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Theoretical and empirical analysis on the relationship between economic growth and environmental policies:

Long-term transformation of the economy−environment nexus in Japan

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ABSTRACT.

Now that ecological crisis is evident, the issue of environment cannot be neglected in discussing growth. There emerged some theoretical studies aiming at incorporating this issue into the *régulation* theory. With a view to proceed with this approach with an emphasis on empirical analysis, this paper elaborates on analytical method and conducts an historical analysis on Japan's case.

The "economy–environment nexus" is analyzed as one of the institutional forms. The dynamics of institutional coordination are specified referring to key concepts of the theory. Environmental costs are estimated as key indices. A variant of Kaleckian growth model is used to analyze their effects on the growth regimes.

Combining these information, we periodize and specify the the economy–environment nexus in Japan, which includes: 1) 1960's to around 70, with intensive accumulation supported by extensive consumption of environment; 2) 1970's to early 80's, with strict regulations formulated through conflicts, which was supportive to growth; 3) 1990's to early 2000's, with institutions of voluntary and flexible nature under weaker actors; and 4) after 2008, with some policies aiming at green growth as common agenda of economic and environmental actors. This historical recognitions have implications on future policies.

Keywords: environment, historical analysis, environmental cost, Kaleckian model, green growth

A. FOREWORD

Ecological crisis is now recognized as a factor that may limit the economic growth. There also emerged an idea of "Green Growth". The issue of environment has become an imperative element in discussing economic growth.

Environmental problems arise along with the economic growth, cause social conflicts between polluters and victims, and come to be controlled by regulations and other rules, which in turn may impact on the growth. Thus it is an issue of institutional coordination of the economy, which fits the framework of the *régulation* theory.

Environmental policy always faces the question of economic growth. Neo-classical environmental economics has not been able to adequately answer it, limiting itself to advocating market instruments such as carbon pricing. Approaches from the *régulation* theory will contribute to filling this gap by providing historical perspectives on growth with political reality. It should be also beneficial for the *régulation* theory to incorporate this issue into its framework in order to enhance its relevance and completeness.

Among economists in the *régulation* school, though Lipietz provided valuable insights and perspectives on the environmental issue [e.g. Lipietz: 1995; 1999], it is recently that works aiming at more analytical approaches incorporating environmental issues into the core of the theory have emerged [e.g. Becker and Raza: 1999; Rousseau and Zuindeau: 2007; Zuindeau: 2007]. They analyzed theoretical properties of *régulation* theory and environment-related studies (i.e., political ecology, ecological economics, and studies on sustainable development) with a view to bridging the gaps between them, and recommended proceeding with analyses on specific forms of the relationship between the economy and the environment[1] based on the framework of *régulation* theory. Becker and Raza [1999] also suggested that the relationship between the economy and the environment be considered as a sixth institutional form. These studies provide a valuable basis for environmental analysis using the *régulation* theory. Building on these studies, it is needed to explore historical or comparative analyses on real economies. Further theoretical consideration is also required to obtain robust frameworks for such empirical analyses.

This paper first proposes a methodological framework to analyze real economies, with referring to surplus approach and focusing on environmental costs. Then, it conducts an historical analysis on post-war to today's Japan to understand how the relationship between economy and the environment has been changed.

B. THEORETICAL STUDY ON FRAMEWORK FOR THE ANALYSIS

B.1. SOCIO-ECONOMIC SYSTEM AS TRIPLE REPRODUCTIONS AND ECONOMY-ENVIRONMENT NEXUS

In order to obtain a sound basis for a consistent framework, we start by clarifying a basic conception of the socio-economic system by referring to the ideas of Polanyi and the surplus approach.

Polanyi [1957] saw the economic crisis in the 1920s as a manifestation of the instability inherent in the market mechanism. His view and *régulation* theory are consistent, both based on the recognition of the potentially destructive nature of the capitalist economy and the necessity of institutional coordination to contain its power [Boyer and Hollingsworth : 1997; Yamada, 2007]. Thus, it is beneficial to refer back to Polanyi's inspirations when considering an application of *régulation* theory. Polanyi [1957] saw the fundamental cause of this destructive nature in "fictitious commodities." He argued that labor, land, and money are not commodities produced by man for sale, and are thus destined to be destroyed if put under the control of the market. Here we

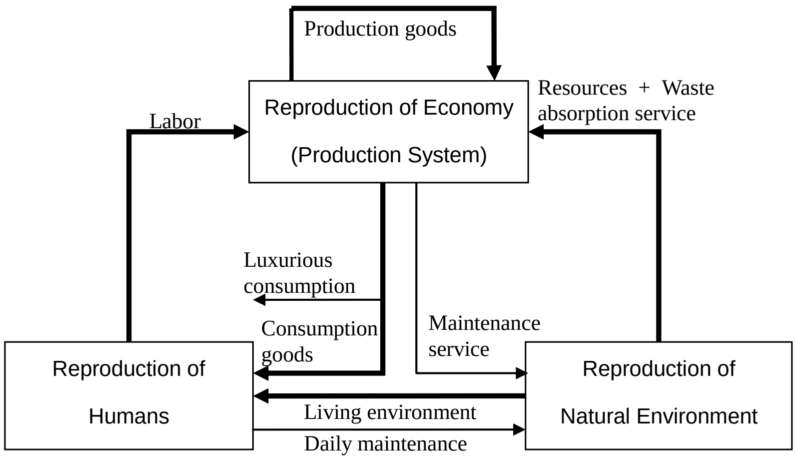
[1] There are several terms used for the relationship between the economy and the environment, including "social relation to the nature," "ecological *régulation*" [Becker and Raza : 1999], and "economic relation to the environment" [Zuindeau : 2007].

emphasize that he raised "land," in other words the "natural environment," as one of three fictitious commodities, and pointed to environmental degradation as one of the problems caused by an excessive market.

Since the concept of sustainability is closely related to that of reproduction, we also consider it beneficial to refer to the surplus approach, which dates back to classical economics. Under this tradition, capital and labor are recognized as distinct reproductions that are interlinked to constitute the socio-economic system.

On the basis of these views, we consider it rational, in today's circumstances of growing ecological concerns, for the environment to be explicitly conceived as one of the primary factors that has its own system of reproduction. This leads to a conception of the socio-economic system as consisting of three subsystems: reproduction of the "economy" (within a narrow meaning), reproduction of "humans" (including the labor force), and reproduction of the "natural environment"[2], which can be presented as Figure 1.[3]

Figure 1. Socio-economic system as triple reproductions



Let us specify the basic nature of these reproductions and the relations between them. Economy reproduction is a production system sustained by three categories of input, i.e., production goods, labor provided by human reproduction, and goods and services provided by the natural environment, consisting of natural resources and waste absorption services (hereafter called "environmental resources"). The natural environment is the reproduction system sustained by the productive capacity of nature itself, but partly supported by maintenance services from the economy and human society. A part of the natural environment is owned under property rights and paid for with rents, a portion of which is appropriated for maintenance services (e.g., fertilization, afforestation). However, larger parts are public goods and not paid for with rents. When they are utilized beyond their reproductive capacity, their depreciation is not recovered, causing environmental problems. Human reproduction is sustained by the reproductive capacity of humans and society together with the input of consumption goods and services from the production system as well as the earth's provision of the living environment (e.g., air, water). It provides the production system with labor and is paid for with wages, which are used to obtain consumption goods. Since these are systems with their own mechanisms, their relations are not automatically harmonized, but need to be coordinated by institutions.

Now, based on this recognition, we incorporate environmental aspects into the *régulation* theory. *Régulation* theory, focusing on accumulation and coordination by institutions, analyzes the structure of the economy using concepts of institutional forms, accumulation regime, and mode of *régulation*. Five institutional forms are identified as areas of institutional coordination: wage–labor nexus, monetary and financial regime, forms of competition, relations between state and e economy, and forms of integration into the world economy [Boyer : 1986; 2000; Yamada : 1991].

[2] Beaud [1997] has already recognized the socio-economic system as the triple reproductions of the earth, humans, and capitalism.

[3] This figure is based on a figure by Uemura [2007], and adds elements related to the environment.

