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THE ECONOMICS OF FISH PROTEIN CONCENTRATE

By
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ADMINISTRATIVE STATEMENT

The study resulting in this report on "The Economics of Fish Protein Concentrate," was carried out at M.I.T. with the financial support from the National Council on Marine Resources and Engineering Development, Executive Office of the President.

The information contained in this report is of particularly timely interest in view of the current review by the United Nations of worldwide progress in fish protein concentrate (FPC) and its prospects. This report lays out the methodology through which FPC should be compared with other protein supplements if a developing country wishes to be efficient in the allocation of its limited resources. This report makes a substantial contribution to the present discussion of FPC primarily by establishing an economically solid framework on which discussion can be based.

The printing and distribution of this special limited edition of the report was organized by the M.I.T. Sea Grant Project Office under the project established to expedite dissemination of important studies and/or research findings developed at M.I.T. under other than Sea Grant support.

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Dr. Alfred A. H. Keil

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"This study was financed by a contract with the National Council on Marine Resources and Engineering Development, Executive Office of the President. However, the findings, recommendations, and opinions in the report are those of the contractor and not necessarily those of the Council, nor do they imply any future Council study, recommendation, or position. It is hoped that this study will contribute to the full discussion of problem areas and issues in marine science affairs."

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This report was prepared by an M.I.T. interdepartmental task group under the direction of Dr. A. H. Keil, Head of the Department of Naval Architecture and Marine Engineering. Nutritional aspects were supervised by Dr. N.S. Scrimshaw, Head of the Department of Nutrition and Food Science, and economic aspects were reviewed by Professor R. S. Eckaus, Department of Economics. Principle authors were Dr. J. W. Devanney III and Mr. G. Mahnken, Department of Naval Architecture, with contributions by Professor N.S. Scrimshaw, Professor S.R. Tannenbaum, and Professor V. Young, Department of Nutrition and Food Science. Chilean production costs and nutritional data were supplied by General Oceanology, Inc.

A large number of governmental, industrial, and academic authorities have taken considerable interest in the report and have carefully reviewed earlier drafts and provided substantial comments. Although it would be infeasible to name them all, we would be particularly remiss if we failed to mention Mr. Roland Finch and Dr. Bruce Stillings of the Bureau of Commercial Fisheries, Mr. George Parman of the Agency for International Development, Dr. Ben Duffy of the Office of the Oceanographer, U.S. Navy, Professor James Crutchfield of the University of Washington, Professor David Call of Cornell and Professor C. O. Chichester, University of California at Davis. Contributions were also received from representatives of the Department of Commerce, the Food and Drug Administration, the Department of State and the Department of Transportation.

This is not to imply that these individuals or the organizations they represent are necessarily in agreement with the results of this study. Indeed, at least some of the above named individuals have very serious reservations about some of the conclusions we draw from our analyses, for which we alone are responsible. However, we feel that the report is a better document as a result of their objective concern for the future of FPC.

Table of Contents

"THE ECONOMICS OF FISH PROTEIN CONCENTRATE"

CONCLUSIONS AND RECOMMENDATIONS

This report examines the economic feasibility of fish protein concentrate in two disparate contexts:*

(a) as a nutritional supplement in the diet of a developing country

(b) as a competitive food additive in the United States.

The report examines these subjects with special reference to the role that the United States Government should play in the development of FPC.

The report is an economic study. We attempt to employ the term economic in a wide sense, that is, to include all the benefits and costs associated with an activity, not just those which are valued by the market. However, there are important sets of values which are outside the realm of the economic theory used herein. Thus, our conclusions and recommendations may have to be modified by political and social constraints which are outside the main thrust of this report. If so, our analyses will give an indication of the magnitude of the costs implied by these modifications.

Furthermore, we have been unable to usefully quantify the benefits which would accrue (market or otherwise) from investment in protein supplementation, although our survey of the problem indicates that there is presumptive evidence supporting some such investment in many developing economies. Our nutritional analysis, therefore, postulates a range of nutritional levels and seeks to discover the costs to an economy of meeting each of these levels by alternate supplements rather than attempting to discover the optimal combination of nutritional level and supplement.

