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Emissions Standard System: A monetary regime for provision of global public goods

KOBAYASHI Keiichiro
RIETI

Research Institute of Economy, Trade & Industry, IAA
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This paper theoretically examines an imaginary monetary regime in which the private provision of global public goods that reduce greenhouse gases (``emissions reducers," e.g., forests) is enhanced and the public goods are held in the private sector as monetary assets. We consider a monetary regime where the government or the central bank makes public goods a means of payment by committing itself to conversion of emissions reducer into cash (and probably by adopting appropriate banking regulations). Using a simple cash-in-advance setting, we show that the monetary regime internalizes the externality of public goods by endowing them with a private function as a means of payment. In the monetary regime, private agents buy and hold emissions reducers voluntarily, and the government need not impose caps on emissions nor pay any costs for public goods provision. Moreover, in an economic boom when greenhouse gas emissions increase, emissions reducers may also increase automatically. Due to the network externalities of money, emissions reducers may become used as money internationally and thus the international free-rider problem may be mitigated.

Our results imply that the monetary regime may be a promising extension of existing policy plans for global warming.

Keywords: Monetary regime, emissions trading, public goods, free-rider problem, global warming

JEL Classification: E5, E6, H0, Q5

The Emissions Standard System: A monetary regime for provision of global public goods*

(Incomplete and preliminary. Comments welcome.)

Keiichiro Kobayashi†

February 20, 2008 (First draft: December 28, 2007)

Abstract

This paper theoretically examines an imaginary monetary regime in which the private provision of global public goods that reduce greenhouse gases ("emissions reducers," e.g., forests) is enhanced and the public goods are held in the private sector as monetary assets. We consider a monetary regime where the government or the central bank makes public goods a means of payment by commiting itself to conversion of emissions reducer into cash (and probably by adopting appropriate banking regulations). Using a simple cash-in-advance setting, we show that the monetary regime internalizes the externality of public goods by endowing them with a private function as a means of payment. In the monetary regime, private agents buy and hold emissions reducers voluntarily, and the government need not impose caps on emissions nor pay any costs for public goods provision. Moreover, in an economic boom when greenhouse gas emissions increase, emissions reducers may also increase automatically. Due to the network externalities of money, emissions reducers may become used as money internationally and thus the international free-rider problem may be mitigated. Our results imply that the monetary regime may be a promising extension of existing policy plans for global warming.

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†Research Institute of Economy, Trade and Industry (RIETI). e-mail: kobayashi-keiichiro@rieti.go.jp

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1 Introduction

This paper may be better understood as a policy proposal rather than an economic analysis, though we try to keep the style and rigor of an academic paper as much as we can.

In this paper we propose and theoretically examine a new policy scheme that enhances the private provision of global public goods and has the potential to mitigate the international free-rider problem. The new policy scheme is a monetary regime in which the government or the central bank makes the (securitized) public goods a means of payment by commiting itself to converting the public goods into money, with the government choosing the rate of conversion as a policy instrument. In the case where the global public goods are those that reduce greenhouse gas emissions, e.g., ownership of forests, we may call this monetary regime the *emissions standard system*, just like the gold standard system. We may call global public goods that reduce emissions *emissions reducers* for the sake of brevity in this paper.

If the public goods are quantitatively observable and verifiable, they can be traded in the market. One such example is the reduction of greenhouse gas emissions: the international and domestic markets for emissions trading are now emerging and we can regard them as markets for trading emissions reducers. In the existing policy scheme, the market values of emissions (or, equivalently, emissions reducers) are generated from the quantity regulation of emissions imposed by governments. To clarify differences in regulatory regimes for public goods provision, we classify the regimes that we examine in this paper into three categories:

- **Fiscal regime with quantity targeting:** The government sets the upper limits for greenhouse gas emissions by private agents, and lets them trade emissions. In other words, the government forces private agents to hold target quantities for emissions reducers. This is the basic structure of the existing policy plan for emissions trading. We call it a *fiscal* regime because it is modeled as a policy in which the government purchases emissions reducers with taxpayer money, gives them to private emitters, and levies cost of emissions reducers directly to the emitting firms (and households) as lump-sum taxes.

- **Fiscal regime with price targeting:** The government sets the price of emissions reducers, q_t, and lets private agents trade and hold them. The government may also buy and hold emissions reducers to control the price. Carbon tax on emissions or subsidized reductions of carbon emissions may be regarded as a version of this regime. In the simple cash-in-advance (CIA) model in the next section, emissions reducers do not enter the CIA constraint.

- **Monetary regime:** The government sets the price of emissions reducers, q_t, and commits itself to converting them into money at the rate of q_t. In the CIA model, emissions reducers enter and relax the CIA constraint. The theoretical difference from price targeting is only that emissions reducers enter the CIA constraint. In the real world, this difference may be interpreted as emissions reducers circulating as a means of payment, i.e., money. The government (or the central bank) may be able to induce this situation by making emissions reducers an eligible means of tax payments or an eligible asset used in open market operations. In the Appendix, we show that making emissions reducers an eligible means of interbank payment may be sufficient to support the monetary regime, regardless of whether the majority of people accept emissions reducers as money or not.

We usually take it for granted that emissions reducers have no value if the government repeals environmental regulations that impose caps or upper limits of the emissions on the private sector. There is no private demand for emissions reducers without environmental regulations because of their externality that they improve people's welfare only through improving the environment. In this paper we explore whether we can induce the private provision of public goods by transforming the demand for money into the demand for public goods. Using a simple cash-in-advance (CIA) model, we show that emissions reducers have positive values and private agents possess them voluntarily even without quantitative caps on emissions only if a monetary regime is in place. This finding sounds trivial but it is not. It sounds trivial because quantity targeting for a public goods provision is equivalent to price targeting in a simple perfect information model. But the equivalence is for suppliers of public goods. It is shown that the government must be the final buyer of the public goods both in the quantity targeting and in price targeting schemes as long as a monetary regime is not in place.

