JARQ 49 (2), 135 - 141 (2015) http://www.jircas.affrc.go.jp

Development of a Tool for Socio-Economic Evaluation of Agricultural Technologies Directed toward Adaptation to Climate Change

Shintaro KOBAYASHI* and Jun FURUYA

Social Sciences Division, Japan International Research Center for Agricultural Sciences (Tsukuba, Ibaraki 305-8686, Japan)

Abstract

In the present world affected by climate change, developing agricultural technologies to adapt to climate change is one of the most important challenges to mitigate the impacts of climate change on food security. In fact, many researchers and engineers are also working to develop adaptation technologies. If there is a low-cost, easy-to-use tool to evaluate such technologies, it will facilitate initial evaluation to consider the appropriate technical development perspective. Accordingly, this paper tries to develop a simple model structure for the tool and consider how best to use the evaluation tool, based on the achievements of a previous study. To enable simple calculations in a spreadsheet, an input-output model is applied to the model structure, assuming minimal impact of shocks on national nominal income. Comparisons of projection results by two alternative candidate models with those by a comprehensive but complex simulation model including flexible and realistic assumptions show that the developed simple models result in realistic and robust projections of real consumption and social welfare index. Accordingly, an evaluation tool based on simple model structures will enable a low-cost initial evaluation with social welfare as a criterion.

Discipline: Agricultural economics
Additional key words: CGE model, initial evaluation, input-output model, spreadsheet

Introduction

The average global temperature has risen by 0.74°C in the last century, and may rise further and more rapidly (Trenberth et al. 2007). With its base on the environment, agriculture is one of the most vulnerable human activities to climate change. Many studies project an increasing difference in agricultural productivity among regions and increasing instability of agricultural production (Easterling et al. 2007). To mitigate the impact of climate change on agriculture, researching and developing adaptation technologies for agriculture is important.

As adaptation technologies are developed, initial economic evaluation of the technologies is thought to be beneficial to determine the appropriate development perspective. Kobayashi et al. (2012) applied the model structure of the Environmental Sector Endogenized Multi-Regional Input-Output Model (ESEMRIO) (Kim et al. 2001) to a simple socio-economic evaluation model of adaptation technologies in agriculture, to facilitate an initial economic evaluation for researchers and engineers of the technologies. The developed simple socio-economic evaluation model is based on input-output model (Leontief 1941). Usually, input-output model cannot calculate price variation and quantitative variation at the same time due to its rigid linear structure. However, when an assumption is made, the model facilitates calculation of both aspects of variation induced by the introduction of adaptation technologies. This allows the initial evaluation to be conducted using a spreadsheet, and may enable researchers and engineers to conduct the initial evaluation by themselves cost-effectively.

The simple evaluation model (Kobayashi et al. 2012) may facilitate the initial evaluation of adaptation technologies. However, some challenges remain before practically implementing the model because a comparison of projection results between this model and a Computable General Equilibrium (CGE) model (e.g. Miller & Blair 2009), which is a comprehensive model of economic simulation including detailed and realistic assumptions, revealed relatively significant differences in production projections.

This paper tries to improve the structure of the simple evaluation model so that the projection results may resemble a CGE model more closely. In addition, this paper consid-

*Corresponding author: e-mail shinkoba@affrc.go.jp
Received 8 November 2013; accepted 13 June 2014.

ers how best to use the simple evaluation model, based on comparison with a CGE model.

Methods

One of the expected merits of the simple evaluation model is simplicity, which can allow researchers and engineers to initially evaluate their technologies cost-effectively. However, if projection accuracy is lost due to the simplicity, it will hinder decision-making based on the model. Accordingly, we compare the projection results of the simple evaluation model with that of a CGE model, widely used for complex economic simulation with realistic assumptions. Based on this comparison, we discuss the merits and demerits of the model and consider how best to use it. Both models are developed based on the 2005 input-output table of Japan, including 34 production sectors (Statistics Bureau 2012).

According to Kobayashi et al. (2012), the results of production projections by the simple evaluation model tend to differ from those of a CGE model and this is considered attributable to the different assumptions related to substitutability and international trade. To ease the gap, we also develop and compare an alternative simple evaluation model, using the same input-output table.

