Revisiting Pareto Inferior Trade with a Stochastic Ricardian Model and Transaction Cost: A Preliminary Investigation under Symmetry

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Abstract

We consider a 2×2 Ricardian model under uncertainty to see if there is Pareto inferior trade, as Newbery and Stiglitz (RES, 1984). Their model is a partial equilibrium model while ours is a general equilibrium with transaction cost. We claim that expected welfare unambiguously improves as trade begins and transaction cost declines. This result is consistent with Newbery and Stiglitz: consumers are unambiguously better off. In addition, we find that the income of workers in a risky sector declines when transaction cost is high and that does not exceed the autarky level, which is analogous to Pareto inferior trade.

I Introduction

Newbery and Stiglitz (1984) consider a trade model under uncertainty in crops production to show there is a possibility of Pareto inferior trade under free trade. In their model, there are risky and non-risky crops, and farmers allocate their resources to the two crops. The nominal income of consumer is given as a parameter, as it is a partial equilibrium model. In our model, we use a similar model to verify their results under a general equilibrium framework to see if the Pareto inferior result still holds for a general equilibrium model. This study is an extension of Newbery and Stiglitz (*op. cit.*). Hallstrom (2004) extends the same model in a different way by including weather forecasting; hence, his model is intrinsically a dynamic model. In our model, the model is extended to be a static general equilibrium model.

For the base model, we use a Ricardian model of international trade under uncertainty. In our model, there are two regions with two sectors called agriculture and manufacturing. Since we focus on a symmetric model, we assume that production technologies of agricultural and manufacturing goods in the two regions are identical, and the two regions are the same size in terms of population. The agricultural sector is affected by weather

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conditions in the respective regions. The weather is either good or bad. For further symmetry, weather conditions of the two regions are perfectly negatively correlated at 50% probability. Turnovsky (1974) provides various versions of Ricardian model under uncertainty. Our model is another version of his model: uncertainty only in one production sector.

The discussions are developed as follows. We set up the basic framework and derive the equilibrium conditions both for autarky and interregional trade in Section II (technical proofs for remarks provided in this section are provided in the appendix). The model is then numerically examined in Section III. For the simulation, parameters are determined to be symmetric. Further inferences and concluding comments are given in Section IV.

II The Model

We consider a model of two regions on an island, the **East** (E) and the**West** (W). E and W are divided by high mountains, which make trade between E and W costly. Both regions are capable of two products, **agricultural** (A) and **manufacturing** (M) goods. E and W are assumed to produce identical agricultural and manufacturing goods using identical technologies. Goods can be traded, but trading between the regions is costly.

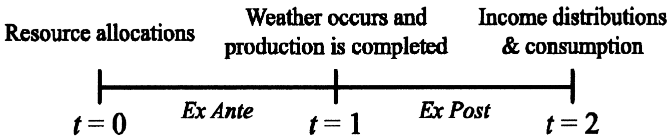
The difference between the regions is weather. If E has a wet year, W has a dry year (drought). Conversely, if W has a wet year, E has a dry year. The harvest of the agricultural good is conditional on the weather: wet is good while dry is bad for A. The production of M is not affected by the weather. The timeline of this model is as shown in Figure 1. In the beginning ($t = 0$), producers and consumers make predictions about the future weather to generate expected prices as a basis for allocating their resources. After the allocations, producers start production. Before production is completed, weather occurs in each region ($t = 1$). After that, actual income is generated and actual consumption takes place ($t = 2$). We call the phase before completion of production *ex ante* and after completion of production *ex post*.

M is produced by labor and A is produced by labor and weather conditions. The production functions of A and M are represented by classical technologies $A = \Omega \times \alpha_A L$ and $M = \alpha_M L$, where L and Ω are labor input and weather conditions, respectively, and α_A and α_M are the marginal products of labor for the respective goods (input coefficients are thus $\beta_A \equiv \alpha_A^{-1}$ and $\beta_M \equiv \alpha_M^{-1}$).[1]

Let p_{ij} be the price of $i \in \{A,M\}$in region $j \in \{E,W\}$. Similarly, let w_{ij} be the corresponding wage rate. The profit maximization and utility maximization problems of each region are

[1] Turnovsky (1974) assumes technologies of both sectors include stochastic factors while ours incudes them only in one sector.

