A Welfare Analysis of El Niño Forecasts in the International Trade of Fish Meal - An Application of Stochastic Spatial Equilibrium Model

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Abstract

This study identifies the potential marine environment and economic effects of El Niño on anchovy, herring and sardine fisheries in the eastern equatorial Pacific. By considering the uncertainly of El Niño, this study used a stochastic spatial equilibrium model to evaluate the social welfare gains of 1997/98 El Niño forecasts in the international trade of fish-meal.

Keywords: International Trade of Fish Meal, ENSO, Stochastic Spatial Equilibrium Model.
Classification code: C68, D58, F10, Q13

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Background and Motivation

El Niño is a disruption of the ocean-atmosphere system in the Tropical East Pacific Ocean having important consequences for weather and climate around the globe. The term El Niño is derived from the Spanish term for "the Christ Child" used by fishermen in Ecuador and Peru to refer to a warm ocean current that has been observed to appear immediately after Christmas about every 3-5 years. These anomalous occurrence last for several months in the Center East Pacific Ocean, resulting in a reduction of nutrients and a corresponding reduction in the fish population, route of migration and fishing area, which influences the living of fisherman. Therefore, the research and forecasts of climate have the momentous meaning for fisherman making decision in the fishing activity.

Strong El Niño phases in the Pacific Ocean, known as El Niño events, are characterized by changes in water temperature and a reduction in intensity of trade winds. These changes affect biological and climatological functions in the eastern equatorial Pacific and North America (Pearcy and Schoener, 1987; Barber and Chavez, 1983; Bertignac, Hampton, Lewis, and Picaut, 1997).

According to FAO fishery statistic database, the total fish landing is about 126,828 thousand metric ton in 1998 and the annual total fish landing had followed a steady increasing trend and the average yearly increment is about 2 million tons from 1950 to 1998. The major landing species is marine pelagic fishes group, which accounts for 28.10% of the total fish landing in 1998.

The landing of marine pelagic fishes in 1998 is about 7,084 thousand metric tons less than its 1997 landings since the strong El. Niño events in 1997/98. It is of interest to note that of the 7,084 thousand metric tons shortage, the shortage of 6,570 thousand metric tons is contributed by the marine pelagic fishes in Peru and Chile. Since almost 90% of Peru and Chile's marine pelagic fishes landing are made for fish meal and supply for the international markets (FAO, 1998), the international fish meal price and the production cost of aquaculture and livestock activities in major fishmeal importing countries were also influence by the El. Niño Phenomenon. The purpose of this study is try to evaluates the impacts of El Niño forecasts on social welfare of the international trade of fish-meal via a stochastic spatial equilibrium model.

Literature Reviews of the Impacts of El Niño on Fisheries

The greatest biological impact of El Niño is upon the fisheries in the coastal regions of the eastern Pacific. But the effects of El Niño have been observed on a wide variety of marine lives and even as far south as Antarctica, more than 6,000 km away. The decline in coastal upwelling causes a reduction in primary production, which in turn decreases the food available to the natural fish population. These combined with an increasing sea surface temperature during El Niño encourages fish located in coastal areas to migrate north and south in search of cooler waters and food. Migrating fish tend to find themselves in waters much too cold for them to survive and perished. However, the causes of this mortality are difficult to determine because the information available is preliminary and limited. The fish that do not leave the region move from the surface waters deeper into the water column, becoming inaccessible to predators, such as birds and to fishing trawlers using existing fishing gear. Fish unable to migrate die from lack of food or intolerable temperature elevations.

Another impact of El Niño on coastal fish populations is the increased rainfall along the South American coast. This results in an increase in turbidity and a decrease in salinity from an enhanced river discharge that brings with it large amounts of sediment and fresh water. The fish either leave their coastal habitat or die from unendurable water conditions.

It is often reported that the collapse of the Peruvian anchovy industry in the early 1970s was a direct result of the El Niño of 1972-73. Such as shown in Figure 1, the total landing of marine pelagic fishes in Peru and Chile from 1950 through 1998 was experience a dramatic reduction during 1972/73 and 1997/98 when the storng El. Niño phemonon occours. Comparing to the landing in 1997, the catch of pelagic fishery in Chile and Peru experienced a 59% and 57% reductions in 1998, respectively.

