiv M \begin{pmatrix} a_t - a^* \\ n_t - n^* \end{pmatrix}. \tag{15}$$

The trace and the determinant of this system are given by:

$$\text{Tr(M)} \equiv F_a + H_n = r(> 0), \tag{16a}$$

$$\text{Det(M)} \equiv F_a H_n - F_n H_a = F_a H_a \left(\frac{H_n}{H_a} - \frac{F_n}{F_a} \right). \tag{16b}$$

Because our dynamic system involves one jumpable variable, a_t, and one predetermined variable, n_t, the economy has a saddlepoint property around the steady-state

[16] As confirmed later, the equation (9) in the steady state is given by $\frac{r-G'(n^*)}{\Gamma'(a^*)} = \frac{v'(n^*)}{(1-\tau^a)u'(\bar{c}^*)}$ where we assume that $r > G'(0)$. Because the level of consumption is constant, we can confirm that $n^* \to \infty$ as $a^* \to 0$ and $n^* \to 0$ as $a^* \to \infty$.

equilibrium if the sign of the determinant is negative. We can obtain the following lemma.

Lemma 1. *When $\tilde{n} < n^*$, the economy satisfies the saddle-path stability. Instead, when $\tilde{n} > n^*$, the steady state satisfies locally determinacy if the following inequality is satisfied.*

$$\frac{H_n}{H_a} < \frac{F_n}{F_a}, \tag{17}$$

Proof. Suppose that $\tilde{n} < n^*$ so that $H_n < 0$. In this case, from (16*b*) the sign of determinant is negative, showing that the steady state has a saddlepoint stability. Next, consider that $\tilde{n} > n^*$ such that $H_n > 0$. Using the condition (18), the determinant has the negative sign. We assume that this inequality holds in the following analysis. ■

From (13) and (14), the condition (18) states that the slope of the $\dot{a}_t = 0$ locus is steeper than that of the $\dot{n}_t = 0$ locus at the steady state. It is depicted that the dotted curve represented by the $\dot{a}_t = 0$ locus crosses the $\dot{n}_t = 0$ as shown in Figure 1. Specially, substituting each terms into this inequality, we can show that

$$r < \frac{v'(n^*)\Gamma'(a^*)}{(1-\tau^a)u'(\bar{c}^*)} + \frac{v''(n^*)\Gamma'(a^*)}{v'(n^*)\Gamma''(a^*)}\left(\Gamma'(a^*) - \frac{\partial z(\cdot)}{\partial a^*}\right). \tag{18}$$

From Lemma 1, the system has one stable root and one unstable root. We denote these eigenvalues as $\lambda_1 < 0$ and $\lambda_2 > 0$. These eigenvalues are:

$$\lambda_1 \equiv \frac{\mathrm{Tr(M)} - \sqrt{(\mathrm{Tr(M)})^2 - 4\mathrm{Det(M)}}}{2} < 0, \;\; \lambda_2 \equiv \frac{\mathrm{Tr(M)} + \sqrt{(\mathrm{Tr(M)})^2 - 4\mathrm{Det(M)}}}{2} > 0. \tag{19}$$

Thus, the solution of the linearized system can be written as follows:

$$n_t = n^* + D_1 e^{\lambda_1 t} + D_2 e^{\lambda_2 t}, \tag{20a}$$

$$a_t = a^* + D_1 \Upsilon_1 e^{\lambda_1 t} + D_2 \Upsilon_2 e^{\lambda_2 t}, \tag{20b}$$

where the entities of the eigenvectors, Υ_s $(s = 1, 2)$, are given by:

$$\Upsilon_1 \equiv \frac{\Gamma'(a^*)}{\Gamma''(a^*)}\left(\frac{G''(n^*) + \frac{v''(n^*)(r-G'(n^*))}{v'(n^*)}}{\lambda_1 + G'(n^*) - r}\right) < 0, \text{ and } \Upsilon_2 \equiv \frac{\Gamma'(a^*)}{\Gamma''(a^*)}\left(\frac{G''(n^*) + \frac{v''(n^*)(r-G'(n^*))}{v'(n^*)}}{\lambda_2 + G'(n^*) - r}\right).$$

Note that $\lambda_1 < 0$ and $\lambda_2 > \rho = r$. Because of the transversality condition, it must hold that $D_2 = 0$. From $(20a)$, we can show that $D_1 = n_0 - n^*$. Thus, the stable adjustment path is given by:

$$n_t = n^* + (n_0 - n^*)e^{\lambda_1 t}, \tag{21a}$$

$$a_t = a^* + \Upsilon_1(n_0 - n^*)e^{\lambda_1 t}. \tag{21b}$$

Next, let us derive the intertemporal solvency condition for this economy. Substituting $(11a)$ into (3) yields:

$$\dot{b}_t = rb_t + f(k) + (1-\tau^y)ph(z_t(a_t, \tau^a, \tau^y)) - \bar{c} - (1-\tau^a)a_t - Z. \tag{22a}$$

Linearizing the budget constraint $(22a)$ around the steady state under the balanced budget of the government (4) yields:

$$\dot{b}_t = \left(ph'(z^*)\frac{\partial z(a^*, \tau^a, \tau^y)}{\partial a^*} - 1\right)(a_t - a^*) + r(b_t - b^*). \tag{22b}$$

Substituting $(21a)$ and $(21b)$ into $(22b)$, we obtain the linearized solution of b_t for an initial stock of the foreign asset b_0.

$$b_t = b^* + \{b_0 - b^* + (n_0 - n^*)\Omega_1\Upsilon_1\}e^{rt} - (n_0 - n^*)\Omega_1\Upsilon_1 e^{\lambda_1 t}, \tag{22c}$$

where Ω_1 is given by:

$$\Omega_1 \equiv \frac{ph'(z^*)\frac{\partial z^*(\cdot)}{\partial a^*} - 1}{\rho - \lambda_1} < 0.$$

Because of the intertemporal solvency condition of the economy, the following equality must hold:

$$b_0 - b^* = -\Omega_1\Upsilon_1(n_0 - n^*). \tag{22d}$$

Then, we obtain the stable path for b_t as follows:

$$b_t = b^* - \Omega_1\Upsilon_1(n_0 - n^*)e^{\lambda_1 t}. \tag{22e}$$

Note that because both Ω_1 and Υ_1 take negative values, the level of the foreign asset moves in the opposite direction to the level of the natural resource along the stable path.

Finally, in order to express the steady-state equilibrium, we consider the economy starting at time T_j and corresponding to a policy set τ_j^a and τ_j^y. Moreover, the viable steady state is associated with the initial levels of the natural resource and the foreign asset n_{T_j} and b_{T_j}, respectively, at time T_j. Taking account of $\dot{n}_t = \dot{a}_t = \dot{b}_t = 0$ with the intertemporal solvency condition, a viable steady state j given by τ_j^a and τ_j^y, ($\bar{c}_j^*$, a_j^*, n_j^*, b_j^*) is determined as follows:

$$\frac{r - G'(n_j^*)}{v'(n_j^*)\Gamma'(a_j^*)} = \frac{1}{(1-\tau_j^a)u'(\bar{c}_j^*)}, \tag{23a}$$

$$G(n_j^*) = z(a_j^*, \tau_j^a, \tau_j^y) - \Gamma(a_j^*), \tag{23b}$$

$$rb_j^* + f(k) + ph(z_j(a_j^*, \tau_j^a, \tau_j^y)) = \bar{c}_j^* + a_j^*, \tag{23c}$$

$$b_{T_j} - b_j^* = -\Omega_1 \Upsilon_1 (n_{T_j} - n_j^*). \tag{23d}$$

4 The effects of government policy

In this section, we analyze how policy changes affect the economy. It is well known that in a closed economy, a temporary policy change influences the economy but, once the policy is removed, the system gradually returns to the original steady-state equilibrium. However, in small open economy models such as the present analysis, it is shown that the economy does not return to its original steady-state equilibrium.[17] Our main result is that when the rate of investment subsidy or the export-income tax temporarily increases, the level of the natural resource in the new steady-state equilibrium always decreases relative to its original level.

Suppose that the economy is initially in the steady-state equilibrium in which $\tau_j^a = \tau_0^a$ and $\tau_j^y = \tau_0^y$. We denote this original steady state with the subscript 0:

$$n_0 = n_0^* = N(\bar{c}_0^*, \tau_0^a, \tau_0^y), \quad N_{\bar{c}} > 0,\ N_{\tau^a} > 0,\ N_{\tau^y} > 0. \tag{24a}$$

$$a_0 = a_0^* = A(\bar{c}_0^*, \tau_0^a, \tau_0^y),\ A_{\bar{c}} > (<) 0 \text{ if } G' < (>) 0,\ A_{\tau^a} > 0 \text{ if } G' < 0,\ A_{\tau^y} < 0 \text{ if } G' > 0. \tag{24b}$$

[17] See, for example, Turnovsky (1997) and Schubert and Turnovsky (2002).

$$b_0 = b_0^* = B(\bar{c}_0^*, \tau_0^a, \tau_0^y), \tag{24c}$$

$$\bar{c}_0 = \bar{c}_0^* = C(\tau_0^a, \tau_0^y, b_0, n_0), \quad C_{\tau^a} < 0,\ C_{\tau^y} < 0,\ C_{b_T} > 0,\ C_{b_T} > 0. \tag{24d}$$

Here, we assume the following condition to obtain the signs of the derivative ($24d$):[18]

$$r < \frac{v'(n^*)\Gamma'(a^*)}{(1-\tau^a)u'(\bar{c}^*)} + \frac{r\left(\Gamma'(a^*) - \frac{\partial z(\cdot)}{\partial a}\right)}{(r - G'(n^*) - \lambda_1)(r - \lambda_1)} \frac{\Gamma'(a^*)}{\Gamma''(a^*)} \left(\frac{v''(n^*)}{v'(n^*)} + G''(n^*)\right). \tag{25}$$

Note that this condition (25) corresponds to the stability condition (18) when λ_1 approaches zero. Furthermore, as $\frac{r(r-G'(n^*))}{(r-\lambda_1)(r-\lambda_1-G'(n^*))} < 1$, this condition is stricter than (18).

