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Strong El Niño–Southern Oscillation events and the economics of the international rice market

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ABSTRACT: EL Niño–Southern Oscillation (ENSO) events are costly to agriculture in that they contribute to its variability. It is possible that climate change will increase ENSO event frequency and severity. This study investigates the economic consequences of ENSO events for the international rice market, along with the consequences of a possible increase in event severity. Historical data are used to estimate the ENSO impact on rice production, and the resulting parameters are incorporated into a stochastic spatial equilibrium model. Our results indicate that an average El Niño or La Niña event reduces annual welfare in the world rice market by US$741 million or US$2058 million, respectively. The additional welfare loss amounts to US$595 million or US$637 million, respectively, if extreme El Niño or La Niña events take place, and to US$1337 million or US$1392 million, respectively, if the frequencies of extreme events increase. The empirical results also show that an expansion in both trade and storage capacity can mitigate ENSO damage.

KEY WORDS: El Niño · La Niña · Extreme weather · Stochastic model · Rice · International trade

1. INTRODUCTION

The El Niño–Southern Oscillation (ENSO) is a pervasive climate phenomenon associated with regional variations in climate throughout the world. ENSO is comprised of 3 phases, a warm (El Niño), a cold (La Niña), and a neutral phase. The economic impacts of the ENSO phases have been widely discussed in recent years. Many studies have estimated the effects of ENSO on crop yields, water resources, and agricultural income or sectoral performance (e.g. Adams et al. 1995, Mjelde et al. 1997, Solow et al. 1998, Centeno et al. 2000, Chen & McCarl 2000, Chen et al. 2001, 2002). Some of these studies have examined the implications of ENSO for rice production. Centeno et al. (2000) estimated the effect of ENSO on Asian rice yields using a crop growth model, while Chen & McCarl (2000) applied an econometric approach to estimate the effect of ENSO on rice production in a number of regions of the world.

However, the results generated by such studies typically represent the effects of average ENSO events. Timmermann et al. (1999) found that global climate change may have altered the ENSO characteristics, with more frequent and extreme episodes. Trenberth & Hoar (1996, 1997) found the frequency of El Niño to increase and the frequency of La Niña to decrease over the period of 1976 to 1995. In this study, we estimate the effects of both average and strong ENSO episodes on the international rice market.

According to the estimates of Timmermann et al. (1999), the probabilities for the ENSO warm, cool and neutral phases to occur are 0.238, 0.250 and 0.512, respectively. They project that the probabilities of these 3 ENSO phases will change under the increasing levels of greenhouse gases assumed in the IPCC scenario IS92 projections. To reflect these projections, the average and strong ENSO event impacts on rice production for major rice-producing nations are estimated using an econometric approach involving time series data. Subsequently, a stochastic world rice model that incorporates production, consumption, trade, and storage activities is employed to simulate the effects of

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average and strong ENSO events on the world rice market. The frequency and severity of ENSO events are adjusted to reflect the global climate change effects. Finally, the possible adaptation strategies of trade and storage are examined, along with policy implications and recommendations.

2. ENSO EFFECTS ON RICE PRODUCTION

Rice is the most important staple food crop in the Asia-Pacific region. Of 25 major rice-producing nations, 17 are located in this region, which together produce 92% and consume 90% of the world's total rice production. Throughout the region, much of the present interannual variability in precipitation is linked to the ENSO phenomenon (Matthews et al. 1995).

Centeno et al. (2000) found that high levels of radiation during an El Niño event promotes high levels of yields through increased photosynthesis under irrigated rice farming, but very high temperatures, such as those >35°C, may give rise to spikelet sterility and, consequently, low yields (Centeno et al. 2000). Therefore, the clear skies and droughts during extreme El Niño events are expected to bring negative effects on rice production. In India, ENSO was found responsible for rice yield variability and caused rice production to drop by 7% during an El Niño event and to increase by 3% during a La Niña event (Selvaraju 2003). However, in Sri Lanka, the rainfall in the El Niño years of 1957/1958, 1965/1966, and 1972/1973 was so high that floods were reported in some areas and rice production dropped (Zubair 2002). Because most of the world's rice production fields are flooded as an ENSO event occurs, large variations in yield due to water stress or radiation changes are unlikely during an average ENSO event, but large fluctuations in both yield and planting area would be possible if a strong event occurs.

Although the classification of the ENSO phase is known with certainty, the strength of ENSO phase is uncertain. Therefore, the approach of Song & Carter (1996) is adopted to capture the unknown impact of ENSO on rice production. Non-climate-related factors are used as explanatory variables, with the residuals representing unknown ENSO effects. Eq. (1) models total rice production as being influenced by planting acreage and technology as follows:

$$Y_i = \alpha + \beta_1 \mathrm{AR}_i + \beta_2 \mathrm{AR}_i^2 + \beta_3 \mathrm{Year} + \varepsilon_i \tag{1}$$

where the subscript i represents production regions, Y is the annual rice production, AR is the planting acreage, Year is a time trend representing technological advances over time, ε is the error term, and α, β_1, β_2, and β_3 are parameters to be estimated. The planting acreage is used as a composite management variable, including the influence of government policies.