We show the following in this paper: On one hand, in a fiscal regime the government must force private agents to hold emissions reducers by quantity targeting or it must buy them all by itself under price targeting; and on the other hand, in a monetary regime private agents are willing to buy and own emissions reducers voluntarily as financial assets. In other words, the government need not impose quantitative regulations that force private agents to reduce greenhouse gas emissions because private agents voluntarily reduce emissions under the monetary regime; and also the government need not pay for the provision of emissions reducers because private agents are willing to pay for public goods provision. That the private agents voluntarily possess emissions reducers as their financial asset may imply that the monetary regime is politically more stable and sustainable than the fiscal regime. This is what McKibbin and Wilcoxen (2006) emphasize: People who own emissions reducers as financial assets will have great zeal for maintaining and enhancing the value of the asset; and therefore, they will have a strong incentive to support the continuation of emissions trading and lobby for it. In the fiscal regime, people do not have such incentive and there is no intrinsic mechanism that prevents political tide against emissions trading.

This result comes from the unique feature of our monetary regime in that it internalizes the externality of emissions reducers by endowing them with a private function as a means of payment. As easily shown in the CIA model, an asset that works as a means of payment has a positive value, since it can relax the liquidity constraint (or it relaxes the CIA constraint). Therefore, if emissions reducers are used as a means of payment, they are given additional value which increases the incentive for private agents to hold them as assets. The government (or the central bank) can control additional value by monetary policy so that private agents produce and finance the public goods by themselves.

The monetary regime may have several virtues in addition to its inducing the provision of public goods without government intervension in economic activities of private agents. One is that it can automatically increase the production of emissions reducers in response to a boom in the economy. Though we cannot formally show this in our excessively stylized model in the next section, we can easily imagine the following course of events: In an economic boom when output and consumption increase, the demand for money also increases; since the monetary regime transforms the demand for money into the demand for public goods, the boom brings about an increase in the demand for public goods, which leads to an increase in the amount of public goods. We may call this effect the *environmental automatic stabilizer*.

Another virtue is that the monetary regime may mitigate the free-rider problem among countries. Concerning provision of global public goods, there is a severe free-rider problem among countries in that if a country provides emissions reducers, other countries can receive the benefit without bearing the cost of their provision. If one country adopts a monetary regime of public goods provision, the network externality of money may effectively mitigate the international free-rider problem. Suppose that banks and firms in one large country use emissions reducers as a means of payment; they must be used as a means of payment also in international trade; therefore, firms and banks in other countries should hold a certain amount of emissions reducers as a means of payment as long as they are involved in international trade with the country. In other words, due to the network externality of money, the monetary regime in one (large) country can invoke the demand for emissions reducers in other countries through the demand for money. (Governments may hold emissions reducers as foreign reserves.) In this case, private agents in other countries become willing to pay for and hold public goods, and they unintentionally bear some part of the cost of public goods provision. This mechanism mitigates the international free-rider problem. This feature may have a significant implication to ongoing policy debates on global warming. In the successive negotiations in the Conference of Parties (COP) meetings at the United Nations, the international community has not yet achieved a concrete agreement on the shared provision of global public goods, i.e, the reduction of carbon dioxide emissions. One reason for the political difficulty in getting international consensus is the free-rider problem concerning the provision of global public goods. The monetary regime proposed in this paper seems effective for mitigating this international free-rider problem and implememting worldwide reduction of greenhouse gases.

On modeling strategy and related literature: Since our aim is to examine whether or not policymakers can utilize the demand for money to invoke the demand for public goods, we need to use a standard model for money demand. As Walsh (2003) reviews systematically, there are several approaches in modeling money and among them the CIA models are among the most standard and tractable models (Clower 1967; Lucas 1980; Lucas and Stokey 1983, 1987; Cooley and Hansen 1989, 1995). Other approaches to model the demand for money are the money-in-the-utility (MIU) function models (Sidrauski 1967), in which money yields direct utility; and shopping time models (Baumol 1952, Tobin 1956, Dittmar, Gavin and Kydland 2005), in which money improves utility by economizing shopping time. Although we use CIA models for simplicity and clarity of exposition, we are confident that our results can be obtained in other models, since our results arise from the existence of the demand for money (or the positive value of money) and that the public goods under consideration can be used as money. The monetary regime that we propose in this paper may be regarded as a commodity money regime, though the commodity money in our regime does not have a positive value as a commodity. For models of commodity money, see Chapter 25 of Ljungqvist and Sargent (2003), Sargent and Wallace (1983), and Sargent and Velde (1999).

The remainder of this paper is organized as follows. In the next section, we formalize the fiscal and monetary regimes of public goods provision using a stylized CIA model, and we show that private agents possess emissions reducers voluntarily only in the monetary regime and the equilibrium path in the monetary regime can converge to the best steady state of the fiscal regime. We also note possibilities that the monetary regime may exert the environmental automatic stabilizer effect and may mitigate the international free-rider problem. Section 3 provides concluding remarks. In the Appendix, we show that the monetary regime can be implemented by an appropriate change in bank regulation regardless of whether ordinary people believe emissions reducers to be a means of payment or not.

2 Model

In this section, we consider a simple closed economy inhabited by a representative household (and competitive firms) and a government.