4.1 Permanent effects

In this subsection, we examine the effects of permanent changes in environmental policies on the natural resource in the long run. Conducting a comparative statics analysis, we obtain the following.

Proposition 1. *A permanent increase in the rate of the investment subsidy increases (decreases) the steady-state level of the natural resource if the following inequality is satisfied:*

$$\frac{\tau^a}{1-\tau^a} < (>) \left(\frac{1}{\beta} - 1\right) \frac{\bar{c}^*}{\sigma p h(z^*)}, \quad \frac{1}{\beta} - 1 \equiv -\frac{h'' h}{(h')^2} (> 0),\ \sigma \equiv -\frac{u''(\bar{c})\bar{c}}{u'(\bar{c})} (> 0) \tag{26}$$

where $0 < \beta < 1$ and $\sigma > 0$.

A permanent increase in the rate of the export-income tax increases (decreases) the steady-state level of the natural resource if the following inequality is satisfied:

$$\frac{\tau^y}{1-\tau^y} < (>) \frac{1-\eta}{\sigma} \times \frac{\bar{c}^*}{a^*}, \quad 1 - \eta \equiv -\frac{\Gamma'' a^*}{\Gamma'} (> 0) \tag{27}$$

Proof. See Appendix B. ■

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[18] Using the following procedure, we derive the equations ($24a$) – ($24d$), where $T_j = 0$. From ($23a$) and ($23b$), we obtain ($24a$) and ($24b$). Furthermore, substituting ($24b$) into ($23c$) yields ($24c$). Finally, incorporating ($24c$) into ($23d$), we obtain ($24d$). We derive the equations explicitly in Appendix A.

We now explain the intuition behind this proposition.[19] Figures 2 and 3 illustrate the effects of the investment subsidy and the export-income tax, respectively. Note that Tem (or Per) in these figures show the cases that the environmental policies change temporarily (or permanently).

First, we examine the effects of the investment subsidy policy where E_0 is the original steady state. By using the equation ($23a$), we can show how the downward sloping $\dot{a}_t = 0$ locus moves as a result of the permanent increase in the rate of investment subsidy:

$$\left.\frac{\partial a_j^*}{\partial \tau_j^a}\right|_{\dot{a}_t=0,\ n_j^*=\text{constant}} = \frac{a_j^*}{1-\eta}\left(\underbrace{\frac{\sigma C_{\tau^a}}{\bar{c}_j^*}}_{\#1} + \underbrace{\frac{1}{1-\tau^a}}_{\#2}\right). \tag{28a}$$

Note that C_{τ^a} has a negative sign, which represents the negative impact of the investment subsidy policy on private consumption; that is, the decrease in the cost of the investment due to the investment subsidy reduces the demand for consumption goods.[20] The equation ($28a$) consists of the indirect effect that occurs through a change in consumption, given by the term #1, and the direct effect, given by the term #2. The term #1 takes a negative value and the term #2 takes a positive value. Therefore, if the effect of the term #2 dominates the term #1, the $\dot{a}_t = 0$ locus moves upward. Figure 2 shows this case.

[19]Since the conditions (26) and (27) are complicated, it would be hard for readers to understand the values given in (26) and (27). To help the understanding of readers, we now use some specific functional forms and parameter values in numerical examples of Section 5.1: $\beta = \eta = 0.5$, $p = 1.25$ and $\sigma = 1.75$ so that $p\sigma \simeq 2.2$ and $\frac{1-\eta}{\sigma} \simeq 0.29$. As a result, each condition is given by:

$$(26)\text{: } \frac{\tau^a}{1-\tau^a} < (>) \frac{\bar{c}^*}{2.2h(z^*)}, \quad (27)\text{: } \frac{\tau^y}{1-\tau^y} < (>) \frac{\bar{c}^*}{0.29a^*}$$

If the rate of investment subsidy or export-income tax is small enough, then we can show that the permanent increase in each rate increases the level of natural resource in the long run. In particular, the numerical examples will give the case where the permanent increase in the rate of investment subsidy or export-income tax, from $\tau_0^a = 0$ (or $\tau_0^y = 0$) to $\tau_1^a = 0.2$ (or $\tau_1^y = 0.2$) leads to the larger level of natural resource as in Figures 2 and 3.

[20]See the equation ($A.9a$) in Appendix A.

On the other hand, the permanent increase in the rate of the investment subsidy always shifts the $\dot{n}_t = 0$ locus upward:

$$\left.\frac{\partial a_j^*}{\partial \tau_j^a}\right|_{\dot{n}_t=0,\ n_j^*=\text{constant}} = \frac{\frac{\partial z(\cdot)}{\partial \tau_j^a}}{\Gamma'(a_j^*) - \frac{\partial z(\cdot)}{\partial a_j^*}}(>0). \tag{28b}$$

Taking account of (28a) and (28b), as the $\dot{n}_t = 0$ locus shifts upward, the extent of the change of the $\dot{a}_t = 0$ locus determines the direction of the impact on the natural resource. When σ and τ^a take sufficiently small values, then the effect of the term #1 relatively becomes weak and, thus, the $\dot{a}_t = 0$ locus moves upward, as shown by Figure 2. Indeed, when σ and τ^a take sufficiently small values, the level of the natural resource increases. In contrast, when σ and τ^a take sufficiently large values, then the effect of the term #1 relatively becomes strong and, thus, the $\dot{a}_t = 0$ locus moves downward. This decreases the level of the natural resource.

Moreover, we characterize changes in the foreign asset over time. From (23d), when the level of the natural resource in the new steady-state equilibrium is greater than that in the initial period, the level of the foreign asset in the steady-state equilibrium is smaller than that in the initial period and vice versa. That is, if $n_j^* > (<) n_0^*$ under a policy set τ_j^a and τ_j^y, it always holds that $b_j^* < (>) b_0^*$. This negative relationship between the foreign asset and the natural resource is depicted in Figure 2(b).[21] As a result, Figure 2(b) shows that an increase in the rate of the investment subsidy decreases the level of the foreign asset from b_0^* to b_1^* where $n_1^* > n_0^*$. This is because the increase in the investment, as a result of the subsidy, decreases exports and, thus, the level of the foreign asset.[22]

Second, we examine the effect of a permanent increase in the rate of the export-income tax on the natural resource in Figure 3. Unlike the case of the investment

[21] The negative relationship also applies to the case of the export-income tax rate, as shown in Figure 3(b).

[22] Instead, suppose that the $\dot{a}_t = 0$ locus moves downward where the $\dot{n}_t = 0$ locus always moves upward. In this case, the level of the natural resource decreases over time as a result of the permanent increase in the rate of the investment subsidy. However, we omit this case to focus on the interesting case.

subsidy policy, there is no direct effect on the $\dot{a}_t = 0$ locus produced by the export-income tax. Thus, any permanent increase in the rate of the export-income tax moves the $\dot{a}_t = 0$ locus downward:

$$\left.\frac{\partial a_j^*}{\partial \tau_j^y}\right|_{\dot{a}_t=0,\ n_j^*=\text{constant}} = \frac{\sigma a_j^* C_{\tau^y}}{(1-\eta)\bar{c}_j^*} < 0. \tag{29a}$$

On the other hand, the $\dot{n}_t = 0$ locus moves downward:

$$\left.\frac{\partial a_j^*}{\partial \tau_j^a}\right|_{\dot{n}_t=0,\ n_j^*=\text{constant}} = \frac{\frac{\partial z(\cdot)}{\partial \tau_j^y}}{\Gamma'(a_j^*) - \frac{\partial z(\cdot)}{\partial a_j^*}} (< 0). \tag{29b}$$

From ($29a$), the downward shift of the $\dot{a}_t = 0$ locus is smaller as the values of σ and η are smaller. Then, a permanent increase in the rate of the export-income tax increases the level of the natural resource. As Figure 3(a) shows, after the investment in the natural resource initially jumps from E_0 to I, the level of the natural resource increases toward the new steady state, E_1.[23] In this case, from ($23d$), the level of the foreign asset decreases from E_0 to E_1 in Figure 3(b).

