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Beyond Ricardian Model: An Optimal Commodity Distribution Based on Absolute Advantage for Multi-Country Multi-Commodity

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Abstract

Ricardo's comparative advantage model asserts that international trade will make every single participant country better off if they traded goods in which they have comparative advantage. Tian (2008) has generalized and expanded this Ricardo's 2-country, 2-commodity comparative advantage into a multi-country, multi-commodity model. His methodology, however, occasionally fails to achieve optimal commodity distribution or to facilitate international trade even if it succeeds in optimal distribution, for it results in a high degree of difference in countries' commodity prices. This paper proposes an algorithm that selects countries' comparatively advantageous goods for multi-country, multi-commodity model based on their absolute advantage. The proposed algorithm simply selects a commodity with the maximum absolute advantage - the minimum price - from each country and reassigns commodities of over-assigned countries to under-assigned countries. This absolute advantage model (AAA) is found to be much simpler than Tian's comparative advantage method and to yield superior results.

Keywords: comparative advantage, absolute advantage, sum price rate, average price rate, multi-country multi-commodity

1. Introduction

In international trade involving two nations, although one country possesses absolute advantage in all goods (i.e., has higher efficiency in the production of all goods), both participant countries could still gain by trading with each other, so long as they have different relative efficiencies (O'Sullivan and Sheffrin, 2003; Baumol, 2009). This concept is called the law of comparative advantage, and it refers to the ability of a party to produce a particular good or service at a lower opportunity cost than another.

Comparative advantage was first developed by David Ricardo (1817) who explained it in his book *On the Principles of Political Economy and Taxation* to explain a possible trade pattern between two countries (England and Portugal) involving two commodities (cloth and wine). This optimal commodity distribution model, dating back almost 200 years, has been bound to a 2-country, 2-commodity matrix. This triggered several researches that have attempted to expand Ricardo's 2-country, 2-commodity comparative advantage model into a multi-country, multi-commodity model: namely Tian's model (Tian, 2008) and Graham's theory (Parchure, 2011). Tian's model (Tian, 2008) is based on the commodity price, and Graham's theory (Parchure, 2011) on a number of variables such as labor cost, wage rate, and exchange rate. This paper only considers the commodity price as Tian's model does. Tian's model repeatedly computes average price rates (apr) and selects the maximum comparative advantage - the smallest average price rate. This model, however, occasionally fails to obtain the optimal value or to facilitate international trade even if it succeeds in optimal distribution, for the difference in countries' commodity prices is large. Additionally, in the existence of multiple commodities with equal maximum comparative advantage, it yields different outcomes depending on which commodity it selects.

To remedy the shortcomings of Tian's apr-CA model, this paper proposes an algorithm that selects a commodity with the maximum absolute advantage - the lowest price - for each country and reassigns commodities of over-assigned countries to under-assigned countries. In chapter 2, we review Tian's apr-CA model for optimal commodity distribution in a multi-country, multi-commodity setting and discuss its limitations. In chapter 3, we propose an optimal commodity distribution algorithm based on absolute advantage (AA), which we name the Absolute Advantage Algorithm (AAA). In chapter 4, we compare the performances of Tian's apr-CA model with those of AAA on various commodity distribution cases.

2. Related Studies and Problems of an M-Country and N-Commodity Model

Although the Ricardian model's comparative advantage concept has been formulated for and confined to a 2-country, 2-commodity case, it could easily be extended to a 2-country, multi-commodity case or a multi-country, 2-commodity case (Deardorff, 2005). However, it is not as easy to generalize and expand the model to a pure multi-country, multi-commodity case. Tian's model has nevertheless attempted to generalize this 2-country, 2-commodity comparative advantage model into a multi-country, multi-commodity model. (Tian, 2008) For a better understanding of this model, let's examine how Tian has generalized Ricardo's comparative advantage and expanded it into the multi-country multi-commodity model.

Let *m*-Country, $i = 1,2,\cdots,m$ and *n*-Commodity, $j = 1,2,\cdots,n$.