Figure 1. Timeline of the model



then given by

$$\text{Maximize } p_{Aj}A_j - w_{Aj}L_{Aj}, \quad \text{and} \quad \text{Maximize } p_{Mj}M_j - w_{Mj}L_{Mj}. \tag{1}$$

The resource constraint of region j is

$$L_{Aj} + L_{Mj} = L_j. \tag{2}$$

The first order conditions for the two problems are

$$w_{Aj} = p_{Aj}\alpha_A\Omega_j \quad \text{and} \quad w_{Mj} = p_{Mj}\alpha_M. \tag{3}$$

Consumers in the two regions have identical tastes represented by a Cobb-Douglas utility function:

$$U(a_{ij}, m_{ij}) = a_{ij}^{\rho} m_{ij}^{1-\rho}, \tag{4}$$

where a_{ij} and m_{ij} are the quantities of consumption of agricultural and manufacturing goods for a consumer in region j working for sector i, respectively, and ρ is the preference parameter (expenditure share of A).

The *ex post* utility maximization problem of the consumer is given by

$$\text{Maximize } U(a_{ij}, m_{ij}) \quad \text{subject to} \quad p_{Aj}a_{ij} + p_{Mj}m_{ij} \le R_{ij}, \tag{5}$$

where $R_{ij} = w_{ij}$ is realized income. The first order conditions of this consumer's problem provide

$$a_{ij}^* = \frac{\rho w_{ij}}{p_{Aj}} \quad \text{and} \quad m_{ij}^* = \frac{(1-\rho) w_{ij}}{p_{Mj}}, \tag{6}$$

where each real income level w_{ij} / p_{ij} , given by (3), is

$$\begin{cases} \dfrac{w_{Aj}}{p_{Aj}} = \alpha_A\Omega_j \\ \dfrac{w_{Aj}}{p_{Mj}} = \pi_j\alpha_A\Omega_j \end{cases} \quad \text{and} \quad \begin{cases} \dfrac{w_{Mj}}{p_{Aj}} = \dfrac{\alpha_M}{\pi_j} \\ \dfrac{w_{Mj}}{p_{Mj}} = \alpha_M \end{cases}. \tag{7}$$

where $\pi_j \equiv p_{Aj} / p_{Mj}$ represents the relative price of A vis-á-vis M.

To obtain labor allocations, we have to obtain an *ex post* equilibrium since workers look at expected utility levels (income and relative price) to choose the sector to join. We apply

Walras Law to compute the equilibrium values. The *ex post* market clearing condition for interregional trade equilibrium is given by

$$\sum_{j\in\{E,W\}} \alpha_A \Omega_j \ell_{Aj} = \sum_{j=\{E,W\}} \left(\rho \alpha_A \Omega_j \ell_{Aj} + \frac{\rho \alpha_M \ell_{Mj}}{\pi_j} \right), \tag{8}$$

where $\ell_{ij} \equiv L_{ij} / L_j$ represents the share of labor in sector i in region j; hence, $\ell_{Aj} + \ell_{Mj} \equiv 1$. By symmetry, the population of the two regions is assumed to be the same: $L_W \equiv L_E$. We then postulate the following remarks to solve the resource allocations *ex ante*.

Remark 1 *Our model is symmetric. In addition, weather conditions in the two regions are perfectly negatively correlated. In interregional trade equilibrium, the ex ante market clearing condition coincides with the ex post market clearing condition.*

Proof. See Appendix 1.

Remark 2 *In our model, the market clearing conditions for the interregional and the ex ante autarky equilibria coincide with each other.*

Proof. See Appendix 2.

Now we suppose W has good weather, so that

$$\Omega_W > \Omega_E. \tag{9}$$

In this case, the relative price of A in W becomes lower than that in E if there is no trade. If the two regions trade their goods, W's A flow into E in exchange for M from E. Let T be a **common transaction cost per unit** of A and M between W and E; hence, the prices in the cost-affected *ex post* equilibrium are

$$p_{AE} = p_{AW} + T \in [\bar{p}_{AW}, \bar{p}_{AE}] \quad \text{and} \quad p_{MW} = p_{ME} + T \in [\bar{p}_{ME}, \bar{p}_{MW}], \tag{10}$$

where $\overline{p}_{ij}$ is the corresponding price in autarky, and the relative price is then

$$\frac{p_{AE}}{p_{ME}} = \frac{p_{AW} + T}{p_{MW} - T}. \tag{11}$$

Let us further define $\tau \equiv T / p_{MW}$ to get

$$\pi_E = \frac{\pi_W + \tau}{1 - \tau}, \quad (\Omega_W > \Omega_E), \tag{12}$$

where $0 \leq \tau \leq \overline{\tau} \leq 1$ for a **prohibitive transaction cost** $\overline{\boldsymbol{\tau}}$, as $p_{MW} > T$ by $p_{ME} > 0$ and $\Omega_W > \Omega_E$.