4.2 Temporary effects

In the previous subsection, we examined the impacts of the permanent environmental policies on the natural resource. However, where environmental policies have been applied in practice, such as in Indonesia and Malaysia, all environmental policies have been implemented temporarily. As a result, it is more important to investigate the effects of temporary changes of the environmental policies on the natural resource over time, as well as the long-run effects.

In the present model, as confirmed in (7), the consumption growth rate is zero; that is, after the initial jump of consumption, the level of consumption is constant over time as long as the given conditions do not unanticipatedly change. When the government announces the initial changes of the policy instruments from the original

[23]Because the $\dot{a}_t = 0$ and $\dot{n}_t = 0$ loci move downward in the initial period, it can be easily confirmed that the initial jump of the investment in the natural resource is always downward, as confirmed in Figure 3(a).

levels to new levels, the household in the small economy changes its consumption behavior only at the initial time. In the case of temporary policy changes, after some duration, $[0, T]$, has passed, the policy instruments permanently return to the original level. However, under the assumption of perfect foresight, the level of consumption does not go back to its original level after its initial jump because the household can initially anticipate the policy change at time T; that is, the consumption level stays there permanently so as to sustain the intertemporal solvency condition. As a result, the temporary policy changes have long-run impacts on the level of the natural resource.

The effects of the temporary environmental policies on the natural resource can be summarized as follows.

Proposition 2. *The temporary increase in the rate of investment subsidy or the export-income tax always lowers the level of the natural resource in the long run.*

Proof. See Appendix C. ■

Let us explain the intuition of this proposition why the temporary policies decrease the level of the natural resource in the long run. The key element is the direction of the initial jump in consumption, showing that both policies have negative impact on consumption in the initial period. In detail, in the case of the investment subsidy policy, the increase in the relative price of consumption commodity compared with the investment in the natural resource lowers the demand in consumption, whereas in the case of the export-income tax, the decrease in income lowers that. As a result, the initial jump of consumption is downwards and thereafter the consumption stays there in the long run.[24]

Remembering that the level of consumption decreases due to these policies, let us suppose that the economy initially stays at the steady-state equilibrium. Suppose further that government unanticipatedly raises the rate of investment subsidy or export-income tax at the initial time, leading to the decrease in consumption at

[24] The negative relation between these policies and consumption is shown by $(A.9a)$ and $(A.9b)$ in Appendix A.

the initial period. When only the negative impact on consumption is considered, equation (9) states that the investment growth rate becomes positive. Namely, the current investment is substituted with the future investment, which delays the investment in the natural resource such as the tree planting. Consequently, because only the negative impact of consumption stays in the long run after the temporary environmental policy is completed, the level of the natural resource decreases relative to the original level.

Finally, we want to confirm the whole economy's evolution by using the phase diagram. At first, we consider the case of investment subsidy policy. We can show how the $\dot{n}_t = 0$ and the $\dot{a}_t = 0$ loci move when the rate of investment subsidy increases. Using (28b), we can show that the $\dot{n}_t = 0$ locus moves upward to $\dot{n}_t = 0$ $(t < T)$ and then returns to its original position if the rate of the investment subsidy policy returns to its original level. From (28a), if the indirect impact is dominated by the direct effect, the $\dot{a}_t = 0$ locus moves upward to $\dot{a}_t = 0$ $(t < T)$ at the initial time as shown in Figure 2(a). However, even if the government returns the investment subsidy to its original level, the $\dot{a}_t = 0$ locus does not go back to its original position because the level of consumption remains constant after the initial jump. Therefore, the indirect impact of the investment subsidy shown by #1 in (28a) remains even after the government policy is removed. This indicates that the $\dot{a}_t = 0$ locus moves downward relative to its original position in the long run, as shown in Figure 2(a).

When an increase in the investment subsidy is temporary, the upward jump of the investment in the natural resource is smaller than the jump when the policy change is permanent. That is, the economy jumps from E_0 to I' at the initial time (see Figure 2(a)).[25] After the jump, the level of the natural resource increases toward

[25] The size of the initial jump is affected by the expected duration of the temporary policy. For instance, when the duration of the policy change is short, the initial jump of investment in the natural resource can be below the level of $\hat{a}$. In this case, the level of the natural resource decreases along an unstable path; when the rate of investment subsidy returns to the original level at time T, the level of the natural resource further decreases along a stable path as in Figure 2(a). However, we omit this case to focus on the interesting case. Alternatively, if the initial point of jump I' were

I'' along the unstable path. When the economy reaches I'', the level of the natural resource begins to decrease; the economy is still on the unstable path. The economy reaches I''' when the government returns to the original policy at time T. After this policy reversion, the economy follows the stable saddle path to reach the new steady state, E_2. In regard to the changes in the foreign assets, we can show the following. Considering that $n_2^* < n_T$, from $(23d)$ it holds that $b_2^* > b_T^*$. Figure 2(b) shows that the level of the foreign asset decreases from E_0 toward L and, thereafter, it increases through L'. After the subsidy policy is removed at the point L', the level of the foreign asset increases from L' to E_2.[26]

Next, let us focus on the case of the export-income tax rate. As confirmed in the last subsection, when the rate of the export-income tax increases, the $\dot{n}_t = 0$ and the $\dot{a}_t = 0$ loci move downward. After the rate of the export-income tax policy returns to its original level, the $\dot{n}_t = 0$ locus returns to its original position, while the $\dot{a}_t = 0$ locus will be located below its original position. Hence, after the initial jump of the investment from E_0 to I', the level of the natural resource increases along the unstable path. However, after the rate of the export-income tax returns to its original level, the level of the natural resource decreases over time. To the end, the level of the natural resource in the new steady-state equilibrium shown by E_2 is lower than its original level in E_0. In Figure 3, we can confirm the movement in the foreign assets which correspond to the changes in the natural resource.

5 Discussion

In the last section, we obtained Proposition 2, which would be interesting beyond our expectation because the temporary environmental policies always harm the renew-

above I, the economy would move upper right, which means that the economy would move along the unstable path at any time. Therefore, the economy cannot follow the stable path at the period T, implying that the economy cannot arrive at the steady state.

[26]Because the level of consumption decreases in the long run, from $(B.1)$ it holds that $b_2^* > b_0$ under $G' < 0$.

able natural resource. In this section, we further support the finding of Proposition 2 in two ways. First, we make use of the numerical examples to see the quantitative impacts of environmental policies. Second, using the non-separable utility function rather than the separable one (2), we suppose the more complicated inter-connection between consumption and the natural resource.

5.1 Numerical examples

The purpose to use the numerical method is mainly to see the quantitative impacts of environmental policies. In addition, our interest is to provide numerical confirmation of our results in Proposition 2, and furthermore Figures 2 and 3 mathematically correct.[27]

At first, we specify the production functions and the utility functions. The production of the single homogeneous good is represented by the production process $f(k) = \xi_1 k^{\alpha}$ and the production function with the harvested natural resource is $h(z_t) = \xi_2 z_t^{\beta}$ where $\xi_1 > 0$, $\xi_2 > 0$, $0 < \alpha < 1$ and $0 < \beta < 1$. The utility functions are given by $u(c_t) = c_t^{1-\sigma}/(1-\sigma)$ and $v(n_t) = \chi \log(n_t)$ where $\sigma > 0$ and $\chi > 0$.

In the natural resource sector, following Brander and Taylor (1997) and Elíasson and Turnovsky (2004), we use the following reproduction function:

$$G(n_t) = \Delta n_t \left(1 - \frac{n_t}{\bar{n}}\right), \quad \Delta > 0. \tag{30}$$

Finally, the investment function in the natural resource is specified as:

$$\Gamma(a_t) = \xi_3 a_t^{\eta}, \quad \xi_3 > 0, \quad 0 < \eta < 1. \tag{31}$$

[27] We make use of Matlab 2014b.

The parameters under our simulations are summarized as follows:

Production parameters: $\alpha = 0.3$, $\beta = 0.5$, $\xi_1 = 2$, $\xi_2 = 1.5$.

Taste parameters: $\sigma = 1.75$, $\chi = 0.8$,

Natural sectors parameters: $\bar{n} = 1.5$, $\Delta = 0.5$, $\eta = 0.5$, $\xi_3 = 0.2$.

Price and tax rates: $p = 1.25$, $\tau_0^a = \tau_0^y = 0$, $r = (\rho =)0.15$.

Initial values: $b_0 = 1$, $n_0 = 1.407$.

By setting $\Delta = 0.5$ and $\bar{n} = 1.5$, we have $G'(0.75) = 0$ and $G'' = -1/\bar{n}$. In particular, we assume that the natural resources moves in the range that $G' < 0$, which means that from Lemma1, the economy always satisfies the saddle-path stability. The price $p = 1.25$ supposes the economy that the export good is more expensive than the domestic one. Finally, the original rates of taxes are zero; instead, when the policy changes, the tax rate is assumed to be $\tau_1^a = 0.2$ (or $\tau_1^y = 0.2$).