The projection results of the three models include vector variables, which are compared by their magnitudes and angles between two vectors. The equality of the algebraic inner product and geometric inner product leads to

$$\vec{a} \cdot \vec{b} = |\vec{a}||\vec{b}|\cos\theta \quad (1)$$

where $\vec{a}$ and $\vec{b}$ are vector variables, and θ is the angle of the two vectors. Solving equation (1) for θ, the following equation for an angle between two vectors is obtained:

$$\theta = \cos^{-1} \frac{\vec{a} \cdot \vec{b}}{|\vec{a}||\vec{b}|} \quad (2)$$

Structure of the model

1. Simple evaluation model

Standard economic theory explains that general market equilibrium can be realized by flexible prices. This theory implies that income, demand, and production are simultaneously determined by cross-references. Accordingly, economic simulation model is a simultaneous equation system in principle, and the process of solving the model is inevitably complicated. To simplify this, Kobayashi et al. (2012) assumed that nominal national income was less affected by the introduction of adaptation technologies and virtually constant. By applying this assumption, the calculation process becomes one-way and simple. Fig. 1 shows the calculation flow of the simple evaluation model of adaptation technologies in agriculture. Based on this assumption, the model omits the function between production and national income (process ⑤), and enables simple one-way calculation without solving simultaneous equations (processes ③, ④, and ⑤). The validity of the assumption will be discussed below.

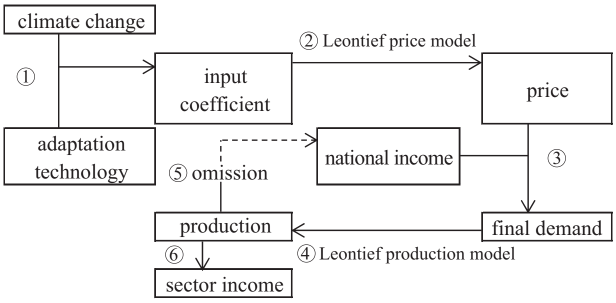

Fig. 1. Calculation flow of the simple evaluation model

The actual equations for the model are as follows. The model is based on the following production function of input-output model (Leontief 1941):

$$x_j = \min\left(\frac{z_{1,j}}{a_{1,j}}, \frac{z_{2,j}}{a_{2,j}}, \cdots, \frac{z_{i,j}}{a_{i,j}}, \cdots, \frac{z_{n,j}}{a_{n,j}}, \frac{g_j}{v_j}\right) \quad (3)$$

where x_j is the production of industrial sector j, $z_{i,j}$ is the intermediate input from industrial sector i to sector j, $a_{i,j}$ is the input coefficient, the parameter to set the input required from sector i for one product unit of sector j, g_j is the input of capital and labor to sector j, and v_j is the value-added ratio to set the necessary input of capital and labor for one product unit of sector j. The input coefficient $a_{i,j}$ of the present situation can be derived from an input-output table. However, for future projections, this parameter must be changed in accordance with future scenarios (process ①). Details of process ① will be described below in the sub-section for the model of adaptation technologies.

Process ② determines the price level affected by the change in input coefficient, using the following Leontief price model:

$$P = V(I - A)^{-1} \quad (4)$$

where P is the row vector of price, V is the row vector of the value-added ratio with v_j as its element, I is the identity matrix, and A is the matrix of the input coefficient with $a_{i,j}$ as its element. If the elements of V and A are exactly derived from a reference input-output table, all the elements of P are 1.

Process ③ determines final demand, assuming the Cobb-Douglas utility function of consumer. The following demand function is derived from utility maximization problem:

$$f_j = \frac{\alpha_j \cdot Y}{p_j} \tag{5}$$

where f_j is the final demand for the product of sector j, α_j is the parameter to set the expenditure share of product j, Y is national income, and p_j is the price of product j.

Process ④ determines production, using the following Leontief production model:

$$X = \{I - (I - \widetilde{M})A\}^{-1}\{(I - \widetilde{M})\}F + E\} \tag{6}$$

where X is the column vector of production with x_j as its element, $\widetilde{M}$ is a parameter matrix to set import ratio to demand, F is the column vector of final demand with f_j as its element, and E is the column vector of exogenous exports.

Process ⑥ determines income by sector as a result of production activity:

$$Q = \widetilde{V} \cdot X \tag{7}$$

where Q is the column vector of income by sector, and $\widetilde{V}$ is the diagonal matrix of the value-added ratio with the same element as V.