In Eq. (1), the residuals measure the deviations from the average production. A positive residual signals the presence of an above-average observation and vice versa. The residuals are grouped by the ENSO phases to reflect the impact of ENSO on rice production. Such an approach also allows us to quantitatively identify the deviation effects of an individual ENSO event (such as the 1982/1983 or 1997/1998 El Niño) from normal production.

Rice can be separated into 2 varieties, Japonica and Indica, on the basis of taste and consumption preferences. We selected the Indica variety as our study target because the global production, consumption, and amount traded of this type of rice are all higher than in the case of the Japonica variety. There are 23 Indica rice production regions defined in Table 1. The data cover the period from 1961 to 1998 and are drawn from the Food and Agriculture Organization (FAO) (faostat.fao.org/default.aspx).

Table 1. Definitions of regions

Region	Country	Region	Country
Importers		**Exporters**	
Bangladesh	Bangladesh	China (1998)	China
China (1995)	China	Taiwan	Taiwan
Indonesia	Indonesia	India	India
DPR Korea	DPR Korea	Myanmar	Myanmar
Philippines	Philippines	Pakistan	Pakistan
Other Asian	Afghanistan, Cambodia, Iran, Iraq, Lao PDR, Malaysia, Nepal, Sri Lanka, Turkey, other Asian	Thailand	Thailand
		Vietnam	Vietnam
Central America	Costa Rica, Cuba, Dominica, Mexico, Panama	USA	USA
Europe	Italy, Portugal, Spain, other Europe	South America	Argentina, Colombia, Ecuador, Guyana, Peru, Surinam, Uruguay, Venezuela
Former USSR	Former USSR		
Brazil	Brazil		
Africa	African countries		
Rest of world		Australia	Australia

The estimation results from Eq. (1) are shown in Table 2. Most of the estimated parameters are found to be statistically significant. The high R-square values and the Theil coefficients being close to zero indicate that these equations perform well statistically and pass the fitness test.

The individual ENSO effects derived from the residuals are shown in Table 3. The results indicate that the La Niña phase gives rise to a poorer harvest than the neutral or El Niño phases. In particular, rice production in Myanmar, the Philippines, North Korea, Central America, and Brazil is reduced by at least 5% during the La Niña phase. However, the El Niño phase is linked with higher yields in a number of major Indica rice producing countries such as India, Pakistan, and Thailand. Only a few countries, such as the Philippines and Indonesia, experience negative effects from the El Niño (warm) phase, but these negative effects are less dramatic than in the La Niña (cold) phase. Note also that the residuals are mostly positive during the neutral years. One possible explanation is that the lower harvests in ENSO years stimulate rice producers to respond with higher production in normal years.

Table 2. Estimation of production by trading regions. AR: planting acreage. *Significant at 10% level, **significant at 5% level

Region	Estimated parameters						Adjusted R-square	Theil-coefficient
	β_1 AR		β_2 AR^2		β_3 Year			
	Mean	SD	Mean	SD	Mean	SD		
Bangladesh	–19.88*	12.76	0.001	0.0006	419.7*	25.5	0.93	0.039
China	40.73**	10.8	–0.0006**	0.0001	3378.6**	117.3	0.98	0.028
India	–41.51**	9.71	0.0005**	0.0001	1161.4**	246.4	0.96	0.040
Indonesia	1.48	3.81	0.0001	0.0001	792.2**	173.4	0.98	0.038
DPR Korea	11.74**	2.83	–0.004**	0.0015	–16.47	12.31	0.75	0.120
Myanmar	–13.00	10.63	0.0013	0.001	286.4**	21.0	0.89	0.064
Pakistan	3.81*	2.05	–0.0001	0.0006	17.7	17.94	0.93	0.053
Philippines	4.00	12.05	–0.0003	0.0017	187.4**	9.50	0.94	0.049
Thailand	–0.0002	0.0003	0	0.0000	338.0**	23.70	0.91	0.045
Vietnam	–23.76**	5.19	0.002**	0.0003	272.7**	63.9	0.96	0.048
Other Asian	–9.70**	2.62	0.001**	0.0002	164.0**	8.21	0.97	0.025
USA	0.21	2.42	0.002*	0.001	90.25**	7.96	0.97	0.034
Central America	7.70	5.75	–0.003	0.004	31.6**	2.91	0.87	0.065
Europe	–32.02**	12.40	0.046**	0.016	21.30**	2.92	0.85	0.047
Former USSR	4.59**	0.62	0.0004	0.0006	–21.04**	2.36	0.98	0.039
Brazil	1.37	1.31	–0.0001	0.0001	117.6**	12.42	0.77	0.066
South America	1.07	1.01	0.001**	0.0003	64.55**	12.47	0.98	0.027
Africa	–2.33**	1.05	0.0003**	0.0001	128.5**	48.6	0.97	0.034
Europe	–1.97	1.37	0.033**	0.007	17.94**	2.38	0.96	0.064