2.1 Benchmark – No emissions trading

We describe as a benchmark the setup of the model in the case with no emissions trading. The representative household's utility is defined as

$$\sum_{t=0}^{\infty} \beta^t \{u(c_t) - v(\overline{D}_t)\}, \tag{1}$$

where β $(0 < \beta < 1)$ is the discount factor, c_t is consumption at date t, $u(c_t)$ is the flow utility at date t from consumption, $\overline{D}_t$ is the social level of the stock of the greenhouse gas, which is perceived as an exogenous parameter by the agent, $v(\overline{D}_t)$ is the disutility from the existence of greenhouse gases. A representative household is subject to the CIA constraint on consumption: it must use cash, M_t, which is carried over from date $t-1$, to pay $P_t c_t$, where P_t is the nominal price of consumption goods. The household provides one unit of labor at the wage rate w_t in the labor market and accumulates the capital stock, k_t, the rental rate of which is r_t in the market. Therefore, the representative household maximizes (1) subject to the budget constraint:

$$c_t + k_{t+1} - (1-\delta)k_t \leq w_t + r_t k_t - \pi_{t+1} m_{t+1} + m_t - \tau_t + \frac{R_t B_t - B_{t+1}}{P_t} + g_t, \tag{2}$$

where δ is the depreciation rate, $\pi_{t+1} \equiv P_{t+1}/P_t$ is the inflation rate, $m_t \equiv M_t/P_t$ is the real money balance, τ_t is the lump-sum tax, R_t is the nominal interest rate, B_{t+1} is the nominal government bond, and $\{g_t\}_{t=0}^{\infty}$ is the lump-sum transfer from the government to the household which is determined as an exogenous process, and also subject to the CIA constraint:

$$c_t \leq m_t. \tag{3}$$

Competitive firms can produce consumption goods, y_t, from labor and capital, using Cobb-Douglas production technology:

$$y_t = Ak_t^{\alpha} n_t^{1-\alpha}, \tag{4}$$

where k_t is capital input and n_t is labor input to the consumption goods-producing sector. A firm that produces consumption goods maximizes $y_t - r_t k_t - w_t n_t$, subject to (4). The evolution of greenhouse gases is governed by

$$D_{t+1} = (1-\xi)D_t + \theta y_t - e_t, \tag{5}$$

where $0 < \xi < 1$, $0 < \theta$, and e_t is the stock of the emissions reducer, i.e., public goods that reduces or absorbs greenhouse gases. An example of e_t is the stock of forest in a country, and z_t in equation (6) is newly forested trees in this case (see below). The emissions reducer is accumulated by

$$e_{t+1} = (1-\eta)e_t + z_t, \tag{6}$$

where $0 < \eta < 1$ and z_t is the investment in the emissions reducer, which is produced from consumption goods by the following installation technology:

$$z_t = \phi\left(\frac{x_t}{e_t}\right)e_t, \tag{7}$$

where x_t is the input of consumption goods, $\phi'(\cdot) > 0$, $\phi''(\cdot) < 0$, and $\phi(\eta) = \eta$. A firm that produces an emissions reducer maximizes $q_t z_t - x_t - r_{et} e_t$, subject to (7), where q_t is the price of the emissions reducer at date t in terms of consumption goods, and r_{et} is the rental rate of e_t in production of z_t. (In the benchmark case where there is no emissions trading, the market price of the emissions reducer is zero, i.e., $q_t = 0$, and production of z_t does not take place.) The resource constraints are

$$c_t + k_{t+1} - (1-\delta)k_t + x_t = y_t, \tag{8}$$

$$n_t = 1, \tag{9}$$

$$\overline{D}_t = D_t. \tag{10}$$

The government budget constraint is

$$g_t \leq \tau_t + \frac{B_{t+1} - R_t B_t}{P_t} + \pi_{t+1} m_{t+1} - m_t. \tag{11}$$

In this economy, the government can set the inflation rate π_{t+1} by setting the nominal interest rate R_{t+1}. We define fiscal revenue, s_t, by

$$s_t = \tau_t + \frac{B_{t+1} - R_t B_t}{P_t}. \tag{12}$$

The division of s_t into τ_t and B_{t+1} is indeterminate in the sense that the equilibrium allocation is uniquely determined as long as s_t and π_{t+1} (or R_{t+1}) are determined. Therefore, we can regard the government's problem as choosing $\{\pi_{t+1}, s_t\}_{t=0}^{\infty}$ subject to

$$g_t \leq s_t + \pi_{t+1} m_{t+1} - m_t. \tag{13}$$

The competitive equilibrium in the case where there is no emissions trading is defined as the set of prices $\{w_t, r_t, q_t, r_{et}, R_t, \pi_{t+1}\}$ and allocations $\{n_t, y_t, c_t, k_{t+1}, x_t, m_t, s_t, z_t, e_{t+1}, D_{t+1}, \overline{D}_{t+1}\}$, such that (i) given prices, the allocations solve the representative household's problem and the firms' profit maximization problem; (ii) given the exogenous process $\{g_t\}_{t=0}^{\infty}$, the government sets $\{\pi_t, s_t\}_{t=0}^{\infty}$ subject to (13); and (iii) the allocations satisfy the technological constraints (4)–(7) and resource constraints (8)–(10). Since nobody buys the emissions reducers, their price is zero: $q_t = 0$. Therefore, production of the emissions reducer does not take place: $z_t = x_t = 0$. The steady state is easily calculated: $r = \beta^{-1} - 1 + \delta$, $k = (\alpha A/r)^{1/(1-\alpha)}$, $y = Ak^{\alpha}$, $c = y - \delta k$, $e = 0$, and $D = \theta y/\xi$. We focus on the steady state where the inflation rate, π, is constant with $\pi > \beta$, and thus the CIA constraint is binding. The real money balance, $m \equiv M_t/P_t$, is determined by the

CIA constraint: $m = c$. Since $\pi_t = \pi$ in the steady state, the price level is determined by $P_t = \pi^t P_0$ and the money supply by $M_t = P_t m$. In this no-emissions-trading case, the government has freedom to set the steady-state inflation rate, π, which is, however, irrelevant to equilibrium allocations in the steady state.