Under normal conditions, the western coast of South America is an upwelling zone, meaning that nutrients dissolved in deep water are being returned to the sea surface. As a result of the nutrient-rich water, many types of fish (and the zooplankton that they feed on) live in abundance along the coastline, making for an ideal fishing industry. For Peru and Chile, the sardine and anchovy fisheries are essential to the nations' economies because of a world market for fishmeal made from these types of fish. When El Niño occurred in 1972, it significantly disturbed the cycle of upwelling along the coast, changing the ecological systems of the region. Instead of temperate water rich in nutrients, a wave of nutrient poor, warm water moved toward the coast, creating an environment unable to support the existing marine life. Before the ENSO of 1972-73, major anchoveta concentrations existed at centers of upwelling along the Peruvian coast at 8^0S and 10^0-12^0S. Following the warm phases, however, the anchoveta centers were found south of 18^0S in Chilean waters, out of reach of the Peruvian fisheries (Cavides and Fik, 1992). For Peru, this meant a total collapse of the already strained fishing industry and a resulting long-term economic struggle.

The 1972-73 ENSO also disrupted the Chilean fisheries. However, the impact was quite different from that sustained by Peru. The anchoveta population along the coast of Chile encountered similar habitat difficulties to those in Peruvian waters, which means a reduction in the number of fish, decreased yields, and loss of revenue. However, Chilean fisheries were able to replace much of the lost anchoveta commerce with jack mackerel and sardines that were abundant in the nation's waters. Later in the decade, when a ban was placed on anchoveta fishing in order to allow the species to recover, the jack mackerel landings increased and became a valuable asset to the Chilean economy. Sardine fisheries also became a significant part of the industry. By 1988, sardines became the most fished species, accounting for 48% of the total fish landings. The ENSO had assisted in the conversion of the Chilean fisheries from a dependence on anchoveta (80%-95% of total fish) to a prominent sardine industry (Cavides and Fik, 1992).

Just as the marine habitat was disrupted in South America as a result of El Niño, the strong 1982-83 ENSO altered the US Northwest salmon abundance (Miller and Fluhary, 1990). The size and availability of coho and Chinook salmon experienced reductions along the Washington, Oregon, and California (WOC) coasts, and the Fraser River sockeyes migrated north into Canadian waters. As a result of the small impact of WOC fishing on the world supply of salmon, the prices did not rise in response to its lowered output, causing economic losses to the area. Even though the US government did not recognize El Niño as a natural disaster, the Small Business Administration gave $28 million in loans to west coast fishing firms, partly in response to the $100 million in aid to South American countries affected by ENSO.

The El Niño-Southern Osciatiom (ENSO) is the largest source of interannual variability in global climate. Variability in climite has been linked to variabilaity in fisherues. The ability to forecast El Niño events alaredy exists and is likely to improve in coming years. An accurate prediction may have value because it allows for better management decisions. In the Costello, Adams, and Polasky's article (1998), they develop a bioeconomic model of the coho salmon fishery and derive the value of information from improve El Niño forecasting ability and find that a perfect El Niño forcast results in an annual weflare gain of approximately $1 million, while imperfect forecast lead to smaller gains. Results also suggest that optiomial management in the fact of uncertainty involues a "conservative" management straegy, resulting in lower harvest, higher wild fish escapement, and lower hatchery releases than management in the absence of such uncertainty.

The Stochastic Spatial Equilibrium Model

The solution of spatial equilibrium problems can de generally divided into the sample transportation model and the transportation model containing price-demand functions and price-supply functions. The former, sometimes noted as classical transportation model, contains mainly three exogenous variables such as transportation costs, surplus and deficits in the model. From this the solution of regional transport quantities of product under minimum transportation costs can be obtained. However, the regional market equilibrium conditions can not be explained by the model.

From the concept of "consumer's surplus," Samuelson (1952) defined a "net social pay-off function," and transferred the regional exchange problem to a solution of maximized problem on a base of this definition. Under the postulate of linear price-supply functions and price-demand functions, Takayama and Judge (1973) developed a quadratic programming model from Samuelson's approach. In area of agricultural production and distribution, Takayama and Judge (1973), Hall, Heady and Plessner (1968), Hall et al. (1975) are just a few of the many applications of the SPE model. In the energy, the model by Kennedy (1974), the PIES model (Hogan, Sweeney and Wagner (1978), and the Zimmerman (1981) Coal Model and the associated paper by Shapiro and White (1982) are based upon the SPE model.