In light of the recognition of the triple reproductions above, we understand that the wage–labor nexus corresponds to coordination of the relationship between human and economic reproduction. Furthermore, in view of the essential role of reproduction of the natural environment, the relationship between the natural environment and economic reproduction should also be recognized as an important area of institutional coordination. Thus, we propose, in line with suggestions from preceding studies such as Becker and Raza [1999], to recognize the institutional coordination of the relationship between the natural environment's reproduction and economic reproduction as the sixth institutional form. In this paper we call it the "economy–environment nexus." The economy–environment nexus is forms of utilization of the natural environment in socio-economic systems, which are temporally and spatially variable depending on production technologies as well as socially formulated institutions. The economy–environment nexus, interacting with other institutional forms and possibly constituting one element of mode of *régulation*, affects the growth regime.

B.2. DYNAMICS OF COORDINATION IN ECONOMY−ENVIRONMENT NEXUS

In order to analyze the institutional forms, it is essential to make clear the dynamics of coordination. In case of wage−labor nexus, labor demanding higher wages is typically the main actor who drives the institutional coordination. What about the economy-environment nexus?

A production system driven by capital accumulation has a tendency to utilize a larger amount of the natural environment with a smaller amount of rents and maintenance services in order to gain larger profits.[4] When it is overused beyond its reproductive capacity, the natural environment is degraded and gives feedback to the production system through two channels. First, in cases of environmental resources covered by property rights, the Ricardian rent rates rise through market mechanisms as well as bargaining between producers and land owners. Second, in cases of public goods, their overuse leads to their reduced supply to human reproduction, resulting in environmental problems. This provokes conflicts between the actors causing the degradation and those suffering from it, which leads to the formulation of institutions requiring measures to protect the environment.

The relations of these actors vary according to the types of problems. The relationship is relatively clear in local industrial pollution, while it is vague for global environmental problems, which are spatially and temporally spread out. In the former, people suffering from pollution become the main actors calling for environmental measures. In the latter, though actors for environmental measures tend to be weak, people who recognize or foresee damages to others and take actions to reduce them, such as scientists, NGOs, and governmental organizations, often in collaboration, can work as such actors.

We can understand institutions of environmental measures as compromises formulated through conflicts of interest between these actors. Such institutions take various forms, including legal systems, agreements, and shared norms.

These institutions are formulated and formalized in particular places of governance. The most important place is the state. Environmental problems arise on various scales, from local to global. For local problems, not only states but also communities and local governments play important roles. For global environmental problems, the formulation of institutions needs to be understood at the national as well as the international level, including international organizations and conventions.

In this connection, it should be noted that phases of the coordination, such as causal activities, induced damages, and places of governance, have their own spatial and temporal scales. For example, in the case of industrial pollution, health damage occurs locally, but effective measures require policy decisions at the state level. In the case of climate change, today's economic activities have consequences for future generations. When there are such gaps in spatial or temporal scale, feedback loops from damage to institutional coordination are not linked

[4] One may go back to Kapp's (1950) concept of the "social costs of private enterprises" to find one of the roots of this kind of recognition.

smoothly, resulting in a delay of countermeasures and expansion of damages.[5] In this paper, we call such phenomena the "temporal/spatial gap of coordination."

Institutions in the economy−environment nexus are formulated through interactions with other institutional forms. This interaction, in particular in the context of institutional changes, can be analyzed in light of the concepts of "institutional complementarity" and "institutional hierarchy", as Zuindeau [2007] suggested. Institutional complementarity refers to a state in which institutions in one domain support those in others. Institutional hierarchy refers to the relative importance of a particular institutional domain in the structure of complementarities [Amable: 2003]. This hierarchy may be reversed in the history. For example, the wage–labor nexus was dominant in the post-war high-growth era, but insertion into the world economy took its place in the 1990s [Boyer: 2000]. So far, the economy-environment nexus generally has been located in the lower level of institutional hierarchy, and its particular forms may be understood from the viewpoint of complementarity with other institutional forms at the higher level. On the other hand, if environmental constraints become severer, the economy−environment nexus may come to influence other domains of institutional forms and also the mode of *régulation* as a whole.

B.3. ENVIRONMENTAL COSTS AS KEY INDICES

When analyzing the institutional forms, quantitative indices play important roles as they enable tracking the historical change and analyzing the impacts on the accumulation. In case of wage−labor nexus, wage level and share are key indices, as institutional coordination there is developed through distributive conflicts over the wage. When analyzing economy−environment nexus, we consider it useful to focus on costs related to the environment, such as rent and cost of environmental measures, as they represent in monetary terms the effects of degraded natural environment's reproduction on the production system.

We refer by the term rent to the Ricardian rent as well as other various fees paid against the usage of the natural environment as source and sink. When the natural environment comes to be degraded and its scarcity increases, rent rates on existing property rights rise, and, in addition, compensation for damages will be arranged and various forms of charge systems related to the utilization of environmental resources, such as tradable permits, may be newly introduced, which we can recognize as sorts of rent.

Next, let us discuss the cost of environmental measures. Since this tends to be scattered and merged into other costs in various sectors, it is an important task to clearly define and capture it. We explore a methodology for it with referring to the System of Integrated Economic and Environmental Accounting (SEEA). SEEA is an accounting system developed as a satellite system of SNA by the United Nations statistical division and other related organizations. Methodologies including disaggregation of environment-related activities, estimation of imputed environmental costs, and hybrid physical and monetary accounting have been proposed [United Nations: 1993; United Nations, et al: 2003]. Here we define and capture the cost of environmental measures by using the methodology for estimating environmental protection expenditure account (EPEA) as adjusted according to the purpose of this study [United Nations et al: 2003, pp. 169-213].

When the natural environment is degraded, through institutional coordination, the production system is forced to produce goods and services that substitute the functions of degraded nature. Examples include alternative energies (substituting fossil fuels) and waste treatment services (substituting nature's absorption function). We call these hereafter environmental-resource-substituting goods and services (ESGSs).[6] Although ESGSs are a kind of products of the economic reproduction, they have a distinct character in that they are produced with additional costs to substitute nature's functions that were freely or very cheaply available when the natural functions were abundant. In this sense, when analyzing the relationship between reproductions of the economy and the natural environment, there is merit

[5] A similar notion is already established in environmental sociology. Funabashi (1998) pointed out that gaps between the "benefit zone" and the "victimized zone" worsen the environmental problems.

[6] SEEA uses the concept of "environmental products," with a focus on environmental protection [United Nations et al : 2003, pp. 173-81]

in treating them separately from other products.

Environmental resource substitutions are categorized into two types: substitutions in the production system and those in human reproduction. The former appear as intermediate consumption in the production processes. Typical examples include consumption of industrial waste management services. Input of facilities and labor for pollution abatement within companies can also be understood as intermediate consumption of pollution abatement services by separating them from other inputs [United Nations, et al: 2003]. The latter appear as final consumption by households. Typical examples include consumption of bottled water made necessary by water pollution. We recognize activities producing and consuming ESGSs as "environmental measures." Expenditures for ESGSs can be defined as the costs of environmental measures.

In addition to these costs, degradation of the nature of public goods needs to be taken into account as one form of environmental costs. We call this "latent environmental cost" in this paper. It is latent because it is not paid at present but will be borne in the future in some form by someone, for example, as health damages to residents or as increased resource costs in production processes.

Among these environment-related costs, rent is determined through distributive conflicts as well as market mechanisms. In addition, cost of environmental measures and latent environmental cost also involve distributive conflicts, as environmental measures generate their costs typically born by producers while reducing latent environmental costs typically borne by society as a whole. The size and sharing of these environmental costs reflect the state of institutional coordination in economy−environment nexus.

As the next step, we formalize these costs as compatible with the macro economic accounting so that we can measure them and analyze their impacts. This study focuses on rent and cost of environmental measure, which are really paid and directly affect the economy.

We start with formalizing rent by presenting the production as an equation of three dimensional distribution. Production is conducted with inputs of capital, labor, and environmental resources, and the products are distributed among profit, wage, and rent. Thus,

$$pY = rpK + wL + \rho N \qquad (1)$$

where Y is output, K is capital stock, L is labor input, N is consumption of environmental resources,[7] r is profit rate, w is money wage rate, ρ is money rent rate, and p is price. This equation is in gross term. If we develop an equation in net term, depreciation of natural capital is specified, which represents the latent environmental cost [Okuma: 2012].

Then, we formalize cost of environmental measures. Focusing on activities producing ESGSs, and referring to the SEEA as a basis [United Nations et al: 2003], we can describe economic interrelations using a two-sector I-O model consisting of the ESGS sector and the "production sector" excluding it (Table 1).