Figures 4(a), 4(b) and 5 show the quantitative effects of the investment subsidy and the export-income tax. Figure 4(a) depicts the permanent effect of the investment subsidy. Figure 4(b) depicts the temporary effect of the investment subsidy. Figure 5 depicts the permanent and the temporary effects of the export-income tax.[28] Furthermore, notice that the signs such as E_0 and I in these figures are the same as those in Figure 2 and 3; instead, the square shows the position of initial economy and the sign (X) shows the end point of the economy.

First, it is shown that Figures 4(a), 4(b) and 5 are qualitatively the same as Figures 2 and 3.

Second, we can confirm the main findings in Proposition 2, that is, the level of natural resource at the new steady state E_2 is less than the original level at E_0, which means that the temporary increase in the rates of investment subsidy and the export-income tax harms the renewable natural resource in the long run. Furthermore, we can confirm the key downward jump of consumption that leads to Proposition 2.

[28]We divided into Figure 4(a) and 4(b) because the points E_1 in Figure 4(a) and I'' in Figure 4(b) are very close so that the readers may be confused. We used other parameter set; however, this relationship was always seen.

More concretely, the level of consumption jumps downward from $c_0^* = 5.6907$ to $c_2^* = 5.6903$ in the case of investment subsidy, and from $c_0^* = 5.6907$ to $c_2^* = 5.6514$ in the case of export-income tax.

Finally, we can see the quantitative impacts of environmental policies. When the rate of investment subsidy increases to $\tau_1^a = 0.2$, from Figures 4(a) and 4(b) we can show that $n_1^* = 1.443$ and $n_2^* = 1.406$. In particular, the temporary impact of investment subsidy on the natural resource would be quantitatively small, that is, the distance between n_0^* and n_2^* is very close, which leads to the similar relationship of the foreign assets, $b_0^* = 1$ and $b_2^* = 1.001$. Even if the rate of investment subsidy further increases to $\tau_1^a = 0.5$, each level of natural resource is given by $n_0^* = 1.407$, $n_1^* = 1.478$ and $n_2^* = 1.403$. In the case of export-income tax, Figure 5 shows that $n_0^* = 1.407$, $n_1^* = 1.468$ and $n_2^* = 1.405$ at $\tau_1^y = 0.2$; instead, when $\tau_1^y = 0.5$, we can show that $n_1^* = 1.499$ and $n_2^* = 1.395$.

5.2 Non-separable utility function

In the baseline model, we make use of the additive separable utility function given in (2) for the tractability, which may be critical to obtain the main findings. Therefore, in this subsection we use a more general utility function as follows:

$$U[0] = \int_0^\infty u(c_t, n_t) e^{-\rho t} dt. \tag{32}$$

In this case, from the first-order condition of consumption we can derive the following:

$$c_t = c(\bar{q}, n_t). \tag{33}$$

Because the level of natural resource is not fixed over time, the level of consumption is not constant unlike the baseline model. However, importantly, the shadow value for the foreign assets is still constant over time, that is, $\dot{q}_t/q_t = 0$ under $r = \rho$. Therefore, the extended model is the same as the baseline model in the sense that the shadow value q_t is constant along time.

We derive the dynamic equation of the investment in the natural resource as follows:

$$\text{Non-separable utility: } \frac{\dot{a}_t}{a_t} = -\frac{\Gamma'(a_t)}{a_t\Gamma''(a_t)}\left(r - G'(n_t) - \frac{u_n(c(\bar{q}, n_t), n_t)\Gamma'(a_t)}{(1-\tau^a)\bar{q}}\right). \tag{34a}$$

We can see the constant shadow value $\bar{q}$ in (34a), which expects that when the temporary shock arises, the new steady state does not coincide with the original steady state where the dynamic equation of the renewable natural resource is identical to (1). In particular, it may be useful to rewrite (9) as follows:

$$\text{Separable utility: } \frac{\dot{a}_t}{a_t} = -\frac{\Gamma'(a_t)}{a_t\Gamma''(a_t)}\left(r - G'(n_t) - \frac{v'(n_t)\Gamma'(a_t)}{(1-\tau^a)\bar{q}}\right). \tag{34b}$$

We can confirm that the difference between (34a) and (34b) is $u_n(c(\bar{q}, n_t), n_t)$ under the non-separable utility and $v'(n_t)$ under the separable utility. Therefore, noting that $v''(n_t) < 0$, the following assumption of decreasing marginal utility leads to the qualitatively identical dynamic behavior of the investment in the natural resource under the constant shadow value $\bar{q}$:

$$\frac{\partial u_n(c(\bar{q}, n_t), n_t)}{\partial n} = \frac{u_{nc}(\cdot)^2}{u_{cc}(\cdot)}\left(\frac{u_{nn}(\cdot)u_{cc}(\cdot)}{u_{nc}(\cdot)^2} - 1\right) (< 0). \tag{35}$$

Note that the concavity of utility function leads to the negative sign of (35). Therefore, our main findings in Lemma 1 and Proposition 2 still hold. For instance, F_n has a positive sign under (35), which leads to Lemma 1.[29] That is, when $\tilde{n} < n^*$, the steady-state equilibrium has the saddlepoint stability; instead, when $\tilde{n} > n^*$, we can see the saddle-path stability under (18). Furthermore, following the similar procedure in Appendix C, we can obtain Proposition 2 under (35), that is, the temporary environmental policies always harm the renewable natural resource in the long run if the marginal utility of the natural resource decreases in the natural resource.

[29] The slope of the $\dot{a}_t = 0$ locus is $\frac{da_t}{dn_t}\big|_{\dot{a}_t=0} = -\frac{F_n}{F_a}$:

$$F_n = \frac{\Gamma'(a^*)}{\Gamma''(a^*)}\left(G''(n^*) + \frac{\partial u_n(c(\bar{q}, n^*), n^*)}{\partial n}\frac{(r - G'(n^*))}{\bar{q}}\right), \quad F_a = r - G'(n^*),$$

6 Conclusion

In this paper, we have presented a dynamic model of a small open economy with a renewable resource. Our main results are that when the rate of an investment subsidy or an export-income tax temporarily increases, the level of the natural resource always decreases in the long run. On the other hand, when permanent increases in these policies are realized, the long-run effects of the environmental policies on the natural resource can be positive. For instance, permanent increases in the investment subsidy or export-income tax can increase the level of the natural resource when the rate of investment subsidy or export-income tax is plausibly set.

We consider that the findings in this paper have some important policy implications in this field. Governments in developing countries are interested in conservation of renewable resources; instead, they have not found the stylized environmental policies. In particular, the environmental policies conducted in Indonesia, Malaysia and the Philippines did not lead to great results. Based on our findings, the reason that these policies was not successful lies in implementation term of environmental policies; that is, the short-term implementation of environmental policies does not bring us any success in the long run; on the contrary, it harms the renewable resources. As given in Proposition 1, when government sets the plausible rate of investment subsidy or the export-income tax and permanently conducts the environmental policies, the long-run level of renewable resource would increase.

Acknowledgments

We are grateful to Jun-ichi Itaya, Noritaka Kudoh, Kazuo Mino, Yasuhiro Takarada, Syunsuke Managi, and seminar participants at The Research Institute of Economy, Trade, and Industry (RIETI) and the Otaru University of Commerce.

Appendices

Appendix A.

Derivation of $(24a)-(24d)$**:**

Using equations $(23a)-(23d)$, we derive $(24a)-(24d)$.[30] First, from $(23b)$, we can show that:

$$a_j^* = \Pi(n_j^*, \tau_j^a, \tau_j^y), \tag{A.1}$$

where the respective derivatives are:

$$\Pi_n \equiv \frac{\partial a_j^*}{\partial n_j^*} = -\frac{G'(n_j^*)}{\Gamma'(a_j^*) - \frac{\partial z_j^*(\cdot)}{\partial a_j^*}} > (<)0, \quad \text{if} \quad G' < (>)0,$$

$$\Pi_{\tau^a} \equiv \frac{\partial a_j^*}{\partial \tau_j^a} = \frac{\frac{\partial z_j^*(\cdot)}{\partial \tau_j^a}}{\Gamma'(a_j^*) - \frac{\partial z_j^*(\cdot)}{\partial a}} > 0,$$

$$\Pi_{\tau^y} \equiv \frac{\partial a_j^*}{\partial \tau_j^y} = \frac{\frac{\partial z_j^*(\cdot)}{\partial \tau_j^y}}{\Gamma'(a_j^*) - \frac{\partial z_j^*(\cdot)}{\partial a_j^*}} < 0.$$

Next, substituting $(A.1)$ into $(23a)$ yields:

$$n_j^* = N(\bar{c}_j^*, \tau_j^a, \tau_j^y), \tag{A.2}$$

where we can show that:

$$N_{\bar{c}} \equiv \frac{\partial n_j^*}{\partial \bar{c}_j^*} = \frac{1}{W}\frac{u''(\bar{c}_j^*)}{u'(\bar{c}_j^*)} > 0,$$

$$N_{\tau^a} \equiv \frac{\partial n_j^*}{\partial \tau_j^a} = -\frac{1}{W}\frac{\Gamma'(a_j^*)}{(1-\tau_j^a)\left(\Gamma'(a_j^*) - \frac{\partial z_j^*(\cdot)}{\partial a_j^*}\right)} > 0,$$

$$N_{\tau^y} \equiv \frac{\partial n_j^*}{\partial \tau_j^y} = -\frac{1}{W}\frac{\Gamma''(a_j^*)}{\Gamma'(a_j^*)}\Pi_{\tau_j^y} > 0,$$

where W is:

$$W \equiv \frac{G''}{r-G'} - \frac{\Gamma''}{\Gamma'\left(\Gamma' - \frac{\partial z(\cdot)}{\partial a}\right)}\left[r - \frac{v'\Gamma'}{(1-\tau_j^a)u'} - \frac{v''\Gamma'}{v'\Gamma''}\left(\Gamma' - \frac{\partial z(\cdot)}{\partial a^*}\right)\right] < 0. \tag{A.3}$$

Note that, from (18), the sign of M takes a negative value.