* Fish protein concentrate as used herein is any stable powder resulting from the removal of oil and water from fish which is aimed at human consumption. When we are referring to a particular variety of FPC, we will attempt to make this specialization clear either explicitly or by the context.

Our analysis is limited still further by the fact that there exists insufficient data to enable a complete analysis of acceptability considerations and promotional and distribution costs. Hence, our cost figures are based on pre-distribution costs and assume all supplements are equally acceptable in the concentrations in which they occur in the diets. We argue in the report that the resulting figures are meaningful --in all but a few of the cases which have been examined-- because of the generally low levels of supplementation, and the fact that acceptability and distributional considerations rarely favor presently available FPC differentially. However, these basic limitations on the analysis should be kept in mind in reviewing our conclusions.

CONCLUSIONS WITH RESPECT TO FISH PROTEIN CONCENTRATE IN THE DEVELOPING COUNTRY

1) The first requirement for beneficial protein supplementation in a developing country is that the population is receiving sufficient calories to meet its energy needs. If this is not the case, any protein supplementation program will be relatively ineffective, as part of the added protein will be converted to energy rather than used in tissue generation, and this energy could be supplied more cheaply by other means. In certain cases, adaptation and other mechanisms may make it desirable to effect protein supplementation when a population is receiving less than a completely adequate level of calories. However, all our analyses are based on regimens which ensure adequate calories.

2) Given that the population is receiving sufficient calories from almost any naturally occurring diet, only a small proportion of the population will be deficient in protein. The possible exceptions are young children during and after weaning, pregnant or lactating mothers, and the very old. Of these groups, the requirements of the young child are most severe and the most economically significant because protein deficiency in the very young is at least partially responsible for the extremely high child mortality rate in the developing countries and causes severe disturbances in mental growth. The weaning and recently weaned lower income child who is receiving adequate calories, then, is the major target group of any protein supplementation program.

3) We accept the fact that the protein needs of a normal, healthy human are adequately described by the Joint Food and Agriculture Organization/World Health Organization estimates of human requirements for essential amino acids and non-specific nitrogen irrespective of their source. The FAO/WHO expresses these needs in terms of reference protein requirements. However, we argue that the target group individual is not a healthy human and that the frequency of acute and chronic infection raises his reference protein requirements by at least 50%. All our nutritional analyses are performed for a range of stipulated levels of reference protein. Specifically, they are undertaken for 100, 150 and 200% of the FAO/WHO recommended levels. Given our assumption of no processing losses, we feel that a

reasonable target level for a protein supplementation program is between 150% and 200% of the FAO/WHO recommendations.

4) Under these assumptions, we have performed a fairly detailed comparison of alternative protein sources under several types of supplementation programs (universal, perfectly selective, infant food) on a handful of basal diets (generally pure wheat, pure rice, pure corn, two Chilean mixed diets and a cassava diet) under the cost situation which we estimate presently exists in Chile. The protein sources considered were synthetic amino acids, dry skim milk, a number of oilseed flours, and isopropanol extracted FPC to present Bureau of Commercial Fisheries standards, which we will henceforth term IPA FPC. We estimate the present opportunity cost of IPA FPC to Chile at 25 cents a pound. The estimates of the cost of the imported alternatives were adjusted to reflect the fact that the market exchange rate does not correctly measure the scarcity of foreign exchange in Chile.

5) Despite the fact that Chile is a relatively fish rich and currency poor country, we were unable to identify any situation in which IPA FPC required less of the country's resources to effect a stipulated nutritional level than at least one of the other alternative protein sources. In most cases, FPC was from 25% to 40% more expensive in terms of net cost of supplementation than the least expensive alternative. Our cost comparisons were based on ex-factory costs and do not include costs of distribution and promotion.

6) Given this limitation and the concentration on the Chilean situation, it is difficult to say to what extent these results can be generalized. To us, they indicate:

(a) that the more extravagant claims which have been made for FPC in the past are unsupported in fact at present.