2.2 Fiscal regime of emissions trading with quantity targeting

Now suppose a fiscal regime with quantity targeting is introduced in this economy. The government sets the quantity target, z_t, for date-t production in the emissions reducer and buys it at market price q_t. The government finances the emissions reducer by lump-sum tax on the representative agent. In this regime, the government budget is described as

$$q_t z_t - r_{et} e_t + g_t \leq s_t + \pi_{t+1} m_{t+1} - m_t, \tag{14}$$

where e_t is the government's stock of the emissions reducer. In this regime, although all emissions reducers are finally purchased and owned by the government, we can regard that the emissions reducer is produced and traded in a competitive market and q_t and r_{et} are set as competitive prices:

$$q_t = [\phi'(x_t/e_t)]^{-1}, \tag{15}$$

$$r_{et} = q_t \phi(x_t/e_t) - x_t/e_t. \tag{16}$$

Note that these equations imply that (14) can be rewritten as

$$x_t + g_t \leq s_t + \pi_{t+1} m_{t+1} - m_t,$$

in equilibrium. The government finances the emissions reducers by fiscal revenue, s_t, and monetary revenue (i.e., the seigniorage), $\pi_{t+1} m_{t+1} - m_t$. Since the lump-sum tax is not distortionary, this regime is the most efficient in all possible fiscal regimes where the government buys and holds emissions reducers. Note that setting caps on the emissions of private agents is a version of a fiscal regime with quantity targeting, in which the government levies the cost of z_t on the emitting agents directly as a lump-sum tax.

The definition of the competitive equilibrium is the same as that in the no-emissions-trading case, except for the government's problem: given $\{g_t\}_{t=0}^{\infty}$, the government chooses $\{z_t, \pi_{t+1}, s_t\}_{=0}^{\infty}$ subject to (14).

With a fiscal regime with quantity targeting, there are many competitive equilibria, indexed by different sequences of $\{z_t\}_{t=0}^{\infty}$. The Ramsey problem (see, for example, Chapter 15 of Ljungqvist and Sargent, 2004) for the government is to choose a competitive equilibrium that maximizes (1) by choosing the corresponding sequence, $\{z_t\}_{t=0}^{\infty}$. Since $z_t = \phi(x_t/e_t)$, choosing z_t is equivalent to choosing x_t. Therefore, the Ramsey problem is to choose $\{c_t, k_{t+1}, x_t, \pi_{t+1}\}$ to maximize (1) subject to

$$\frac{u'(c_t)}{\beta u'(c_{t+1})} = \frac{\pi_t}{\pi_{t+1}}(\alpha A k_t^{\alpha-1} + 1 - \delta), \tag{17}$$

(3)–(10) and (14).

The steady state is easily specified: $r = \beta^{-1} - 1 + \delta$, $k = (\alpha A/r)^{1/(1-\alpha)}$, $y = Ak^{\alpha}$, $c = y - \delta k - x$, $e = x/\eta$, and $D = (\theta y - x/\eta)/\xi$. The value of x is determined as the solution to the Ramsey problem: $x^* = \arg\max u(y - \delta k - x) - v((\theta y - x/\eta)/\xi)$. Note that the government must finance x^* (and g_t) by fiscal and monetary revenues:

$$x^* + g_t = s_t + (\pi - 1)m, \tag{18}$$

where $m = c$ from the CIA constraint. Although the composition of the fiscal and monetary revenues can be changed by changing π, the government needs to pay for all emissions reducers anyway. This is also the case in a fiscal regime with price targeting.

2.3 Fiscal regime of emissions trading with price targeting

In a fiscal regime with price targeting, the government sets the price of the emissions reducer, q_t, instead of its quantity, z_t. Since the emissions reducer is produced by competitive firms, equation (15) holds in equilibrium. Therefore, setting q_t is equivalent to setting $z_t = \phi'^{-1}(1/q_t)e_t$. If the government purchases all emissions reducers z_t for all t, the price targeting regime becomes completely equivalent to the quantity targeting regime.

Now we specify the condition for a representative household to possess the emissions reducer voluntarily as its financial asset and show that this condition cannot be satisfied in the long run under the fiscal regime.

We assume that a representative household can buy and possess the emissions reducer as its asset if it wants. In this case, the budget constraint for the representative household becomes

$$c_t + k_{t+1} - (1-\delta)k_t + q_t\{e_{t+1} - (1-\eta)e_t\} \leq w_t + r_t k_t + r_{et}e_t - \pi_{t+1}m_{t+1} + m_t - s_t + g_t, \tag{19}$$

where throughout this subsection e_{t+1} denotes emissions reducers purchased by a household at date t. The first order conditions (FOCs) with respect to e_{t+1} and k_{t+1} imply that

$$q_t = \frac{r_{et+1} + (1-\eta)q_{t+1}}{r_{t+1} + 1 - \delta}, \quad \text{if } e_{t+1} > 0, \tag{20}$$

$$q_t > \frac{r_{et+1} + (1-\eta)q_{t+1}}{r_{t+1} + 1 - \delta}, \quad \text{if } e_{t+1} = 0. \tag{21}$$