The study is the first paper applies this SPE model to the analysis of the world fishmeal industry. By considering the uncertainly of El Niño, this study specifies a stochastic spatial equilibrium model to evaluate the gains in social welfare of El Niño forecasts in the international trade of fish-meal. The model is specified as follows

$$\text{MAX} \quad \sum_{s}\sum_{j=1}^{m}\rho(s)(a_j M_{js} + \frac{1}{2}b_j M_{js}^2) - \sum_{s}\sum_{i=1}^{n}\rho(s)(c_i + \frac{1}{2}d_i E_{is}^2) - \sum_{s}\sum_{i=1}^{n}\sum_{j=1}^{m}\rho(s)t_{ij}X_{ijs} \quad (1)$$

$$\text{Subject to} \ -\sum_{i} X_{ijs} + M_{js} + SQ_{js} \le 0 \quad (2)$$

$$\sum_{j} X_{ijs} - E_{is} + SQ_{is} \le 0 \quad (3)$$

$$X_{ijs}, E_{is}, M_{js} \ge 0$$

where subscript *s* represents the normal, weak and strong El Niño phases; *i* represents the ith import country; *j* represents the jth export country; ñ(s) represents the probability of normal, weak, and strong El Niño phases; M_{js} is the import quantity of jth country; E_i is the export quantity of the ith country; t_{ij} is the transportation cost of per unit product from country i to country j; X_{ij} is the transported quantity from ith country to jth country; SQ_{is} is the export quantity shortage variable for the ith export country result from El Niño; SQ_{js} is the import quantity shortage variable for the jth import country result from El Niño.

Data

Based on the FAO FISHSTAT Global Production Database, this study collect twenty-three yearly data on Fish Meal for the period beginning from 1976 through 1998. In 1996, Chile and Peru were the top two major export countries, their fish-meal exports accounted for 66% the total world exports. Such as shown in Figure 2, the total production of fish meal in four major production countries, the El Niño Phenomnon in 1997/98 had caused the production of fish meal in Peru and Chile experienced 47% and 53% reductions in 1998. Figure 3a and Figure 3b show the export quantity and price from Peru and Chile, who are the top two exporting countries. The El Niño in 1997/98 had caused 58% and 48% reductions in the fish meal export quantity in Peru and Chile. Furthermore, the shortage of fish-meal in international markets in 1998 caused the export prices to increase by about 13.8% and 10.3% from 1996 level in Chile and Peru, respectively.

China, Japan, Taiwan, and Germany were four major importing countries, their imports account for 47% the total world imports. Such as shown in Figure 4, the import quantity of China, Japan, Taiwan, Germany and other countries in 1996 are mostly provided by Peru and Chile. However, under the 1997/98 strong El Niño phase, the catch of pelagic fishery in Chile and Peru had experienced 50% and 52% reductions, respectively, and had caused the import quantity of China, Japan, Taiwan, Germany experienced 52%, 24%, 54%,and 4% reductions, respectively.

Results and Discussion

In 1997/98, the strong El Niño phases in the Pacific Ocean decreased Chile and Peru fish meal exports by US$8,166 million. Since fish-meal is a major portein source for the feed industry, high fish-meal prices translate into high feed costs for the livestock and aquaculture sectors in four major import countries. The social welfare losses evaluated by the Stochastic Spatial Equilibrium Model will be even higher than the reduction in Chile and Peru's fish-meal export value. This study would provide useful information for all fish-meal related industries in four major import countries, such as China, Japan, Taiwan, and Germany.

The simulation result of the consumer and producer surplus in the Spatial Equilibrium Model is shown in Table 1. The welfare decomposition of the international trade of fish meal under strong ENSO, weak ENSO and normal scenarios is evaluated in 1998, 1991 and 1996 in Peru and Chile, respectively. By comparing the social welfare under the strong ENSO in 1998 with the Normal Situation in 1996, it is clear that the welfare loss under strong ENSO situation in 1998 is about 319.32 million US dollars, which is about 31% below the social welfare in 1996. The welfare loss under weak

ENSO situation in 1991 is about 248.49 million US dollars, which about 24% less than the social welfare in 1996.