2. Alternative simple evaluation model

Kobayashi et al. (2012) pointed out that production projections made by the simple evaluation model of adaptation technologies in agriculture tend to differ from those of a CGE model. Because CGE models are based on more flexible and realistic assumptions, it is preferable to improve the simple model so that it can produce results which resemble a CGE model more closely. The key difference between the models is linearity. The simple model is based on a linear system, and cannot reproduce the substitutability of an economic agent's selection and action. Conversely, CGE models are based on a non-linear system, and can reproduce flexible selection and action. The difference between both production projections is considered attributable to the degree of reality of international trade strongly affected by the substitutability.

To improve projection results, we adopt alternative structures for the simple evaluation model. The price model expressed by equation (4) is replaced by the following alternative equation of the Leontief price model so that prices of imported goods can be reflected in domestic prices.

$$P_d = (P_m \cdot \widetilde{M} \cdot A + V)\{I - (I - \widetilde{M})A\}^{-1} \tag{8}$$

where P_d and P_m are the row price vectors for domestic and imported products respectively.

As equation (8) shows, the alternative model has two types of prices. Accordingly, the demand function expressed by equation (5) is replaced by the following two equations:

$$f_{d,j} = \frac{\alpha_{d,j} \cdot Y}{p_{d,j}} \tag{9}$$

$$f_{m,j} = \frac{\alpha_{m,j} \cdot Y}{p_{m,j}} \tag{10}$$

where $f_{d,j}$ and $f_{m,j}$ indicate the final demand for domestic product j and imported product j respectively. By introducing this model, the substitutability between domestic and imported goods is partially expressed. Equation (10) is not necessary to analyze domestic economy, but is used for comparison with a CGE model. With this replacement of demand function, equation (6) is also replaced by the following alternative production model:

$$X = \{I - (I - \widetilde{M})A\}^{-1}(F_d + E) \tag{11}$$

where F_d is the column vector of final demand for domestic goods with $f_{d,j}$ as its element.

3. CGE model

CGE model types vary depending on the range of target economies. In this study, we develop a CGE model for the same economy as the simple evaluation model, Japan, following the structure developed by Kobayashi et al. (2008). An important change in the new model structure from the reference model is the introduction of an export demand function in place of a CET export supply function. The purpose of the change is to simplify the export model so that we can apply the same simulation scenarios and exogenous variables to all the models. The export demand function is as follows:

$$e_j = e_{0,j} - e_{0,j}(p_{f,j} - 1)\,\theta_j \tag{12}$$

where e_j is the product export of sector j, $e_{0,j}$ is constant and the export of sector j in reference year, $p_{f,j}$ is the domestic product price of sector j converted to international currency with $(p_{f,j} - 1)$ representing the relative price change to exogenous international price, and θ_j is the price elasticity of export demand.

4. Model of climate change impacts and adaptation technologies

The production technology of input-output model (equation (3)) is explained by input coefficient $a_{i,j}$ and value-added ratio v_j. These parameters refer to the necessary inputs for one product unit. By assuming that climate change impacts and adaptation technologies will change the productivity of these inputs, the following equations for updated parameters are derived.

Table 1. Technical information required to evaluate adaptation technologies

technical parameter		actual information
k_j	productivity change ratio	ratio of productivity change due to climate change without adaptation
$h_{i,j}$	input change ratio	ratio of intermediate input change due to adaptation technology
q_j	value-added change ratio	ratio of value-added change due to adaptation technology
r_j	productivity recovery ratio	ratio of productivity recovery due to adaptation technology

Table 2. Hypothetical scenario for climate change and adaptation technology

type of scenario	technical parameter		sector	value
climate change impact	productivity change ratio	k_j	agriculture	-3.84%
cost of adaptation technology	input change ratio	$h_{i,j}$	agriculture	20%
			chemicals	100%
			oil products	50%
			electricity, gas, and heat	50%
			others	0%
	value-added change ratio	q_j	value-added	0%
effect of adaptation technology	productivity recovery ratio	r_j	agriculture	4.80%