In order to make the emissions reducer be owned by the private sector, the government must choose the sequence $\{q_t\}_{t=0}^{\infty}$ such that (20) is satisfied for all t. The Ramsey problem in this case is the same one in the quantity targeting regime with one additional constraint, (20). Therefore, the solution to the Ramsey problem, if it exists at all, should be more inefficient than that in the quantity targeting regime. To make matters worse, the solution does not exist. Supposing it does exists, it should converge to a steady state where $x/e = z/e = \eta$, where x, z, e are the values of respective variables at the steady state, since otherwise x_t and e_t must diverge to infinity and c_t must become negative eventually. In the steady state, (15) and (16) imply $q = \phi'(\eta)^{-1}$ and $r_e = (q-1)\eta$. These expressions and (20) imply that $q = -\eta/(\beta^{-1}-1) < 0 < \phi'(\eta)^{-1}$, which is a contradiction. Therefore, (20) cannot hold in the steady state, while it is easily confirmed that (21) is satisfied in the steady state. This analysis shows that (20) cannot be satisfied in the long run under the fiscal regime (both with price targeting and, as easily confirmed, with quantity targeting). Since (21) holds in the long run, the representative household will eventually sell all emissions reducers and e_t will become zero. Therefore, the government has no other choice than to buy and own all emissions reducers in the long run, unless imposing a quantity regulation on the private sector.[1]

Comments on McKibbin and Wilcoxen (2006): McKibbin and Wilcoxen (2006) propose a "hybrid" system, which is a version of the fiscal regime with price targeting, in which caps of emissions are also imposed on private agents. They argue that in the hybrid system people who own emissions reducers as financial assets will have a strong incentive to politically support the continuation of emissions trading and lobby for it. Our results imply, however, that their proposition may not hold robustly as long as the emissions trading is allowed in the fiscal regime. Since (21) holds in the long run under the fiscal regime, the owners of the emissions reducers will eventually have incentive to sell them all if they are allowed. Therefore, while each owner supports the emissions trading system as a whole, it has an incentive to lobby for repeal of the cap on itself only; for example, on one hand the automobile industry will lobby for repeal of its cap expecting that the cap on the energy industry will continue, aiming at selling its emissions reducers to the power companies, and on the other hand the energy industry will lobby for repeal of its own cap. These political activities by each industry may eventually succeed in repealing the most of the caps on industries and encroach on the fiscal regime. On the other hand, as we show below, the owners of emissions reducers are willing to continue holding them in the monetary regime. Therefore, we would say that the political advantage that McKibbin and Wilcoxen (2006) attribute to their hybrid system may actually be realized

[1] If a subsidy for asset purchase is introduced, the government can make private agents willing to hold e_t as their financial assets. Suppose that the government pays $\tau_t q_t e_{t+1}$ as a subsidy to a private agent who buys e_{t+1}. In this case, (20) becomes

$$(1-\tau_t)q_t = \frac{r_{et+1} + (1-\eta)q_{t+1}}{r_{t+1} + 1 - \delta},$$

which can be satisfied at all t if the government sets $\tau_t > 0$ appropriately. This subsidy for asset purchase is, however, prohibitively difficult to implement in the real world because a trader can draw an indefinitely huge amount of subsidy from the government by repetitive sellings and buyings of the asset. Therefore, I simply neglect the possibility of this type of policy in this paper.

only in the monetary regime.

We have confirmed so far that under the fiscal regime the emissions trading system cannot be sustainable unless the government imposes a quantity regulation on the private sector or buys up all public goods. This is not the case in the following monetary regime.

2.4 Monetary regime of emissions trading

In the monetary regime of emissions trading, the government commits itself to converting the emissions reducer into cash. It exchanges one unit of the emissions reducer to $Q_t = P_t q_t$ units of cash at date t, where P_t is the nominal price of consumption goods and the government chooses the sequence $\{q_t\}_{t=0}^{\infty}$. In this environment, the emissions reducer is circulated in the market as a cash-equivalent asset and the CIA constraint for the representative agent under the monetary regime becomes

$$c_t \leq (1-\eta) q_t e_t + m_t, \tag{22}$$

where q_t is the government-declared conversion rate in terms of consumption goods, and $(1-\eta)e_t$ is the remaining amount of the emissions reducer held by a representative household at the end of date t.

The emission reducer as a means of payment: Although we assume in this simplified model that e_t is observable and verifiable so that it is easily traded, it must be costly in the real world for private agents to monitor and verify emissions reducers of greenhouse gases. And therefore, financial intermediation should be necessary: $(1-\eta)e_t$ in the CIA constraint, (22), should be interpreted as asset-backed securities, which are issued by large banks or other financial institutions.[2] Securitization is not sufficient for an emissions reducer to enter the CIA constraint. A (securitized) emissions reducer must be accepted as a means of payment, or money, by the majority of people in the economy. To specify comprehensively the way to establish social acknowledgement that a particular asset is money may involve many practical problems that await further

[2] To enhance the securitization of the emissions reducer, the government may set the capital requirement for banks that they hold a certain portion of their capital in the form of the emissions reducer.

reseach and are beyond the scope of this short paper (see Lotz and Rocheteau 2002, and references therein for theoretical models and case studies on launching a new currency). Some policy ideas to enhance public acceptance that the asset can be used as a means of payment are as follows: The government may restrict that major tax payments must be done only by means of the emissions reducer; the central bank may make the emissions reducer an eligible asset for the open market operations. The European experience of the transition from national currencies to the unified currency, the euro, may give us practical lessons and solutions to make the emissions reducer a currency so that the CIA constraint becomes (22). In any case, to make an asset a new currency may crucially depend on common belief of the people, which may not be controllable for policymakers. In the Appendix, we explore another possibility that the government (or the central bank) can effectively generate a constraint equivalent to (22) without depending on a change in public belief, but by changing bank regulations. We consider a case wherein banks can settle their transactions in the interbank payments system by means of emissions reducers.[3] As we show in the Appendix, the CIA constraint may be interpreted as a reduced form of a technological constraint on interbank payments in which banks must reserve a certain amount of cash in case of payment. Under this technological environment, the government can implement a monetary regime by setting the emissions reducer as an eligible means of interbank payment. The Appendix shows that our results in this subsection do not change qualitatively in the model with banks. In our analysis that follows, we use the CIA model for simplicity of exposition and simply assume that people accept the emissions reducer as money and the CIA constraint becomes (22).