In generalizing Ricardo's comparative advantage, one may derive the equation for sum price rate $r_{s(i,j)}$ for i^{th}-country, j^{th}-commodity as shown in equation (1).

$$\text{Sum price rate: } r_{s(i,j)} = \frac{P_{(i,j)}}{(\sum_{i=1}^{m} P_{(i,j)} - P_{(i,j)})} \quad (1)$$

$$\text{where } \sum_{i=1}^{m} P_{(i,j)} - P_{(i,j)}) \text{ for } |i| \geq 2$$

$$P_{(i,j)} \text{for} |i| = 1$$

Tian (2008) on the other hand proposed an average price rate model for a multi-country and multi-commodity case based on Ricardo's comparative advantage model as shown in equation (2).

$$\text{Average price rate: } r_{a(i,j)} = \frac{P_{(i,j)}}{(\sum_{i=1}^{m} P_{(i,j)} - P_{(i,j)})/(n-1)} \quad (2)$$

Tian (2008) computes and takes into the consideration the average price of identical commodities of all other countries instead of their sum price in calculating the price rate of a commodity produced by a country, and selects the optimal commodity as Ricardian model does in the comparative advantage model. Tian thus transforms an $n \times n$ matrix of nominal prices into an $n \times n$ matrix of average price rates.

Subsequently, Tian selects the minimum average price rate from the $n \times n$ matrix of average price rates and obtains a new $(n-1) \times (n-1)$ matrix of prices, derived from deleting the column and the row of the selected commodity possessing the minimum average price rate. This is then converted into an$(n-1) \times (n-1)$ matrix of average price rates and the minimum average price rate is selected once again. This process is repeated until it transforms the original matrix into a 1×1 price set, leaving all *n* countries allocated with a single commodity to specialize in.

Tian's apr-CA model of commodity distribution, however, has several drawbacks as follows:

(1) apr-CA model executes $n^3 + (n-1)^3 + (n-2)^3 + \cdots + 2^3 = \left(\frac{n(n+1)}{2}\right)^2 - 1$ times the computation of the average price rates; $n^2 + (n-1)^2 + (n-2)^2 + \cdots + 2^2 + 1 = \frac{n(n+1)(2n+1)}{6}$ times the selection of the minimum average price rates; and $2(n + (n-1) + \cdots + 2 + 1) = n(n+1)$ times the deletion of each row and column, making it a highly complicated process. As the values of m and n increase, so would the complexity by multifold.

(2) apr-CA model is a 'Greedy Algorithm', i.e., it selects a good with the maximum comparative advantage at that specific point in time with no regard whatsoever to the price rates of the rest of the commodities. This type of method could yield one of the following three results:

- A case where countries are left with extreme values although the sum price of the selected commodities turns out optimal provided that the difference between the minimum cost and the maximum cost is large. Put another way, some countries will be left specializing in commodities in which they have the best price competitiveness and others in commodities in which they have the worst price competitiveness, driving the latter countries out of the competition in the arena of international trade. Let's term this an 'unsatisfyingly accepted case' (or interchangeably a 'nominal case');

- A case where the sum price of the selected commodities is optimal and the difference between the minimum cost and the maximum cost is minimal such that international trade could be proliferated. Let's term this a 'satisfyingly accepted case' (or interchangeably the 'best case'); or
- A case where the sum price of the selected commodities fails to be optimal. Let's call this a 'rejected case' (or interchangeably the 'worst case'). In the presence of multiple commodities with equal maximum comparative advantage, Tian's model could yield highly different results depending on a commodity it selects

(3) apr-CA model could only be applied when $m = n$, not when $m \neq n\ (m < n)$. Let's term $m = n$ as a 'balanced distribution' and $m \neq n\ (m < n)$ an 'unbalanced distribution'.

In the following chapter, we propose an alternate algorithm based on absolute advantage for *m*-country, *n*-commodity where $m = n$ and alsowhere$m \neq n\ (m < n)$.