[30] We consider that the initial time is time T in Appendix A. Thus, taking account of the initial time zero rather than T, equations derived in Appendix A correspond to $(24a)--(24d)$.

Now, substituting $(A.2)$ into $(A.1)$ yields:

$$a_j^* = \Pi(N(\bar{c}_j^*, \tau_j^a, \tau_j^y), \tau_j^a, \tau_j^y) \equiv A(\bar{c}_j^*, \tau_j^a, \tau_j^y), \tag{A.4}$$

where:

$$A_{\bar{c}} \equiv \frac{\partial a_j^*}{\partial \bar{c}_j^*} = \Pi_n N_{\bar{c}} > (<) 0, \quad \text{if } \; G' < (>) 0,$$

$$A_{\tau^a} \equiv \frac{\partial a_j^*}{\partial \tau^a} = \Pi_n N_{\tau^a} + \Pi_{\tau^a} > 0, \; \text{ if } G' < 0,$$

$$A_{\tau^y} \equiv \frac{\partial a_j^*}{\partial \tau^y} = \Pi_n N_{\tau^y} + \Pi_{\tau^y} < 0, \; \text{if } G' > 0.$$

Hence, equation $(23c)$ can be rewritten as:

$$rb_j^* + f(k) + ph(z_j^*(A(\bar{c}_j^*, \tau_j^a, \tau_j^y), \tau_j^a, \tau_j^y)) = \bar{c}_j^* + A(\bar{c}_j^*, \tau_j^a, \tau_j^y).$$

Then, we can obtain the following:

$$b_j^* = B(\bar{c}_j^*, \tau_j^a, \tau_j^y). \tag{A.5}$$

where each derivative is given by:

$$B_{\bar{c}} \equiv \frac{\partial b_j^*}{\partial \bar{c}_j^*} = \frac{1}{r} \left\{ A_{\bar{c}} \left(1 - ph'(z_j^*) \frac{z_j^*(\cdot)}{\partial a_j^*} \right) + 1 \right\}, \tag{A.6a}$$

$$B_{\tau^a} \equiv \frac{\partial b_j^*}{\partial \tau_j^a} = \frac{1}{r} \left\{ -ph'(z_j^*) \left(A_{\tau^a} \frac{\partial z_j^*(\cdot)}{\partial a_j^*} + \frac{\partial z_j^*(\cdot)}{\partial \tau_j^a} \right) + A_{\tau^a} \right\}, \tag{A.6b}$$

$$B_{\tau^y} \equiv \frac{\partial b_j^*}{\partial \tau_j^y} = \frac{1}{r} \left\{ -ph'(z_j^*) \left(A_{\tau^y} \frac{\partial z_j^*(\cdot)}{\partial a_j^*} + \frac{\partial z_j^*(\cdot)}{\partial \tau_j^y} \right) + A_{\tau^y} \right\}. \tag{A.6c}$$

Finally, substituting $(A.5)$ and $(A.2)$ into $(23d)$ yields:

$$B(\bar{c}_j^*, \tau_j^a, \tau_j^y) - b_{T_j} = \Omega_1 \Upsilon_1 \left\{ n_{T_j} - N(\bar{c}_j^*, \tau_j^a, \tau_j^y) \right\}. \tag{A.7}$$

Thus, consumption can be determined by:

$$\bar{c}_j^* = C(\tau_j^a, \tau_j^y, b_{T_j}, n_{T_j}), \tag{A.8}$$

where we can show that:

$$C_{\tau^a} \equiv \frac{\partial \bar{c}_j^*}{\partial \tau_j^a} = -\frac{B_{\tau^a} + \Omega_1 \Upsilon_1 N_{\tau^a}}{B_{\bar{c}} + \Omega_1 \Upsilon_1 N_{\bar{c}}} < 0, \tag{A.9a}$$

$$C_{\tau^y} \equiv \frac{\partial \bar{c}_j^*}{\partial \tau_j^y} = -\frac{B_{\tau^y} + \Omega_1 \Upsilon_1 N_{\tau^y}}{B_{\bar{c}} + \Omega_1 \Upsilon_1 N_{\bar{c}}} < 0, \tag{A.9b}$$

$$C_{b_T} \equiv \frac{\partial \bar{c}_j^*}{\partial b_{T_j}} = \frac{1}{B_{\bar{c}} + \Omega_1 \Upsilon_1 N_{\bar{c}}} > 0, \tag{A.9c}$$

$$C_{n_T} \equiv \frac{\partial \bar{c}_j^*}{\partial n_{T_j}} = \frac{\Omega_1 \Upsilon_1}{B_{\bar{c}} + \Omega_1 \Upsilon_1 N_{\bar{c}}} > 0. \tag{A.9d}$$

The sign of the denominator in $(A.9a) - (A.9d)$ is positive:

$$B_{\bar{c}} + \Omega_1 \Upsilon_1 N_{\bar{c}}$$
$$= \frac{1}{r}\left\{1 - N_{\bar{c}} \frac{1 - ph' \frac{\partial z(\cdot)}{\partial a}}{\Gamma' - \frac{\partial z(\cdot)}{\partial a}} \left(G' - \frac{\Gamma'}{\Gamma''}\left(G'' + \frac{v''(r - G')}{v'}\right) \frac{r\left(\Gamma' - \frac{\partial z(\cdot)}{\partial a}\right)}{(r - G' - \lambda_1)(r - \lambda_1)}\right)\right\},$$

where $N_{\bar{c}} > 0$.

Finally, using $(23a)$, we can show that:

$$B_{\bar{c}} + \Omega_1 \Upsilon_1 N_{\bar{c}}$$
$$= \frac{1}{r}\left\{1 - N_{\bar{c}} \frac{1 - ph' \frac{\partial z(\cdot)}{\partial a}}{\Gamma' - \frac{\partial z(\cdot)}{\partial a}} \left(r - \frac{v'\Gamma'}{(1-\tau^a)u'} - \frac{\Gamma'}{\Gamma''}\left(G'' + \frac{v''(r - G')}{v'}\right) \frac{r\left(\Gamma' - \frac{\partial z(\cdot)}{\partial a}\right)}{(r - G' - \lambda_1)(r - \lambda_1)}\right)\right\} > 0, \tag{A.10}$$

where we make use of the condition (25).

Appendix B.

Taking account of the initial jump in consumption, differentiating $(24a)$ with respect to τ^a yields:

$$\frac{\partial n^*}{\partial \tau^a} = N_{\bar{c}} C_{\tau^a} + N_{\tau^a},$$
$$= \frac{-N_{\bar{c}} B_{\tau^a} + N_{\tau^a} B_{\bar{c}}}{B_{\bar{c}} + \Upsilon_1 \Omega_1 N_{\bar{c}}}, \tag{B.1}$$

where the sign of $B_{\bar{c}} + \Upsilon_1 \Omega_1 N_{\bar{c}}$ is positive, as in $(A.10)$. Arranging the numerator on the right-hand side in $(B.1)$ yields:

$$-N_{\bar{c}} B_{\tau^a} + N_{\tau^a} B_{\bar{c}} = \frac{1}{rW\left(\Gamma' - \frac{\partial z}{\partial a}\right)}\left\{\frac{u''}{u'}\frac{\partial z}{\partial \tau^a}(ph'\Gamma' - 1) - \frac{\Gamma'}{1 - \tau^a}\right\}. \tag{B.2}$$

Finally, making use of (10) and $\tau^y = 0$, equation $(B.2)$ can be rewritten as:

$$-N_{\bar{c}} B_{\tau^a} + N_{\tau^a} B_{\bar{c}} = \frac{1}{(1-\tau^a) rW\left(\Gamma' - \frac{\partial z}{\partial a}\right)} \frac{h'u''}{h''u'}\left(\tau^a - \frac{\Gamma' u' h''}{u'' h'}\right). \tag{B.3}$$

This shows the relationship between n_0 and n_1^*. Substituting (10) into the parenthesis in $(B.3)$ obtains the result in (26).

