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Original Article

Sustainable Development in Four East Asian Countries? Agricultural Sectors Post-World War II: Measuring Nutrient Balance and Estimating the Environmental Kuznets Curve

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Abstract

The purpose of this study is to measure agricultural waste and estimate the environmental Kuznets curve in four East Asian countries using time series data from the 1960s to the 2010s. Positive nutrient balance (NB) suggests there is pressure on arable land, causing water pollution and greenhouse gases. For crop farming, only China's NB per arable land unit (NBAL) has risen recently, while NB per product (NBP) in all four countries has declined. Regarding livestock farming, NBAL in all countries except Japan has risen. Even more recently, China's NBP has risen differently to other countries' movements. The estimation results of the environmental Kuznets curve suggest China's NBAL will rise continuously with gross domestic product per capita increases in crop farming. For livestock farming, the estimated indexes are confirmed to have worsened with the advance of economic growth.

Key words: nutrient balance, farm gateway method, environmental Kuznets curve, breaking point unit-root test, non-linear co-integrating regression

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1. Introduction

The purpose of this study is to measure agricultural waste in four East Asian countries, China, Taiwan, Japan and South Korea, using time series data covering the periods from the 1960s to the 2010s. Measured agricultural waste is transformed to some indexes, representing environmental efficiency. We confirm whether the environmental Kuznets curve (EKC) hypothesis has been established in the studied periods using measured environmental efficiency.

Following Japan, in which modern economic growth as defined by Kuznets (1966) started in the late 1880s, after World War II, Taiwan and South Korea have achieved high economic growth by the introduction of export-oriented industrial policies. In China, the adoption of the open-door policy in 1978 caused high economic growth.

Many previous studies reveal that the main power for high growth in those countries is rapid industrialization. Specifically, in Taiwan, South Korea and China, compressed industrialization processes have been accomplished through international trade and foreign direct investment. Such high-speed industrialization has to be supported by rapid agricultural development so as to secure sufficient food supply for workers. For the purpose of avoiding the trap of food scarcity, caused by drastic labour mobilization between industries, it is critical that the agricultural sector raises labour productivity.

There are two popular ways to raise labour productivity in agriculture: increase arable land per labour unit and increase output per arable land unit. Egaitzu (1985) describes mechanical and biochemical aspects of agricultural technology. In order to realize scale economies and raise the arable land per labour unit, it is necessary to utilize mechanical technology fully. The effective use of biochemical technology leads to increased outputs per arable land unit. The four East Asian countries' arable land per labour unit is much smaller than that of European countries and the United States.¹ Because of the common productive conditions of small land area per labour unit, these countries experienced similar agricultural development processes that depended more intensively on biochemical technology.

As a result, the four countries' arable land productivity increased during the 1960s–2010s. Arable land productivity in Japan, Taiwan, South Korea and China increased 1.8, 2.6, 4.9 and 7.9 times, respectively.² Japan's arable land productivity has been constant at \$4,000 per hectare since the late 1980s. Taiwan's arable land productivity peaked at \$7,000 per hectare in the 1990s and then decreased modestly. However, arable land productivity in China and Korea has increased. Massive use of chemical fertilizers and constant improvement of seeds are important factors for this rapid increase of arable land productivity in these countries. As Hayami and Godo (2005) show, in Asian countries, technological innovation induced by the relative scarcity of arable land to materials has been widely observed.

The dependence on improvements and intensive use of agricultural materials has enabled sufficient food supply to be accomplished but coincidentally has produced over-nutrients into arable land. From the

point of view of the material balance approach, a positive deduction of nutrients included in output from the nutrients of inputs means the existence of over-nutrients and will be a potential pressure on arable land as waste materials: chemical fertilizers that are not absorbed in crops and livestock manure. The accumulation and dumping of these surpluses of materials into arable land causes pollution of groundwater and greenhouse gas emissions.

The rapid increase of arable land productivity in the four countries analysed in this study suggests that agricultural waste has coincidentally increased in these countries. Specifically, in the 2010s, Taiwan, South Korea and China's arable land productivity was superior to Japan's, which suggests the existence of more serious pollution problems in their agricultural sectors than in Japan's. Environmental problems by agricultural production appear to be compressed and intensified like rapid industrialization. Besides confirming the significance of agricultural development on economic development in the four countries, we also need to examine the impact of agricultural development on the environment.

Nishio (2005) and Shindo (2012, 2013) are previous studies measuring material balance in East Asia. Nishio (2005) shows that nitrogen balance is positive in all crops, excluding rice and legumes while phosphorus acid balance is positive in all crops in Japan in 1998. A different approach focusing on Japan is that of Shindo (2012, 2013), who measure long-term nitrogen load on agricultural land and gross nitrogen balance related to food production and consumption in Asian countries. In addition, the studies of Shindo (2012, 2013) measure inflow of nitrogen into rivers and could be evaluated as comprehensive studies calculating inflow and outflow of nitrogen to soil surface. However, these studies do not directly confirm the relationship between nutrient balance in agriculture and high-speed economic growth in East Asia. Although yearly movement of the nitrogen balance is measured in East Asia, the EKC hypothesis in the nitrogen balance has not been examined clearly.

1. According to the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), in 2013, arable land and permanent crops per agricultural employment is 0.5 ha in China, 1.9 ha in Japan, 1.1 ha in Korea, 24.5 ha in France, 21.1 ha in Germany and 72.5 ha in the United States.

2. We calculate land productivity in the four countries using the data from FAOSTAT.

We finally estimate the relationship between the measured environmental efficiency measured using nutrient balance and gross domestic product (GDP) per capita so as to confirm whether the EKC in the crop and livestock farming sector in the four East Asian countries has existed in the post-war period. Considering specific differences of the agricultural sectors in these countries, we use the concept of time series analysis. Although there have been many previous studies using time series data to estimate the EKC using the CO₂ or SO₂ emissions that cause global warming and acid rain, it appears that studies focusing on the EKC hypothesis related to waste from agriculture in East Asia are very rare.