Table 1. Environmental resources substituting goods and services in I-O structure

		Intermediate consumption			Final demand			Total
		Production sector	ESGS Sector	Total	Con-sumption	Invest-ment	Total	
Intermedi-ate inputs	Production sector	―	integrated	―	pC_p	pI_p	$\approx pY$	$\approx pY$
	ESGS sector	p_eX_{ep}	―	p_eX_{ep}	$p_eC_e \approx 0$	$p_eI_e \approx 0$	≈ 0	$p_eE \approx p_eX_{ep}$
	Total	p_eX_{ep}	―	p_eX_{ep}	pC_p	pI_p	pY	$pY + p_eX_{ep}$
Values added	Wages	wL_p	wL_e	wL				
	Profits	rpK_p	rpK_e	rpK				
	Rents	ρN_p	ρN_e	ρN				
	Total	$pY - p_eE$	p_eE	pY				
Total		$\approx pY$	p_eE	$pY + p_eX_{ep}$				

[7] This denotes the amount of the earth's source and sink functions consumed in the production process. Its measurement is an important subject of environmental studies, and some indicators have been proposed, such as the Ecological Footprint and the Material Flow Accounts, though accurate measurements are not possible yet.

In this model, the ESGS sector is defined as including activities that produce intermediate input into it, so that the box representing intermediate input from the production sector to the ESGS sector is empty.[8] Diagonal boxes are also empty since each sector is conceived as a consolidated process with a single product.[9] The value of intermediate input from the ESGS sector to the production sector (p_eX_{ep}) can be regarded as the environmental measure cost in the production system.[10]

This makes it possible for costs of environmental measures to be integrated into a one-sector distribution equation as production costs. By dividing each factor of production into the portion used for production of ESGSs and that used for other production under the assumption that profit rate, wage rate, and rent rate are uniform across sectors, equation (1) can be transformed into

$$pY = rpK_p + wL_p + \rho N_p + p_eE \qquad (2)$$

with $p_eE = rpK_e + wL_e + \rho N_e$

where E is consumption of ESGSs and p_e is its price;[11] K_e, L_e, and N_e are the portions of factors used for production of ESGSs; K_p, L_p, and N_p are the portions of factors used for other production (hereafter called "production capital," "production labor," and "production resources," respectively).

This formalizes environmental measure cost as an element of distribution. This enables analyzing impacts of environmental costs on accumulation by modeling.

B.4. ECONOMY−ENVIRONMENT NEXUS AND GROWTH REGIME

The economy–environment nexus influences the growth regime through multiple routes. We attempt to specify these routes by focusing on rents and environmental measure costs as key parameters. This is done by referring to the structure of growth regimes in *régulation* theory (Figure 2).

The growth regime is understood in terms of the relation of production and productivity. Productivity rises not only through exogenous innovations, but also through increases in production through dynamic increasing returns (productivity regime). Production is determined by the demand as long as the capacity is not fully utilized, and improved productivity leads to an increase in demand under a certain distributional coordination (demand regime). Here we use the basic Fordist structure of demand regime and productivity regime as a frame upon which to identify impacts from the economy–environment nexus.

In the economy–environment nexus, levels of rents, environmental measure costs, and latent environmental costs are determined under institutional as well as market coordination.

Economic growth, without resource productivity improvement, increases the consumption of environmental resources. If it is within the reproductive capacity of the natural environment, the rent rate remains at a low level and costs of environmental measures are not generated. In this case, the economy–environment nexus does not have visible impacts on the growth regime. Even when the economy is beyond the ecological capacity, the same condition can be maintained if environmental resources are utilized without paying the cost necessary for their reproduction, generating latent environmental costs. When a growth regime is supported by the growing input of environmental resources without rising costs for them, accumulation can be regarded as having an extensive nature in terms of utilization of environmental resources in that it is supported by expanding inputs produced outside the production system.

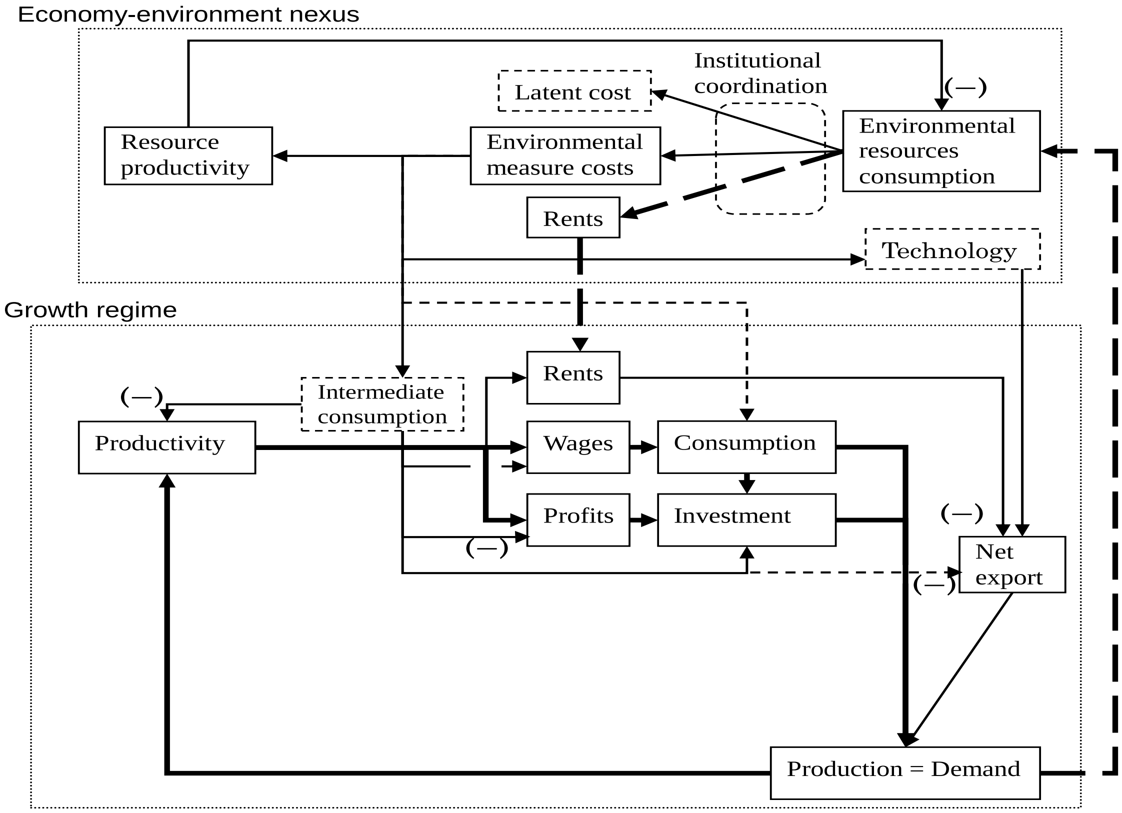
[8] This definition is made by referring to the concept of vertical integration [Pasinetti: 1973]. However, investment is not transformed into annual intermediate input and is thus not vertically integrated in order to keep the model empirically traceable.

[9] Georgescu-Roegen [1971] pointed out that, according to the analytical view of a process, each process of the I-O table should be associated with one product and diagonal boxes should be empty.

[10] Here we focus on the costs of environmental measures in the production system (X_{ep}), and assume away that in consumption (C_e) and other final demands. This is justified by the recognition that there have not been such large increases in this cost in consumption as to change the aggregate propensity to consume so far. However, in view of the increasing importance of environmental loads from households as well as the possible development of governmental policy measures, further analysis on the costs in final demands remains to be pursued.

[11] Let us give brief consideration to the relative price of ESGSs and other products. If we assume production factors are utilized in the same proportion between these sectors (i.e., K_p:L_p:N_p = K_e:L_e:N_e), we have $p_e/p = Y/(Y + E)$. Here, in the current economy, $E \ll Y$. Therefore, we can understand that $p_e/p \approx 1$. With this understood, we proceed with the analysis using the one-sector model.

Figure 2. Relationship between the economy-environment nexus and the growth regime



Note: (—) indicates a negative effect.

On the other hand, when rents and environmental measure costs increase, they have visible impacts on growth regimes.

An increase in rents reduces distribution to wages and profits, and, in the case of resource-importing countries, works as a leakage from the economy. In resource-producing countries, the effects of increasing rents depend on the properties of specific economies such as propensity to save from rents. Although level of rents is influenced by institutional coordination, when consumption of environmental resources continues to expand, the long-term rent rate trend will be upward (the bold broken arrows in Figure 2). A continuous increase in rent rate leads to a reduction in demand in resource-importing countries. This means that a growth regime that continues to expand its resource consumption, such as the Fordist regime, has inner dynamics to undermine its own basis, which may contribute to the crisis of the regime.