(b) in those countries which must import protein sources other than fish, the opportunity cost of FPC must be less than

20 cents per pound before FPC can be expected to offer any substantial economic advantage over imported alternatives, despite the typical scarcity of foreign exchange in the less developed countries. This statement is based on our Chilean analysis which we regard as a typical fish rich, currency poor situation.

(c) FPC will not be an economically efficient source of protein for nutrition on the world market at opportunity costs much above 15 cents per pound.

We estimate the present opportunity cost of IPA FPC in Chile to be about 25 cents per pound.

(7) We feel that refinement of the present IPA extraction process by itself is unlikely to reduce unit costs below 20 cents per pound even in areas where the opportunity cost of fish is about a penny per pound. We have performed no detailed analysis on the production process with which to substantiate this statement. It is based on our review of the literature and the fact that no suggestions as to where significant cost improvement could be obtained have been forthcoming. In any event, if the statement is true, IPA FPC will be at best a marginally efficient protein supplement in even fish rich, currency poor situations.

(8) There are other possible directions of research which have the potential to offer the large reductions in present FPC costs necessary if it is to become an important tool in combating protein deficiency. These include:

(a) FPC resulting from a process involving a lower degree of extraction, and whose higher fat content is compensated for by treatment in order to increase shelf life.

(b) other extraction processes such as: (i) microbiological processes, which not only require less processing equipment, which must be purchased by the developing country with scarce foreign exchange, but also can produce a product which is valued for something more than its nutritional characteristics.

(ii) combinations of microbiological and physical processes with some solvent extraction.

9) The protein in fish is extremely cheap at dockside: Fishmeal producers in Peru are able to sell a product that contains 65 to 70% high quality protein at a profit at 8.7¢/lb. If an acceptable human grade FPC could be produced at twice this price, it would have a role to play in the world situation.

10) Our analyses indicate that the calorie content of the protein supplement can be a very important contributor to its nutritional efficiency. Since fish oil has a high caloric density, processes which stabilize this oil and return it to the product should be investigated.

11) We believe that there is a substantial probability that imaginative, broad-based research on all promising methods of protein extraction from fish could result in the understanding and technology necessary to produce a human grade FPC at prices which are more than competitive with alternative supplements in many situations throughout the developing world.

CONCLUSIONS REGARDING FISH PROTEIN CONCENTRATE IN THE UNITED STATES

1) There exist two bodies of opinion with respect to the potential marketability of FPC in the United States:

a) There exists sufficient demand for the bland, nutritional content of present solvent extracted FPC to make its production profitable at present. The three most often mentioned markets are: pet food, high protein snacks, and institutional diets. The most impressive proponent of this view is Cardinal Proteins, LTD. which is investing close to $5 million of its own and the Canadian Government's money in Nova Scotia in a plant which produces 30 tons of FPC per day.

b) The domestic demand is for functional rather than nutritional qualities. Solvent extracted FPC has few or no functional qualities and hence little marketability.

All the authorities that we have interviewed agree that there is a significant probability that processes which retain or produce the desired functional qualities using fish protein can be developed.

2) This report makes no judgment on which of the above two opinions, (a) or (b), is correct. It concentrates rather on making those statements about government participation in FPC which can be made independently of the characteristics of the present domestic market for solvent extracted FPC.

3) On the supply side, the cost of producing FPC, whether it be solvent extracted or not, will depend primarily on the cost and regularity of the supply of raw material.

4) We see no reason to believe that groundfish, such as hake, can be landed regularly at less than three cents per pound on the Atlantic Coast. Herring and other oily fish might be landed on the East Coast at 1 to 1.5 cents a pound, but the supply will be extremely irregular. The costs to the processor of obtaining hake or anchovy on the West Coast in a reasonably regular manner may go as low as 1¢ per pound, assuming an efficiently designed and efficiently sized fishing fleet.

5) As a result, the cost of producing solvent extracted FPC, based on hake, on the Atlantic coast will be about 36 cents per pound. The cost of producing FPC based on any available fish on the West coast may be as low as 20 cents per pound, assuming an optimally designed and regulated fishing fleet.