We note that W imports A from E in exchange for exporting M if W has bad weather (*e.g.,* $\Omega_W < \Omega_E$). Thus, by symmetry, the relative prices and the transportation cost are related as

$$\pi_W = \frac{\pi_E + \tau'}{1-\tau'}, \quad (\Omega_W < \Omega_E), \tag{13}$$

where $\tau' \equiv t \;/\; p_{ME}$. Since the positions of East and West in (12) are interchanged in (13)— *i.e.*, the importer of A for the former case is now the exporter of A and *vice versa* for M— we can easily find $\tau|_{\Omega W > \Omega E} \equiv \tau'|_{\Omega W < \Omega E}$.

Remark 3 *There is interregional trade when West has good weather so long as* $\overline{\pi}_W \leq \pi_W + \tau \leq \overline{\pi}_E$. *Analogously, there is interregional trade when East has good weather so long as* $\overline{\pi}_E \leq \pi_E + \tau' \leq \overline{\pi}_W$.

Proof. See Appendix 3.

Currently, there are two conditions, (8) and (12) (for $\Omega_W > \Omega_E$), and four unknowns, π_j and ℓ_{Aj} for $j = \{E,W\}$, to solve the equilibrium when there is interregional trade. Thus, we have to provide two additional equilibrium conditions to solve the model. The one comes from symmetry. For instance, labor allocations must be identical across two regions in the equilibrium:

$$\ell_{iE} = \ell_{iW} = \ell_i^*. \tag{14}$$

The other comes from the labor market clearing condition for risk-averse consumers:

$$\mathbb{E}\left[U(a_{Aj}^*, m_{Aj}^*)\right] = \mathbb{E}\left[U(a_{Mj}^*, m_{Mj}^*)\right], \tag{15}$$

where a_{ij}^* and m_{ij}^* are optimum consumption levels of agricultural and manufacturing goods of workers of sector i in region j, as given by (6). In general, we have labor market clearing conditions in the two regions. However, in the symmetric model, the two conditions become identical; hence, only one equation results from (15). Eventually, we find four conditions for four unknowns to solve interregional trade equilibrium. In autarky, there are two conditions, analogue of (8) and (15), and two unknowns, π_j and ℓ_{Aj} for each region. Thus, the autarky equilibrium is now also solved.

It is worthwhile clarifying attitudes to risk in our model and other related studies before we go on to numerical investigations. In (15), we are intrinsically looking at risk-averse agents. In our model, farmers and manufacturing workers are consumers, as in general equilibrium. In Newbery and Stiglitz (1984), farmers and consumers are separately defined, in a partial equilibrium. Farmers look only at their income level, which corresponds to (7) in our model. Since consumers are intrinsically risk-averse, their payoffs are represented by a concave utility function (*i.e.*, risk-averse CRRA utility function). Therefore, Newbery and Stiglitz consider risk-neutral farmers and risk-averse consumers. Hallstrom (2004) focuses only on risk-neutral farmers to study the value of forecasting.

III Numerical Simulations

A Parameters

We compute the model with parameter values shown in Table 1. These parameters are chosen to create symmetry in production and consumption. In particular, the expenditure share of the agricultural good (ρ=0.5) is equal to the expenditure share of the manufacturing good (1− ρ= 0.5); and the input coefficient of the agricultural good ($\beta_A \equiv \alpha_A^{-1} \equiv 1$) is equal to the input coefficient of the manufacturing good ($\beta_M \equiv \alpha_M^{-1} \equiv 1$) . In addition, the probability of good weather in West (and the probability of bad weather in East) is given by 50% and the coefficients of good weather and bad weather are given by 0.5 (−50% from the expected value) and 1.5 (+50% from the expected value), respectively. In this case, the expected value of marginal product of A is $\alpha_A \equiv 1$ and then the marginal products of A and M become symmetric when labor allocations are determined.