3. Absolute Advantage Model for Multi-Country and Multi-Commodity

In this chapter, we propose a simple algorithm that could be universally applied to any given multi-country, multi-commodity model, be it a balanced distribution, where $m = n$ or an unbalanced distribution, where $m \neq n\ (m < n)$. Whereas Tian'sapr-CA model is based on comparative advantage (average price rates), the proposed algorithm is solely based on absolute advantage - relying on nominal prices. We name this algorithm an absolute advantage algorithm (AAA).

Amongst rows in this algorithm, we make set A_o stand for an over-assigned set, set A_u for an under-assigned set, and set A_n for a normally-assigned set.

Step 1. Select the minimum price, $\min P_{(i,j)}$ from each column ($j = 1,2,\cdots,n$).

Step 2. Identify A_o, A_u, and A_n for each row ($i = 1,2,\cdots,m$)

Step 3. If $|A_n| = m$, where $|A_n|$ is the cardinality of A_n, the optimal value is obtained and thus the algorithm comes to an end.

If, however, $|A_u| > 0$ and $|A_o| > 0$, an excess commodity must be shifted from A_o to A_u. In this case, there are two options. One is a direct moving path where a commodity is moved directly from $A_o$to A_u. The other is an indirect moving path where an excess commodity of A_o is shifted to A_n, and again a commodity belonging to A_n, which is pricier than that of A_o by the smallest margin, is moved from A_n to A_u. Here, we employ whichever method that entails the minimum price increase. If both methods result in an equal price increase, we move first the commodity with the minimum price from A_o and leave the commodity with the maximum price fixed. This process is repeated until $|A_u| = 0$. In cases where $m \leq kn$, we leave as many commodities as k for each country and reassign excessively assigned commodities.

This would allow this algorithm to be applied in all cases whether $m = n$or $m \neq n\ (m < n)$.

The proposed AAA executes $n \times n = n^2$ times the selection of the minimum prices and at most $n \times n = n^2$ times the rearrangement of commodities from over-assigned countries to under-assigned countries, hence $2n^2$ times for the total process. This algorithm could therefore simplify the optimal commodity distribution process of Tian's $\left(\frac{n(n+1)}{2}\right)^2 + \frac{n(n+1)(2n+1)}{6} + n(n+1) - 1$ times into $2n^2$ times. Additionally, despite its relative simplicity, it yields superior results in optimal commodity distribution.

Numerous past researches on optimal commodity distribution have only adopted the concept of comparative advantage. This paper proposes the first algorithm based on absolute advantage and simultaneously succeeds in bringing about better results than do existing algorithms, which have applied the concept of comparative advantage.

4. Experimental Study and Result Analysis

Table 1 demonstrates test results of apr-CA model and AAA on the case data among which BD_1 and UBD_1 have been directly quoted from Tian (Tian, 2008). As shown in the 'Case of Result' columns, whereas AAA has achieved 'Accepted' for all the case data, apr-CA model has obtained 'Rejected' for BD_2, BD_4, BD_7 and UBD_4, and 'Nominal' for BD_5, BD_6 and UBD_2. Moreover, apr-CA model faced selection dilemma in BD_2 and BD_3 in the presence of commodities with equal maximum comparative advantage and demonstrated different results each time a different commodity had been chosen. AAA nevertheless has successfully rectified the flaws of Tian's apr-CA model. Cells containing bolded numbers show cases where the AAA has obtained superior optimal value (the sum price of the selected commodities) and/ or price difference (the spread between the maximum and minimum prices of the selected commodities). Detailed processes of commodity distribution of the experimental data and computational results are shown in <Table 2> through <Table 12>. Bolded values in these tables stand for values selected.