Table 3. The effects of ENSO on rice production (in metric tonnes). AvNiño: average El Niño; AvNiña: average La Niña

		Production (1000 t)	Percentage change (%) due to:		
			Average ENSO		Extreme event
			AvNiño	AvNiña	1997/1998 El Niño
Exporters	China	104 518	–0.23	–1.05	–3.91
	India	86 381	0.23	–1.71	–8.57
	Myanmar	10 586	–2.67	–7.34	–4.91
	Pakistan	4 697	1.32	2.37	7.20
	Thailand	15 037	1.83	–2.73	4.24
	Vietnam	18 944	–0.76	1.02	–8.42
	USA	4 854	–2.59	2.62	–3.55
	South America	5 435	0.87	1.34	1.03
	Australia	889	–3.68	–1.36	–8.49
Importers	Bangladesh	19 904	1.44	–1.49	7.30
	Indonesia	33 455	–1.79	–1.83	–13.77
	Korea DRP	1 591	–5.36	–9.25	–5.02
	Philippines	5 560	–5.85	–5.82	–32.30
	Other Asian	10 351	–1.65	2.31	1.83
	Central America	1 450	–1.91	–5.87	–13.79
	Europe	300	–0.59	–4.64	13.79
	Former USSR	737	4.22	–2.61	35.51
	Brazil	5 265	0.51	–10.23	–21.5
	Africa	10 493	1.83	2.15	–3.24
Total production		340 447	339 532	335 606	321 418

The effects of strong ENSO events on rice production can be estimated from Eq. (1). Based on classification by Redmond (2007), a strong El Niño event occurs when the Southern Oscillation Index (SOI) is less than –1, while a strong La Niña event is found when the SOI is more than +1. Therefore, the years 1965/1966, 1972/1973, 1977/1978, 1982/1983, and 1997/1998 are classified as strong El Niño events and the years 1973/1974, 1975/1976, and 1988/1989 are classified as strong La Niña events. The last column of Table 3 shows the effects of the strong El Niño in 1997/1998 on rice production. The results indicate that the effects are more intense than those of the average ENSO phases.

Table 4. Definitions of variables

Variables	Definitions	Units
$\rho(s)$	Probability of ENSO state *s*	%
t_{em}	Transportation cost from exporter *e* to importer *m*	US\$ t^{-1}
tar_m	Import tariff imposed by importer *m*	US\$
prs_i	Domestic subsidy in trading region *i*	US\$
exs_e	Export subsidy employed by exporter *e*	US\$
stoc_i	Storage cost in trading region *i*	US\$ t^{-1}
YENSO_{is}	ENSO impact on rice production in trading region *i* under ENSO state *s*	t
QD_{is}	Domestic demand in trading region *i* under ENSO state *s*	t
QS_i	Domestic supply in trading region *i*	t
$f_i(\text{QD}_{is})$	Inverse demand function in trading region *i*	–
$g_i(\text{QS}_i + \text{YENSO}_{is})$	Inverse supply function in trading region *i*	–
TRE_{ems}	Quantity traded between exporter *e* and importer *m*	t
STOA_{is}	Addition to storage in trading region *i* under ENSO state *s*	t
STOR_{is}	Removal from storage in trading region *i* under ENSO state *s*	t

3. STOCHASTIC RICE TRADE MODEL

A mathematical programming-based spatial equilibrium (SE) model (Samuelson 1952, Takayama & Judge 1971) is applied here to depict the international rice market. The SE model has been applied in many agricultural trade studies, mostly in a deterministic fashion. Here, the model is extended into a stochastic version to show how rice planting is influenced by ENSO events. Following the technique of Lambert & McCarl (1989), a 2-step decision is embedded in the stochastic SE model. The first step is to decide how much acreage will be planted given uncertain climate and crop yield conditions. Subsequently, prices, as well as the quantities traded, are determined in the second step given the rice production for each ENSO state of nature (i.e. phase and strength).

The model is outlined in the following optimization formulation with the subscript *s* representing the ENSO state and the subscripts *i*, *m*, and *e* representing, respectively, the trading region, importing region, and exporting region:

$$
\begin{aligned}
&\text{Max CSPS} = \qquad (2)\\
&\sum_s \rho(s) \times \Bigg\{ \sum_i \Big[\int f_i(\text{QD}_{is}) \text{dQD}_{is} - \int g_i(\text{QS}_i + \text{YENSO}_{is}) \text{dQS}_i \Big] \\
&- \sum_e \sum_m t_{em} \times \text{TRE}_{ems} - \sum_i \text{stoc}_i \times (\text{STOA}_{is} - \text{STOR}_{is}) \\
&- \sum_i \text{prs}_i \times \text{QS}_i - \sum_m \text{tar}_m \times \sum_e \text{TRE}_{ems} + \sum_e \text{exs}_e \times \sum_m \text{TRE}_{ems} \Bigg\}
\end{aligned}
$$