Table 1. Parameters for the simulation

Expenditure share of A	0.5
Input coefficient of A	1
Input coefficient of M	1
Probability of good weather	0.5
Coefficient of bad weather	0.5
Coefficient of good weather	1.5

B Autarky

"Autarky" in our model means that there is no inter-regional trade. Later on when we consider interregional trade, it provides the prohibitive transaction cost $\bar{\tau}$ and values in the autarky equilibrium (*e.g.*, prices, welfare levels, and so on) when $\tau > \bar{\tau}$. To compute the autarky equilibrium, we apply Remark 2 to obtain the labor allocation ℓ_A^* before weather conditions occur. We then use ℓ_A^* to compute the autarky *ex post* equilibrium prices under good and bad weather conditions, which provide welfare levels of workers in each sector under each weather condition. The result is reported in Table 2.

From this result, we can confirm that the labor shares of agricultural and manufacturing sectors are 50% each since the two sectors are indifferent in expected income levels in autarky. In addition, it is noteworthy that the welfare levels of the two sectors are identical under respective weather conditions. This result confirms that our model leads to an analogous result to that shown by Newbery and Stiglitz (1984): risks are covered by price adjustments when there is no interregional trade.

Table 2. Key values in the autarky equilibrium

Relative price in bad weather	0.6667
Relative price in good weather	2.0000
Population of farmers (sector A workers)	0.5000
Welfare of sector A worker in bad weather	*0.3536*
Welfare of sector A worker in good weather	*0.6124*
Welfare of sector M worker in bad weather	*0.3536*
Welfare of sector M worker in good weather	*0.6124*

C Interregional Trade

We know that the *ex ante* and *ex post* market clearing conditions coincide with each other (Remark 1). To obtain equilibrium values, we initially solve (8) and (15) for each i and j with $\ell^*_{AE} \equiv \ell^*_{AW} \equiv \ell^*_A(\tau)$ for $\tau \in [0,1]$. We then compare the obtained *ex post* relative price with the *ex post* relative price in the autarky equilibrium to determine the prohibitive transaction cost $\bar{\tau}$ (*cf.*, Remark 3).

Comparing the autarky and interregional trade equilibrium prices, the prohibitive transaction cost is computed as $\bar{\tau} \simeq 0.4006$; hence, the autarky equilibrium is realized for $\tau \geq \bar{\tau}$. The relative prices in East and West for each transaction cost, $\pi_E(\tau)$ and $\pi_W(\tau)$, are shown in Figure 2 (left) and $\ell^*_A(\tau) \equiv 1 - \ell^*_M(\tau)$ in Figure 2 (right). According to this result, the realized relative price decreases with transaction cost in the bad weather region while it increases in the good weather region. Here, we can confirm that the relative price of the two regions coincide with each other when there is no transaction cost (*i.e.*, free trade). In addition, we can also see that the population of farmers falls when trade becomes open and continues declining until it reaches a certain transaction cost $\tau^* \simeq 0.2433$. It starts rising as transaction cost declines further than τ^*. When there is no transaction cost, the population of farmers reverts to the autarky level.

Movements of relative prices are quite natural in trade theory and those under free trade are consistent with Newbery and Stiglitz's result. To understand the movement of ℓ^*_A, one needs to see the movement of the wage rate of farmers ω_A as shown in Figure 3, where the right chart represents first order derivatives of the curves in the left chart. In this figure, the population of farmers is normalized to be unity under autarky. Without loss of generality, assuming that region k has good weather, $\omega_A \equiv \mathrm{E}[w_{Aj} / p_{Mk}]$ is defined to be the real wage rate vis-á-vis M, as M in the good weather region is considered as *de facto* numéraire in this model. This figure shows that population of farmers is positively correlated with the expected income (wage) level of farmers for the most part. However, the critical point of population and expected wage of farmers do not coincide with each other. This result stems from the condition for labor allocations (15) that equates expected utility levels. By such a specification, we are looking at risk-averse agents. There are risks in production of A that affect the wage level of farmers. The difference in the critical points is thus explained by the risk-averse preference: as Figure 3 (right) shows, an increase in ω_A does not immediately induce an increase in ℓ_A^* until ω_A reaches a sufficient level to compensate for the risks in production.