We consider a competitive equilibria where all cash and the emissions reducers are purchased and owned by a representative household. In this case, the representative household maximizes (1) subject to (19) and (22). Since e_{t+1} (or z_t) is produced competitively, equations (15) and (16) hold in this regime. The FOC for the representative household with respect to e_{t+1} gives the condition for the emissions reducer to be held

[3] I would like to thank Tomoyuki Nakajima for suggesting this policy scheme.

by the representative household as a monetary asset:

$$q_t = \frac{r_{et+1}}{r_{t+1} + 1 - \delta} + (1 - \eta)\pi_{t+1}q_{t+1}. \tag{23}$$

This condition corresponds to (20) in the fiscal regime. The difference from (20) is that it depends on the inflation rate because e_t enters the CIA constraint in the monetary regime. By adjusting π_{t+1} appropriately, the government can make the representative household possess the emissions reducer voluntarily. The government must choose π_{t+1} and q_{t+1} such that equation (23) is satisfied, since otherwise either only the emissions reducer or only cash is held by the representative household. Therefore, the government does not have freedom to choose the inflation rate once it sets the conversion rates, $\{q_t\}_{t=0}^{\infty}$. If the monetary regime is introduced at $t = 0$, where M_0 is already fixed, the government chooses $\{q_t, \pi_{t+1}, s_t\}_{t=0}^{\infty}$ subject to (13) and (23). Note that the government budget constraint is not (14). The government need not buy the emissions reducer in the monetary regime. The competitive equilibria are defined accordingly, and indexed by different policies, given the initial value of M_0. The Ramsey problem for the government in the monetary regime is to choose $\{c_t, k_{t+1}, x_t, q_t, \pi_{t+1}\}$ to maximize (1) subject to (4)–(10), (13), (15), (16), (17), (22), and (23).

The Ramsey problem in the monetary regime is almost equivalent to that in the fiscal regime with quantity targeting except for one additional constraint, which is (23). The tradeoff between the two regimes is as follows: in the monetary regime, the government can make the private agents possess the emissions reducer voluntarily and can avoid purchasing it (see the government budget), while it loses the freedom to choose the inflation rate. Therefore, the path of the allocations, $\{c_t, k_{t+1}, x_t\}_{t=0}^{\infty}$, in the monetary regime cannot necessarily replicate the best outcome in the fiscal regime. We can show, however, that the optimal steady state in the fiscal regime can be also attained in the monetary regime.

Steady state: The allocations of the steady state in the monetary regime are identical to those in the fiscal regime: $r = \beta^{-1} - 1 + \delta$, $k = (\alpha A/r)^{1/(1-\alpha)}$, $y = Ak^{\alpha}$, $c = y - \delta k - x$, $e = x/\eta$, and $D = (\theta y - x/\eta)/\xi$. The value of x is determined as the solution to the

Ramsey problem: $x^* = \arg\max u(y - \delta k - x) - v((\theta y - x/\eta)/\xi)$. The difference from the fiscal regime is in the cost for the government: the government does not need to finance x^* by fiscal and monetary revenues:

$$g_t = s_t + (\pi - 1)m', \tag{24}$$

where $m' = c - (\eta^{-1} - 1)qx^*$ from the CIA constraint, and $q = [\phi'(\eta)]^{-1}$, $r_e = (q-1)\eta$ and $\pi = \{1 - (1 - \phi'(\eta))\beta\eta\}/(1-\eta)$. Note that the inflation rate, π, cannot be chosen freely. Note that in the monetary regime the existence of the steady state is guaranteed by the fact that the government can choose π such that two variables, q and r_e, satisfy three conditions, (15), (16), and (23). This fact arises from that q in (23) depends on π in the monetary regime. By contrast, in the fiscal regime with price targeting, the steady state where private agents possess the emissions reducer cannot exist because q and r_e must satisfy (15), (16) and (20) in such a steady state, while (20) does not depend on policy variables.

Implementation: The government can implement the Ramsey path, $\{c_t^*, k_{t+1}^*, x_t^*\}_{t=0}^{\infty}$, the allocations of the solution to the Ramsey problem, by setting $\{q_t, R_{t+1}\}_{t=0}^{\infty}$ as follows, given M_0, k_0, and e_0. (We assume for simplicity that $e_0 > 0$.) Since there is a (unique) sequence of $\{q_t^*, \pi_{t+1}^*\}_{t=0}^{\infty}$ that supports the Ramsey path, it is sufficient to materialize this sequence by setting policy tools. The government can commit directly to the optimal conversion rate q_t^* and it can commit to π_{t+1}^* by setting $R_{t+1} = \pi_{t+1}^*(r_{t+1}^* + 1 - \delta)$, where $r_{t+1}^* = \alpha A(k_{t+1}^*)^{\alpha-1}$. Note that the nominal price at date 0 is endogenously determined by $P_0^* = M_0/m_0^*$, where m_0^* is the real money balance at date 0 in the Ramsey path. Therefore, under our assumption that M_0 cannot be changed at date 0 when the monetary regime is introduced, the price level at date 0 jumps to P_0^* instantaneously. Note that the government commits itself to the real conversion rate q_t^*, not the nominal conversion rate Q_t; the government commits itself to setting $Q_t = [\prod_{s=1}^{t} \pi_s] P_0 q_t^*$, whatever P_0 is. Observing and anticipating the realization of P_0^*, the government sets the nominal conversion rate at $Q_t = [\prod_{s=1}^{t} \pi_s^*] P_0^* q_t^*$.