$$
\begin{aligned}
st \;\; - &\sum_e \text{TRE}_{ems} - (\text{QS}_m + \text{YENSO}_{ms}) \\
&- \text{STOR}_{is} + \text{QD}_{ms} + \text{STOA}_{ms} \le 0 \quad \forall m, s
\end{aligned} \qquad (3)
$$

$$
\begin{aligned}
&\sum_m \text{TRE}_{ems} - (\text{QS}_e + \text{YENSO}_{es}) \\
&\qquad - \text{STOR}_{es} + \text{QD}_{es} + \text{STOA}_{es} \le 0 \quad \forall e, s
\end{aligned} \qquad (4)
$$

$$
\sum_s \rho(\text{s}) \times [\text{STOA}_{is} - \text{STOR}_{is}] = 0 \quad \forall i \qquad (5)
$$

Equation variables are defined in Table 4. The model in Eqs. (2) to (5) maximizes total expected surplus of the consumer and producer together (CSPS) subject to market equilibrium and stock clearance conditions in each region. The consumer surplus is a proxy for the welfare of consumers, while the producer surplus is a proxy for the welfare of producers. The first line in Eq. (2) is the probability-weighted area under the demand curve minus the area under the supply curve, while the second line is the transportation and storage costs. The third line represents government policy interventions in the rice market, including a domestic price subsidy (prs × QS), an import tariff ($\text{tar}_m \times \sum_e \text{TRE}_{ems}$) and an export subsidy ($\text{exs}_e \times \sum_m \text{TRE}_{ems}$).

Eqs. (3) & (4) are the supply and demand balance constraints for importers and exporters under each ENSO state. Eq. (3) states that the total supply in each region, including imports (TRE), domestic supply (QS), and variations from ENSO (YENSO) should exceed total demand, which includes domestic demand (QD) and net storage additions (STOA – STOR). Eq. (5) is a long-run equilibrium constraint for storage activities, which ensures average storage withdrawals equal to average storage additions.

There are 2 important properties in this model. First, since production in each trading region is affected by the ENSO state, the residual estimates from Eq. (1) will be transported into Eqs. (3) & (4) as YENSO_{is}. This

YENSO_{is} term will shift the domestic supply curve, and, thus, domestic demand, trade, storage, and prices in each trading region are affected and become ENSO-state dependent.

Second, the trading prices are endogenously determined in the model. From the Kuhn-Tucker conditions (i.e. the necessary conditions for a solution in nonlinear programming to be optimal), we obtain:

$$\mu - \lambda - t - \text{stoc} - \text{prs} - \text{tar} = 0 \qquad (6)$$

where μ and λ are the ENSO-state dependent equilibrium prices of Eqs. (3) & (4), respectively, which are interpreted as the import and export prices. Eq. (6) implies that transportation cost (t), storage cost (stoc) and policy interventions (prs and tar) play a role in forming the price wedges between importing and exporting countries and determining the import volume in each country. If there is no policy intervention, i.e. $\text{prs} = \text{tar} = 0$, then Eq. (6) may be simplified as $\mu - \lambda - t = 0$. Such a condition characterizes a perfectly competitive market as shown in Takayama & Judge (1971).

This model is applied to the international rice market using 1998 data as the baseline. The model requires bilateral trade flows among all regions, as well as quantities and prices of supply and demand in each region. The main data source is the FAO (faostat.fao.org/default.aspx). All quantities are converted into milled rice. Demand and supply elasticities are obtained from Cramer et al. (1993). The storage cost is assumed to be the supply price multiplied by an assumed annual interest rate of 7%. Trade data are obtained from the World Trade Database on CD-ROM complied by Statistics Canada (www.statcan.ca/menu-en.htm). Finally, transportation cost and policy parameters, including import tariffs, export subsidies, and production subsidies are obtained from Chen & McCarl (2000) and the Global Trade Analysis Project (GTAP) database (McDougall et al. 1998).

4. MODEL CALIBRATION

Model calibration is an important step of the model development process before it is ready for policy simulations. The 3 policy intervention parameters in the objective function are used as adjustment tools to allow the model solutions to be consistent with the observed data. For instance, if the modelled quantity consumed is higher but production is lower than the observed data in an importing country, the import tariff parameter is adjusted downward to reduce consumption but increase production simultaneously. When the model solutions for all trading countries are close to the observed data, the prices will also be very close to the observed data.