However, by considering the demand expanding from 1983 to 1998, the information gain/loss under 1998 strong ENSO situation is defined as comparing the actual social welfare to the simulated social welfare in 1998, which is simulated based on previous strong ENSO experience in 1983. Since the strength and duration of the 1983 and 1998 ENSO phenomenon are quite comparable, we assume that the supply side shock is same in 1983 and 1998. By allowing the fish meal demand expand to the level in 1998, Figure 5 shown that the equilibrium point D will be simulated as strong ENSO in 1998 based on the previous strong ENSO experience in 1983. It is of interest that the equilibrium point D for Peru in Figure 5 is on the west-north of the actual equilibrium point B in 1998, but the equilibrium point D for Chile in Figure 6 is on the south-east of the actual equilibrium point B in 1998.

Under the normal condition, major anchoveta concentrations existed at centers of upwelling along the Peruvian coast at 10^0S-12^0S. Following the warm phases in 1972/73 and 1982/83, however, the anchoveta centers were found south of 18^0S in Chilean waters, which is out of reach of the Peruvian fisheries but is beneficial for Chile (Cavides and Fik, 1992). For Peru, this meant a total collapse of the already strained fishing industry and a resulting long-term economic struggle. Since the experience in the strong ENSO 1997/98 is not the same as before, i.e., the fish meal production in Chile actual experiences the production reduction effect in 1997/98 strong ENSO, which is not expected by the Chilean fishermen before. Hence, there exist a welfare loss in 1998, which is even worse than the experience based on 1983 information. Hence, the ENSO forecast effect in 1998 are beneficial for the fish meal industry in Peru, since the fishermen in Peru remember how bad in 1983 and try to have cost saving in their fishing activity. But the ENSO forecast effect in 1998 is not beneficial for the fish meal industry in Chile.

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Table 1. Welfare Decomposition of the International Trade under Strong ENSO, Weak ENSO and Normal Scenarios in Respective Years in Peru and Chile

Units: Million US$

Welfare Decomposition in (1) Chile (2) Peru	Weak ENSO in 1991 (A)	Normal ENSO in 1996 (B)	Strong ENSO in 1998 (C)	Simulation[1] (1998|1983) (D)	Weak ENSO (%) (E)=[(A)-(B)]/(B)	Strong ENSO (%) (F)=[(C)-(B)]/(B)	Information Gain in 1998[2] (G)=(C)-(D)
(1) Consumer Surplus	57310	637.95	521.23	510.89	-50%	-65%	11.65
China	17.67	35.09	12.35	0.71	-9%	-22%	0.45
Japan	17.53	19.20	14.90	14.44	-40%	-70%	0.44
Taiwan	2.57	4.31	1.29	0.85	-40%	-70%	0.44
Germany	397.87	376.53	393.68	393.15	6%	5%	0.53
Other Countries	137.45	202.82	99.01	95.38	-32%	-51%	3.63
Producer Surplus	380.81	208.24	247.14	127.62	-25%	-51%	119.52
Transport Cost	179.43	123.22	64.72	37.70	46%	-47%	27.02
Social Welfare	774.48	1022.97	703.65	600.81	-24%	-31%	102.84
(2) Consumer Surplus	176.53	183.09	137.84	121.30	-4%	-25%	16.55
China	9.96	13.26	7.95	6.81	-25%	-40%	1.14
Japan	132.24	123.81	108.30	107.15	7%	-13%	1.15
Taiwan	12.89	17.33	6.63	3.37	-26%	-62%	3.27
Germany	7.08	9.01	4.68	3.79	-21%	-48%	0.89
Other Countries	14.35	19.68	10.29	0.18	-27%	-48%	10.10
Producer Surplus	358.84	416.31	248.34	492.09	-14%	-40%	-243.75
Transport Cost	105.33	84.76	59.87	111.18	24%	-29%	-51.96
Social Welfare	430.03	514.64	326.32	501.56	-16%	-37%	-175.24

[1] The strong ENSO simulate for year 1998 based on previous experience in 1983.