Environmental automatic stabilizer: It may be interesting to consider what happens if a productivity shock, i.e., a sudden increase in A, hits the economy under the monetary regime. Suppose the monetary regime is a variant in which the government commits itself to buying an emissions reducer at the price of q_t^*, but it does not commit itself to *selling* it at q_t^*. In this variant of the monetary regime, the price of the emissions reducer may exceed the target price q_t^* in response to a productivity shock. Suppose that the productivity, A, unexpectedly rises at date t. (This is a simple representation of an unexpected boom.) Since both output, Ak_t^α, and consumption, c_t, tend to increase, the CIA constraint, (22), implies that q_t and/or m_t must increase. If q_t increases, the production of the emissions reducer increases (see equation 15). Therefore, in response to an economic boom, which increases greenhouse gas emissions, the emissions reducers may also increase in the monetary regime. We can call this effect the environmental automatic stabilizer. Of course, this observation is very casual since we do not formally argue how fiscal and monetary policies respond to the productivity shock. For example, if m_t increases sufficiently in response to the increase in A, then q_t may not change.[4] But if there are some inertia in fiscal and monetary policies in the real world, there should exist some degree of environmental automatic stabilizer. This feature may be a virtue of the monetary regime in contrast to the fiscal regimes where there is no environmental stabilizer effect.

International free-rider problem: Another noticeable feature of the monetary regime may be in its international aspect. In the fiscal regime of public goods provision each country's government can choose independently whether it adopts the regime, and thus in the case of global public goods, such as the reduction of greenhouse gases, there emerges a severe free-rider problem, that is, when a country provides emissions reducers other countries can receive the benefit of public goods without bearing the cost of their provision. The existence of the free-rider problem makes international agreement for

[4] In the ordinary CIA model, i.e., the benchmark model in Section 2.1, when an unexpected productivity shock hits the economy at date t, m_t increases sufficiently to cover consumption through a decrease in the equilibrium price level, P_t, even if the money supply, M_t, cannot be changed.

implementation of a fiscal regime almost impossible to attain. A monetary regime may be able to mitigate the international free-rider problem. This is because money has network externality. As often mentioned, "[o]ur willingness to use and hold money is greater the more that money is used by other people"(King, 2004). This is the case not only for transactions in domestic markets but also for those in international markets. Suppose that banks and firms in one large country use emissions reducers as a means of payment; they must be used as a means of payment also in international trade; therefore, firms and banks in other countries should hold a certain amount of emissions reducers as a means of payment as long as they are involved in international trade with the country. In other words, due to the network externality of money, the monetary regime in one (large) country can invoke demand for emissions reducers in other countries through the demand for money. (Governments may hold emissions reducers as foreign reserves.) In this case, private agents in the other countries become willing to pay for and hold public goods, and they unintentionally bear some part of the cost of public goods provision. This mechanism mitigates the international free-rider problem and is unique to the monetary regime for the provision of global public goods.

3 Conclusion

We theoretically analyzed a monetary regime for public goods provision. If the government (or the central bank) commits itself to converting public goods into cash, it can enhance the private provision of public goods by choosing a conversion rate and inflation rate appropriately. It was shown that only in this monetary regime the private agents voluntarily possess public goods, i.e., the emissions reducers, as their assets even without government regulation which imposes caps on emissions. Moreover, in an economic boom when greenhouse gas emissions increase, emissions reducers may also increase automatically under a variant of the monetary regime. Due to the network externalities of money, emissions reducers may become used as a means of payment internationally and thus the international free-rider problem may be also mitigated. These features of the monetary regime of public goods provision seem to make it a promising extension of existing policy plans for emissions trading.

There are, however, possible side-effects of the monetary regime that should be studied further. Since the government cannot adjust the inflation rate freely once it sets conversion rates, monetary policy will be severely constrained and volatility in business cycles may become as large as it was in the gold standard system. We need to inquire about an optimal policy rule for setting a conversion rate q_t that enhances public goods provision and mitigates business cycles at the same time. We also need to construct a method to establish and maintain public confidence on government commitment to the monetary regime. The fixed-rate conversion of money and an asset is in some cases vulnerable to attack by speculators. We can conceive a currency attack to the monetary regime, in which speculators sell the emissions reducer short. If the government tries to defend the regime, it is forced to buy emissions reducers indefinitely and sell bonds (that is, raise the nominal interest rate) to keep the money supply. One policy design that prevents short-selling may be a precommitment to a heavy transaction tax on emissions trading levyed only in the case of collapse of the fixed-rate monetary conversion of the emissions reducer. Under the tax precommitment, speculators may refrain from selling the emissions reducer short, expecting that they will have to pay heavy tax when the monetary regime collapses. There may be other types of attack on the monetary regime. Whether or how the monetary regime is made sustainable against such attacks should be analyzed further in future research.

In any case, we may predict that monetary policy and bank regulations will become closely interdependent with the emissions trading system and these policies will have to be mutually consistent as the emissions reducers become circulated as a liquid asset in financial markets.

4 Appendix

In this section we describe a modified model in which bank deposits play the role of money and banks are subject to a technological constraint in that they need to reserve a certain amount of cash in case of (interbank) payments. In this model, the government or central bank can implement the monetary regime by accepting the emissions reducer as an eligible means of payment for banks to settle their interbank transactions. Primarily, this model implies that there may be no need to establish a common belief of the people that the emissions reducer is money, which may not be controllable by policymakers.