Behind this adjustment process is the theory of strategic trade policy. Assuming that the transportation and storage costs remain constant, any change in government intervention policies could change the deviations of the equilibrium prices between importing

Table 5. Comparisons between observed and model-generated supply/demand quantities and prices by region. Dev.: deviation

Regions	Demand quantities (t)			Supply quantities (t)			Prices (US$ t^{-1})		
	Observed	Model	% Dev.	Observed	Model	% Dev.	Observed	Model	% Dev.
Importers									
Bangladesh	21 447 463	23 543 603	9.77	19 904 360	19 039 023	−4.35	322.39	325.10	0.84
Indonesia	42 426 871	44 374 690	4.59	33 455 894	31 875 444	−4.72	313.97	318.39	1.41
DPR Korea	1 896 330	1 959 169	3.31	1 591 830	1 691 767	6.28	133 524.00	129 307.00	−3.16
Philippines	8 286 056	8 994 094	8.54	5 560 100	5 164 405	−7.12	445.55	432.52	−2.92
Other Asian	15 165 648	14 037 835	−7.44	10 351 270	11 085 981	7.10	466.56	473.95	1.58
Central America	3 053 385	3 030 883	−0.74	1 450 690	1 362 022	−6.11	680.26	661.78	−2.72
Europe	797 034	786 249	−1.35	300 737	274 593	−8.69	1 316.86	1 332.16	1.16
Former USSR	1 264 828	1 216 647	−3.81	737 761	757 937	2.73	218.94	234.25	6.99
Brazil	5 892 084	5 496 900	−6.71	5 265 692	5 483 850	4.14	359.64	370.66	3.06
Africa	14 450 901	15 403 388	6.59	10 493 283	9 568 530	−8.81	416.52	408.78	−1.86
Rest of world	105 679	97 737	−7.51	–	–	–	416.52	424.31	1.87
Exporters									
China	101 487 300	103 099 900	1.59	104 518 100	103 133 500	−1.32	163.88	164.86	0.60
India	79 937 454	72 955 085	−8.73	86 381 760	89 727 863	3.87	164.67	155.23	−5.73
Myanmar	11 036 305	10 810 018	−2.05	10 586 252	10 810 879	2.12	3 279.02	3 448.27	5.16
Pakistan	2 726 422	2 882 951	5.74	4 697 169	4 570 548	−2.70	261.20	240.88	−7.78
Thailand	9 245 072	8 944 096	−3.26	15 037 728	13 861 057	−7.82	346.27	331.22	−4.35
Vietnam	14 942 875	14 472 738	−3.15	18 944 575	19 789 302	4.46	1 504.44	1 461.80	−2.83
USA	1 990 552	2 031 067	2.04	4 854 809	4 853 177	−0.03	662.90	622.57	−6.08
South America	4 341 989	4 427 590	1.97	5 434 986	5 147 488	−5.29	361.86	343.90	−4.96
Australia	435 556	446 138	2.43	888 873	813 397	−8.49	256.92	239.06	−6.95

and exporting countries and result in different solutions for production, consumption, and trade. Given that government policy is very difficult to measure, policy parameters were used to fine-tune calibration by matching the model solutions with the observed data for 1998. The comparisons between model solutions and observed data of demand/supply quantities and prices for each trading region are listed in Table 5. Because the percentage deviations are mostly <8%, the comparisons indicate that the model is verified and is suitable for depicting the international rice market.

5. SCENARIO DESIGN

Six scenarios simulate the economic impacts of strong and more frequent ENSO phenomena on the international rice market and the possible outcome of governmental mitigation efforts. They are as follows:

1. Base: This scenario ignores ENSO impacts. The model becomes deterministic with 1 ENSO-state across all years. The average production levels in each trading country are used in this simulation; they are displayed in the first column of Table 3.

2. AvNiño and AvNiña (average El Niño and La Niña): The model is simulated using the production from an average El Niño or an average La Niña event. The percentage changes in production based on the average of El Niño phase and the average of La Niña phase in each trading country are displayed in the fourth and fifth columns of Table 3. These percentages are also used to calculate YENSO_{is} for Eqs. (3) & (4).

3. SNiño1 to SNiño5 and SNiña1 to SNiña3 (strong El Niño and La Niña, respectively): The model is designed to simulate the impact from extreme El Niño or extreme La Niña events. Based on the classification by Redmond (2007), scenarios SNiño1 to SNiño5 simulate the production changes that characterize 5 strong El Niño events in 1965/1966, 1972/1973, 1977/1978, 1982/1983, and 1997/1998, respectively. Scenarios SNiña1 to SNiña3 simulate the impacts from 3 strong La Niña episodes in the years 1973/1974, 1975/1976, and 1988/1989.

4. FNiño1 to FNiño5 and FNiña1 to FNiña3 (increase in frequency of strong and more frequent El Niño and La Niña events, respectively): These 2 scenarios simulate the impacts from changes in the magnitudes and frequencies of the El Niño and La Niña events. In the past 38 yr, El Niño and La Niña events occurred on 10 and 8 occasions, respectively. Therefore, we assume that the probabilities of these 2 ENSO phases are 0.263 (i.e. 10/38) and 0.210 (i.e. 8/38), respectively, in our baseline model. Timmermann et al. (1999) found that global warming has the potential to increase the frequencies of these 2 phases to 0.339 and 0.310, respectively. The predicted El Niño probability was used for scenarios FNiño1 to FNiño5, which simulate the composite effects from the higher frequency along with the strong production effect specified in scenarios SNiño1 to SNiño5 for the El Niño phase. Similarly, scenarios FNiña1 to FNiña3 integrate the higher La Niña frequency with the 3 strong production effects in scenarios SNiña1 to SNiña3 for the La Niña phase.