6) An extremely important factor in the potential profitability of the Cardinal Protein operation is its ability to receive one third of its raw material supply in the form of fish trimmings from a neighboring fish processing plant, and to dispose of excess raw material at a nearby fishmeal plant. Due to the randomness of the catch in both species and size, at least on the East coast, any profitable fish protein concentrate operation will have to be integrated into a complete fish processing complex.

7) There has been no solid analysis of the effect of the variability of the supply on the cost of producing FPC and none is included herein. We look forward to the complete development of the fisheries simulation program under construction at the M.I.T. Instrumentation Laboratory for the Bureau of Commercial Fisheries, which will facilitate such an analysis.

THE ROLE OF THE UNITED STATES FEDERAL GOVERNMENT IN THE DEVELOPMENT OF FPC

1) The fact that FPC has the potential to become competitive on the domestic marketplace is a necessary but not sufficient condition for government investment in the development of a commercially marketable product. Government investment in the development of an FPC for domestic marketing presupposes the existence of benefits that would result from this program which are not properly valued by the market processes.

2) Increased fishing activity can be properly counted a benefit of an FPC industry only if substantial involuntary unemployment exists in the fishing industry and if this unemployment would be affected by FPC production. The economy is at close to full employment, and at least the New England fishing industry, one of the nation's least healthy, faces labor shortages rather than labor surpluses. It is necessary to distinguish an unprofitable industry from one in which unemployment exists. Only in the latter case are secondary benefits, such as the effect of FPC on fishing activity, not a wash on national accounts. There exists some structural unemployment in the West Coast fishing industry due to lack of cultural assimilation. However, there are more direct and generally more efficient means of getting at this unemployment than investment in research and development of FPC. The burden of proof is on the FPC R&D program to estimate how much the development of FPC will lower the costs of a program aimed at the unemployment in the West Coast fishing industry. We have not attempted this estimation. However, the connection between FPC research and domestic fishing unemployment is considerably more tenuous than is sometimes argued.

In view of the above, we do not believe that the possible effects of FPC development on the fishing industry can be heavily weighed in evaluating the benefits to be obtained from domestic FPC production.

It is worth noting that the same argument can and should be used with respect to almost all our food support programs, many of which are based on improper counting of secondary benefits.

3) If the country were to subsidize a level of fishing above that which would otherwise occur (for example, to maintain the country's influence in the regulation of international fisheries) and if the early development of a domestic FPC industry through government investment resulted in a decrease in the subsidy required to maintain the desired level of fishing, then this decrease can properly be counted as a benefit of the government FPC development program. This is the only economically valid situation we have uncovered where the effect of government investment in a domestic FPC on the fishing industry is a net benefit of the development program given full employment. Since the country has chosen to subsidize its fishermen only on a very small scale, and since there exists little evidence that a domestic FPC industry would make very much difference in even a large scale subsidy program if it did exist, we do not regard this as a persuasive argument.

4) One can validly argue that government activity in the development of FPC is economically justified on the grounds that such investment serves to correct inefficient allocations of resources caused by present Food and Drug Administration restrictions on FPC. The present FDA restrictions on FPC effectively remove FPC from its only possible market. Economically, they are as restrictive as outright prohibition. We believe them to be without justification and contrary to the public interest. They should be changed.

5) In our view, the most persuasive argument for government support of basic research on protein extraction processes and basic FPC technology is that the resulting information is a public good, and therefore we cannot expect private enterprise to allocate an optimal amount of resources to the generation of this information. We believe this argument alone is more than adequate justification for an aggressive government program in FPC research. This argument is given added urgency by the fact that the information which would be generated by such research may make FPC an important tool in world nutrition.

RECOMMENDATIONS

1) Efforts to tie the FPC program to the domestic fisheries should be resisted.

2) We believe that a reasoned, broadbased program of research into the basic technology of FPC is one of the better investments that this country could presently make. We believe that such a program should be supported and strengthened.

3) Specifically, we feel that the Bureau of Commercial Fisheries should make a conscious effort to develop the Aberdeen installation into a flexible, pilot scale testing center for a variety of processes and combinations of processes.