We introduce banks and bank deposits, the nominal amount of which is denoted by N_{t+1}, into our benchmark model. Bank deposits can be used as money so that the representative household's problem becomes

$$\max_{c_t, k_{ht+1}, m_{ht+1}, n_{t+1}} \sum_{t=0}^{\infty} \{u(c_t) - v(\overline{D}_t)\}$$

subject to

$$c_t + k_{ht+1} - (1-\delta)k_{ht} \leq w_t + r_t k_{ht} + m_{ht} + (1+r_{dt})n_t - \pi_{t+1}(m_{ht+1} + n_{t+1}) - s_t + g_t, \tag{25}$$

$$c_t \leq m_{ht} + (1+r_{dt})n_t, \tag{26}$$

where k_{ht+1} is the capital held by the household, m_{ht+1} is cash held by the household, $n_{t+1} \equiv N_{t+1}/P_{t+1}$, and r_{dt} is the deposit rate. Since both cash and bank deposits are the means of payment, the CIA constraint becomes (26).

There are competitive banks with unit mass that issue bank deposits, n_{t+1}, as their liabilities and hold capital stock, k_{bt+1}, emissions reducers, e_{t+1}, and cash reserves, $\pi_{t+1} m_{bt+1} \equiv M_{bt+1}/P_t$, where M_{bt+1} is its nominal amount and $m_{bt+1} = M_{bt+1}/P_{t+1}$, as their assets. Banks maximize their profits period-by-period so that their profit maximization problem becomes:

$$\max_{k_{bt+1}, e_{t+1}, m_{bt+1}, n_{t+1}} (r_{t+1} + 1 - \delta)k_{bt+1} + \{r_{et+1} + (1-\eta)q_{t+1}\}e_{t+1} + m_{bt+1} - (1 + r_{dt+1})n_{t+1},$$

subject to

$$\pi_{t+1} n_{t+1} = k_{bt+1} + q_t e_{t+1} + \pi_{t+1} m_{bt+1}, \tag{27}$$

$$\pi_{t+1} m_{bt+1} \geq \kappa \pi_{t+1} n_{t+1}, \tag{28}$$

where (27) is the balance-sheet identity and (28) is the technological constraint on bank payments, which represents an assumption that banks need to reserve cash, $\pi_{t+1} m_{bt+1}$, that exceeds a κ percentage of total liabilities, in case of payments to other banks in order to maintain their deposits, $\pi_{t+1}n_{t+1}$. The resource constraints of this model are $k_{ht} + k_{bt} = k_t$, where k_t is the total of capital stocks, and $m_{ht} + m_{bt} = m_t$, where m_t is the base money supplied by the central bank.

In this economy, the government (or the central bank) can implement the monetary regime and can obtain qualitatively the same equilibrium as that in Section 2.4 by changing the bank regulation as follows: The government decides that interbank payments can be done by means of emissions reducers, in addition to cash. This change in regulation makes the constraint on interbank payments as follows:

$$q_t e_{t+1} + \pi_{t+1} m_{bt+1} \geq \kappa \pi_{t+1} n_{t+1}, \tag{29}$$

instead of (28). In this simplified model, all cash is held by the banks in equilibrium: $m_{ht} = 0$ and $m_{bt} = m_t$. Conditions (27) and (29) imply that the banks' problem reduces to

$$\begin{aligned} \max_{e_{t+1}, m_{bt+1}} \quad & \left[r_{et+1} + (1-\eta) q_{t+1} - \frac{1}{\kappa} \frac{(1+r_{nt+1})}{\pi_{t+1}} q_t + \frac{1-\kappa}{\kappa} (r_{t+1} + 1 - \delta) q_t \right] e_{t+1} \\ & + \left[-\frac{1}{\kappa}(1+r_{nt+1}) + 1 + \frac{1-\kappa}{\kappa}(r_{t+1} + 1 - \delta)\pi_{t+1} \right] m_{bt+1}. \end{aligned}$$

Since the total supplies of e_{t+1} and m_t are finite, it must be the case in the equilibrium that

$$\begin{aligned} & r_{et+1} + (1-\eta) q_{t+1} - \frac{1}{\kappa} \frac{(1+r_{nt+1})}{\pi_{t+1}} q_t + \frac{1-\kappa}{\kappa} (r_{t+1} + 1 - \delta) q_t = 0, \\ & 1 + r_{nt+1} = \kappa + (1-\kappa)(r_{t+1} + 1 - \delta)\pi_{t+1}. \end{aligned}$$

Therefore,

$$q_t = \pi_{t+1}\{r_{et+1} + (1-\eta) q_{t+1}\}, \tag{30}$$

which is equivalent to (23) in the original model. If the government chooses q_{t+1} and π_{t+1} such that (30) is satisfied in the equilibrium, the banks possess the emissions reducer voluntarily as their asset. Equation (30) implies that the government needs to set q_{t+1} and π_{t+1} so that the gross rate of return on the emissions reducer is equal to that on cash, i.e., π_{t+1}^{-1}. The interdependence of q_{t+1} and π_{t+1} in this equation makes our arguments in Section 2.4 also hold in this modified model. Therefore, the government can choose q_{t+1} and π_{t+1} appropriately, without imposing caps on emissions, such that private agents (i.e., banks) possess emissions reducers voluntarily. It is easily confirmed that in the steady state where $q = [\phi'(\eta)]^{-1}$ and $r_e = (q-1)\eta$, the government can make (30) satisfied by setting

$$\pi = \frac{1}{1 - \eta\phi'(\eta)}.$$

This model also has the same implications for the environmental automatic stabilizer and for the international free-rider problem as those we argued in Section 2.4.

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