[2] Information gain/loss in 1998 comparing to simulation in 1998 based on previous experience in 1983.

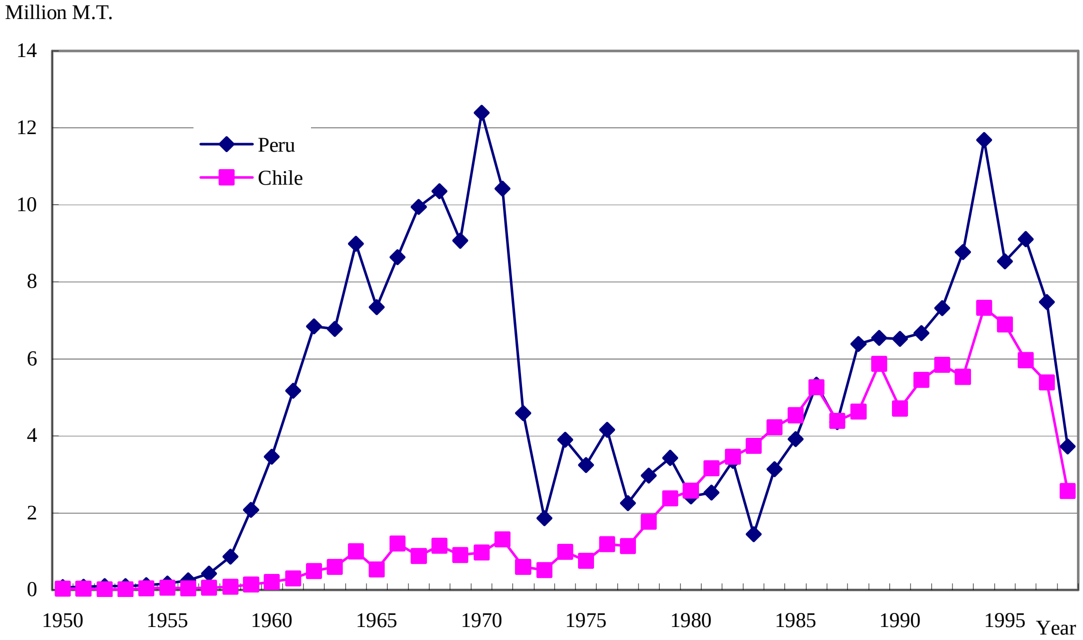

Figure 1. The Total Landing of Marine Pelagic Fishes in Peru and Chile (1950~1998)