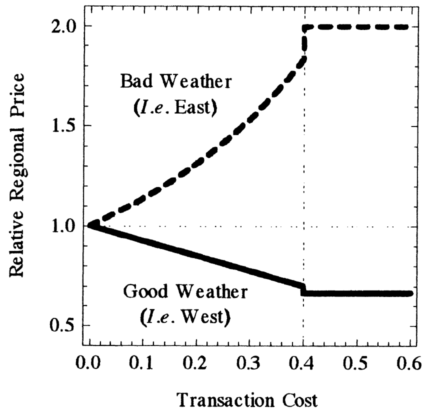
From π_j (τ) and ℓ_A^* (τ), the realized welfare levels of the respective sectors in the two regions are computed as shown in Figure 4. As shown, the welfare level of sector A increases with τ in good weather while it decreases with τ in bad weather. This implies that the risk in the agricultural sector increases as transaction cost declines. In contrast, the welfare level of sector M decreases with τ in good weather while it increases with τ in bad weather to reduce the risk from fluctuations of commodity prices, and finally the risk of sector M workers is eliminated under free trade. In order to see the further relationship between ℓ_A^* and welfare levels, we consider the expected welfare level.

Table 3 shows welfare levels in good and bad weather conditions and expected welfare levels for some τ. As this table shows, the expected welfare levels of the agricultural and manufacturing sectors are equal to each other. This result is consistent with the labor market clearing condition given by equating expected utility levels, as in (15). The expected welfare level for all τ is depicted in Figure 5. From Figure 4, we have learned that the risk of workers in the agricultural sector increases as τ declines. An increase in the risk is thus compensated by an increase in the expected welfare when the population of farmers increases. When the population of farmers goes down, the compensation is insufficient.

It should be noted that Pareto inferior trade as shown in Newbery and Stiglitz (1984) cannot be confirmed if we focus on the expected welfare level (*e.g.*, the average social welfare level in the long run). However, if we focus separately on the welfare level and the income level, we do find a similar result to Newbery and Stiglitz. Under interregional trade, consumers are unambiguously better-off in their result and expected welfare is unambiguously improved in our model. By interregional trade, risky crop planters are unambiguously worse-off in their result and the expected income level decreases with τ if compensations are insufficient between the critical value and $\bar{\tau}$ in our model, as depicted in Figure 3.[2] In other words, it is due to the critical difference of our general equilibrium framework from the partial equilibrium framework of Newbery and Stiglitz that free trade

2 If we consider Pareto inferiority in comparison with autarky, we can say that Pareto inferior trade is observed if there is transaction cost (*cf.*, free trade and autarky are indifferent).

Figure 2. Regional prices and population of farmers for each transportation cost



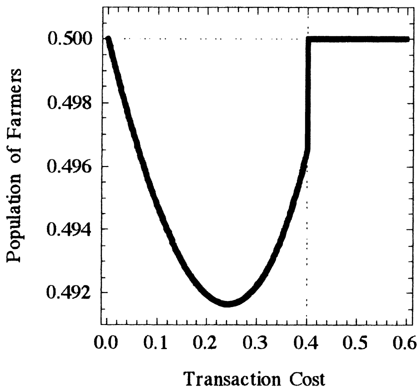
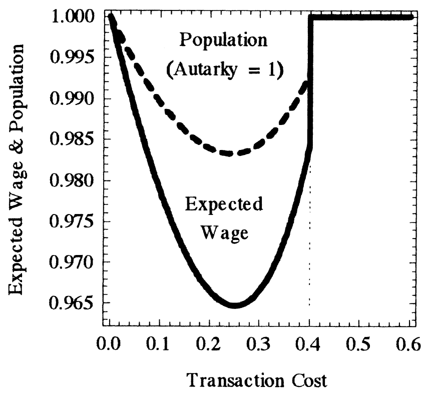