Table 1. Comparison of apr-CA model and AAA

Problem	*m**n*	No. of Specialized Commodity	Tian's apr-CA model			AAA		
			Optimal Value	Difference of Prices	Case of Result	Optimal Value	Difference of Prices	Case of Result
BD_1	3*3	3	14	4	Accept	14	4	Accept
BD_2	4*4	4	30	15	Reject	20	2	Accept
BD_3	4*4	4	4	0	Accept	4	0	Accept
BD_4	4*4	4	19	7	Reject	16	4	Accept
BD_5	4*4	4	16	6	Nominal	16	0	Accept
BD_6	6*6	6	49	7	Nominal	49	6	Accept
BD_7	12*12	12	275	61	Reject	181	35	Accept
UBD_1	2*3	2	7	1	Accept	7	1	Accept
		3	11	1	Accept	11	1	Accept
UBD_2	3*4	3	9	4	Nominal	9	0	Accept
		4	13	4	Nominal	13	1	Accept
UBD_3	4*5	4	54	12	Accept	54	12	Accept
		5	63	12	Accept	63	12	Accept
UBD_4	10*13	10	182	10	Reject	178	8	Accept
		13	239	10	Reject	235	7	Accept

Table 2. Optimal commodity distribution for BD_1

Tian's apr-CA model

Price		Commodity		
		a	*b*	*c*
Country	*A*	4	7	9
	B	2	3	4
	C	3	7	10

3*3	Rate	*a*	*b*	*c*	Minimum
	A	0.4000	0.3500	0.3214	
	B	0.1429	0.1071	0.1053	0.1053
	C	0.2500	0.3500	0.3846	

AAA

Price		*Commodity*			
		a	*b*	*c*	
Country	*A*	*4*	*7*	*9*	Au
	B	*2*	*3*	*4*	Ao
	C	*3*	*7*	*10*	An
		2->3:+1	3->7:+4	4->9:+5	

Price		Commodity	
		a	*b*
Country	*A*	4	7
	C	3	7

2*2	Rate	*a*	*b*
	A	1.3333	1.0000
	C	0.7500	1.0000

Minimum

0.7500

Price		Commodity
		b
Country	*A*	7

1*1	Price	*b*
	A	7.0000

Minimum

7.0000

Optimal Distribution

Price		Commodity		
		a	*b*	*c*
Country	*A*	4	7	9
	B	2	3	4
	C	3	7	10

Optimal value, z=7+4+3=14

Max - Min = 7-3=4

Price		Commodity		
		a	*b*	*c*
Country	*A*	4	7	9
	B	2	3	4
	C	3	7	10

Optimal Distribution

Price		Commodity		
		a	*b*	*c*
Country	*A*	4	7	9
	B	2	3	4
	C	3	7	10

Optimal value, z=7+4+3=14

Max - Min = 7-3=4

Table 3. Optimal commodity distribution for BD_2

Tian's apr-CA model

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	4	6	8
	C	3	6	9	12
	D	4	8	12	16

Optimal value, z=1+4+9+16=30

Max-Min = 16-1=15

AAA

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	4	6	8
	C	3	6	9	12
	D	4	8	12	16

Optimal value, z=4+6+6+4=20

Max-Min = 6-4=2

Table 4. Optimal commodity distribution for BD_3

Tian's apr-CA model

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	4	3	2
	B	2	1	4	3
	C	3	2	1	4
	D	4	3	2	1

Optimal value, z=1+1+1+1=4

Max-Min=1-1=0

AAA

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	4	3	2
	B	2	1	4	3
	C	3	2	1	4
	D	4	3	2	1

Optimal value, z=1+1+1+1=4

Max-Min=1-1=0

Table 5. Optimal commodity distribution for BD_4

Tian's apr-CA model

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	6	12	8
	C	3	4	9	16
	D	4	8	6	12

Optimal value, z=1+8+4+6=19

Max-Min=8-1=7

AAA

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	6	12	8
	C	3	4	9	16
	D	4	8	6	12

Optimal value, z=4+2+4+6=16

Max-Min=6-2=4

Table 6. Optimal commodity distribution for BD_5

Tian's apr-CA model

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	3	4	5
	C	3	4	5	6
	D	4	5	6	7