We measure the nitrogen and phosphorus balance as waste from agriculture. Shindo (2012, 2013) measures nitrogen balance only but does not measure the total nutrient balance, which would require adding phosphorus to nitrogen. Nitrogen surplus left in the soil is released into the atmosphere as nitrous oxide by nitrification, causing global warming. Similar to nitrogen surplus, phosphorus surplus causes water pollution by flowing out from the soil to rivers and groundwater. By measuring material balance through adding phosphorus to nitrogen, we can estimate the EKC in agriculture more precisely in the four East Asian countries. Although Zhang et al. (2015) estimate the EKC-related material balance using worldwide time series data, they focus on nitrogen balance only. Li et al. (2016) estimate the EKC in agrochemicals using regional panel data and confirm the relationship between the nitrogen or phosphorus surplus and GDP per capita. However, their analysis is limited to China, covering the period 1989–2009.

The rest of this article is organized as follows. In Section 2, the measurement and estimation models for our research are explained and the data for the empirical study are described in Section 3. After two environmental indexes in crop farming and livestock farming are measured and compared between the four East Asian countries in Section 4, the estimated results of the EKC are confirmed in Section 5. Finally, our conclusion in Section 6 discusses effective policy that we should adopt.

2. Model

2.1. Measurement of nutrient balance from crop and livestock farming

We define waste from the agricultural sector as nutrient balance that deducts nutrients included in outputs from the nutrients of inputs. This equation is represented as follows:

$$NB_i = m_i x - n_i y \quad (1)$$

where NB is nutrient balance, m is the nutrient–input ratio, n is the nutrient–output ratio, i is the nutrient, x is the production factor and y is the agricultural output.

If this balance is positive (negative), the pressure of nutrient surplus in the agricultural area could be positive (negative).³

We can write NB in crop and livestock farming sector as equations 2 and 3.

$$NB_{crop\ farming} = NU_{chemical\ fertilizer} + NU_{seed} - NU_{output} \quad (2)$$

$$NB_{livestock\ farming} = NU_{feed} + \quad (3)$$

$$NU_{opening\ stock\ and\ imports\ of\ live\ animal} -$$

$$NU_{output} -$$

$$NU_{ending\ stock\ and\ exports\ of\ live\ animal}$$

where NU represents the total weight of the nitrogen and phosphorus.

The measurement using equations 2 and 3 is similar to the farm gate method. The farm gate method defines NB as the difference of the nutrients included in inputs and outputs in the agricultural production process. According to Hoang and Alauddin (2010), the farm gate method, soil surface and soil system methods are listed as the main methods for calculating NB . In the soil surface and system methods, livestock waste nutrients are considered as

3. A negative surplus means that the nutrients necessary for growing agricultural products are deficient. In this case, it seems that the nutrients stored in the arable land supplement the deficiency.

inputs and livestock production nutrients are not used as outputs for calculating *NB* in order to measure *NB* from the difference of inflow and outflow into the soil surface. Meanwhile, the farm gate method enables us to measure *NB* in crop and livestock farming from equations 2 and 3, respectively.⁴ Because the crop farming sector uses a different technology to livestock farming, it is more desirable to analyse them separately. For measuring equations 2 and 3, we use Hoang and Alauddin's (2010) inputs, excluding non-agricultural atmospheric deposition, and their outputs, besides withdrawals, owing to the availability and credibility of the data.

Using a measured *NB*, we calculate two indexes that represent environmental efficiency. As a potential environmental pressure on agricultural land, *NB* per agricultural land unit was measured. Like Shindo (2013), we adopt the area of arable land and permanent crops as a proxy for agricultural land. Considering *NB* as undesirable outputs and agricultural outputs as desirable outputs, the ratio of undesirable goods to desirable goods is defined as another environmental efficiency, which means the efficiency of the agricultural products measured by the undesirable goods. We separately calculate these indexes in the crop and livestock farming sector.

We estimate *NB* per arable land unit (*NBAL*) and per product price (*NBP*) in the crop or livestock farming sector as environmental efficiency and compare these efficiencies between the four countries in the periods 1961–2013 or 1961–2011. Measured *NB* is the sum of nitrogen and phosphorus.

$$NBAL = \frac{\text{nutrient balance}}{\text{arable land}} \quad (4)$$

4. *NB* obtained by the soil system method is the value obtained by subtracting leaching and run-off to the water system from *NB* obtained by the soil surface method. Shindo's (2012, 2013) measurement methods are similar to the soil surface and system methods. For details of the three methods, see Hoang and Alauddin (2010, p. 361, Table 1).

$$NBP = \frac{\text{nutrient balance}}{\text{crop or livestock products}} \quad (5)$$

2.2. Environmental Kuznets curve in the agricultural sector

We estimate whether the EKC has existed in the four countries' crop or livestock farming sectors using *NBAL* and *NBP* as the dependent variables. For example, in the case of *NBAL*, the estimated EKC is represented in logarithmic form.

$$\ln NBAL_t = a_0 + a_q \ln q_t + a_{qq} (\ln q_t)^2 + a_t t + u_t \quad (6)$$

where *t* is year, *q* is GDP per capita and *u_t* is an error term.

There appear to be some cases in which environmental efficiency is negative, especially in the early stage of our studied periods, as we estimate environmental efficiency using just chemical fertilizer. To be precise, we need to perform a calculation that includes organic fertilizer. However, because comparable statistics about organic fertilizer are scarce, we cannot measure the nutrient balance by the total sum of organic and chemical fertilizer. As a result, some negative efficiency is measured, although it is limited to China's *NBAL* and *NBP* in the crop farming sector in the 1960s. In those cases, equation 6 cannot be represented in logarithmic form and so replaced in semi-logarithmic form.

$$NBAL_t = a_0 + a_q \ln q_t + a_{qq} (\ln q_t)^2 + a_t t + u_t \quad (7)$$

In the co-integration test examining the long-run relationship between variables, those variables need to be *I*(1). Before the estimation of equation 6 or 7, we confirm whether variables are *I*(1) by the unit-root test. In the unit-root test, considering estimated periods over 50 years, we conduct the Zivot–Andrews unit-root test, including structural change.

To check the long-run relationship between variables in the EKC, many previous studies use the co-integration test. Wagner (2015) indicates that the EKC is a non-linear equation and criticizes use of the conventional co-integration test for checking the linear relationships between variables. Although Zhang et al. (2015) also estimate the EKC in the agricultural sector, they use an autoregressive distributed lag model to confirm the linear co-integration and focus on nitrogen balance only. Following Lin and Granger (2004), to test non-linear co-integration, after non-linear regression is estimated, Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests using the residual should be adopted.