Table 3. Exogenous parameters of the CGE model

	high	mid	low
elasticity of substitution between domestic and imported goods			
agriculture	5	4	3
mining	4	3	2
fiber and garment	3	2.5	2
price elasticity of export demand			
all sectors	5	3.5	2

$$a'_{i,j} = \frac{(1+h_{i,j})a_{i,j}}{(1+r_j)(1+k_j)} \quad (13)$$

$$v'_j = \frac{(1+q_j)v_j}{(1+r_j)(1+k_j)} \quad (14)$$

where $a'_{i,j}$ and v'_j are updated parameters, $h_{i,j}$ is the ratio of additional input from sector i necessary to introduce an adaptation technology in sector j, r_j is the ratio of production recovery induced by an adaptation technology, k_j is the ratio of change in production caused by climate change without adaptation, and q_j is the ratio of additional capital and labor necessary to introduce an adaptation technology in sector j. The technical information required to evaluate adaptation technologies is summarized in Table 1.

Results and discussion

1. Hypothetical scenario and sensitivity analysis

Projections by both model types for comparison are all based on the same hypothetical scenario for climate change impact and adaptation technology. Table 2 shows the scenario, which is determined with reference to technical information of adaptation technologies under development.

In CGE models, non-linear functions are frequently used; some of which need the parameters to be determined independently of reference data of a base year. This study assumes that these exogenous parameters have standard ranges. The assumed parameter values are shown in Table 3, while Table 4 shows the result of sensitivity analysis of the exogenous parameters. Important aggregate variables of the model reveal a reasonable reaction to the shock of tech-

Table 4. Sensitivity analysis of the CGE model

elasticity scenario		change induced by adaptation scenario (%)			
domestic or imported	export	real production	price level	nominal production	value-added
low	high	0.06	-0.63	-0.57	-0.89
	mid	0.06	-0.65	-0.59	-0.91
	low	0.06	-0.69	-0.63	-0.96
mid	high	0.07	-0.81	-0.75	-1.07
	mid	0.07	-0.83	-0.77	-1.10
	low	0.07	-0.87	-0.81	-1.15
high	high	0.08	-0.98	-0.92	-1.25
	mid	0.08	-1.01	-0.94	-1.28
	low	0.08	-1.05	-0.99	-1.33

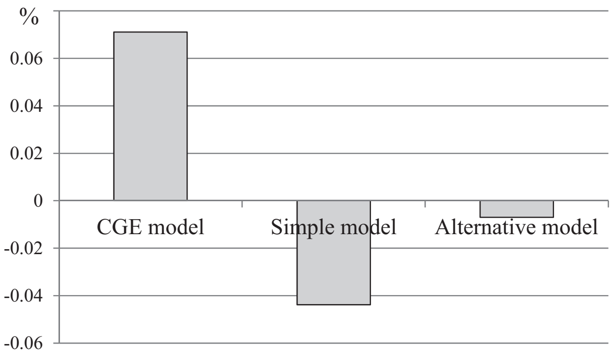

Fig. 2. Percentage change in real production projected by the three models

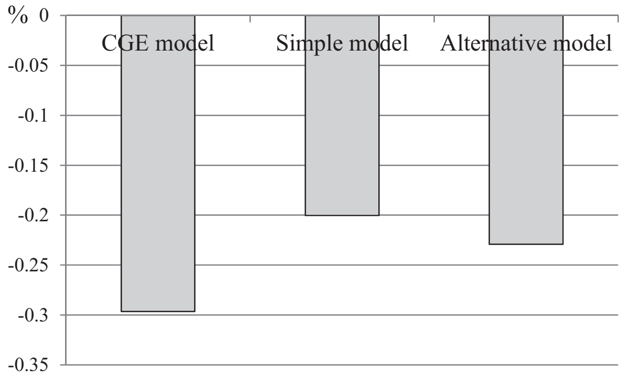

Fig. 3. Percentage change in real income projected by the three models

nology introduction assumed by Table 2. According to the result, parameter selection is unlikely to change the direction of the model reaction. Accordingly, the following discussion will focus on the mid-mid scenario of Table 4, which returns virtually average values of variation ranges.

2. Aggregate variables

In this section, we compare between the aggregate variables projected by the models. According to Kobayashi et al. (2012), production projections made by the simple model tend to differ from those made by the CGE model because the simple model assumes no substitutability of economic activities or flexibility of international trade. Variations observed in percentages in real production, as projected by the three models based on the assumption made in Table 2, are shown in Fig. 2. According to this figure, any improved accuracy in production projection derived by introducing the alternative model is slight. This result implies that it is difficult, even for the alternative model, to reproduce the substitutability of an economy and flexibility of international trade.