Source: FAO FISHSTAT Global Production Database

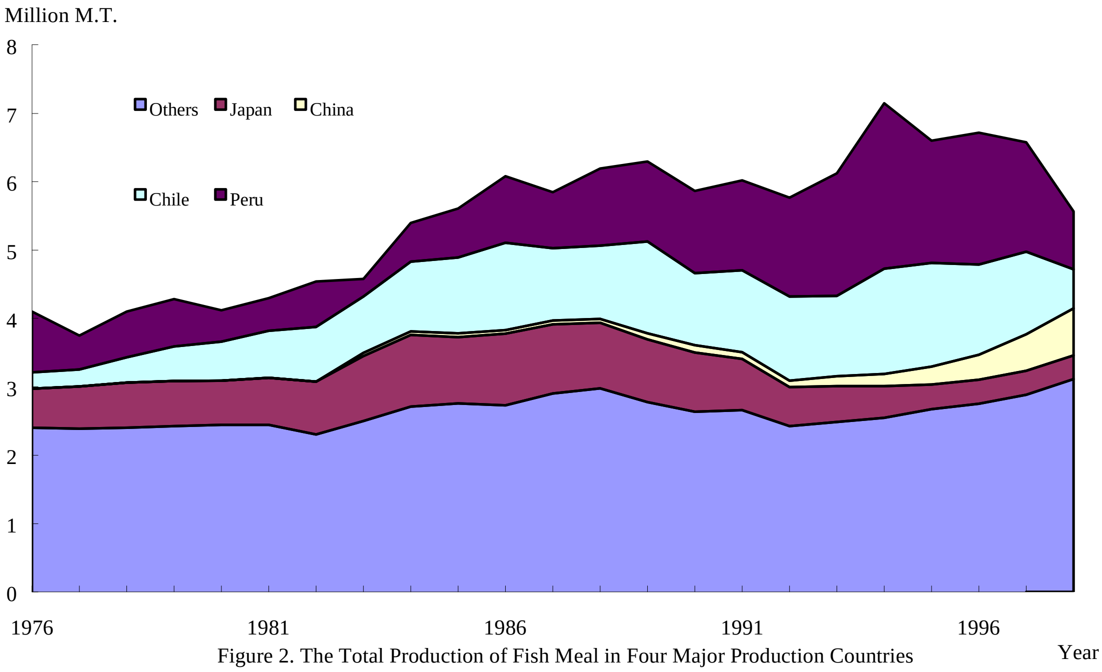

Figure 2. The Total Production of Fish Meal in Four Major Production Countries

Source: FAO FISHSTAT Global Production Database

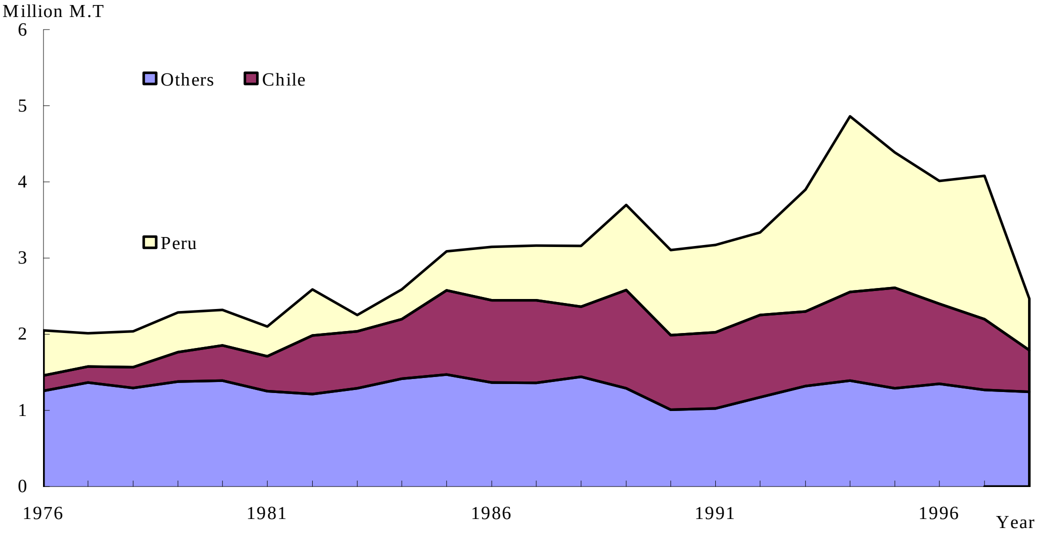

Figure3a. The Export Quantity of Fish Meal origin from Peru, Chile and Other countries (1976~1998)

Source: FAO FISHSTAT Global Production Database

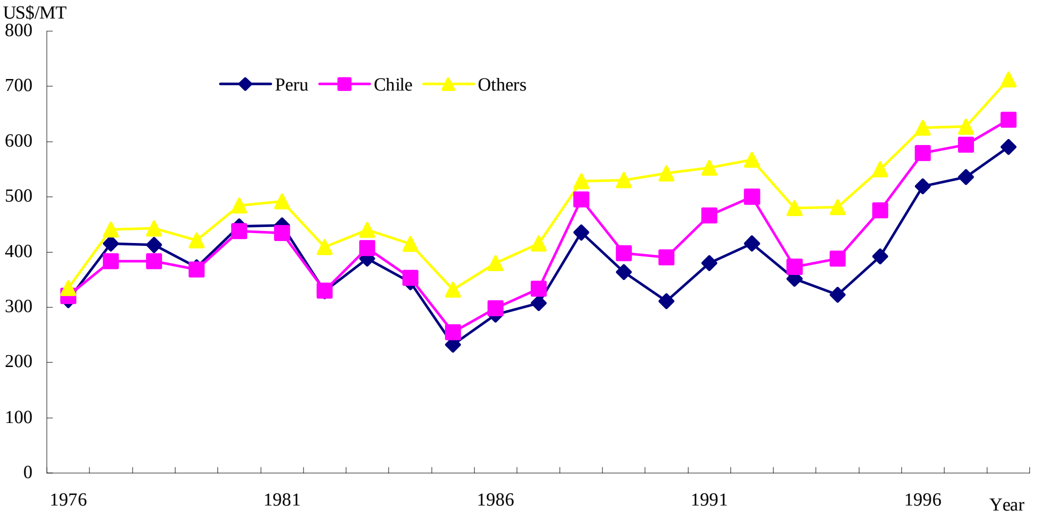

Figure3b.The Export Price of Fish Meal origin from Peru, Chile and Other Countries (1976~1998)