In the estimation of equation 6 or 7, we adopt the integrated modified ordinary least squares method, which can estimate non-linear regression, following Vogelsang and Wagner (2014). For example, equation 6 is shown in the form of the co-integrating regression like equations 6 and 8

$$\ln NBAL_t = a_0 + a_q \ln q_t + a_{qq} (\ln q_t)^2 + a_t t + u_t \quad (6)$$

$$\ln q_t = \ln q_{t-1} + v_t \quad (8)$$

where u_t and v_t are zero-mean stationary processes. Following Vogelsang and Wagner (2014), for the estimation of the integrated modified ordinary least squares, equations 6 and 7 are transformed as equations 9 and 10 measuring the partial sum, respectively.

$$S_t^{\ln NBAL} = S_t^{f'} + a_q S_t^{\ln q} + a_{qq} S_t^{(\ln q)^2} + S_t^u \quad (9)$$

$$S_t^{NBAL} = S_t^{f'} + a_q S_t^{\ln q} + a_{qq} S_t^{(\ln q)^2} + S_t^u \quad (10)$$

where $S_t^{\ln NBAL} = \sum_{j=1}^t \ln NBAL_j$, and $f' = 1$ and t , other variables and error term like $S_t^{\ln NBAL}$.

Vogelsang and Wagner (2014) indicate that the effect from the additive nuisance parameters can be avoided by partial summing

different to conventional ordinary least squares. In addition, to deal with endogeneity induced from correlation between u_t and v_t , we add $\ln q_t$ into equations 9 and 10 as independent variables following Vogelsang and Wagner (2014).

$$S_t^{\ln NBAL} = S_t^{f'} + a_q S_t^{\ln q} + a_{qq} S_t^{(\ln q)^2} + b_q \ln q_t + S_t^u \quad (11)$$

$$S_t^{NBAL} = S_t^{f'} + a_q S_t^{\ln q} + a_{qq} S_t^{(\ln q)^2} + b_q \ln q_t + S_t^u \quad (12)$$

We estimate equations 11 and 12 using time series data covering 1961–2011 or 1961–2013 in the crop and livestock farming sector, and in NBP or $\ln NBP$, the EKCs are estimated.

Thereafter, using the residuals of the estimated equation, we conduct the co-integration test to confirm long-run relationships between variables. In the co-integration tests, we use the KPSS test of Choi and Saikkonen's (2010) sub-residuals method. The test statistics for the conventional KPSS type is described as in equation 13.

$$C = T^{-2} \omega_u^{-2} \sum_{t=1}^T \left(\sum_{j=1}^t S^u \right)^2 \quad (13)$$

where ω_u is the long-run variance using total estimated residuals. The null hypothesis of equation 13 that the residuals are stationary is rejected if the test value is beyond the critical value at a significant level. We cannot use the test statistics of equation 13 because its limiting distribution depends on nuisance parameters in the case of non-linear regressions unless its explanatory values are strictly exogenous.⁵

To avoid some problems, Choi and Saikkonen (2010) modify equation 13's test

5. For details, see Choi and Saikkonen (2010, Section 4.1).

statistics through the use of the sub-residuals method.⁶

$$C^{b,i} = b^{-2} \omega_{i,u}^{-2} \sum_{t=i}^{i+b-1} \left(\sum_{j=i}^t S_j^u \right)^2 \quad (14)$$

In equation 14, we need to explain how b of block size and b_i of its initial point are decided. First, we decide the value of b_{small} and b_{big} , as in equation 15:

$$b_{small} = T^{0.7} \text{ and } b_{big} = T^{0.9} \quad (15)$$

Next, we calculate $C^{b,i}$ of test statistics using a measured block size by equation 14. In the measured test statistics, we choose b_i that minimizes the standard deviation that is estimated in each set of b_{i-2} , b_{i-1} , b_i , b_{i+1} and b_{i+2} . The block size is decided by the estimated b_i and b_{big} , and we choose the most desirable one in the calculated statistics. To obtain the critical value, we use Hong and Wagner's (2011) Table B1 in Appendix B.

3. Data

We use most of the input–output data from the Food Balance Sheets (FBS) developed by the Food and Agriculture Organization (FAO) for measuring the nutrient balance. Because the FBS covered the periods 1961–2011 or 1961–2013, our studied periods are limited to 51 or 53 years. To replace the lack of data on phosphorus content by percentage in the FBS, we use data of the local Food Composition Table made by the government of each country in order to calculate the quantity of nitrogen and phosphorus included in the outputs and inputs (Food and Drug Administration, 2016; Institute of Nutrition and Food Safety, 2009; Ministry of Education, Culture, Sports,

Science and Technology, 2015; Rural Development Administration, 2013). To obtain nutrients of the agricultural products that are not written in the governments' food tables, we use other countries' data in the four East Asian countries. If we cannot obtain the data, we use data from the Institute for Rural Engineering (2006), Leung et al. (1972) and US Department of Agriculture (2016). The quantity of nitrogen is measured by multiplying the quantity of protein and the FAO's (2012) conversion rate.

3.1. Nutrient balance estimation

- Output: annual production quantity of crops or livestock farming from the FBS.
- Livestock amount of change: we obtained annual change of livestock using the FAOSTAT and each country's data and measured the amounts of nutrients.
- Seeds and feeds: annual consumption of seeds and feeds from the FBS. As feeds, from the commodity balances, soybean cake, groundnut cake, sunflower seed cake, rape and mustard cake, cottonseed cake, palm kernel cake, copra cake, sesame seed cake, oilseed cakes and other brands are added for the estimation.
- Chemical fertilizer: China's annual consumption of chemical fertilizer is obtained from the China Statistical Yearbook and China Compendium of Statistics. Taiwan's annual consumption of chemical fertilizer is obtained from the Taiwan Agricultural Yearbook. In Japan and Korea, we use modified data from the FAOSTAT.
- Arable land: area of arable land and permanent crops from the FAOSTAT.
- Output value: annual production value of crops and livestock from the FAOSTAT expressed in constant 2004–06 prices in international dollars.