Figure 3. Expected wage and population of farmers



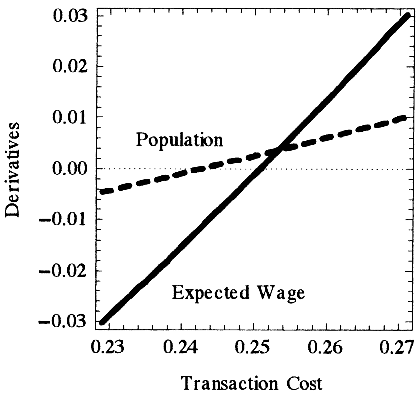


Figure 4. Welfare levels

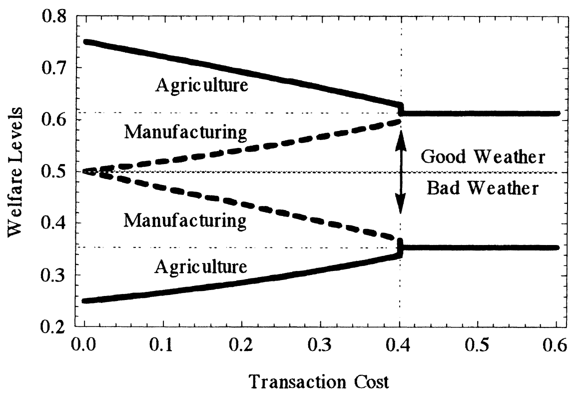
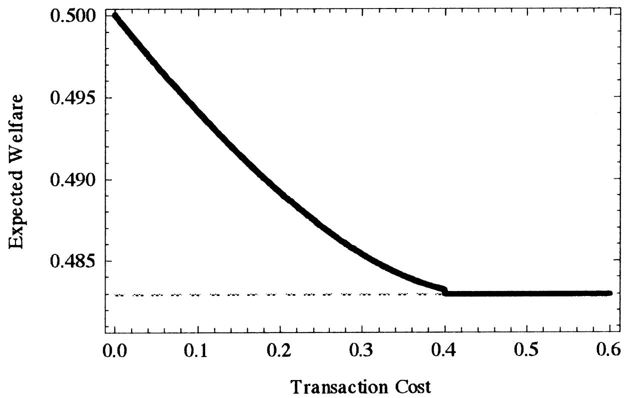


Table 3. Welfare levels

	Agriculture			Manufacturing		
Weather	Good	Bad	*Expected*	Good	Bad	*Expected*
$\tau > \bar{\tau}$	0.6124	0.3536	*0.4830*	0.6124	0.3536	*0.4830*
$\tau = 0.4$	0.6278	0.3386	*0.4832*	0.5973	0.3691	*0.4832*
$\tau = 0.3$	0.6608	0.3100	*0.4854*	0.5675	0.4032	*0.4854*
$\tau = 0.2$	0.6918	0.2865	*0.4892*	0.5421	0.4363	*0.4892*
$\tau = 0.1$	0.7214	0.2668	*0.4941*	0.5198	0.4685	*0.4941*
$\tau = 0$	0.7500	0.2500	*0.5000*	0.5000	0.5000	*0.5000*

Figure 5. Expected welfare



unambiguously improves "payoffs" in our model while free trade may lead to Pareto inferior trade in Newbery and Stiglitz's. In addition, to study a possibility of Pareto inferior trade in a general equilibrium framework, the existence of transaction cost will be one of the key factors in theoretical modeling.

IV Inferences and Conclusions

We have studied an extension of Newbery and Stiglitz (1984) under symmetry. In our general equilibrium framework, by focusing on the income of farmers, Pareto inferior trade is observed when transaction cost is postulated; otherwise, we cannot observe Pareto inferior trade. Based on the expected welfare level, Pareto inferior trade is not observed. However, Newbery and Stiglitz also suggest that consumers are made unambiguously better off by trade. Thus, to some extent, our result does not contradicts to theirs.

In addition to Pareto inferiority, we could discuss transfer of risk as transaction cost declines. The risky sector (agriculture) experiences an increase in price variation while the non-risky sector (manufacturing) experiences a decrease in price variation. The risk in the non-risky sector ultimately vanishes under free trade. Accuracy of forecasting can be considered as a reduction of transaction cost. In this sense, Hallstrom's (2004) and our result are comparable. In Hallstrom (*op. cit.*), an increase in the accuracy of forecasting increases price variations, as our result also suggests. In his model, the income level unambiguously improves. However, our model suggests the expected income level of farmers shows an inverse hump-shaped curve and this in turn produces an inverse hump-shaped curve for the population of farmers.

Trade and environmental issues are possible further applications of this model. Decades have passed since environmental problems were first recognized as an important concern, but the problems have not yet been resolved, and indeed are getting more serious. Environmental changes affect trade patterns, since they affect agriculture sectors (*i.e.*, Tol, 2009, and Moon, 2011). For instance, international and interregional trades are affected by agricultural protectionism, agricultural sustainability, food insecurity in the least developed countries, climate change, greenhouse gas emissions, and so on: for example, global environmental change on agricultural products is explored by Reilly and Hohmann (1993), while the importance of forecasting under uncertain weather is studied by Hallstrom (*op. cit.*). Furthermore, transaction cost is improved by improvements in fuel economy (technological progress, decline in fuel prices, etc.). If a country imports resources, it can reduce energy costs by developing low-cost energy resources, subsidizing cost-cutting technologies, exchange rate policies, and so on. The directions of such extensions are also shown in Nordhaus and Yang (1996). In their study, strategies against climate change in diff erent countries are discussed.