Optimal value, z=1+3+5+7=16

Max-Min=7-1=6

AAA

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	3	4	5
	C	3	4	5	6
	D	4	5	6	7

Optimal value, z=4+4+4+4=16

Max-Min=4-4=0

Table 7. Optimal commodity distribution for BD_6

Tian's apr-CA model

Price		Commodity					
		a	*b*	*c*	*d*	*e*	*f*
Country	*A*	10	9	8	12	9	7
	B	12	10	7	13	9	8
	C	8	8	8	14	9	9
	D	10	7	8	14	8	9
	E	8	8	8	15	8	9
	F	12	9	6	14	10	8

Optimal value, z=7+13+8+7+8+6=49

Max-Min=13-6=7

AAA

Price		Commodity					
		a	*b*	*c*	*d*	*e*	*f*
Country	*A*	10	9	8	12	9	7
	B	12	10	7	13	9	8
	C	8	8	8	14	9	9
	D	10	7	8	14	8	9
	E	8	8	8	15	8	9
	F	12	9	6	14	10	8

Optimal value, z=12+8+8+7+8+6=49

Max-Min=12-6=6

Table 8. Optimal commodity distribution for BD_7

Tian's apr-CA model

Price		Commodity											
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*
Country	*A*	79	43	29	88	65	44	35	50	25	68	93	19
	B	24	59	52	83	90	79	51	12	17	45	36	36
	C	13	33	26	64	56	86	9	59	39	99	91	5
	D	53	95	27	72	62	93	91	23	1	1	30	50
	E	47	55	13	90	53	71	39	23	38	94	44	49
	F	66	97	33	67	91	7	32	64	63	44	69	94
	G	85	34	70	27	48	86	3	20	87	99	68	95
	H	17	55	11	47	23	59	12	94	14	59	67	17
	I	92	84	71	83	6	17	79	97	4	37	81	63
	J	47	94	86	62	89	56	25	14	18	18	62	41
	K	46	26	6	35	49	45	79	11	11	38	66	81
	L	13	56	76	38	33	59	81	97	45	74	37	1

Optimal value, z=43+12+13+1+44+7+3+14+6+62+6+1=275

Max-Min=62-1=61

AAA

Price		Commodity											
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*
Country	*A*	79	43	29	88	65	44	35	50	25	68	93	19
	B	24	59	52	83	90	79	51	12	17	45	36	36
	C	13	33	26	64	56	86	9	59	39	99	91	5
	D	53	95	27	72	62	93	91	23	1	1	30	50
	E	47	55	13	90	53	71	39	23	38	94	44	49
	F	66	97	33	67	91	7	32	64	63	44	69	94
	G	85	34	70	27	48	86	3	20	87	99	68	95
	H	17	55	11	47	23	59	12	94	14	59	67	17
	I	92	84	71	83	6	17	79	97	4	37	81	63
	J	47	94	86	62	89	56	25	14	18	18	62	41
	K	46	26	6	35	49	45	79	11	11	38	66	81
	L	13	56	76	38	33	59	81	97	45	74	37	1

Optimal value, z=25+36+13+1+13+7+27+12+6+14+26+1=181

Max-Min=36-1=35

Table 9. Optimal commodity distribution for UBD_1

Tian's apr-CA model

Price		Commodity		
		a	*b*	*c*
Country	*A*	4	7	9
	B	2	3	4

Optimal value, z=4+3+4=11

Max-Min=4-3=1

AAA

Price		Commodity		
		a	*b*	*c*
Country	*A*	4	7	9
	B	2	3	4

Optimal value, z=4+3=7

Max-Min=4-3=1

Table 10. Optimal commodity distribution for UBD_2

Tian's apr-CA model

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	3	4	5
	C	3	4	5	6

Optimal value, z=1+4+3+5=13

Max-Min=5-1=4

Proposed AAA

Price		Commodity			
		a	*b*	*c*	*d*
Country	*A*	1	2	3	4
	B	2	3	4	5
	C	3	4	5	6

Optimal value, z=3+3+3=9

Max-Min=3-3=0

Table 11.Optimal commodity distribution for UBD_3

Tian's apr-CA model

Price		Commodity				
		a	*b*	*c*	*d*	*e*
Country	*A*	9	7	9	10	10
	B	14	17	18	12	15
	C	19	20	21	18	21
	D	15	19	18	19	16