3.2. Estimation of the environmental Kuznets curve

- Real GDP per capita: GDP per capita expressed in 2004–06 prices in international

6. Instead of the method by the dummy variables, Davidson and Monticini (2010) propose the co-integration test based on the sub-sampling method. Their model, which could be adapted to the model with structural breaks, is a kind of non-linear co-integration test, but it is not intended to apply to a polynomial equation like in this study.

dollars from the Total Economy Database of Groningen Growth and Development Centre.

In Table 1, descriptive statistics for our empirical study are shown. In the studied periods, the four countries' GDP per capita rose sharply concurrently. In all countries except Japan, the production of crops and live-stock increased. Although Japan's $NB_{farming}$ decreased, the other three countries' $NB_{farming}$ increased. In the livestock farming sector, all countries' NB increased.

4. Nutrient balance in the four countries

4.1. Crop farming sector

The measured results of the nutrient balance per arable land unit ($NBAL$) in the crop farming sector in the four countries are shown in Figure 1. $NBAL$ of China rose continuously while fluctuating repeatedly since 1961. During the 1960s, China's $NBAL$ was negative and the phenomenon suggests that in the periods studied, the stage of agricultural development was pre-modern and it appeared there was stagnation from rapid socialization in the sector. However, by adopting agricultural reform in its open-door policy, in the latter 1970s, China's $NBAL$ became positive and, since then, has increased. Meanwhile, Japan's $NBAL$ peaked in the latter 1970s and, since then, has decreased modestly. In Taiwan, the peak of $NBAL$ was observed in the latter 1990s, and in South Korea, it was observed in the latter 2000s. In both countries, after the peak, $NBAL$ decreased, and the decrease in South Korea was observed to be more rapid than that in Taiwan. In the early stage, $NBAL$ in Japan was the highest in the four countries, but recently, $NBAL$ in Japan has been the lowest. In the near future, China's $NBAL$ will exceed Taiwan's ratio because of the rapid increase. The polluting pressure on arable land has been strengthened in China, which is different from other countries.

Nutrient balance per product (NBP) in the four countries is shown in Figure 2. China's

NBP rose until the latter 1990s from a negative ratio in the early phase, and while fluctuating repeatedly since then, the NBP has shown a downward trend. Taiwan's NBP rose until the latter 1990s, but a clear downward trend was observed after the latter 2000s. Japan's NBP rose from the early 1960s to the late 1970s, and since then, a downward trend has been evident. In South Korea, since the 1960s, the NBP had fluctuated repeatedly and significantly, and since the latter 2000s, it has declined sharply. Recently, the NBP in the four countries concurrently showed a downward trend, which is different from the movement of the $NBAL$.

$NBAL$ and NBP could be decomposed using the output per arable land unit, as follows:

$$\begin{aligned} NBAL &= NBP \times \frac{\text{output}}{\text{arable land}} \\ NBP &= NBAL \times \frac{\text{arable land}}{\text{output}} \end{aligned} \quad (16)$$

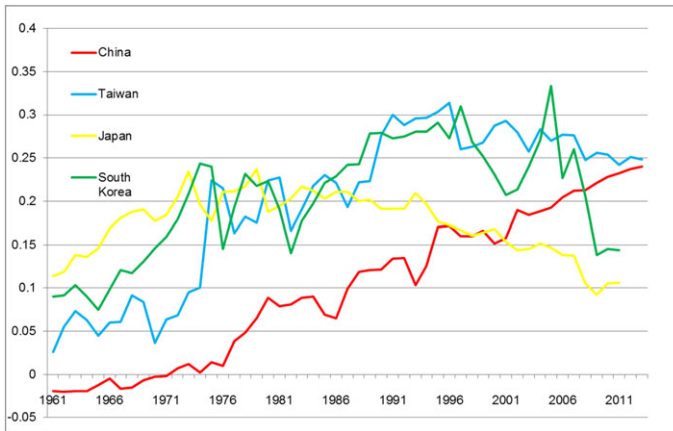
respectively.

Equation 16 is an established formula in the crop farming and livestock farming sectors. The movements of $NBAL$ and NBP are affected by the interdependence of these variables and output per arable land unit or its reverse ratio. According to Table 2, reflecting consistent increases of output per arable land unit, China's $NBAL$ has risen. China's NBP was rising until falling beyond the turning point. This is because after the turning point, the decrease rate of China's arable land unit per output exceeds the increase rate of $NBAL$. In Japan, $NBAL$, NBP and output per arable land unit depict the reverse U-type curve, and thus, the movement of $NBAL$ is affected by the movement of NBP and output per arable land unit. Meanwhile, regarding NBP , the influence of the movement of $NBAL$ is stronger than that of arable land unit per output. The decrease of $NBAL$ and NBP in Taiwan and South Korea in the 2000s could be influenced by interdependence.

Table 1 Descriptive Statistics and Results of the Organisation for Economic Co-operation and Development (OECD, 2008) and This Study