CHAPTER I

INTRODUCTION AND APPROACH

The basic purpose behind the initiation of this study was to shed light on the following question: Under what conditions, to what extent, and how, should the United States Federal Government invest in fish protein concentrate at this time?*

This question, concerning as it does the allocation of resources, is explicitly economic. It is an obvious tautology that, in order to answer our basic question, one must understand the economic environment and function of FPC and its substitutes, both domestically and in the developing countries. However, FPC, by its very nature, competes in an economic environment in which market processes either have often been judged unsatisfactory or have often been interfered with on a massive scale. That is, the problem of Federal investment in FPC cannot be divorced from social and political judgments which, in turn, cannot be valued by market processes. Furthermore, given the present state of the art, these judgments are difficult or impossible to quantitatively value by any means. Yet, conceivable differentials in these nonmarket values might be many times the quantifiable costs of FPC.

The objectives of this study are therefore, to identify and investigate:

a. presently quantifiable economic aspects related to FPC,

b. the economic aspects of competing protein products and,

c. on a more general basis, the social and political aspects of FPC which economic theory has not yet learned to value.

* As noted earlier, for the purpose of this report fish protein concentrate refers to any stable product involving the removal of water and oil from fish powder which is aimed at human consumption.

These investigations will be further complicated by the fact that these social and political values will differ in kind, as well as in quantity, depending on whether one is considering investment in FPC from the viewpoint of a developed or a developing country.

The developed country typically faces protein surpluses rather than shortages, and its economy operates through a highly refined food distribution and marketing system which caters primarily to relatively sophisticated and malleable tastes. Therefore, such a country is basically interested in the ability of FPC to compete in a relatively free market with meat, milk, soy, eggs, etc., as a constituent of highly processed foods in which the function of these proteins is often only remotely related to nutritional value. The developed country will be interested also in the potential of exporting FPC or FPC technology to the developing countries, in the potential employment generated by an FPC industry and, possibly, in the subsidization of protein deficient foreigners, either in self interest or through humanitarian considerations.

The developing country, on the other hand, is typically interested in upgrading protein deficient diets and in the effects that this upgrading will have on disease prevention, labor productivity, population control, and political stability. The developing country is often in a situation where almost all resources, including foreign exchange, are so scarce in terms of national development goals that government edict and investment largely supplant market processes,making market prices unreliable indicators of economic value. Furthermore, the developing economy operates through a rudimentary food processing and distribution system in which dietary habits sometimes prove extremely resistent to change.

In short, the only common aspects between FPC in the developed economy and FPC in the developing economy are the raw materials, the processing technology, and sometimes a human bond; i.e., the desire of the developed nations to improve the plight of the protein-deficient populations of the developing nations.

In view of the above considerations, the substance of our report has been divided into five segments in a pattern which roughly follows the chronology of Federal interest in FPC, moving from general considerations of the role of FPC in world nutrition through specific applications in developing countries, to consideration of the future of FPC in the domestic food market.

Chapter II reviews the dimensions of the world protein situation and explores the possibility of applying cost benefit analysis to investment in protein supplement programs. Chapter II concludes that, at present, it is not useful to attempt to quantify the benefits which would accrue from protein supplementation.

In the face of this inability, Chapter III compares FPC with its alternatives taking as given a level of nutritional effectiveness for a range of such levels. The results of this analysis form the basis for our conclusion that, at present costs, FPC will rarely be the most efficient source of supplementary protein for a developing country.

Chapter IV is devoted to some technical problems in evaluating costs associated with balance of payments considerations, unemployment, and the opportunity cost of capital.

Chapter V develops cost and demand data for the specific case of Chile. The results of Chapters IV and V serve as inputs to the nutritional efficiency analyses of Chapter III.

Chapter VI deals with the possibility of commercial marketing of FPC within the United States and its relationship to a federally supported FPC research and development program. Chapter VI concludes with our recommendations for future Federal policy toward FPC and the arguments for them.