Next, we examine the effects of an increase in the rate of the export-income tax on the natural resource. Conducting the static comparative analysis in $(23b)$, we obtain:

$$\begin{aligned}\frac{\partial n^*}{\partial \tau^y} &= N_{\bar{c}} C_{\tau^y} + N_{\tau^y}, \\ &= \frac{(-N_{\bar{c}} B_{\tau^y} + N_{\tau^y} B_{\bar{c}})}{B_{\bar{c}} + \Upsilon_1 \Omega_1 N_{\bar{c}}}.\end{aligned} \tag{B.4}$$

The numerator on the right-hand side in $(B.4)$ can be rewritten as:

$$-N_{\bar{c}} B_{\tau^y} + N_{\tau^y} B_{\bar{c}} = \frac{1}{rW\left(\Gamma' - \frac{\partial z}{\partial a}\right)} \frac{\partial z}{\partial \tau^y} \left\{ \frac{u''}{u'} (ph'\Gamma' - 1) - \frac{\Gamma''}{\Gamma'} \right\}. \tag{B.5}$$

Then, substituting (10) and $\tau^a = 0$ into $(B.5)$, we can show the effect of a permanent increase in the rate of the export-income tax on the natural resource as follows:

$$(B.5) = \frac{u''}{rW\left(\Gamma' - \frac{\partial z}{\partial a}\right) u'} \frac{\partial z}{\partial \tau^y} \left(\frac{\tau^y}{1 - \tau^y} - \frac{\Gamma'' u'}{\Gamma' u''} \right). \tag{B.6}$$

Appendix C.

In this appendix, we show the temporary impacts of the environmental policies on the natural resource. Let us suppose that the government announces changes of the policy instruments from the original levels τ_0^a and τ_0^y to τ_1^a and τ_1^y until time T, which thereafter revert permanently to their original levels. Under the assumption of perfect foresight, the households can initially anticipate the policy change at time T. This implies that new information arrives only at time zero. Hence, consumption jumps to the new steady state at the initial time zero and remains there permanently.

We divide the dynamics into two separate dynamics, Periods 1 and 2, as follows.

Period 1: $0 \leq t < T$

During Period 1, the economy moves along the unstable transitional path:

$$n_t = n_1^* + D_1 e^{\lambda_1 t} + D_2 e^{\lambda_2 t}, \tag{C.1a}$$

$$a_t = a_1^* + D_1 \Upsilon_1 e^{\lambda_1 t} + D_2 \Upsilon_2 e^{\lambda_2 t}, \tag{C.1b}$$

$$b_t = b_1^* - D_1 \Omega_1 \Upsilon_1 e^{\lambda_1 t} - D_2 \Omega_2 \Upsilon_2 e^{\lambda_2 t}, \tag{C.1c}$$

where Ω_2 is defined by $\frac{ph'(z^*)\frac{\partial z^*(\cdot)}{\partial a^*}-1}{\rho-\lambda_2}$. In addition, the steady-state levels of each variable are determined by:

$$n_1^* = N(\bar{c}_1^*, \tau_1^a, \tau_1^y) = N(C(\tau_1^a, \tau_1^y, b_0, n_0), \tau_1^a, \tau_1^y), \tag{C.2a}$$

$$a_1^* = A(\bar{c}_1^*, \tau_1^a, \tau_1^y) = A(C(\tau_1^a, \tau_1^y, b_0, n_0), \tau_1^a, \tau_1^y), \tag{C.2b}$$

$$b_1^* = B(\bar{c}_1^*, \tau_1^a, \tau_1^y) = B(C(\tau_1^a, \tau_1^y, b_0, n_0), \tau_1^a, \tau_1^y), \tag{C.2c}$$

$$\bar{c}_1^* = C(\tau_1^a, \tau_1^y, b_0, n_0). \tag{C.2d}$$

Notice that the initial stocks of the natural resource and the foreign asset are n_0 and b_0, respectively, and the rates of the investment subsidy and the export-income tax are τ_1^a and τ_1^y, respectively. Furthermore, we must note that $c_0 \neq \bar{c}_1^*$ because the level of consumption jumps at the initial time.

Period 2: $T \leq t$

During Period 2, the economy follows the stable path defined by:[31]

$$n_t = n_2^* + D_1' e^{\lambda_1' t}, \tag{C.3a}$$

$$a_t = a_2^* + D_1' \Upsilon_1 e^{\lambda_1' t}, \tag{C.3b}$$

$$b_t = b_2^* - D_1' \Omega_1' \Upsilon_1' e^{\lambda_1' t}. \tag{C.3c}$$

The steady-state levels of n_2^*, a_2^* and b_2^* are determined by:

$$n_2^* = N(\bar{c}_2^*, \tau_0^a, \tau_0^y) = N(C(\tau_0^a, \tau_0^y, b_T, n_T), \tau_0^a, \tau_0^y), \tag{C.4a}$$

$$a_2^* = A(\bar{c}_2^*, \tau_0^a, \tau_0^y) = I(C(\tau_0^a, \tau_0^y, b_T, n_T), \tau_0^a, \tau_0^y), \tag{C.4b}$$

$$b_2^* = B(\bar{c}_2^*, \tau_0^a, \tau_0^y) = B(C(\tau_0^a, \tau_0^y, b_T, n_T), \tau_0^a, \tau_0^y), \tag{C.4c}$$

$$\bar{c}_2^* = C(\tau_0^a, \tau_0^y, b_T, n_T). \tag{C.4d}$$

Note that the level of consumption does not change $\bar{c}_1^* = \bar{c}_2^*$ because the household anticipates the removal of the policy under the assumption of perfect foresight.

[31]Because the initial conditions are different in Period 1 and Period 2, the values of D_1, Ω_1, Υ_1 and λ_1 are different from D_1', Ω_1', Υ_1' and λ_1'; however, the fundamental forms and signs are the same.

For simplicity, let us denote the policy changes as follows:

$$\tau_1^a - \tau_0^a \equiv d\tau^a, \quad \tau_1^y - \tau_0^y \equiv d\tau^y \tag{C.5}$$

Furthermore, approximating the steady-state changes with the differentials, we can show that:

$$n_2^* - n_1^* \equiv N(\bar{c}_2^*, \tau_0^a, \tau_0^y) - N(\bar{c}_1^*, \tau_1^a, \tau_1^y) = -N_{\tau^a} d\tau^a - N_{\tau^y} d\tau^y, \tag{C.6a}$$

$$n_1^* - n_0^* \equiv N(\bar{c}_1^*, \tau_1^a, \tau_1^y) - N(\bar{c}_0^*, \tau_0^a, \tau_0^y) = N_{\bar{c}} \left(C_{\tau^a} d\tau^a + C_{\tau^y} d\tau^y \right) + N_{\tau^a} d\tau^a + N_{\tau^y} d\tau^y, \tag{C.6b}$$

$$a_2^* - a_1^* \equiv A(\bar{c}_2^*, \tau_0^a, \tau_0^y) - I(\bar{c}_1^*, \tau_1^a, \tau_1^y) = -A_{\tau^a} d\tau^a - A_{\tau^y} d\tau^y, \tag{C.6c}$$

$$a_1^* - a_0^* \equiv A(\bar{c}_1^*, \tau_1^a, \tau_1^y) - A(\bar{c}_0^*, \tau_0^a, \tau_0^y) = A_{\bar{c}} \left(C_{\tau^a} d\tau^a + C_{\tau^y} d\tau^y \right) + A_{\tau^a} d\tau^a + A_{\tau^y} d\tau^y. \tag{C.6d}$$

Please note that the equality $\bar{c}_1^* = \bar{c}_2^*$ holds.

Finally, from $(C.6a)$ and $(C.6b)$, we can characterize the effects of a temporary policy change on the natural resource as follows:

$$n_2^* - n_0^* = N_{\bar{c}} C_{\tau^a} d\tau^a, \quad n_2^* - n_0^* = N_{\bar{c}} C_{\tau^y} d\tau^y. \tag{C.7}$$

where $N_{\bar{c}} > 0$, $C_{\tau^i} < 0$, and $C_{\tau^y} < 0$. The level of the natural resource in the new steady state is lower than the original level when the rate of investment subsidy or the export-income tax temporarily increases. Because the results in Proposition 2 are derived by only the steady-state differences in $(C.6a)$ and $(C.6b)$, we must notice that those are irrespective of the constants D_1, D_2 and D_1' which affect the movement of variables along time.[32]

[32]We define the constants D_1, D_2 and D_1' where we note that these constants are irrespective of our main results in Proposition 2. By setting $t = 0$ in $(C.1a)$ and $(C.1b)$, these equations can be rewritten as:

$$-(n_1^* - n_0) = D_1 + D_2,$$

Next, using $(C.1a)$, $(C.1b)$, $(C.3a)$, and $(C.3b)$ at $t = T$, the matching conditions on the natural

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resource and the investment in the natural resource are:

$$n_2^* - n_1^* = D_1 e^{\lambda_1 T} + D_2 e^{\lambda_2 T} - D_1' e^{\lambda_1' T}, \quad a_2^* - a_1^* = D_1 \Upsilon_1 e^{\lambda_1 T} + D_2 \Upsilon_2 e^{\lambda_2 T} - D_1' \Upsilon_1' e^{\lambda_1' T}.$$

Using the above-written three equations, we can obtain the conditions D_1, D_2 and D_1'.