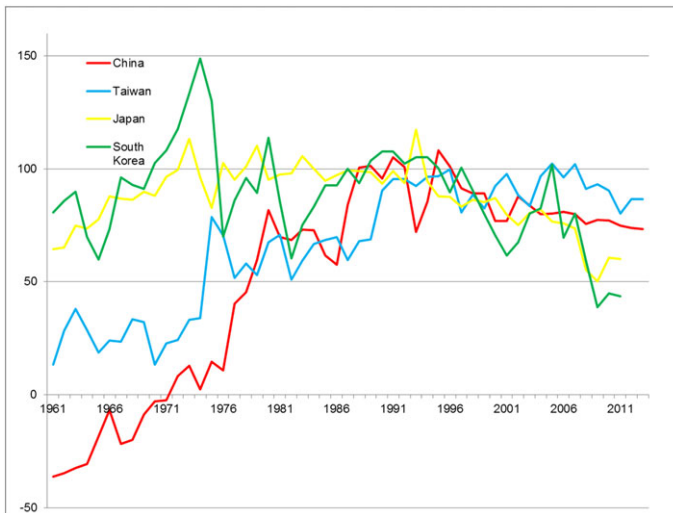
	Country	1961	2011	Mean	Median	Maximum	Minimum	Observations
Real crop production (1,000 international dollar)	China	56,751,709	377,762,986	178,000,000	150,000,000	398,000,000	56,751,709	53
	Taiwan	1,731,338	2,433,525	2,559,058	2,609,046	3,016,080	1,722,863	53
	Japan	10,619,993	8,040,993	10,509,105	10,824,325	12,817,277	8,015,043	51
Real livestock production (1,000 international dollar)	South Korea	2,341,471	5,619,012	4,814,989	5,297,530	6,356,078	2,200,610	51
	China	6,473,697	178,393,773	71,544,805	46,977,519	188,000,000	6,473,697	53
	Taiwan	419,633	2,847,881	2,001,237	2,310,633	3,418,239	419,633	53
$NB_{farming}$ (1,000 ton)	Japan	2,960,571	9,654,939	8,381,567	9,679,160	10,598,949	2,960,571	51
	South Korea	247,330	4,299,419	2,240,475	2,062,933	4,687,634	224,227	51
	China	-2,050	28,312	12,285	12,631	29,196	-2,064	53
$NB_{livestock}$ (1,000 ton)	Taiwan	23	195	173	200	274	23	53
	Japan	684	484	929	999	1322	424	51
	South Korea	189	245	419	443	609	168	51
Arable land and permanent crops (1,000 ha)	China	601	6,467	2,010	1,378	7,090	601	53
	Taiwan	23	194	123	130	216	20	53
	Japan	212	720	617	715	807	207	51
Real GDP per capita (international dollar)	South Korea	12	376	191	180	430	12	51
	China	104,350	121,720	2,687	1,902	8,684	603	53
	Taiwan	884	808	15,185	12,825	37,241	2,085	53
$NB_{nitrogen}$ (1,000 ton)	Japan	6,010	4,561	21,324	21,928	31,366	6,190	51
	South Korea	2,095	1,698	10,756	7,721	28,387	1,535	51
	China	606	8,088	2,687	1,902	8,684	603	53
$NB_{phosphorus}$ (1,000 ton)	Taiwan	2,085	36,092	15,185	12,825	37,241	2,085	53
	Japan	6,190	30,640	21,324	21,928	31,366	6,190	51
	South Korea	1,537	28,387	10,756	7,721	28,387	1,535	51
			1990–92 average	2002–04 average		1990–92 average	2002–04 average	
	OECD (2008)		935	813	This study	928	836	
	Japan		465	456		581	522	
	South Korea		339	243		369	268	
	Japan		103	92		118	112	
	South Korea							

Note: NB = nutrient balance. We use this study's measurement results and figures in the OECD (2008, pp. 51–52, Figures 1.2.2 and 1.2.8).

Figure 1 Nutrient Balance Per Arable Land Unit in the Crop Farming Sector 1961–2011/13 (Tons Per Hectare)

Note: For Japan and South Korea, the provisional value is published only until 2011, and thus, the measurement period is from 1961 to 2011.

Source: Author's calculation using the provisional value of the Food Table from the FAOSTAT.

Figure 2 Nutrient Balance Per Product in the Crop Farming Sector 1961–2011/13 (Grams Per International Dollar)

Note: For Japan and South Korea, the provisional value is published only until 2011, and thus, the measurement period is from 1961 to 2011.

Source: Author's calculation using the provisional value of the Food Table from the FAOSTAT.

4.2. Livestock farming sector

Japan's *NBAL* in the livestock farming sector showed an increasing trend until the early 1990s, and the efficiency has remained almost constant since then (Figure 3). *NBAL* in South Korea and Taiwan increased consistently in

the studied periods while fluctuating repeatedly. Although China's *NBAL* was almost constant for a long period, the ratio has risen since 2000. In the livestock farming sector, China's *NBAL* was much smaller than that of other countries, which differs from the case of the crop farming sector. China's lower *NBAL*

Table 2 Crop and Livestock Production Per Land Unit

	China	Taiwan	Japan	South Korea
Crop production per land unit (international dollars/hectare)				
1961	544	1,959	1,767	1,118
1971	843	2,795	1,907	1,473
1981	1,132	3,215	1,993	2,236
1991	1,277	3,141	1,930	2,533
2001	2,049	2,997	1,926	3,365
2011	3,104	3,012	1,763	3,309
Livestock production per land unit (international dollars/hectare)				
1961	62	475	493	118
1971	164	979	1,115	233
1981	288	1,697	1,649	577
1991	497	3,125	2,010	1,239
2001	999	3,557	1,991	2,119
2011	1,466	3,525	2,117	2,532

Source: FAOSTAT.

compared with other countries could be explained by lower output per land unit, which is shown in Table 2. In 2011, the output per arable land unit in China in livestock farming was the lowest in the four countries.⁷ Meanwhile, recently, *NBAL* of livestock farming in Japan and South Korea was higher than the efficiency in the crop farming sector and Taiwan's efficiency was slightly lower than the crop farming sector's *NBAL*.

Like Figure 4, Japan's *NBP* in the livestock farming sector has fluctuated between 60 and 80 g per international dollar and Taiwan's *NBP* has varied between 50 and 70 g per international dollar. In both countries, clear decreasing and increasing trends could not have been observed. In South Korea, while repeating relatively large fluctuations, *NBP* has shown an upward trend since the early phase. After an obvious decline in the late 1990s, the ratio has varied between 80 and 90 g per international dollar since then. In China, after a rapid decline in the 1980s, *NBP* had been almost constant for about 20 years, and recently, the ratio has risen rapidly.

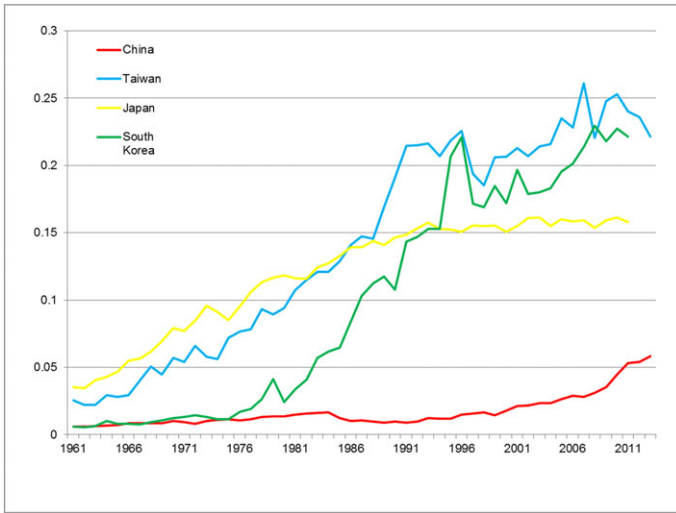
In China, although the livestock output per land unit has risen in the studied periods, it influenced a rapid increase of *NBAL* after