Conversely, the simple and alternative models can make real income projections resembling that of CGE, as shown in Fig. 3. This result implies that the simple model family, including the alternative model, can make realistic

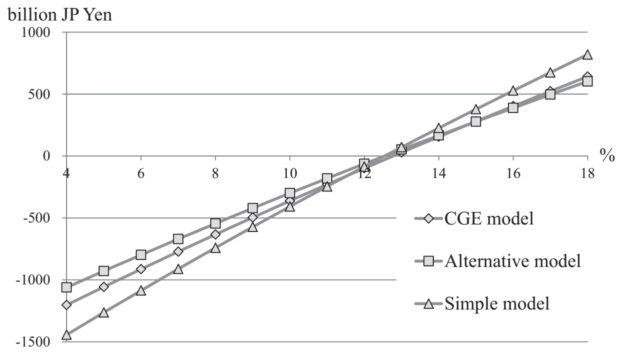

Fig. 4. Projected social welfare (equivalent variation) and adaptation technology efficiency

projections of real income and be used to estimate welfare. Fig. 4 shows the projected relation between adaptation technology efficiency and social welfare. Social welfare is measured by the equivalent variation (e.g. Mas-Colell et al. 1995), which is one of the major welfare indices related to real income used in economics. Adaptation technology efficiency is determined by the productivity recovery ratio, r_j, in Table 1. As shown in Fig. 4, projections of social welfare made by the simple model family, particularly by the alternative model, are almost the same as that of the CGE model.

Accordingly, using the simple model family, we can consider a preferable level of efficiency of an adaptation technology. In the case of Fig. 4, social welfare returns to the base level of 0 billion JP Yen, just the same level as observed before the impact of climate change, if the technology efficiency level (productivity recovery ratio in Table 1) is around 12-13%. This implies that the target technical development level should exceed 13%.

In Figs. 3 and 4, the values of aggregate variables related to real income and welfare, as projected by the simple model family, seem relatively reliable and robust, though values of other variables are not necessarily reliable, as shown in Fig. 2. The reason can be explained through Fig. 5 as follows. Nominal income projections and price level projections made by the CGE model and simple model family vary significantly. The nominal income projected by the simple model family is so inelastic to exogenous shocks. The price level projected by the simple model family rises when the assumed adaptation technology is introduced to mitigate climate change impacts. The consequence of the rise in price is also a decline in real income. Conversely, the nominal income projected by the CGE model is so elastic to the shock of climate change and adaptation technology that it decreases significantly in response to climate change. The price level projected by the CGE model is also elastic and changes in a different direction from the simple model family because it reflects flexible international trade, which can mitigate any rise in price of domestic products. The significant decline in nominal income is mitigated by the decline in price level, and hence real income shows a slight decline. Accordingly, both the CGE model and the simple model family show similar changes in real income, which exposes similar variation in social welfare, albeit via different process of change.

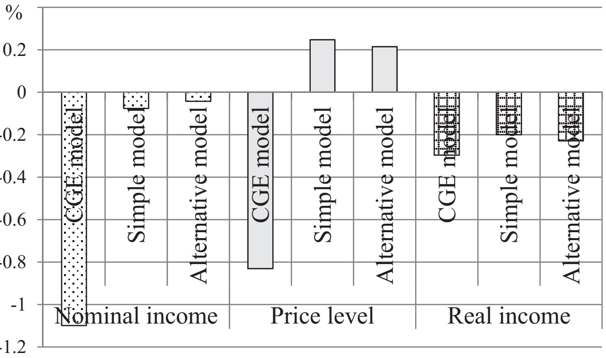

Fig. 5. Percentage change in some aggregates projected by the three models

3. Vector variables

Similarity in vector variables projected by the CGE model and the simple model family will imply that projec-