Appendix 1 Proof of Remark 1

Let Ω^G and $\Omega^B < \Omega^G$ be coefficients of good and bad weather conditions, respectively. Let γ_j be probability of good weather in region j. The expected aggregate production of A is

$$\gamma_E\left(\alpha_A\Omega^G\ell_{AE}+\alpha_A\Omega^B\ell_{AW}\right)+\gamma_W\left(\alpha_A\Omega^B\ell_{AE}+\alpha_A\Omega^G\ell_{AW}\right), \tag{16}$$

where $\gamma_W \equiv 1-\gamma_E$ as weather is perfectly negatively correlated. Let $\gamma_W=\gamma$ to rewrite the above equation to get

$$\begin{aligned} &(1-\gamma)\left(\alpha_A\Omega^G\ell_{AE}+\alpha_A\Omega^B\ell_{AW}\right)+\gamma\left(\alpha_A\Omega^B\ell_{AE}+\alpha_A\Omega^G\ell_{AW}\right)\\ =\;&\left(\alpha_A\Omega^G\ell_{AE}+\alpha_A\Omega^B\ell_{AW}\right)+\gamma(\ell_{AE}-\ell_{AW})\left(\alpha_A\Omega^B+\alpha_A\Omega^G\right). \end{aligned} \tag{17}$$

In the symmetric equilibrium, $\ell_{AE} = \ell_{AW}$ is held,[3] so that the second term of (17) vanishes and it becomes

$$\left(\Omega^{G}+\Omega^{B}\right)\alpha_{A}\ell_{A}^{*}, \tag{18}$$

where $\ell_{i}^{*} \equiv \ell_{ij}$ is the equilibrium labor allocations to sector i. We can then easily find that (18) is the same as the *ex post* value of production of the agricultural good.

Next, we consider the expected value of aggregate demand:

$$\begin{aligned}&\gamma_{E}\left\{\left(\rho\alpha_{A}\Omega^{G}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi_{E}^{E}}\right)+\left(\rho\alpha_{A}\Omega^{B}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi_{W}^{E}}\right)\right\}\\&+\gamma_{W}\left\{\left(\rho\alpha_{A}\Omega^{B}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi_{E}^{W}}\right)+\left(\rho\alpha_{A}\Omega^{G}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi_{W}^{W}}\right)\right\},\end{aligned} \tag{19}$$

where π_{j}^{k} is the relative regional price in region j when region k has a good weather. By symmetry, we then find $\pi_{E}^{E} \equiv \pi_{W}^{W}$ and $\pi_{E}^{W} \equiv \pi_{W}^{E}$. Let $\pi_{j}^{j} = \pi$ and $\pi_{j}^{k} = \pi'$ for $j \neq k$ to arrange (19) as

$$\begin{aligned}&(1-\gamma)\left\{\left(\rho\alpha_{A}\Omega^{G}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi}\right)+\left(\rho\alpha_{A}\Omega^{B}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi'}\right)\right\}\\&+\gamma\left\{\left(\rho\alpha_{A}\Omega^{B}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi'}\right)+\left(\rho\alpha_{A}\Omega^{G}\ell_{A}^{*}+\frac{\rho\alpha_{M}\ell_{M}^{*}}{\pi}\right)\right\}\\=\;&\left(\Omega^{G}+\Omega^{B}\right)\rho\alpha_{A}\ell_{A}^{*}+\rho\alpha_{M}\ell_{M}^{*}\left(\frac{1}{\pi}+\frac{1}{\pi'}\right).\end{aligned} \tag{20}$$

This equation is the same as the *ex post* aggregate demand, as the first term is the demand for the agricultural good in the good weather region and the second term is that in the bad weather region. Therefore, the *ex ante* market clearing condition assumes the same form as the *ex post* market clearing condition:

$$\left(\Omega^{G}+\Omega^{B}\right)\times\alpha_{A}\ell_{A}^{*}=\left(\Omega^{G}+\Omega^{B}\right)\rho\alpha_{A}\ell_{A}^{*}+\rho\alpha_{M}\ell_{M}^{*}\left(\frac{1}{\pi}+\frac{1}{\pi'}\right). \tag{21}$$

Appendix 2 Proof of Remark 2

The expected supply of A in region j is computed as

$$\gamma_{j}\alpha_{A}\Omega^{G}\ell_{Aj}+(1-\gamma_{j})\alpha_{A}\Omega^{B}\ell_{Aj}. \tag{22}$$

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3 It must also have $\gamma_{E} \equiv \gamma_{W} \equiv 0.5$.