5 & 6. Trade and Store: To demonstrate the effects of policy response, the scenario Trade simulates the composite effects of scenarios FNiño1 to FNiño5, with a 50% reduction in rice import tariffs for all rice-trading countries. This scenario attempts to show how trade policy instruments can be used to mitigate the negative effects from strong and more frequent El Niño phenomena. The scenario Store simulates the composite effects of scenarios FNiño1 to FNiño3, with a 50% storage capacity increase for all rice-trading countries. In contrast to the scenario Trade, the scenario store can provide the rice storage policy outcomes of a domestic mitigation strategy that are useful for decision-making purposes.

6. SIMULATION RESULTS

Four sets of empirical results are given in this section. The first setis simulated based on the current ENSO probability distribution (i.e. average scenario) while the second set is simulated based on the extreme El Niño/La Niña events. The third set is simulated on the ENSO probability (i.e. frequency) shifting with the strong El Niño/La Niña events, and the final set is a simulation for the effect of the possible mitigation strategies. The empirical results of economic impacts include trade amount, price, and welfare for all of the trading regions. The major economic outcomes of model solutions for each scenario will focus on trade, prices, and welfare.

6.1. The effects of an average ENSO

Table 6 describes the economic effects on trade, prices, and welfare resulting from the occurrence of an average El Niño and an average La Niña event (i.e. scenarios AvNiño and AvNiña). In Table 6, the total amount of rice traded under the El Niño phase increases slightly from 32.6 to 33.0 million metric tonnes, while the La Niña phase does not have much effect on the overall trade volume. However, the individual impact of the ENSO on production and trade is far more profound across trading regions. For instance, the El Niño phase increases rice production in India,

Table 6. Effects of average ENSO events on trade, prices and welfare by region. Values in parentheses are changes from the Base scenario. AvNiño: average El Niño; AvNiña: average La Niña

	Trade (1000 t)			Price (US$ t^{-1})			Welfare (US$ million)		
	Base	AvNiño	AvNiña	Base	AvNiño	AvNiña	Base	AvNiño	AvNiña
Exporters									
China	34	34	34	168	170	176	174 068	174 049	173 971
India	16 772	17 052	16 121	158	159	165	51 307	51 281	51 149
Myanmar	1	1	1	3 513	3 642	3 925	239 329	238 824	237 734
Pakistan	1 687	1 739	1 802	245	247	253	8 331	8 332	8 331
Thailand	4 917	5 152	4 780	337	339	345	18 583	18 579	18 565
Vietnam	5 316	5 199	5 516	1 489	1 491	1 497	147 170	147 108	147 244
USA	2 821	2 734	3 017	634	635	642	2 887	2 887	2 879
South America	719	772	885	350	352	358	8 562	8 560	8 549
Australia	367	346	374	243	245	251	615	615	613
Importers									
Bangladesh	4 504	4 268	4 655	331	332	338	115 137	115 152	115 112
Indonesia	12 499	12 874	12 508	324	326	332	106 511	106 454	106 418
Philippines	3 829	4 060	4 025	440	442	448	32 012	31 966	31 959
Other Asian	2 951	3 080	2 613	482	484	490	35 131	35 077	35 212
Central America	1 669	1 684	1 708	674	675	681	8 095	8 086	8 065
Europe	511	512	520	1 357	1 358	1 365	5 214	5 213	5 203
Former USSR	458	429	452	238	240	246	1 489	1 490	1 485
Brazil	13	13	49	377	376	417	10 145	10 150	10 018
Africa	5 835	5 669	5 498	416	418	424	44 962	44 984	44 983
Rest of world	97	97	97	432	434	440	195	195	195
Total	32 636	33 030	32 533				1 009 743	1 009 002	1 007 685
		(394)	(–103)					(–741)	(–2 058)
Average export price				251.24	251.15	263.61			
Average import price				403.68	405.25	410.43			

but production is reduced during the La Niña phase. Therefore, India exports more rice in El Niño years, and decreases its exports during La Niña years. However, both the El Niño and La Niña phases have negative effects on rice production in the Philippines (Table 3), and as a result, this country increases its imports of rice during these 2 ENSO phases (Table 6).

The domestic supply for trading regions differs according to the ENSO phases, and this causes variations in trade prices. Whether price levels increase or decrease depends on the effects of ENSO on rice production. We find that rice production in most trading regions decreases during an El Niño phase, and therefore prices increase under El Niño (Table 6).

The welfare implications are also calculated in Table 6. We find that annual total welfare in the international rice market is reduced by US$741 and US$2058 million during El Niño and La Niña years, respectively, as shown in the last 3 columns in Table 6 (relative to the Base).