Table 5. Comparison of changes in vector variables between the CGE and the alternative model

	price[a]		domestic product price		real production		nominal production		real income		nominal income		real consumption[b]	
	relative ratio[c]	angle (°)[d]	relative ratio[c]	angle (°)[d]	relative ratio[c]	angle (°)[d]	relative ratio[c]	angle (°)[d]	relative ratio[c]	angle (°)[d]	relative ratio[c]	angle (°)[d]	relative ratio[c]	angle (°)[d]
impact[e]	0.97	31.7	0.98	28.7	0.34	18.0	1.74	93.2	1.79	90.5	1.11	96.1	0.97	5.7
adaptation[f]	0.88	41.3	0.91	37.4	0.38	43.3	1.58	78.4	0.44	39.7	0.35	46.7	0.94	7.1

a: Price level determined by domestic and imported product prices. b: Change in real consumption projected by the alternative model is regarded as change in final demand. c: Ratio of vector magnitude of the alternative model to that of the CGE model. d: Inner angle between the two vectors calculated by equation (2). e: On the assumption with only climate change. f: On the assumption with climate change and adaptation.

Table 6. Investigating the robustness of real consumption similarity between the CGE and alternative model

scenario	productivity change rate k_j [a]	-10.00	-5.00	-3.84	-3.84	-3.84	-3.84	-3.84	-1.00
	productivity recovery rate r_j [a]	0.00	0.00	2.00	4.80	4.80	4.80	8.00	0.00
	elasticity (import-export)[b]	mid-mid	mid-mid	mid-mid	low-low	mid-mid	high-high	mid-mid	mid-mid
	relative ratio[c]	0.97	0.97	0.95	0.93	0.94	0.94	0.91	0.97
	angle(°)[d]	6.28	5.83	7.06	7.46	7.12	7.04	7.63	5.54

a: For details, see Tables 1 and 2. b: For details, see Table 3. c: Ratio of vector magnitude of the alternative model to that of the CGE model. d: Inner angle between the two vectors calculated by equation (2).

tions made by the simple model family for a sector are sufficiently realistic, and will enable discussion by sector. Table 5 compares the CGE and alternative models in terms of some important vector variables, using the relative ratio of vector magnitude and the inner angle of the two vectors. The vector elements comprise changes in percentage by sector induced by exogenous shocks. Accordingly, it should be noted that the magnitude of the vectors is not necessarily proportional to the magnitude of the corresponding aggregates.

In Table 5, the relative ratios of price, domestic product price, and real consumption are near 1.00 for exogenous shocks, climate change impact (impact) and adaptation technology introduction (adaptation). This means that the magnitudes of changes projected by the two models for price, domestic product price, and real consumption are almost the same. Regarding the other criterion, angle of vectors, only real consumption has small angles. This means that the directions of changes projected by the two models for real consumption are almost the same. Judging from these results, real consumption by sector can be analyzed based on the projections made by the simple model family. Conversely, sector analysis of other variables using the simple model family is considered less accurate than that of real consumption. These results also imply that the aggregate of real income, but not the sector real income, can be discussed based on projections made by the simple model family.

Table 6 investigates the robustness of real consumption similarity. The results imply that the similarity between both models is robust, though the difference between them tends to grow with increasing productivity recovery rate.

Conclusions

This paper has introduced alternative structures to the simple evaluation model of agricultural technologies to adapt to climate change, which was developed by a previous study to enable low-cost initial evaluation. Comparing the aggregate variables of the simple model family with those of the CGE model developed based on the same data set, reveals only slight improvement in the similarity of production projections, which was very low in the previous study. Conversely, it shows that the high similarity of real income and welfare projections with the CGE model is additionally improved following the introduction of alternative structures. Accordingly, the alternative model is slightly preferable to the original simple evaluation model.

A comparison of vector variables demonstrates that only real consumption in the simple model family resembles that of the CGE model. This implies that using the simple model family, including the alternative model, allows us to conduct sector analysis for real consumption only.

Judging from the results of both comparisons, it can be said that a tool based on the simple model family to evaluate agricultural technologies to adapt to climate change, can make realistic projections of social welfare of a target economy. Accordingly, the tool will enable a low-cost initial evaluation based on social welfare as a criterion.

Acknowledgements

This study is part of both research project "Economic Evaluation of Agricultural Mitigation and Adaptation Technologies for Climate Change" funded by the Agriculture, Forestry, and Fisheries Research Council (AFFRC) of Japan and research project "Development of Agricultural Technologies based on Sustainable Management of Environment and Natural Resources in Developing Regions" funded by Japan International Research Center for Agricultural Sciences (JIRCAS). The financial supports provided by AFFRC and JIRCAS are gratefully acknowledged.

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