Finally, considering that the tax rate reverts to the original rate at given period T after the free change of the tax rate at the initial period, the foreign asset may not satisfy the transversality condition given the initial level of the natural resource. Hence, only when the temporary impact is examined, using the matching condition of the foreign asset at $t = T$ in $(C.1c)$ and $(C.3c)$, we need to restrict the initial level of the foreign asset so that the foreign asset would move along the stable path towards the new steady state:

$$b_1^* + \left[(b_0 - b_1^*) + D_1 \Omega_1 \Upsilon_1 + D_2 \Omega_2 \Upsilon_2\right] e^{rT} - D_1 \Omega_1 \Upsilon_1 e^{\lambda_1 T} - D_2 \Omega_2 \Upsilon_2 e^{\lambda_2 T} = b_2^* - D_1' \Omega_1' \Upsilon_1' e^{\lambda_1' T}$$

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Figure 1: Phase diagram

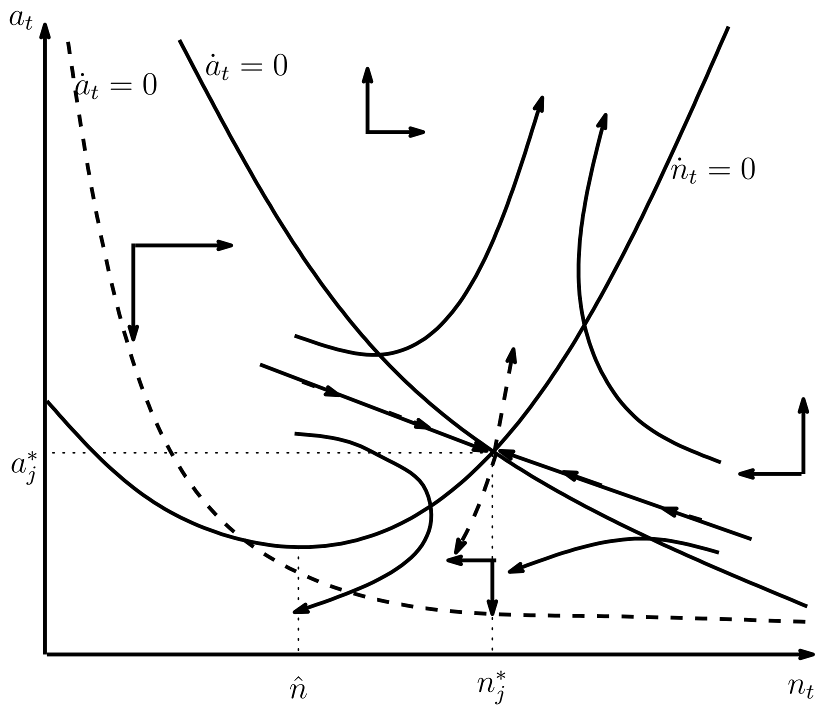

Figure 2: The effects of an increase in the rate of the investment subsidy

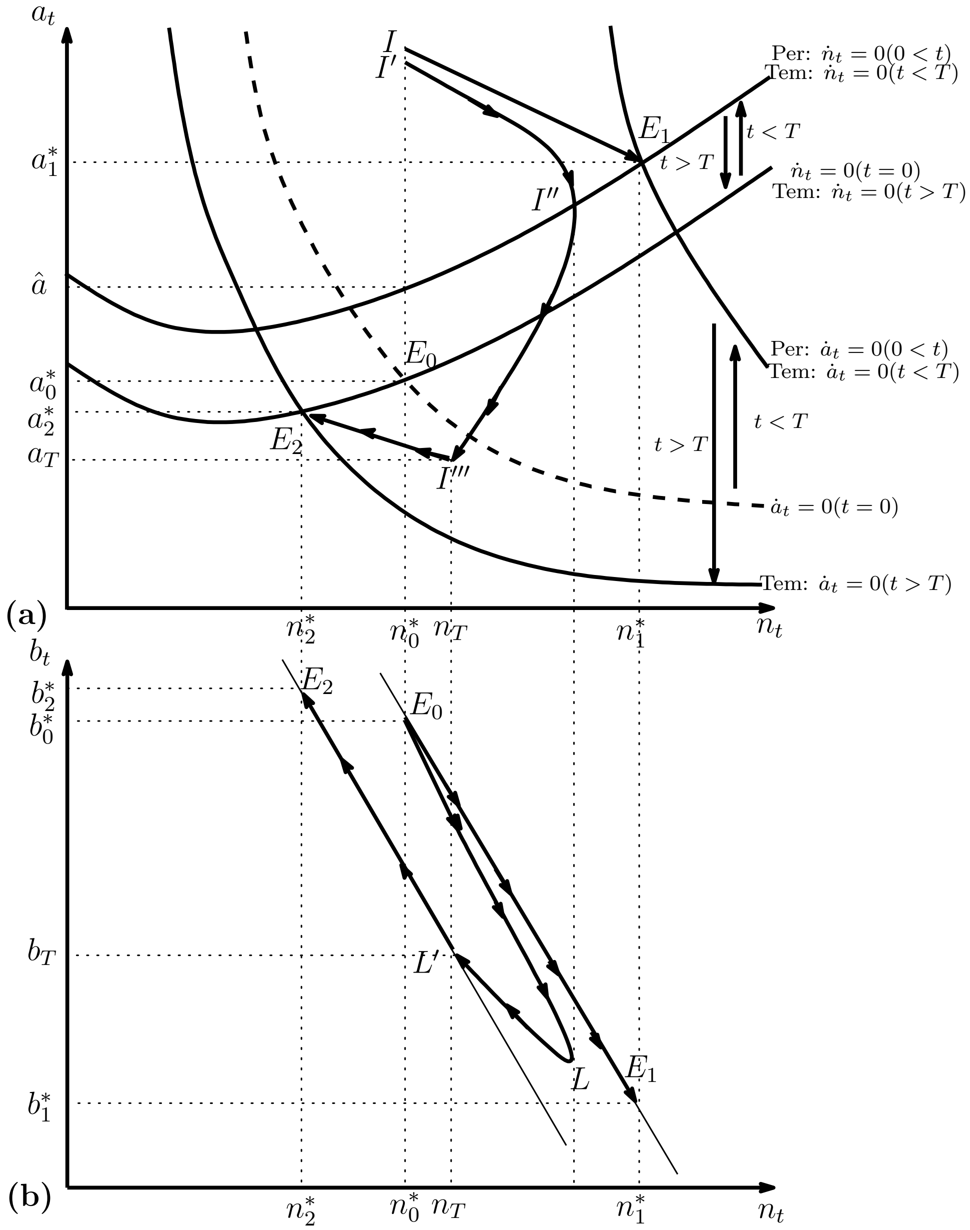

Figure 3: The effects of an increase in the rate of the export-income tax

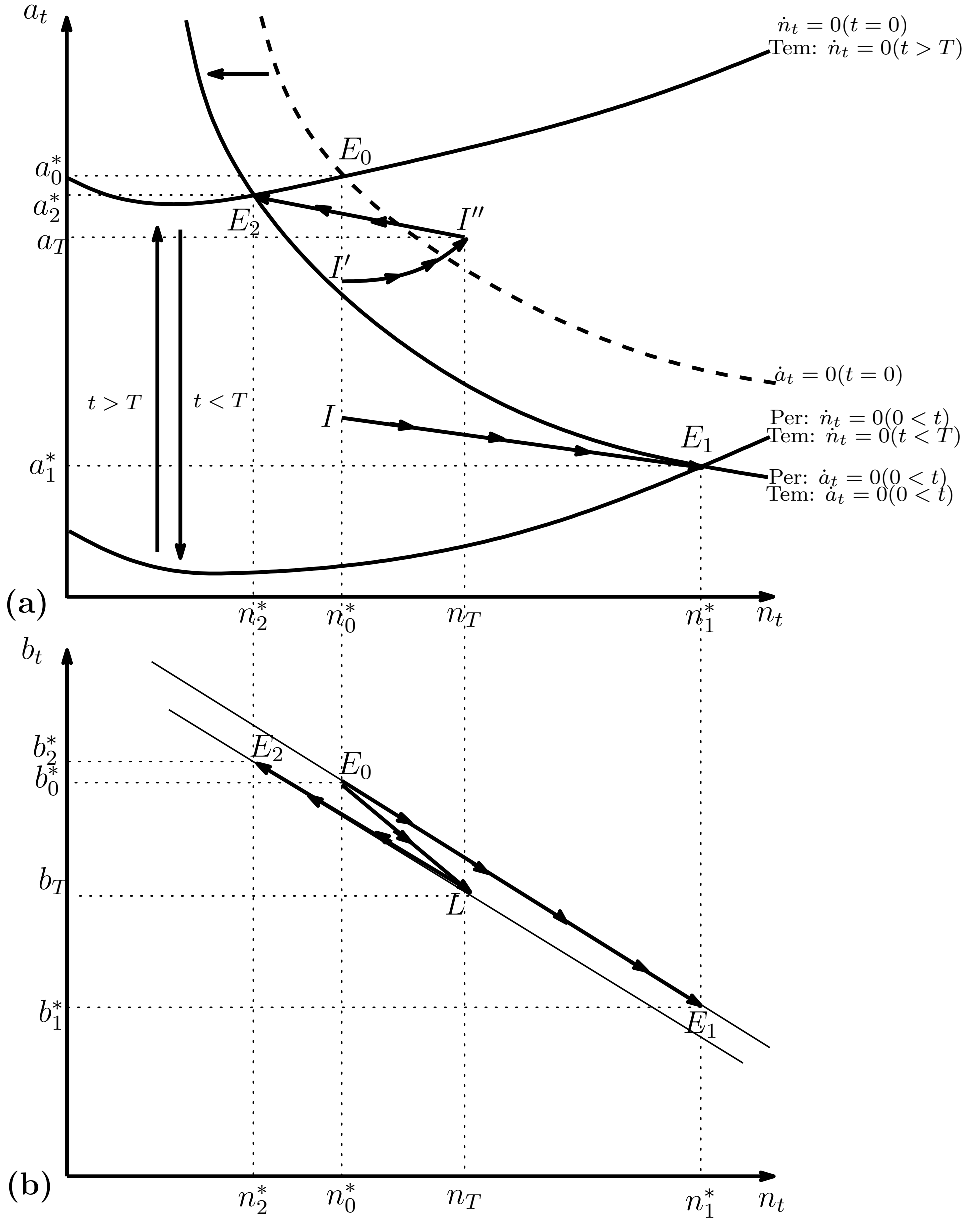

Figure 4(a): The investment subsidy

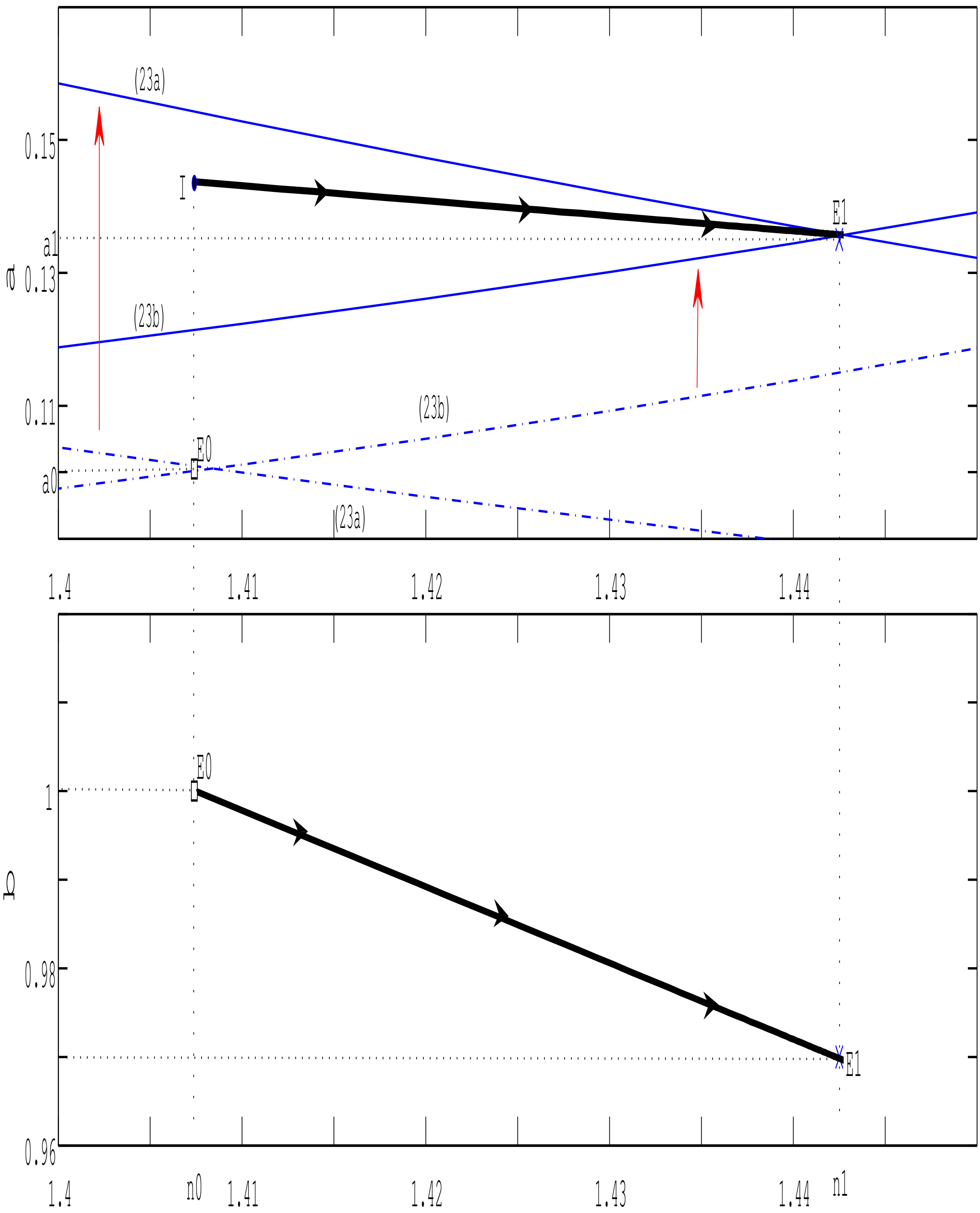

Figure 4(b): The investment subsidy

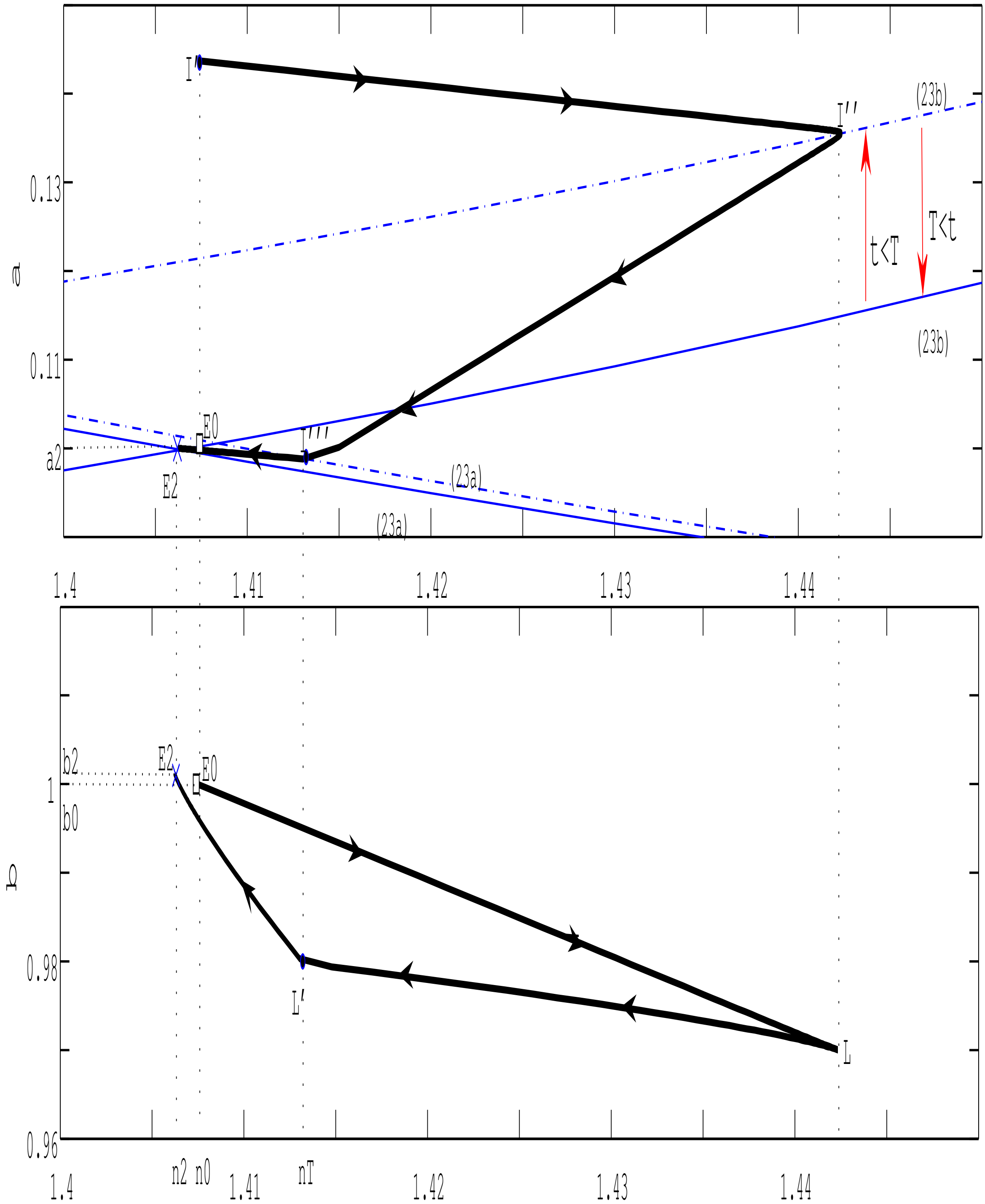

Figure 5: The export-income tax