CHAPTER II

THE ECONOMICS OF INVESTMENT IN PROTEIN SUPPLEMENTATION

II.1 The Protein Problem and Our Basic Protein Resources

The Dimensions of the World Food Problem

In 1965, the world population was approximately 3.3 billion persons, 69% of whom lived in the less developed countries. According to the middle United Nations estimates, by the year 2000 there will be 6.7 billion humans on the earth, 80% of whom will reside in the less developed countries. That is, in the next 40 years we expect the population of the less developed countries to increase 230%. Even the most dramatic downturn in birth rates which could be reasonably hoped for will decrease the year 2000 population of the less developed countries by less than 15% of the above projections.

The reason why these figures are of concern is that even today the human race is doing an inadequate job of feeding itself and; thus one may well wonder about the future. The most recent survey by the Food and Agriculture Organization (FAO) indicated that 20% of the population of developing countries is receiving less than the FAO estimates of minimal calorie requirements, and at least that many people are receiving less than the FAO's estimated requirements for protein (1). While, as we shall see, there are some questions concerning the reliability of the FAO protein requirements, there can be no doubt about the widespread prevalence of malnutrition in the developing countries. Figure I shows the mortality rates of children in several developing countries compared with those in the U.S. In some cases, these rates are 40 times their developed country equivalents. Such death rates are a closely coupled product of environment, sanitation, medical care, social habits and nutrition, where the latter includes not only protein and caloric deficiencies but deficiencies in vitamins and minerals as well. It is dangerously misleading and almost certainly ineffective to attempt to single out any one of these as the sole or primary cause and to attack it alone.