6.2. Effects of extreme ENSOs

The effects of the extreme El Niño and La Niña events (i.e. scenarios SNiño1 to SNiño5 and scenarios SNiña1 to SNiña3) on trade, prices, and welfare are averaged separately and summarized in Table 7. The trade effects of each event on the top 3 trading countries are shown in Fig. 1. Extreme El Niño and La Niña events have a varying effect on the total amount of rice traded in the world, as well as the amount traded in individual countries, during the event. For instance, the model simulations show that the extreme 1965/1966, 1982/1983, and 1997/1998 El Niño events and the extreme 1975/1976 and 1988/1989 La Niña events are likely to have opposite effects on the exports of the 2 major rice exporters, India and Thailand. The reason is the differing effects of the extreme ENSO on their domestic rice production differ. So the effect of the strong El Niño and La Niña events on total trade is negative, while the effects on the average export prices are positive (Table 7).

Table 7 also shows that additional welfare losses of US$595 to US$637 million are likely to occur in the international rice market during extreme ENSO phases. The losses are greater in the extreme La Niña phase, because higher trading volume limitation triggers a higher price in the world market during such an event.

6.3. Effects of extreme and more frequent ENSOs

Since ENSO frequency and strength may be altered by climate change, the effects of more frequent ex-

Table 7. Economic impacts of extreme ENSO events on international rice markets. Values in parentheses are changes from the Base scenario

Scenario	Total amount traded (1 000 t)	Average export price (US$ t^{-1})	Average import price (US$ t^{-1})	Total social welfare (US$ million)
Base	32 636	251.24	403.68	1 009 743
SNiño1(1965/1966 El Niño)	31 666	271.38	414.12	1 008 636
SNiño2(1972/1973 El Niño)	32 838	250.33	402.53	1 009 184
SNiño3(1977/1978 El Niño)	32 654	257.61	407.74	1 008 613
SNiño4(1982/1983 El Niño)	31 505	259.46	410.33	1 010 732
SNiño5(1997/1998 El Niño)	32 059	270.71	416.04	1 008 576
Average of SNiño1 to SNiño5	32 144 (–492)	261.89 (+10.65)	410.15 (+6.47)	1 009 148 (–595)
SNiña1(1973/1974 La Niña)	32 020	265.62	412.37	1 008 508
SNiña2(1975/1976 La Niña)	32 236	268.20	413.74	1 008 501
SNiña3(1988/1989 La Niña)	33 031	239.48	396.06	1 010 309
Average of SNiña1 to SNiña3	32 429 (–207)	257.76 (+6.52)	407.39 (+3.71)	1 009 106 (–637)

treme strong El Niño and La Niña events are examined here. The average economic effects on total world trade, rice exports, and welfare are listed in the second to fifth columns of Table 8. Such estimation results indicate that total trade volumes are not affected exceedingly by the more frequent occurrences of extreme events, but changes in the trade prices are more volatile. Welfare losses might be doubled, as rice exports are interrupted more frequently by extreme El Niño and La Niña events. The total welfare losses could amount to >US$1300 million under these 2 scenarios.

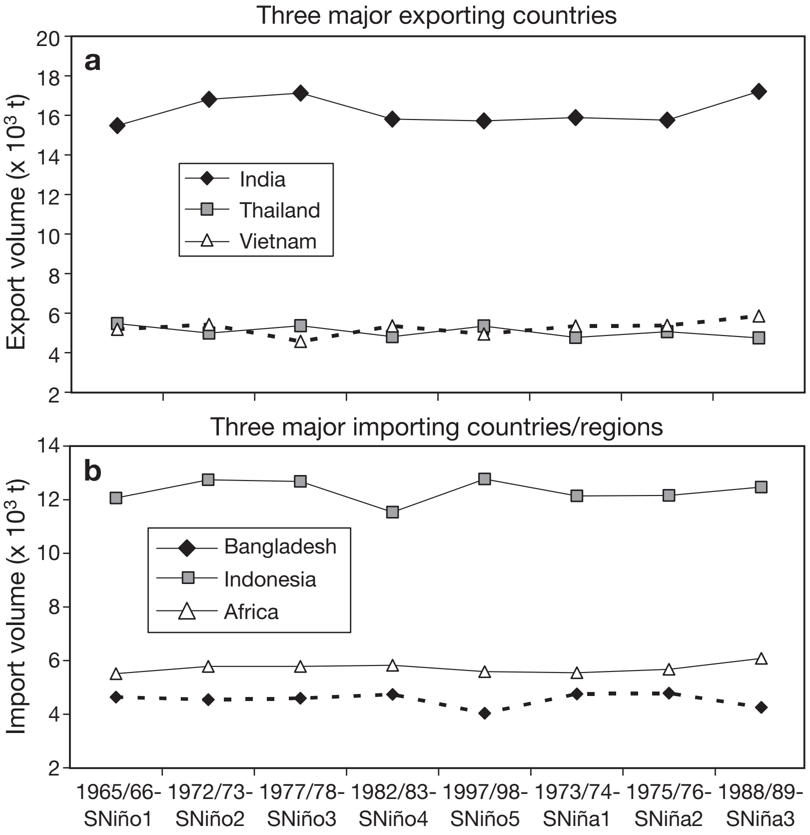

Fig. 1. Effect of extreme ENSO on export and import volumes in major rice trading countries. Due to space limitations, only the trade effect of the top 3 trading countries are shown. The complete results of each extreme event are available upon request