Since the model is symmetric, we apply $\gamma_j \equiv 0.5$ to get the expected production for the autarky equilibrium:

$$\frac{\left(\Omega^G+\Omega^B\right)\alpha_A\ell_A^*}{2}. \tag{23}$$

The expected demand is computed as

$$\gamma_j\left(\rho\alpha_A\Omega^G\ell_A^*+\frac{\rho\alpha_M\ell_M^*}{\pi}\right)+(1-\gamma_j)\left(\rho\alpha_A\Omega^B\ell_A^*+\frac{\rho\alpha_M\ell_M^*}{\pi'}\right). \tag{24}$$

Similarly, we apply $\gamma_j \equiv 0.5$ to get

$$\frac{\left(\Omega^G+\Omega^B\right)\rho\alpha_A\ell_A^*+\rho\alpha_M\ell_M^*\left(1/\pi+1/\pi'\right)}{2}. \tag{25}$$

From (23) and (25), the market clearing condition for the *ex ante* autarky equilibrium is given by

$$\frac{\left(\Omega^G+\Omega^B\right)\alpha_A\ell_A^*}{2}=\frac{\left(\Omega^G+\Omega^B\right)\rho\alpha_A\ell_A^*+\rho\alpha_M\ell_M^*\left(1/\pi+1/\pi'\right)}{2}. \tag{26}$$

We then easily find that 1=2 in both sides of the market clearing condition for the *ex ante* autarky equilibrium (26) cancels out to leave this condition identical to that for the interregional trade equilibrium (21).

Appendix 3 Proof of Remark 3

We consider the case in which West has a good weather. From (10), we find

$$\bar{p}_{AW}\le p_{AE}\le\bar{p}_{AE} \quad \text{and} \quad \frac{1}{\bar{p}_{MW}}\le\frac{1}{p_{MW}}\le\frac{1}{\bar{p}_{ME}}, \tag{27}$$

which implies

$$\frac{\bar{p}_{AW}}{\bar{p}_{MW}}\le\frac{p_{AE}}{p_{MW}}=\frac{p_{AW}+T}{p_{MW}}\le\frac{\bar{p}_{AE}}{\bar{p}_{ME}}. \tag{28}$$

Therefore, the condition for interregional trade is written as $\overline{\pi}_W \le \pi_W + \tau \le \overline{\pi}_E$ (by symmetry, the condition for interregional trade is $\overline{\pi}_E \le \pi_E + \tau' \le \overline{\pi}_W$ if East has good weather).

References

Hallstrom, Daniel G. (2004). Interannual Climate Variation, Climate Prediction, and Agricultural Trade: The Cost of Surprise versus Variability, *Review of International Economics*, 12(3), 441-55.

Moon, Wanki (2011). Is Agriculture Compatible with Free Trade?, *Ecological Economics* 71(C), 13-24.

Newbery, David M. G.; Stiglitz, Joseph E. (1984) Pareto Inferior Trade, *Review of Economic Studies*, 51 (1), 1-12.

Nordhaus, William D.; Yang, Zili (1996). A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies, *American Economic Review*, 86(4), 741-65.

Reilly, John; Hohmann, Neil (1993). Climate Change and Agriculture: The Role of International Trade, *American Economic Review — Papers and Proceedings*, 83(2), 306-12.

Tol, Richard S. J. (2009). The Economic Effects of Climate Change, *Journal of Economic Perspectives*, 23 (2), 29-51.

Turnovsky, Stephen J. (1974) Technological and Price Uncertainty in a Ricardian Model of International Trade, *Review of Economic Studies*, 41(2), 201-17.Daniel G. Hallstrom (2004). Interannual Climate Variation, Climate Prediction, and Agricultural Trade: the Cost of Surprise versus Variability, *Review of International Economics*, 12(3), 441-55.