Optimal value, z=7+9+12+19+16=63

Max-Min=19-7=12

AAA

Price		Commodity				
		a	*b*	*c*	*d*	*e*
Country	*A*	9	7	9	10	10
	B	14	17	18	12	15
	C	19	20	21	18	21
	D	15	19	18	19	16

Optimal value, z=7+12+19+16=54

Max-Min=19-7=12

Table 12. Optimal commodity distribution for UBD_4

Tian's apr-CA algorithm

Price		Commodity												
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*
Country	*A*	34	14	22	17	17	26	30	28	19	30	29	15	27
	B	31	14	16	21	29	29	28	21	18	22	25	19	32
	C	20	22	21	24	22	37	37	30	19	29	35	19	27
	D	27	34	27	16	31	34	28	24	28	19	29	33	29
	E	24	26	35	31	18	37	29	35	28	30	27	22	29
	F	24	19	25	22	19	20	23	20	27	29	18	24	21
	G	18	22	30	20	26	21	19	24	26	29	30	25	19
	H	33	29	22	27	24	25	33	24	32	21	28	31	25
	I	35	22	23	26	25	27	30	32	23	20	19	33	20
	J	19	19	23	17	14	27	21	24	22	18	23	21	27

Optimal value, z=15+14+19+16+24+20+20+19+19+22+19+14+18=239

Max-Min=24-14=10

AAA

Price		Commodity												
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*
Country	*A*	34	14	22	17	17	26	30	28	19	30	29	15	27
	B	31	14	16	21	29	29	28	21	18	22	25	19	32
	C	20	22	21	24	22	37	37	30	19	29	35	19	27
	D	27	34	27	16	31	34	28	24	28	19	29	33	29
	E	24	26	35	31	18	37	29	35	28	30	27	22	29
	F	24	19	25	22	19	20	23	20	27	29	18	24	21
	G	18	22	30	20	26	21	19	24	26	29	30	25	19
	H	33	29	22	27	24	25	33	24	32	21	28	31	25
	I	35	22	23	26	25	27	30	32	23	20	19	33	20
	J	19	19	23	17	14	27	21	24	22	18	23	21	27

Optimal value, z=14+16+19+16+22+18+18+21+20+14=178

Max-Min=22-14=8

5. Concluding Remarks

In international trade, all participant countries can gain from specializing in the production of a good and trading it for another. Ricardo's comparative advantage model has provided a commodity distribution method for 2-country, 2-commodity case. Tian (2008) has generalized this model into a multi-country, multi-commodity model by taking average price rates in lieu of sum price rates. This algorithm nevertheless occasionally fails to achieve optimal commodity distribution or to facilitate international trade even if it succeeds in optimal distribution for the price difference – difference between the maximum price and the minimum price of the selected commodities – is large. Moreover, in the existence of multiple commodities with equal maximum comparative advantage, it yields different results depending on the commodity it selects. To remedy these shortcomings of Tian's model (Tian, 2008), this paper proposes a simple algorithm that selects a commodity for each country based on their absolute advantage (prices) instead of comparative advantage (price rates). Whereas Tian's model (Tian, 2008) repeatedly computes average price rates (apr) and selects the maximum comparative advantage (the smallest average price rate), the proposed algorithm simply selects a commodity with the maximum absolute advantage (minimum price) for each country and reassigns commodities of over-assigned countries to under-assigned countries. When applied to various balanced-distribution and unbalanced-distribution case data, the proposed AAA is found to yield results superior to those of Tian's apr-CA model through a much simpler process.

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