Source: FAO FISHSTAT Global Production Database

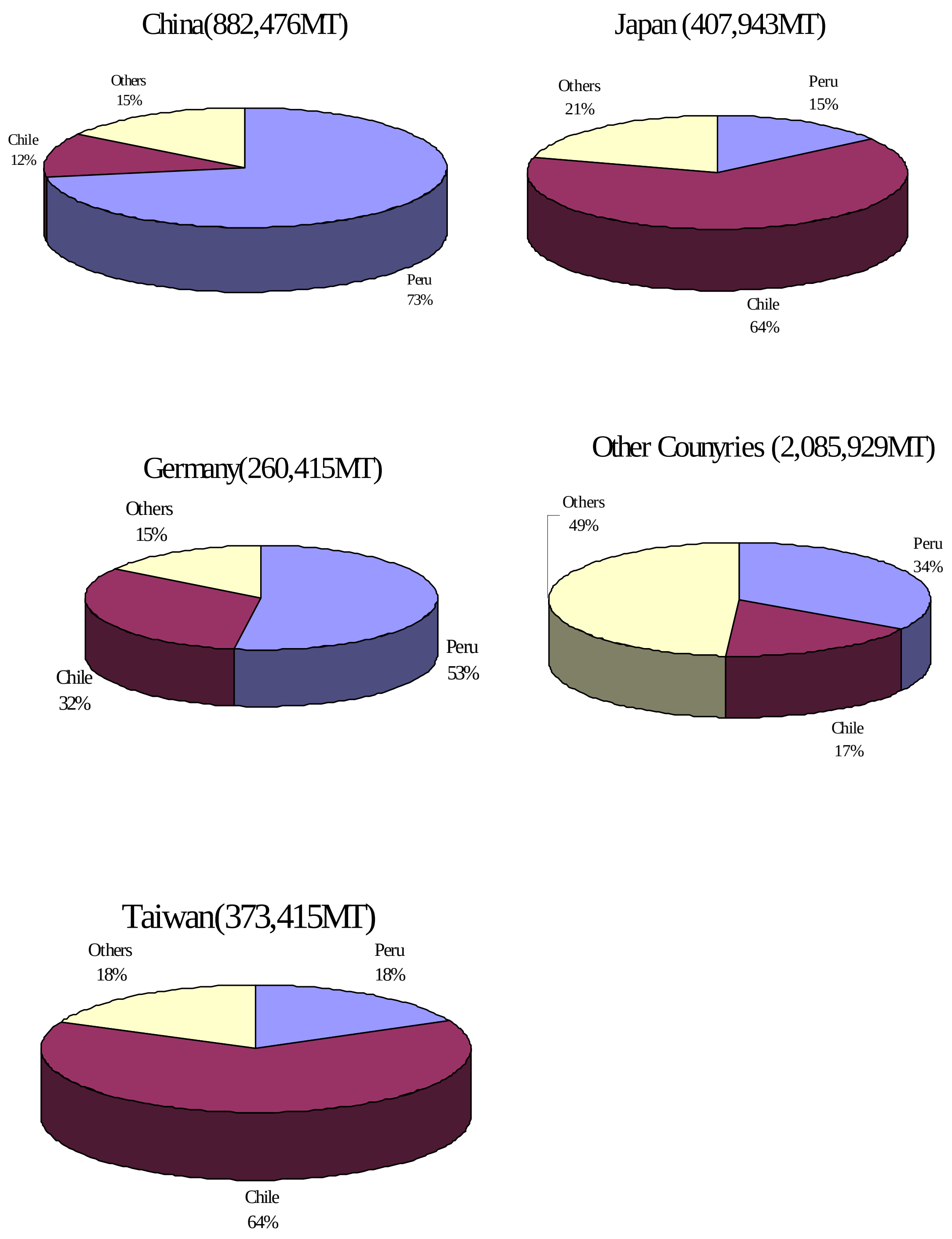

Figure 4. Fish Meal Import Quantity in Major Import Countries Origin from Peru, Chile and Other Countries (1996)