An increase in environmental measure costs impacts both the demand regime and productivity regime. Impacts on the demand regime are multi-facetted. First, environmental measures reduce rents by improving resource productivity and reducing consumption of environmental resources. This leads to the reduction of imports in resource-importing countries. We call this resource-saving effect.

Second, an increase in these costs means an increase in the consumption of ESGSs. In the case of ESGSs as an intermediate input, an increase in their production requires increased inputs of labor and capital while not directly increasing the total value addition of the economy. Thus, these costs are reflected in increased total wages and reduced profits when assuming a constant real wage rate under quantitative adjustments. Increased total wages lead to increased consumption. Reduced profits lead to reduced investment. Increased costs may affect competitiveness and reduce exports. These effects, starting from costs, through distributive change, impact on demand in combination either positively or negatively. We call it cost-demand effect.

Third, if we consider ESGSs for consumer goods and services, an increase in their consumption may increase final demand and thus the output of the economy, but this happens only when propensity to consume as a whole rises.

Fourth, increased demand for ESGSs induces investment in their production. Since

ESGSs are a new category of products, growth in their consumption requires new sorts of capital equipment to produce them and thus gives rise to investment. We call this effect of inducing environmental investment. This effect works only while this demand is increasing.

Fifth, environmental measures should promote innovation in environmental technologies through "learning by doing." Induced innovation leads to strengthened competitiveness and increased exports. This effect can be understood as a first-mover advantage in the global trend of structural change of expanding consumption of ESGSs. We call this export-competitiveness effect. This effect should appear only after a certain amount of experience with environmental measures is accumulated.

Looking at the impacts on the productivity regime, environmental measures raise resource productivity through substitution of environmental resources as well as induced investment and innovation mentioned above. On the other hand, they have the effect of reducing labor productivity through additional labor and capital inputs for intermediate consumption. This may weaken the effect of cumulative causation between productivity and demand growth.

These multiple effects, when aggregated, may either support or impede the structure of the growth regime depending on the state of the economy and the nature of the environmental measures. To obtain a clearer expression of the multiple effects, in particular those of environmental costs on the demand regime described above, Okuma [2012] developed a variant of Kaleckian growth model. Kaleckian models, sharing some important viewpoints with the *régulation* theory, have been used by some *régulationists* [e.g. Bowls and Boyer: 1990].[12] Here we present the outline of the model.

A basic model of Kaleckian, referring to Lavoie [1992; 2010] and Blecker [2002], is presented as following three equations:

$$r = \pi u v$$

$$g_s = s_r r$$

$$g_i = \gamma_0 + \gamma_u u + \gamma_r \pi v$$

where π is profit share; v is the ratio of output at full capacity utilization to capital; g_s is saving and g_i is investment, both normalized by capital stock; and s_r is propensity to save out of profit. The impacts of π on u and r are analyzed by comparative statics.

By incorporating the rent and the environmental measure cost into the profit function using the formalization in equation (2) in section B.2, and adding functions of import and export assuming resource-importing countries, we obtain the model to analyze the impacts of environmental measure cost on the growth. The outline is presented in Table 2.

Table 2. Outline of the Model

Main Equations	
$r = [\pi_0 - (1-\theta)(1-\phi)e]uv_p$	(e: environmental-measure-cost (EMC) share; θ: share of EMC borne by wage; ϕ: recovery rate of EMC; v_p: potential-output to production-capital rate; u: capacity utilization)
$g^s = s_r r$	
$g^i = \gamma_0 + \gamma_u u + \gamma_r \pi_p v_p$	(π_p: profit share for production-capital)
$m = m_0 + m_u u - m_e e$	(m: import normalized by capital)
$x = x_0 + x_\pi \pi_p$	(x: export normalized by capital)
$g^s = g^i + x - m$	
Analyzing impacts of environmental measure cost	
a) Condition for capacity utilization to rise : $F_u(1-\phi) + m_e > 0$ where $F_u = (s_r u v_p - \gamma_r v_p - x_\pi)(1-\theta)$	
b) Condition for profit rate to rise (paradox of cost) : $F_r(1-\phi) + m_e > 0$ where $F_r = [(\gamma_u - m_u)u/\pi_p - (\gamma_r v_p + x_\pi)](1-\theta)$	
c) Inequality to calculate minimum recovery rate of EMC that raise profit rate: $\phi/(1-\phi) > -F_r/uv_p$	

[12] Other approaches, such as one directly specifying the productivity regime and demand regime, or one analyzing two or more sectors should also be important. For example, Uni (2011) took steps to apply the cumulative causation model as in Boyer (1988) to environmental issues by estimating the "productivity regime in a broader sense" and considering its institutional implications.

Impacts of e on u and r are analyzed by comparative statics, essences of which are shown in a), b) and c) in Table 2. In a) and b), F_u and F_r represent cost-demand effect, while ϕ and m_e represent resource-saving effect explained above. When the condition b) is met, increasing environmental measure cost results in higher profit rate. We call this phenomenon "paradox of cost" for environmental measures, following Rowthorn [1982]. This phenomenon can be regarded as "green growth". Using the inequality in c), we can roughly estimate what types of environmental measures in terms of recovery rate of costs will raise the profit rate.

This model can incorporate two additional factors with dynamic nature: environmental-investment-inducing effect and export-competitiveness effect explained above. Incorporating them, investment function and export function can be changed respectively into,

$$g_i = \gamma_0 + \gamma_u u + \gamma_r \pi v_p + \gamma_e \dot{E}/K \quad (\dot{E} = E_t - E_{t-1} \text{ is growth of } E)$$

$$x = x_0 + x_\pi \pi + x_e T/K \quad (T \text{ is accumulation of experiences: } T_t = E_t + (1-\delta)\, T_{t-1})$$

Though these are effects of dynamic nature beyond the comparative statics, if interpreted with caution regarding the timings that these effects appear, their impacts can be evaluated by adding $[(\gamma_e \dot{E}/K + x_e T/K)/e]$ to m_e in the inequalities in a) and b) (refer to Okuma [2012] for the detailed explanation of the model).

The above model helps us to understand the relationships among multiple routes of effects described above, and opens the possibility for quantitative estimations in empirical analysis of specific economies.

C. EMPIRICAL ANALYSIS OF THE LONG-TERM TRANSFORMATION IN JAPAN

Using the analytical framework presented above, we analyze Japanese history since post-war era. First, as basic information, we trace the historical development of institutions in economy-environment nexus. Second, we conduct long-term estimation of environmental costs as key indices. Third, we also carry out econometric analysis of the Kaleckian model useing these indices. Finally, through combining these information, we analyze long-term transformation of economy-environment nexus and its relation to growth regimes.

C.1. HISTORICAL DEVELOPMENT OF ENVIRONMENTAL INSTITUTIONS

Institutions that coordinate the relationship between economy and environment, which typically take the form of legislation, have developed in varying speed with varying nature. Examples of important legislations and other institutions are chronologically listed in Table 3.

A rough description can be made as follows. In 1970's, legislations for pollution abatement were introduced and strict regulations were implemented. In parallel, policies to promote energy-saving were introduced. This can be called the first wave of environmental policy development.

In 1980's development of environmental institution was stagnated. Typical example was the abolition of the bill of environmental assessment due to the opposition from industries.

In 1990's, stated with the enactment of the Basic Environment Law, legislations and other policies related to waste recycling and global warming are rapidly introduced. This can be called the second wave of environmental policy development.

These observations lead to historical interpretations in section C.4.