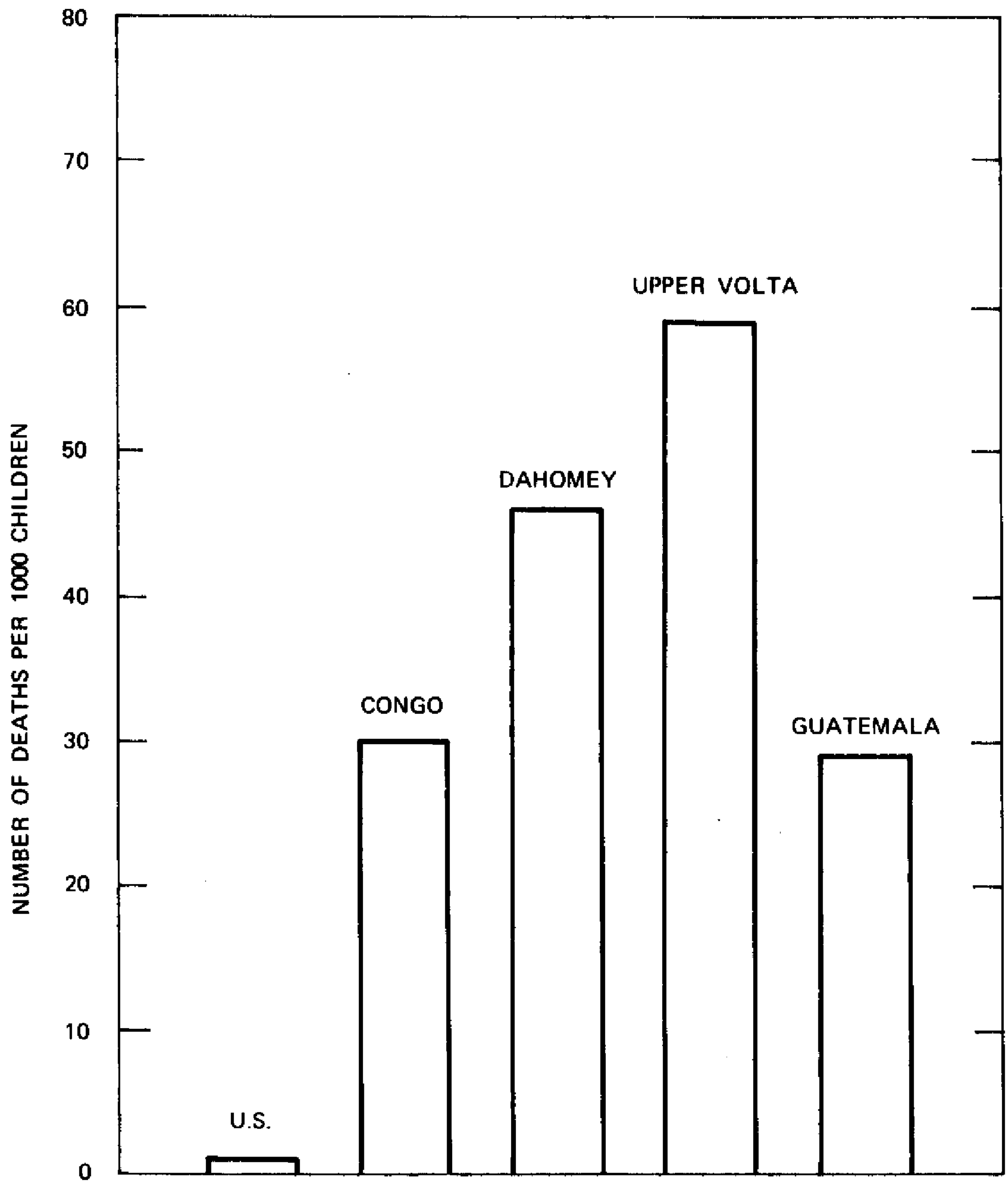

FIGURE I MORTALITY RATES FOR PRE-SCHOOL CHILDREN (AGE 1-4)

At present, it is impossible to say what percentage of these additional deaths are due to malnutrition. Respiratory and gastrointestinal disorders are the most frequently reported causes of death. Seldom are registered deaths attributed to malnutrition. However, Behar *et al.* (4) in a detailed investigation of all deaths occurring in four Guatemalan villages over a period of two years noted that of the 109 deaths occurring in children less than five years of age, 38 were typical cases of severe malnutrition accompanied by edema. In other words, about 37% of all deaths in these children were unquestionably associated with severe malnutrition. Cravioto (2) comments, "If one adds to this figure all other cases in which malnutrition was an important contributory factor, the evidence suggests that malnutrition has played an important role in no less than 50% of the deaths of preschool children."

Thus, there can be no doubt that protein-calorie malnutrition is an extremely important factor in infant mortality. Furthermore, as we shall see, protein deficiencies can have a marked effect on the mental growth of young children.

The clinical manifestations of generalized malnutrition, marasmus and kwashiorkor, are observed throughout the developing world. Marasmus is associated with deficiencies in both protein and calories, while kwashiorkor results from an imbalance in the ratio of protein to calories . In practice, they are often found in combination in the same malnourished child. Kwashiorkor, the syndrome most directly connected with pure protein deficiency, is usually observed in the weaning or recently weaned child who has transferred, or is in the process of transferring, from mother's milk to the family diet. A recent survey of 4,000 children under five in Southern India indicated that at a given time, 1% of preschool children in this area were suffering from kwashiorkor, and it has been estimated that 10% of this population suffered clinical levels of this disease at some time during childhood (5). In West Africa, where some 200 million people subsist on a staple diet based on cassava and other tubers extremely low in protein, kwashiorkor among small children is even more prevalent. Surveys indicate that, at any one time, 2.9% of the preschool population suffers clinical levels of kwashiorkor, and estimates of the percentage of the population of this area encountering kwashiorkor at some time in childhood range from 20-50% (6).

It should be noted that cases of pure protein deficiency are relatively rare and that most kwashiorkor patients are suffering from severe protein deficiency superimposed on chronic calorie malnutrition. Furthermore, symptoms of protein deficiency could occur in a calorie-deficient diet which is not severely deficient in protein by usual standards, because the body would metabolize much of the protein in this diet to supply its energy needs. It should be obvious that the problems of calorie and protein needs cannot be separated.