7. The absence of crude feed, discarded food, human waste etc. in the feed data provided by the FAO partially affects our estimate.

around the 2000s. In addition, *NBP* started to rise in the late 2000s and the increase by the interdependence effect is confirmed. The rapid decline of *NBP* from the early 1980s to the early 1990s in China was induced by the concurrent decline of *NBAL* and arable land unit per output. Regarding the rapid increase of the output in the livestock farming in these periods, Fuller et al. (2001) point out that according to the excess supply of meat or eggs in the livestock statistics of the Chinese government, meat or egg production is over-measured and the trend has been on the increase. However, the government statistics that Fuller et al. (2001) criticize are greatly modified by the results of the Agricultural Census in 1997. Thus, the annual average growth rate of pork, whose share is largest among meat eaten by the Chinese, measured from modified data in the FAOSTAT is lower by 2.9 percentage points than the growth rate from the old version of government statistics in Fuller et al. (2001). Thus, we believe that the influence of excessive measurement results, if any, is considerably reduced.⁸ In Taiwan, the increase of *NBAL* is affected by the increase of the output per land unit until around 2000, after which movement from interdependence with *NBP* is observed. In Japan, the movement of *NBAL* could be explained by the movement of output per arable land unit around early 1990, and thereafter, the constant trend of *NBP* and output per arable land unit determine the trend of *NBAL*. In South Korea, *NBAL* has risen since around 1975 by the rise of output per arable land unit while *NBP* also affects *NBAL* with fluctuations. *NBP* has risen with fluctuations by the increase of *NBAL*, which cancels out the decrease in arable land unit per output after around 1975. However, after

8. Even now, a large gap between the demand and supply of meat or egg production in government statistics has been observed. Although Ma et al. (2004) and Yu and Abler (2014) propose methods to shrink the gap, their methods have not yet reflected in government statistics. Since Fuller et al. (2001), the results of two agricultural censuses have been published in China. Therefore, if assuming that excessive measurements on the supply side continue to shrink, ambiguous definitions and coverage on the demand side need to be clarified in order to prevent underestimation.

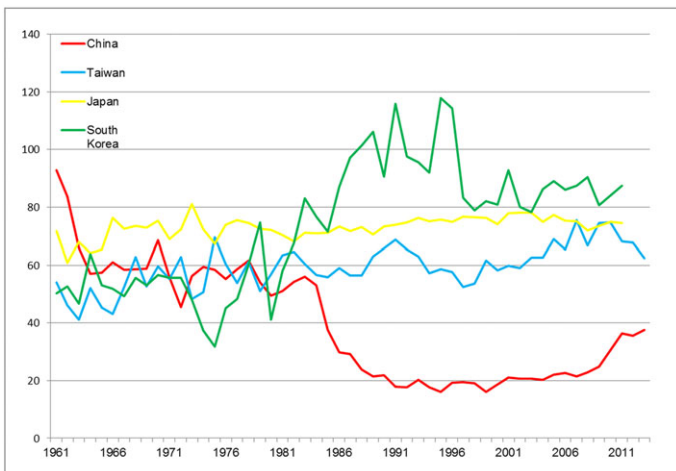
Figure 3 Nutrient Balance Per Arable Land Unit in the Livestock Farming Sector 1961–2011/13 (Tons Per Hectare)



Note: For Japan and South Korea, the provisional value is published only until 2011, and thus, the measurement period is from 1961 to 2011.

Source: Author’s calculation using the provisional value of the Food Table from the FAOSTAT.

Figure 4 Nutrient Balance Per Product in the Livestock Farming Sector 1961–2011/13 (Grams Per International Dollar)



Note: For Japan and South Korea, the provisional value is published only until 2011, and thus, the measurement period is from 1961 to 2011.

Source: Author’s calculation using the provisional value of the Food Table from the FAOSTAT.

a drastic decline around 1995, *NBP* has remained in the range of about 80 to 90 g per international dollar since the rise of *NBAL* and the decline of arable land unit per output are offset.

Finally, we compare the results of this study with previous work. Although there are few

previous studies that measure the nitrogen and phosphorus balance in the four East Asian countries in our study throughout the post-war periods, the Organisation for Economic Co-operation and Development (OECD, 2008) calculates the nitrogen and phosphorus balance in the 1990s–2000s in Japan and South Korea.

The measured results of the OECD (2008) and this study are shown in Table 1.

In Japan, the difference of the measured results is within 10%, but in South Korea, the difference expands to within 20%. It can be inferred that differences in the measurement method caused the disparity.⁹ The trend of decreasing measured values is similar in both studies.

5. Estimation results

5.1. Breaking point unit-root test

In order to estimate the co-integrating regression and conduct the non-linear co-integration tests, we check the stationarity of the variables used for those procedures. We show the results of the breaking point unit-root test by Zivot–Andrews for the stationarity check in Table 3.

In the crop farming sector, China's and Taiwan's results indicate we cannot reject the null hypothesis that all series have unit roots at the 10% level, but in first differences, we can reject the null at the 10% level. The series for our estimation in both countries are $I(1)$. Meanwhile, Japan's $\ln NBAL$ and Korea's $\ln NBP$ are not $I(1)$, but the other variables in both countries are $I(1)$.

In the livestock farming sector, excluding $\ln NBAL$ in China and $\ln NBAL$ and $\ln NBP$ in Taiwan, we cannot reject the null in the series at any level and can reject the null in the series in the first differences. Those series for the estimation are $I(1)$.

5.2. Non-linear co-integration test

For the confirmation of the long-run relationship between the series for the estimation, we conduct the non-linear co-integration test by Choi and Saikkonen (2010), who contrived the modified KPSS unit-root test using the

residuals of the estimated equations as the non-linear co-integration test. We estimate the modified KPSS test statistics using the way that we choose the value minimizing the standard errors calculated in the series of the KPSS statistics in the block size, measured by following Choi and Saikkonen (2010).¹⁰ Table 4 shows the results of the non-linear co-integration test. Except for the equation of China's NBP in the crop farming sector, we cannot reject the null at the 5% level in any of the estimated equations. Summarizing the results of Tables 3 and 4, except for China's NBP , Japan's $\ln NBAL$ and South Korea's $\ln NBP$ in the crop farming sector and China's $\ln NBAL$ and Taiwan's $\ln NBAL$ and $\ln NBP$ in the livestock farming sector, the co-integration in the estimated equations of the EKC has been established.