Table 3. Development of the environmental institutions in Japan

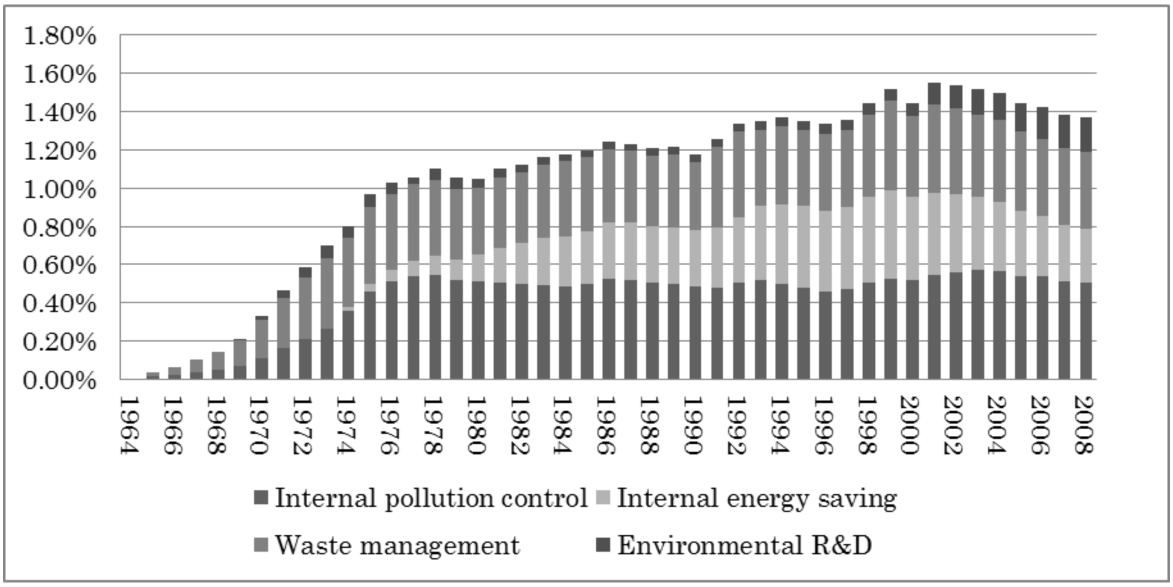
Year	Legislation/Policies
1965	
1966	
1967	
1968	Basic Law for Pollution Control, Air Pollution Prevention Law
1969	
1970	"Pollution Diet" (14 bills: Waste Management Law, Amended Basic Law, etc.)
1971	Environment Agency establised
1972	
1973	Regulatory standards continuously tightened
1974	Total emission control of SOx
1975	
1976	
1977	
1978	Strict standard on automobile exhaust ("Japanese Muskie Act")
1979	Energy Saving Law
1980	
1981	
1982	
1983	(Abolition of Environmental Impact Assessment Bill)
1984	
1985	
1986	
1987	
1988	
1989	
1990	Recycled Resources Utilization Law, Amended Waste Control Law
1991	
1992	
1993	Basic Environment Law
1994	
1995	Containers and Packaging Recycling Law
1996	
1997	Environmental Assessment Law, Voluntary Action Plan by industry
1998	Global Warming Law, Amended Energy-saving Law, Electric Appliances Recycling Law
1999	
2000	Basic Act for Sound-material-based Society, Green Procurement Law
2001	Ministry of the Environment establised
2002	End-of-life Vehicle Recycling Law
2003	
2004	
2005	
2006	
2007	
2008	
2009	Eco-car Subsidy Scheme, Eco-points Scheme for electric appliances
2010	
2011	
2012	Carbon Tax, Feed-in Tariff Scheme

C.2. LONG-TERM ESTIMATION OF ENVIRONMENTAL COSTS

In order to obtain objective indices, we conduct long-term estimation of costs related to the environment, i.e. costs of environmental measures, rents, and latent environmental costs. First, we estimate environmental measure costs as expenditure to ESGSs in production system, referring to methodology used in Japanese SEEA estimation [Japan Research Institute: 2004]. We take up costs for internal pollution control, internal energy saving, waste management, and environmental research and development. The results presented as shares in the output are shown in Figure 3.[13] When compared with estimation by Japanese Research Institute [2004], this estimation covers long-term period, with omitting some categories of smaller magnitude, while adding energy-saving and environmental R&D in line with our interest in climate change and competitiveness respectively. Data sources and estimation methods are shown in the appendix 1.

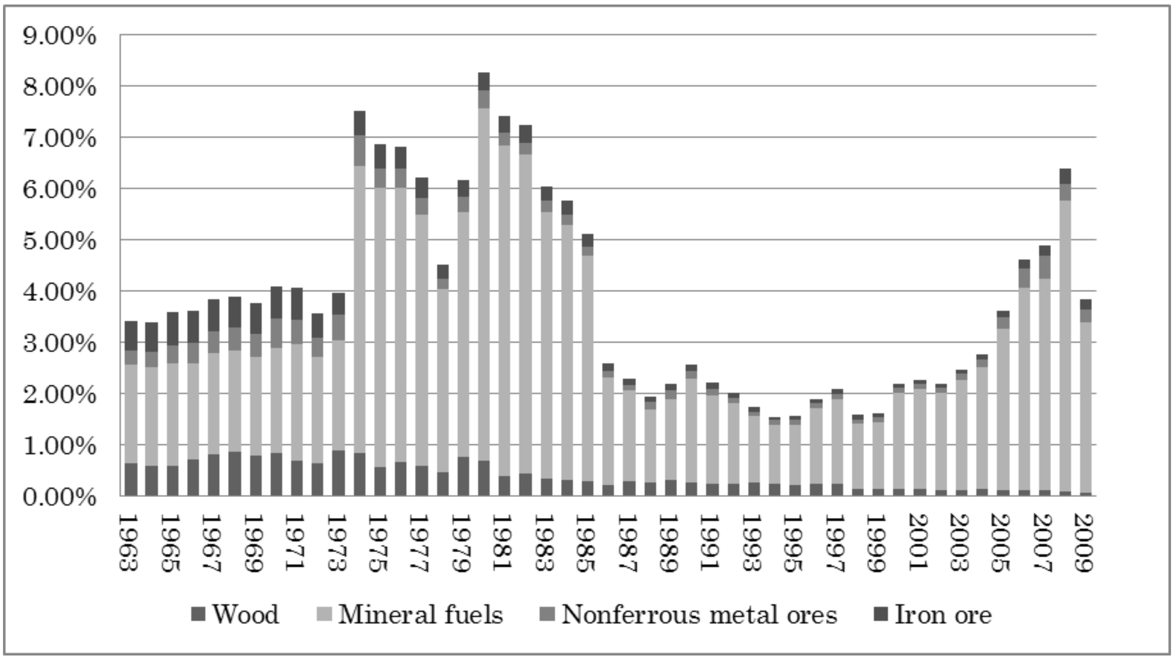
[13] Intermediate inputs between different environmental measures should be deducted from the total costs in order to estimate the exact value in accordance with the concept of vertically integrated sector of ESGSs in section B.3. However, since their amounts are small, we assume them away here.

Figure 3. Ratio of environmental-measure-cost to output



Second, we estimate rents. In case of resource importing countries as Japan, most of rents are included in importation. Though values corresponding to rents are included in various goods and services, this study regard importation value of natural resources as rent equivalent in view of its magnitude and data availability. The results presented as shares in the output are shown in Figure 4.

Figure 4. Ratio of rent to output



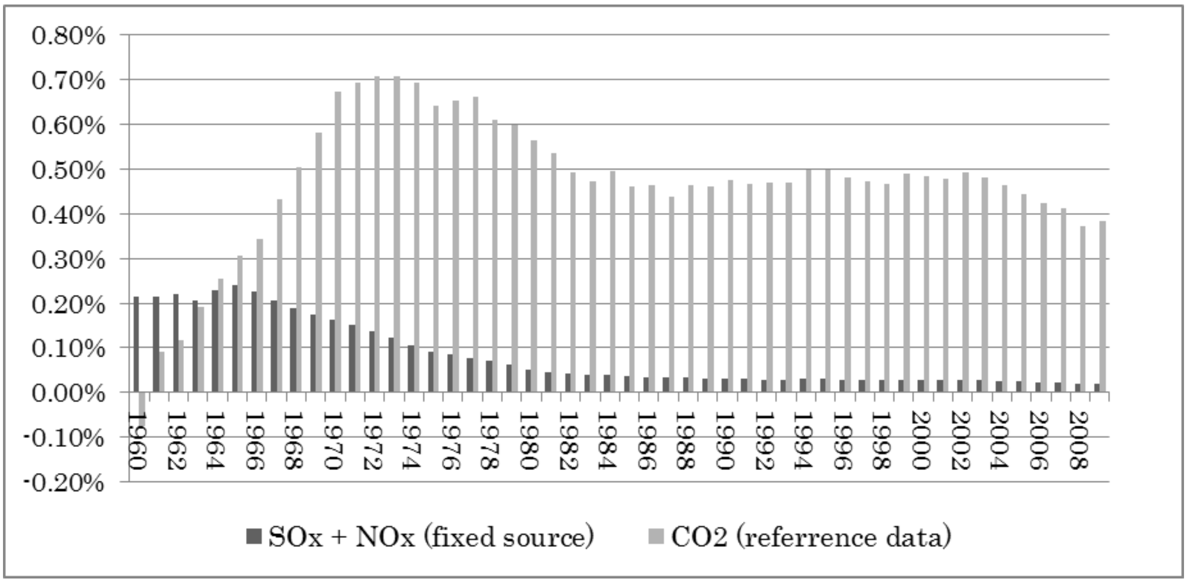
Note: Estimated as importation value of natural resources.