6.4. Effects of trade and storage policy responses

Adaptation strategies including expanding storage capacity, lowering trade barriers, and crop switching could be adopted to mitigate damage to the international rice markets from extreme ENSOs. To simulate the effects of these strategies, the import tariff in each trading country is reduced by 50% in the scenario Trade, while the storage capacity for each trading country is increased by 50% in the scenario Store. The economic results are shown in the last 2 rows of Table 8. We find that both mitigation strategies could be welfare enhancing. However, the Trade strategy, based on a reduction in import tariffs, seems to be slightly more effective than that of a Store strategy, because the former increases the total amount of rice traded significantly. Such an increase in trading activity not only offsets the effects of ENSO, but also increases the total welfare as compared with other scenarios.

Table 8. Economic effects of extreme and more frequent ENSO events and mitigation policies on international rice markets. Values in parentheses are changes from the Base scenario

Scenarios	Total amount traded (1 000 t)	Average export price (US$ t^{-1})	Average import price (US$ t^{-1})	Total social welfare (US$ million)
Base	32 636	251.24	403.68	1 009 743
Average of SNiño1 to SNiño5	32 144 (–492)	261.89 (10.65)	410.15 (6.47)	1 009 148 (–595)
Average of SNiña1 to SNiña3	32 429 (–207)	257.76 (6.52)	407.39 (3.71)	1 009 106 (–637)
Average of FNiño1 to FNiño5 (strong and more frequent El Niño)	32 339 (–297)	267.75 (16.51)	413.85 (10.17)	1 008 406 (–1 337)
Average of FNiña1 to FNiña3 (strong and more frequent La Niña)	32 427 (–209)	262.43 (11.19)	410.3 (6.62)	1 008 351 (–1 392)
Trade (tariff reduced)	41 280 (8 644)	324.91 (73.67)	356.17 (–47.51)	1 011 383 (1 640)
Store (storage increased)	31 881 (–755)	245.39 (–5.85)	393.73 (–9.95)	1 011 121 (1 378)

7. CONCLUSIONS

The main purpose of this study was to investigate the economic effeccts of extreme El Niño and La Niña events on international rice markets, as well as to estimate the economic effects of more frequent extreme ENSO occurrences. In order to do this, the impacts of average and extreme ENSO events on rice production in major rice-producing countries are estimated using regression analysis utilizing time-series data. We find that there are negative effects on rice production in many major rice-producing countries during strong El Niño and La Niña years.

By using a stochastic spatial equilibrium model, 3 major empirical findings arise. First, rice production decreases and trade volume fluctuates in average ENSO years, resulting in welfare losses up to US$2800 million on an annual basis. Second, the extreme El Niño and La Niña events could lead to an additional US$500 to US$600 million welfare loss, as trade volume is also negatively affected. More frequent extreme ENSO event occurrences as projected by Timmermann et al. (1999) under global warming could raise the economic damages to US$1.300 million losses in welfare terms. Third, the aforementioned ENSO damages could be partially offset by government mitigation efforts to smooth out the market price fluctuations by lowering tariffs or raising storage capacities.

The simulation results provide 2 policy implications. The first is that the strong 1997/1998 El Niño event resulted in a significant decrease in rice production in India, Vietnam, Indonesia, and the Philippines, which are all less developed economies. Rice is their major staple food, and any instability in production may result in a food security crisis. Therefore, how to mitigate such a negative impact is a serious policy issue in these countries.

The second policy issue is the efficiency of alternative mitigation options. Two adaptation strategies, including the reduction of import tariffs and an increase in storage capacity are evaluated in this study. We find that the strategy of reducing import tariffs is more effective than that of increasing storage capacity. Rice is a staple food for nearly half of the world's population and is traded internationally. However, only a small proportion of total production is traded, with consumption and production being almost in balance. The reason why there is such a thin international rice market is due to the protectionist policies of the rice-trading countries. However, the new Doha round of negotiations under the auspices of the World Trade Organization (WTO) has asked rice-trading countries to open up their markets through a reduction in import tariffs or an expansion of quotas. Our results suggest that a move in the direction of free trade could be a very effective measure to mitigate the damage caused by the ENSOs.

Nevertheless, there are some assumptions and limitations associated with the simulation model. First, the probability projections of ENSO frequencies are based on the Timmermann et al. (1999) estimation based on the IPCC's earlier projections of greenhouse gas concentration levels. The second limitation is that due to the partial equilibrium nature of the trade model, the economic participants in the model are countries but not necessarily representative of firms or consumers. The linkage effects on the upstream (e.g. seeds, fertilizer) and downstream sectors (e.g. milling, marketing) are also ignored. Therefore, caution should be taken in addressing the policy issues.

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