Source: FAO FISHSTAT Global Production Database

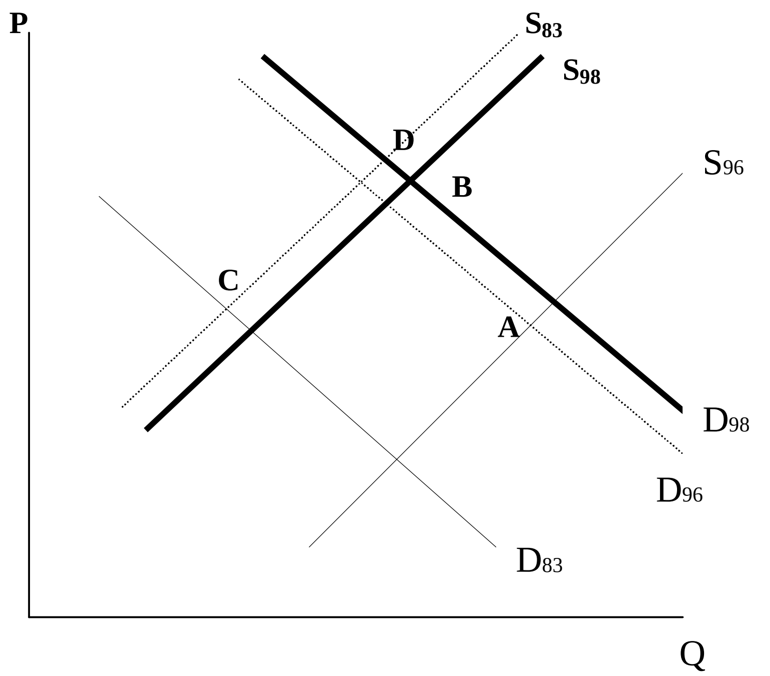

Figure 5. The Demand Supply Equilibrium under ENSO in Peru in 1983, 1996 and 1998

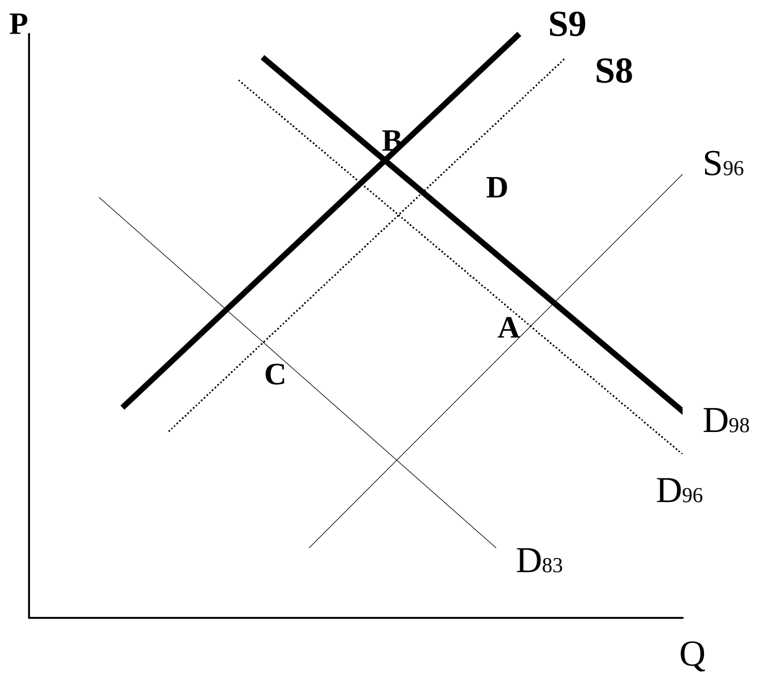

Figure 6. The Demand Supply Equilibrium under ENSO in Peru in 1983, 1996 and 1998