Third, we consider latent environmental costs. Recognizing the inherent difficulty in evaluating nonmarket values, we conduct a minimum estimation within the extent necessary to observe the general trend in comparison with other environmental costs. Among various possible methodologies, we use maintenance cost approach as compatible with the concept of depreciation of natural environment in section B.[14] Thus, using the periodical estimation of imputed environmental costs by Japan Research Institute [1998] as a basis, with extending the timeline while narrowing the scope, we obtain long-terms estimation of the cost of sulfur oxides

[14] SEEA 1993 proposed maintenance cost approach, recognizing that it "corresponds to the method of calculating the value of the depreciation of produced fixed assets" [United Nations : 1993, pp.107].

and nitrogen oxides (from fixed sources) emission, and that of carbon dioxide emission.[15] The results are presented as shares in the output in Fig. 5. Data sources and estimation methods are shown in the appendix 1.

Figure 5. Ratio of latent environmental costs to output



Note: Estimation on selected elements.

These estimations of environmental costs are used as key indices in historical analysis of the economy-environment nexus in section C.4.

C.3. ECONOMETRIC ANALYSIS OF THE IMPACTS ON GROWTH

Estimated data of environmental costs can be used in econometric analysis to evaluate their impacts on growth. We have done this using the Kaleckian model introduced in section B.4.

First, we adjusted the functions of the model to fit the econometric analysis of real economies. Asuming that real wage rate is determined by institutional coordination and thus wage share for production labor ($W_s = wL_p/pY$) is constant in relation to enviornmental-measure-cost share (e),[16] we replace θ with zero in the profit function. Taking into account the saving from wages, we add $[s_w W_s u v_p]$ to the saving function as a second member. Accordingly, F_r is changed into $[(\gamma_u - m_u - s_w W_s v_p)u/\pi_p - (\gamma_r v_p + x_\pi)]$.

Then, using the data of environmental measure cost and rent estimated above together with economic data such as profit rate and capacity utilization, we carried out multiple regressions for the functions to estimate parameters. Periods were set firstly by three major partitions: establishment of the high growth (1963), collaption of the bubble (1991) and the global financial crisis (2008) ; and secondly by structural changes indicated by CUSUM tests and Stepwize Chow Tests for each function. Functions and the results of the estimation are shown in appendix 2.

Using estimated parameters, we analyze the impacts of environmental measure cost on the profit rate. F_r representing cost-demand effect, and $[F_r(1-\phi)+m_e]$ representing combined effect of cost-demand and resource-saving are caluculated for periods chosen based on the resuts of the estimation.[17] In addition, $[F_r + (\gamma_e \dot{E}/K + x_e T/K)/e]$ representing combined effect of cost-demand, environmental-investment-inducing and export-compatitiveness is also calculated using average values during the periods. Using these values we anlalyze whether or not, and how paradox of cost for environmental measures worked in particular periods. The outline of the

[15] Cost of carbon dioxide should be regarded as a reference data by which one cannot evaluate the magnitude but observe the trend, since it is estimated using the unit cost of 6% reduction from 1990 (Kyoto Protocol commitment) under the recognition that the immediate full-scale reduction is impossible and its cost is immeasurable [Japan Research Institute : 1998, p.158].

[16] This assumption is supported by the empirical fact in 1970 Japan that industry's pollution abatement expenses were covered by reduction in other costs and profits [Environment Agency : 1992]

[17] For W_s, π, u, and v_p, average values during the periods are used.

results is presented in Table 4.

Table 4. Impacts of the environmental measure cost on the profit rate

	Cost-demand effect	Cost-demand effect + Resource saving effect	Cost-demand effect + Environmental investment & Export competitiveness effect*
	F_r	$F_r(1-\phi) + m_e$	$F_r+(\gamma_e\dot{E}/K+x_eT/K)/e$
1971-74	-0.80	-0.80	4.02
1975-1982	**-0.65**	**28.46**	**3.41**
1983 -87	-0.90	23.17	2.72
Interpre-tation	Profit rate falls.	Profit rate rises by resource saving effect. ⇒ Paradox of cost works.	Profit rate rises by environmental investment and export competitiveness effects. ⇒ Paradox of cost works.
2001-2008	**-0.61**	**-0.36**	**-0.61**
Interpre-tation	Profit rate falls.	Import reduction effect is not statistically significant. (Impacts of strengthened measures are unknown.)	Dynamic effects are not statistically significant. (Impacts of strengthened measures are unknown.)

Note: * Though these effects of dynamic nature cannot be analyzed by comparative statics, we evaluated them by using the average value of $[(\gamma_e\dot{E}/K+x_eT/K)/e]$. In the period from 1971 to 87, its value was constantly high, with decreasing $[\gamma_e\dot{E}/K]$ and increasing $[x_eT/K]$ conbined.

In the period from 1975, environmental measures in general raised the profit rate through resource-saving effects. Pollution abatement measures without energy-saving effects also had the positive impacts on the profit rate through environmental-investment-inducing effect and export-competitiveness effect which appeared consecutively.

In the period of 2001 to 08, resource-saving effect (in particular effect of reducing import) as well as dynamic effects of inducing environmental investment and improving export competitiveness were not observed with statistical significance, the reason of which should be that environmental measure costs did not significantly increase.

Then, using inequality $[\phi/(1-\phi) > -F_r/uv_p]$, we calculate minimum recovery rate of environmental measure costs to raise the profit rate. It is 0.57 in the period of 2001 to 08, while 0.48 in 1975 to 82, which means that conditions for paradox of cost became stricter. This is because of higher m_u (indicating leakage effect) and higher x_π (indicating competitiveness negatively influenced by costs), both of which appear to reflect the globalizing economy.

Now, assuming the same economic conditions as in early 2000's, we speculate as to whether environmental measures, if significantly strengthened, can have positive impacts on the growth. Results above indicate that environmental measures with high cost-recovery rate should have positive effects on the profit. In addition, in view of the significant effects of environmental-investment and export-competitiveness seen in 1970's, it is sensible to say that, if environmental measures are strengthened, these effects, though in smaller magnitude, will probably appear. Thus, we understand that, if environmental measures are strengthened in such a manner that effects of saving resources, inducing environmental investments and improving export competitiveness work, it will be probable that they have positive impacts on the profit rate, which implys possible green growth (refer to Okuma [2013a; 2013b] for further explanation).

C.4. INTERPRETATION OF THE HISTORICAL TRANSFORMATION OF THE ECONOMY−ENVIRONMENT NEXUS

By using information obtained in section C.1 to C.3, we periodize the history and specify the economy−environment nexus in each period, and thus analyze its long-term transformation. Japanese postwar history is divided into five periods: 1960's to around 1970; around 1970 to early 1980's: early1980's to around 1990; 1990's to around 2008; and after around 2008. Outline of specifications of each period is presented in Table 5.

Table 5. Economy-environment nexus and growth regimes in Japan

	1960 70	80		90	2000 2008
Growth regime	Fordism	Export-led			(Export-led)
Economy-environment nexus	Environmental resources mass consumption with low cost type	Pollution regulation & energy-saving type	(Stagnation of environ-mental measures)	Voluntary measure type	Green growth oriented type
Dynamics of institutional coordination	Insufficient measures due to gaps of coordination.	Local campaigns led to state political issues, and pollution regulation introduced.		Wider environmental concerns led to voluntary measures.	Cooperation between business and environment led to subsidies.
Status of environ-mental costs	Low environ-mental measure cost and rent; Latent cost rises.	Environmental measure cost and rent rise; Latent cost is reduced.		No significant change in environmental measure cost and latent cost.	Measures that increase costs also gradually introduced.
Effects on growth regime	Contributed to high profit by restraining environmental costs under mass production.	Contributed to smooth transition to the next regime through resource-saving, investment, and competitiveness effects.		Compatible with competitive international regime with restraining costs. Less effect of technical competitiveness.	Future effect depends on resource-saving, investment, and competitiveness effects.