5.3. Estimated results of environmental Kuznets curve equations

The estimation results of the co-integrating regressions by Vogelsang and Wagner (2014) are shown in Table 4.¹¹ All regressions' parameters are significantly estimated at the 1% level. Considering the results of the unit-root tests and co-integration tests, the hypotheses of the EKC are significantly supported in the equations of China's $NBAL$, Taiwan's $\ln NBAL$ and $\ln NBP$, Japan's $\ln NBP$ and South Korea's $\ln NBAL$ in the crop farming sector. In the livestock farming sector, the EKC are observed in Japan's $\ln NBAL$ and $\ln NBP$. Meanwhile, China's $\ln NBP$ and South Korea's $\ln NBAL$ and $\ln NBP$ significantly depict the reverse shape of the EKC.

Gross domestic product per capita at the turning point of the EKC is described in Table 4.¹² In the crop farming sector, Taiwan and Japan had surpassed the phase in which

9. Although the OECD (2008) measures livestock manure as an input in farmland, our study does not calculate it. The OECD's measurement method is similar to the soil surface method. For more detail, see the OECD (2008, p. 50, Figure 1.2.1).

10. For details, see Section 2.

11. We use integrated modified ordinary least squares for the estimation. For details, see equations 6–12.

12. Calculating the turning point, we use the method for obtaining the maximum value of the quadratic function. For example, see Stern (2015, equation (3)).

Table 3 Results of Unit Root Tests (H0: A Series Has a Unit Root)

	Crop farming sector				Livestock farming sector			
	China	Taiwan	Japan	South Korea	China	Taiwan	Japan	South Korea
NBAL	-4.47 (0.252)							
lnNBAL		-4.82 (0.118)	-4.26 (0.356)	-3.68 (0.719)	-5.21** (0.045)	-6.24*** (<0.01)	-4.49 (0.243)	-4.30 (0.301)
NBP	-4.22 (0.382)							
lnNBP		-4.86 (0.110)	-3.22 (0.92)	-5.11* (0.060)	-3.45 (0.835)	-5.11* (0.060)	-4.43 (0.268)	-4.73 (0.147)
ln γ	-3.72 (0.696)	-4.43 (0.271)	-3.50 (0.815)	-4.65 (0.173)				
(ln γ) ²	-2.40 (>0.99)	-4.85 (0.112)	-3.20 (0.925)	-3.81 (0.644)				
dNBAL	-7.91*** (<0.01)							
dlnNBAL		-8.08*** (<0.01)	-4.26 (0.356)	-5.51** (0.020)	-7.17*** (<0.01)	-8.07*** (<0.01)	-5.14* (0.056)	-8.94*** (<0.01)
dNBP	-6.94*** (<0.01)							
dlnNBP		-7.74*** (<0.01)	-5.80*** (<0.01)	-6.03*** (<0.01)	-8.34*** (<0.01)	-9.12*** (<0.01)	-5.02* (0.074)	-8.98*** (<0.01)
dln γ	-5.25** (0.042)	-6.78*** (<0.01)	-5.81*** (<0.01)	-8.01*** (<0.01)				
d(ln γ) ²	-5.08* (0.065)	-6.97*** (<0.01)	-5.81*** (<0.01)	-8.37*** (<0.01)				

Note: NBAL = nutrient balance per arable land unit; NBP = nutrient balance per product; γ = real gross domestic product per capita. Figures in parentheses indicate p -values. We conduct the augmented Dickey-Fuller test, including trend and intercept. We decide the lag using the F -statistic in each test. We choose the trend and intercept as the variables allowing the breaks, and we choose the way of minimizing the Dickey-Fuller t -statistic in order to decide the break point. Source: Author's calculation.

* $p < 0.1$,

** $p < 0.05$,

*** $p < 0.01$.

Table 4 Estimated Results of Co-integrating Regressions, Kwiatkowski–Phillips–Schmidt–Shin (KPSS) Test and Real Gross Domestic Product Per Capita at Turning Point

	Livestock farming sector															
	Crop farming sector				Taiwan				Japan				South Korea			
	China		Taiwan		Japan		South Korea		China		Taiwan		Japan		South Korea	
	NBAL	NBP	lnNBAL	lnNBP	lnNBAL	lnNBP	lnNBAL	lnNBP	lnNBAL	lnNBP	lnNBAL	lnNBP	lnNBAL	lnNBP	lnNBAL	lnNBP
a_0	-13.32***	-0.03***	364.4***	369.2***	206.6***	129.3***	-246.1***	-272.3***	-5.7***	-0.01	270.7***	-211.3***	240.3***	-182.2***	1,078.8***	721.6***
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
a_q	0.46***	0.001***	7.52***	4.45***	17.1***	13.3***	5.4**	2.6	-0.18***	-0.00***	1.2***	1.6***	2.3***	3.0***	-6.3***	-6.7***
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
a_{qq}	-0.02***	0.000***	-0.404***	-0.24***	-0.87***	-0.67***	-0.26***	-0.13***	0.01***	0.00***	-0.04***	-0.07***	-0.08***	-0.14***	0.34***	0.33***
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
b_q	3.4***	0.007***	-75.2***	-77.2***	-47.7***	1.8***	54.9***	58.4***	1.4***	0.00***	-63.7***	45.6***	-50.6***	38.3***	-261.7***	-177.0***
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
a_t	-2.1***	-0.003***	-35.9***	-29.8***	-86.3***	-75.5***	-28.6***	-23.0***	0.66***	0.002***	-9.7***	-18.8***	-17.4***	-24.9***	25.0***	23.0***
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
KPSS	0.318	54.866	0.081	0.056	0.021	0.023	0.160	0.187	0.030	0.045	0.032	0.083	0.064	0.060	0.012	0.013
test value	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Block size	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
M	0.05	2.135	0.01	1.656	NA	20,289	26,364	NA	0.05	2.135	0.01	1.656	NA	4,439	NA	23,738
Turning point	42,577	NA	11,093	10,873	NA	20,289	26,364	NA	0.01	1.656	0.01	1.656	NA	4,439	NA	23,738

Note: NBAL = nutrient balance per arable land unit; NBP = nutrient balance per product. Figures in parentheses indicate p -values. In the KPSS test, we use the critical value measured in Hong and Wagner (2011, Appendix B). Turning point indicates real GDP per capita at the turning point of the environmental Kuznets curve expressed in international dollar. For the results of the unit root tests and co-integration tests, when the turning point of the equation is unmeasurable, NA is inserted. Source: Author's calculation.