C.4.1. 1960's to around 70

Rapid economic growth expanded resource and energy consumption and pollutant emission, which increased latent environmental costs. In spite of severe damages and anti-pollution campaigns in local communities, effective countermeasures were not taken for long time [Kawana: 1987]. "Spatial gap of coordination" between local communities and large companies/central government caused this delay. Thus environmental measure costs did not increase significantly. In addition, oil price, which reflects rents, were kept in low level under the international institutional settings.

We call this economy−environment nexus, characterized with low rent and environmental measure cost vis-a-vis high latent environmental cost, "environmental resources mass consumption with low cost type".

The Fordist growth regime[18] in this period required mass-production for cumulative causation. In spite of mass-production that involves mass-consumption of environmental resources, environmental measure costs and rents were suppressed and profits were ensured, leading to high level of investment. Thus, it is sensible to understand that the economy–environment nexus of this type contributed to the Fordist growth regime.

In this connection, Fordism is generally characterized as intensive accumulation supported by increasing productivity (not quantity) of labor input. In terms of input of environmental resources, it is supported by the expansion in quantity. Thus, we may consider that Fordist accumulation has an extensive nature in the environmental aspect.

C.4.2. 1970's to early 80's

In 1970's, legislations against pollution were introduced and strict regulations were implemented. This development was launched in the political coordination at the Diet session in 1970, so-called "Pollution Diet". In late 1960's, faced with severe pollutions, local anti-pollution campaigns proliferated and legal cases were also presented, which gradually acquired supports from scientists, mass-media, and wider public opinions, and finally came to be a priority issue in the national politics [Kawana : 1987; Miyamoto: 1989]. We understand that democratic

[18] It should be noted that there are various views as to whether a Fordist regime was working in Japan, and if so, what type.

mechanisms such as judicial system and mass media filled the "spatial gap of coordination" between environmental interests represented by local communities and national politics. After mid 1970's, faced with oil crises, legislation and other policies to promote saving energy were also introduced.

Consequently, environmental measure costs significantly rose around 1970 to 80 and rents as oil imports followed. Accordingly, latent environmental costs of pollutants such as SOx fell and that of CO2 turned downward.

We call this economy−environment nexus, characterized with increasing environmental measure cost and rent due to strengthened institutional coordination, "pollution regulation and energy-saving type".

Looking at the growth regime, from the mid-1970s, Japan's economy went through a severe recession until an export-led growth regime was formed in the early 1980s [Uemura: 2000]. Strict environmental regulations in this period were said to have positive impacts on the economy through investment in pollution-control plants and equipments and induced technological competitiveness [OECD : 1991; Environment Agency : 1992]. Econometric analysis in section C.3 indicated that increasing environmental measure cost in this period had a positive impacts on economic growth through resource-saving effect, investment-inducing effect, and export-competitiveness effect, which are consistent with the above mentioned discourses. Thus, we can understand that the economy–environment nexus in this period probably had an effect of smoothing the transition from the crisis to the next growth regime.

C.4.3. Late 1980's

While industrial pollution became alleviated, continued mass-production and mass-consumption led to so-called urban and lifestyle-related pollution such as automobile exhaust problems. In such type of pollution, polluters and victims are sparsely spread in wider economic activities, and the pressure from anti-pollution campaign became weaker compared with industrial pollution.

Environmental policy lost its driving forces in political coordination, and institutional development became stagnated. One symbolic case was the environmental impact assessment bill, which was proposed to the Diet for several times but finally discarded in 1983 due to oppositions from industries, Ministry of Industry and allied politicians [Environment Agency: 1991; Kawana: 1995].

Under such circumstances, environmental measure costs (in terms of ratio to output) ceased rising. We understand this period as stagnation of institutional development.

C.4.4. 1990's to early 2000's

As a consequence of continued mass-production and mass-consumption, waste disposal problems and global environmental problems became evident. International movements, such as the Earth Summit in 1992, also became active. Under such circumstances, citizen's organizations and scientists emerged as new kinds of actors supporting environmental interests. There also emerged politicians interested in environmental issues.

Emergence of these new actors led to formulation of institutions to promote environmental measures. The basic environment law was established in 1993. Several legislations to promote recycling were formulated, including the recycled resources utilization law in 1990, the container and packaging recycling law in 1995, the electric appliances recycling law in 1998. Institutions to address global warming were also developed. In 1998, the global warming mitigation law was established, the energy-saving law was strengthened, and voluntary action plans were established by industry associations. On the other hand, carbon tax and tradable permits were not introduced in this period in the face of oppositions from businesses.

These institutions, when compared with regulations in 1970's, placed emphasis on cooperation and shared roles among actors including consumers, and on voluntariness and flexibility in business activities.[19] One of the reasons of such characteristics is said to be a need to address wider range of economic activities that generates environmental loads. Another reason should be the greater importance of support and consent from businesses as the pressures from actors of environment side were weak compared with anti-pollution campaigns. In the case of global environmental problems, gaps between polluters and victims, e.g. gap between industrialized/industrializing countries and island states, or one between current generations and future generations, weakens the pressure from actors and thus the strength of institutions.

As a consequence, environmental measure costs did not significantly increase in this period. Latent environmental costs was also almost stable, with CO2 continued to be emitted far beyond the nature's absorption.

We call the economy−environment nexus in this period, characterized with institutions of voluntary nature without increasing costs, "voluntary measure type".

With regard to its relationship with the mode of regulation and the growth regime, its emphasis on voluntariness and flexibility to businesses was in line with growing flexibility in the wage–labor nexus, which was forced by integration into the world economy [Uemura: 2011]. Thus, we consider that institutional complementarities to be explanatory of the above characteristics of the economy–environment nexus. Under this economy−environment nexus, environmental measure costs did not increase, which appears to have been compatible with export-led growth in early-2000's through contributing to curbing production costs. However, when looking at some environment-related products such as windmills and solar panels, Japanese manufactures lagged behind those in states with more strict institutions in terms of competitiveness, which may have negative implications to growth in longer term.

C.4.5. After 2008

Faced with global economic crisis triggered by the subprime problems, and backed by shared recognition that greenhouse gas emissions need be halved globally until 2050, ideas of "green growth" or "green new deal" were proposed in high level of politics in many states including Japan. This can be understood as an initiative under cooperation between actors for economic interests and those for environmental ones.

In Japan, large-scale subsidies were introduced as temporary measures for eco-cars and energy-efficient electric appliances. Institutions that involve increasing production costs were not readily introduced, though gradually started to be: feed in tariff system in July 2012, carbon tax system in October 2012.

We call this currently developing economy−environment nexus, characterized by simultaneous pursuit of economic and environmental benefit, "green growth oriented type" as a tentative specification.

On the other hand, the Great East Japan earthquake and the nuclear accident in 2011 gave severe shock to Japanese economy and society. Policies of the Abe administration places great emphasis on economic growth. It is not clear at this stage how they change the economy−environment nexus, and whether "green growth oriented type" stands and continues.

Although it is too early to evaluate the impact of such economy−environment nexus on the growth regime, we try to make tentative consideration to the extent possible at this stage. Subsidies mentioned above raised sales of eco-cars and electric appliances, which worked as stimulus measures. However, these measures cannot last long under budgetary constraints. On the other hand, environmental measures involving increasing production costs, if implemented, could form a lasting institution. As mentioned above, such measures in 1970's gave positive impacts on growth through "paradox of cost". Although conditions of this paradox became stricter in 2000's, there seems to be a good probability for environmental measures to impact positively on growth if implemented in such a way that their effects of resource-saving, environmental investment-inducing, and export-competitiveness are enhanced.

[19] For example, energy-saving law shows guidelines to promote voluntarily activities. Electric appliances recycling laws sets shared roles of actors where consumers pay the costs. Business voluntary action plans are attached importance in the national policy.

Institutional coordination with such measures will, if any, be formulated as a compromise among actors. Here, it should be noted that it is beyond the scope of existing cooperation between economic and environmental actors mentioned above in the sense that this positive impact on economy is paradoxical with apparent negative impact of rising costs on each company. Feasibility of such institutional coordination depends on how wide the scope of cooperation could extend, as well as how powerful new environmental actors could become.

D. CONCLUSION

This paper analyzed the relation of economy and the environment based on *régulation* theory. We proposed an analytical framework and conducted historical analysis on Japan's case.