* $p < 0.1$,
 ** $p < 0.05$,
 *** $p < 0.01$.

NBP had risen, and specifically, Taiwan had already entered the phase in which *NBAL* had declined. China's turning point in the *NBAL* equation could be a higher level of GDP per capita than the recent level. While Taiwan's actual GDP per capita exceeds the value at the turning point around 1986 in *NBAL* and *NBP*, in Japan's *NBP*, crossing the turning point is observed around 1983. In South Korea's *NBAL*, reaching the turning point is the most delayed but was accomplished around 2010.

In the livestock farming sector, the GDP per capita at the turning point has been much higher than the current value in Japan and *NBAL* and *NBP* in Japan could be expected to continue increasing along the line of the EKC towards the turning point. In *NBAL*, South Korea's GDP per capita exceeds the value at the turning point around 1989. Regarding *NBP*, China crossed the turning point around 2004, but shortly after that, around 2006, South Korea exceeded the turning point. Recently, those countries had already surpassed the turning point and their *NBAL* and *NBP* will continue to expand along the line of the reverse EKC with economic growth.

6. Conclusions and policy implications

From our measurement results of environmental efficiency, a rapid increase of *NBAL* in China's crop farming sector was observed in the studied periods. In China, after the early 2000s, *NBAL* in the livestock farming sector rose, suggesting that there is an increased pressure of pollution on arable land in both sectors. Meanwhile, following Japan's turning point that was reached in the 1970s, Taiwan and South Korea have surpassed the turning point, changing from an increase to a decrease for *NBAL* in the 1990s and 2000s. However, in the livestock farming sector, a clear turning point was not observed in Taiwan, Japan or South Korea in the studied periods. Although *NBAL* in the livestock farming sector was stable since the early 1990s in Japan, an upward trend has still been observed in Taiwan and South Korea.

In *NBP* in the crop farming sector, China's movement has most clearly depicted a reverse U-shaped curve throughout the studied periods. After the late 2000s, the downward trend continued across all countries. In the livestock farming sector, a U-shaped curve in China's *NBP* was observed throughout the studied periods. After the late 2000s, China's *NBP* rose although that of other countries remained stable with temporary fluctuations. Recently, China's *NBP* movement suggests the occurrence in the livestock farming sector of a phenomenon like counteracting improvement in the crop farming sector.

From the estimated results in the EKC, with GDP per capita rising, in the crop farming sector, *NBAL* in Taiwan and South Korea and *NBP* in Japan and Taiwan will be improved. Although China's estimated results of *NBAL* satisfy the EKC hypothesis, as China has not reached the turning point, if a high-level growth of GDP per capita could be realized in China in the future, *NBAL* will continue to rise. The order of arrival of turning points, such as in Japan, Taiwan, South Korea and China, on the EKC in *NBAL* or *NBP* essentially overlaps the turning points of the measurement results of each year. Regarding the crop farming sector, in which the EKC is established, the degree of industrialization can explain the trend of environmental efficiency.

In the livestock farming sector, although Japan's *NBAL* and *NBP* each satisfy the EKC hypothesis, they have not reached the turning point, and with the growth of GDP per capita, they are expected to rise. China's *NBP* and South Korea's *NBAL* and *NBP* indicate the reverse results of the EKC hypothesis. With economic growth, those indexes will worsen along the lines of the reverse EKC. The estimation results of the EKC in *NBAL* and *NBP* in livestock farming could endorse measurement results that the reverse U shape, like the crop farming sector, is not definitely observed in the studied periods. In the livestock farming sector, the four East Asian countries have not entered the declining phase of the EKC. Therefore, it is suggested that the influence from common factors, such as the degree of industrialization, is relatively small.

In the four East Asian countries, China's *NBAL* could be affected by rapid economic growth most significantly in the crop and livestock farming sector. Recently, the *NBP* indicates that the environmental efficiency of pollution has improved in the crop farming sector but worsened in the livestock farming sector. It is more desirable for China's government to adopt a policy that promotes the optimal use of chemical fertilizers and concentrated feed. In order to reach the turning point more rapidly, it might be effective to develop varieties that need smaller amounts of fertilizers. Because *NBAL* in the crop farming sector in China has recently been more than four times larger than that of the livestock farming sector, policy implementation that prioritizes the crop farming sector could be effective for total pollution cuts in the agricultural sector. After the National People's Congress in 2015, the Chinese government announced that the total use of fertilizers would be suppressed to the current level for 5 years to reduce pollution effects on arable land and water.¹³ That suggests China's government has recognized the serious condition of the crop farming sector and measurement of the overuse of chemical fertilizers is required.

In Taiwan, Japan and South Korea, *NBAL* and *NBP* in the crop farming sector recently have improved, and in some indexes, the EKC has been established in the periods. In three countries, *NBAL* in the livestock farming sector was almost the same or higher than that in the crop farming sector in the 2010s. Considering that three countries in the crop farming sector entered the decrease phase of the EKC, indicating a negative relationship between *NBAL* or *NBP* and GDP per capita, the measurement for pollution cut should focus on the livestock farming sector.

In this study, we calculate the nutrient balance and estimate the EKC in the four East Asian countries' crop farming and livestock agricultural sectors. Although measured environmental efficiencies are limited to *NBAL* and *NBP*, we can also measure a more

comprehensive index, including not only desirable and undesirable goods, but also production factors, such as labour power, capital and energy, by the method of data envelopment analysis. By narrowing the target of measurement to, for example, rice and pig farming, we are able to obtain more precise data. Specifically, because we can obtain data for chemical and organic fertilizer in the 1950s–2010s in Japan's rice farming sector, we can measure nutrient balance more precisely. In addition, we would like to estimate the relationship between measured environmental efficiency using nutrient balance and not only GDP per capita but also income disparity and price of waste materials.

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