As a basis, we recognized the socio-economic system as triple reproductions of the economy, humans, and the environment. Relationship between the environment reproduction and economy reproduction is analyzed as one of the institutional forms, which we call "economy–environment nexus". Main actors who drive institutional coordination are people suffering from environmental problems and their supporters. There are often gaps between relevant actors in terms of space or time, typically in global environmental problems, which leads to delay of formulation of institutions. Institutional hierarchy and complementarity also impacts on its characteristics. Environmental costs, i.e. environmental measure costs, rents, and latent costs, are key indices to specify economy–environment nexus and analyze its impacts on the growth regime. A variant of the Kaleckian growth model incorporating them was also introduced.

Using this framework, we conducted empirical analysis on Japan's history from hight growth era to today. Chronological development of environmental institutions was reviewed. Environmental costs were estimated for the long periods. Econometric analysis using the model was also carried out. Combining these information, we periodized and specified the economy–environment nexus in the history.

Identified periods include: 1) 1960's to around 70, with intensive accumulation regime supported by extensive consumption of environmental resources, which had endogenous mechanisms leading to ecological crisis; 2) 1970's to early 80's, with institutional coordination by strict regulations formulated through conflicts between polluters and victims, which was supportive to the growth through the "paradox of cost": an example of "green growth"; 3) 1990's to early 2000's, with institutional coordination of voluntary and flexible nature without increasing costs, formulated under weaker actors and competition-oriented institutional hierarchy; and 4) after 2008, with some policies aiming at green growth, formulated under cooperation between economic and environmental actors.

This historical recognition may lead to some policy implications on future challenges and opportunities. First, we are facing structural difficulty of formulating institutions in the absence of strong actors under spatial and temporal gaps. Second, all past accumulation regimes were supported by extensive consumption of environment, as typically seen in the intensive accumulation of Fordism. Thus our challenge of sercing for institutional coordination that can ease the ecological crisis and realize a stable accumulation must be a fundamental and formidable one. Third, in 1970's, environmental measures positively impacted on the economy through "paradox of cost". There still remains a good chances of mid-term "green growth" through this effect if social compromise is reached. In the face of gaps of global governance, state-level environmental measures aiming at this effect can be a realistic strategy for the moment. Shared understanding of this paradox may help realize such compromise.

Though this paper tried to proceed with both theoretical and empirical analysis, some important areas are not adequately dealt with and left to be addressed in future researches, which includes modeling of longer term perspective with more focus on productivity regime; further analysis on environmental costs in final demand, improved estimation of environmental costs with wider scope; updated econometric and histrical analysis to incorporate latest policy development. Works on historical analysis of various countries as well as comparative analysis among different economies should be needed to deepen the understanding of the economy−environment nexus.

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APPENDIX 1 : DATA SOURCES AND ESTIMATION METHODS

1. Internal pollution control cost

Following the method in Japan Research Institute [2004], we estimated maintenance cost of pollution abatement plant and equipment based on accumulated value of investment. Investment was estimated by combining the ratio of pollution abatement purpose in METI's Survey of Plant and Equipment Investment and the investment value in the JIP database. METI's Survey of Pollution Abatement Investment and some other sources are also used to complement them for the early periods.

2. Internal energy-saving cost

Following the same method as above, we estimated maintenance cost of energy-saving plant and equipment based on accumulated value of investment. Investment was estimated by combining the ratio of energy-saving purpose in METI's Survey of Plant and Equipment Investment and the investment value in the JIP database. DBJ's Survey of Plant and Equipment Investment and some other sources are also used to complement them for the early periods.

3. Waste management cost

Value of intermediate input from waste management sector to other sectors in JIP database. Extension in the trend of pollution control cost and linear interpolation were used for the early periods.

4. Environmental research and development

Internal research expenditure for the purpose of environmental protection in MIC's Survey on Science and Technology Research.

5. Import of natural resources

Values of import of particular items in MOF's Trade Statistics.

6. Maintenance cost of SOx and NOx

Following the method in Japan Research Institute [1998], we estimated the maintenance cost by multiplying emissions of SOx and NOx from fixed sources, and their unit reduction costs. As for unit reduction costs, values in 1995 are consistently used. As for emissions, we used data in Japan's Third National Communication under the UNFCCC (for 1990 to 99), estimation by National Institute of Science and Technology Policy referred to in Japan Research Institute [1998] (for 1970, 75, 80 and 85), and estimation by Li, et al. [2000] (for SOx before 1970), complemented by original estimation using MOE's General Survey of the Emissions of Air Pollutants and energy consumption data (for the rest of years).

7. Maintenance cost of CO2

Following the method in Japan Research Institute [1998], we estimated the maintenance cost by multiplying excessive emission calculated as emission minus nature's absorption, and unit reduction cost. As for emission, we used the data in National Greenhouse Gas Inventory Report of Japan, complemented by Borden, et al. [2014] for the earlier period.

APPENDIX 2 : RESULTS OF THE ECONOMETRIC ANALYSIS

1. Functions used for estimation

$$S = s_0 + s_r rpK + s_w wL$$
$$g^i = \gamma_0 + \gamma_u u(-1) + \gamma_r \pi_p v_p(-1) + \gamma_e \dot{E}/K$$
$$m = m_0 + m_{0p}(oilp) + m_u u - m_e e$$
$$x = x_0 + x_{0w}(wldtd) + x_{0c}(exchrt) + x_\pi \pi_p(-1) + x_e T/K$$
$$R_s = R_{s0} + R_{s0p}(oilp) - \phi e$$

Note : γ_u, γ_r, and x_π are estimated with lag in view of formation of expectation and possible multi-colinearity. Some elements are extracted from constent terms, i.e. wldtd: world trade normalized by capital; exchrt: exchange rate; oilp: oil price index. Function of rent share (R_s) is specified to estimate ϕ.

2. Results of the estimation

S	Periods	**63-74**	**75-82**	**83-91**			**01-08**
	s_0	-10970 (-7.40)	31794 (2.31)	-45867 (-20.86)			24370 (0.55)
	s_r	0.695 (14.16)	0.424 (2.26)	0.654 (7.72)			0.588 (3.10)
	s_w	0.365 (11.82)	0.126 (0.65)	0.420 (7.64)			0.026 (0.10)
	adjusted R2	1.00	0.97	1.00			0.82
	DW	1.51	2.31	1.91			1.38
g^i	Periods	**71-87**			**88-91**	**92-97**	**98-08**
	γ_0	-0.018 (-0.99)			-0.159 (-0.98)	-0.217 (-7.67)	-0.066 (-3.01)
	γ_u	0.037 (1.55)			0.265 (2.11)	0.287 (6.63)	0.100 (3.51)
	γ_r	0.364 (13.76)			0.149 (0.58)	0.286 (3.39)	0.337 (3.28)
	γ_e	11.253 (6.08)			-	-	-
	adjusted R2	0.99			0.68	0.98	0.81
	DW	1.86			3.15	2.96	2.05
m	Periods	**63-74**	**75-91**				**96-08**
	m_0	0.029 (1.30)	0.185 (7.65)				-0.124 (-4.57)
	m_{0p}	0.043 (6.22)	0.016 (12.16)				0.015 (17.26)
	m_u	0.042 (1.80)	0.085 (2.83)				0.186 (5.84)
	m_e	-	18.459 (17.05)				-
	adjusted R2	0.77	0.97				0.99
	DW	1.83	2.57				1.31
x	Periods	**71-91**				**92-08**	
	x_0	-0.030 (-1.67)				-0.010 (-0.74)	
	x_{0w}	0.031 (3.74)				0.035 (28.85)	
	x_{0c}	0.020 (5.60)				-0.002 (-0.50)	
	x_π	0.035 (1.12)				0.152 (3.76)	
	x_e	0.740 (5.67)				-	
	adjusted R2	0.94				0.98	
	DW	2.64				2.07	
R_s	Periods		**75-82**	**82-91**		**92-08**	
	R_{S0}		0.210 (6.13)	0.074 (2.07)		0.009 (3.02)	
	R_{S0p}		0.018 (7.16)	0.025 (15.29)		0.019 (92.42)	
	φ		16.344 (4.79)	6.225 (2.20)		0.409 (2.07)	
	adjusted R2		0.88	0.99		1.00	
	DW		1.89	2.61		1.46	

Note 1: T-ratios are shown in ( ).

Note 2 : Results are checked against spurious regression by unit root test on environmental variables (e, $\dot{E}/K$ and T/K) and cointegration test on each function. Functions of investment, import and export are estimated without environmental variables when their parameters are not estimated with significance under the recognition that their impacts were not visible.