At present, the basic food problem of the world as a whole is one of distribution more than production. Nutritionists estimate the present world food requirements at 850 million tons of cereal equivalent (a cereal equivalent is a unit of food corresponding roughly to a unit of wheat in protein and calorie content) (7). World production of cereal grains is approximately 880 million tons, which comprises only two-thirds of human diets, the other third being derived from legumes (peas, beans, etc.) and animals. Thus, at present, total world production of foodstuffs appears adequate. Unfortunately, there is a severe mismatch between the geographical distribution of production and the distribution of the population. The less developed countries with 70% of the population produce less than 40% of the cereal grains (8). The less developed countries produce about 1860 calories per capita/day of foodstuffs in contrast to the average of 5,220 calories/day in the developed countries. The United States produces 11,000 calories of grain per capita-day of which it eats 2,000 calories, exports 2,000 and feeds 7,000 to animals to obtain 1,000 calories of animal food products (8).

Even this unbalanced situation would be adequate were it not for inequities and inefficiencies within the distribution system of the developing countries themselves. India, for example, currently produces about 2,100 calories per capita day and about 31 grams of reference protein per capita*. FAO minimal requirements for this population are 1900 calories per day and about 29 grams of reference protein. Yet it has been estimated that 20% of the

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* As we small see, protein differs in nutritional quality. The term reference protein refers to a particular quality protein to which all proteins can be related. The exact definition of reference protein will be given later.

Indian population obtains less than 80% of its calorie requirements and less than 90% of its protein requirements (8). An important contributor to this deficiency is waste, as illustrated by the next example. All the figures above are estimates of food available at the retail level.

An extensive survey of the nutritional situation in Chile on a sample of some 4000 military personnel and 5400 civilians reveals that there is a 25% differential between food available and food actually consumed (9). This figure includes only spoilage at the retail outlet, wastage in the kitchen, and food left on the plate. It does not, however, include losses in production and at wholesale warehouses. If this figure can be generalized, then it is clear that the present marginal sufficiencies in total food requirements may not be marginal at all, but dangerously deficient even before inequities in distribution are considered. This may not be a valid generalization, for the sample population in this study was in general eating well and thus had no pressing need to be concerned with waste. But to say the least, it is a thought provoking figure.

Clearly, if the present situation were our only concern, then major emphasis might well be put on redistribution and efficiency of distribution.

However, the problems of the present pale before the problems of the future. Revelle (10) estimates that world food production must increase at 4% per annum if minimal requirements are to be met for everybody. This rate is about 1.5% faster than the projected population growth. This higher than population rate growth is requiredin order to correct present inadequacies, to meet the needs of the older and thus heavier population implied by the population projections, and to meet the increased requirements of the heavier population which would arise from a better diet. A 5'10" man of 175 lbs. has 40% higher protein requirements than a 5'2", 110 lb. man. Past experience indicates that improved diet implies a 6% per decade increase in mean weight of population (11).

Since about 60% of total income in developing countries is spent on diet, achieving this goal with technology of the past would require a growth rate of real income of over 6%. There is little evidence that the developing economies can sustain anything like a 6% real increase in national product. Thus, our attention naturally turns to the application of science and technology to develop means of supplementing our food supplies from conventional sources. We will not make it otherwise. Revelle lists six possible ways of meeting the above food needs:

1) Decreasing losses in the fields and in storage;
2) Distributing food from developed to developing countries;
3) Increasing emphasis on industrial production of foods;
4) Increasing the production of fish;
5) Increasing land under cultivation; and,
6) Producing greater yields per acre with improved technology.

Revelle sees the contribution of the first four of these as being quite minor compared to the last two. We will not go into his arguments here but merely note that if this is the case, the present heavy dependence on grain for both calories and protein in the developing countries (see Table I) will necessarily increase. As we shall see, this increased dependence on grain would have important implications with respect to the need for, and the design of, protein supplementation programs.

It is not the purpose of this report to comment on whether or not the world will indeed meet its future caloric requirements. At this point, this issue is far from resolved. We do note that it does appear likely that, if the world's caloric requirements are to be met, then it will be through increased dependence on cereal grains which already account for 70% of the calories in the diet of the developing countries. Increased dependence on cereal grains implies a lower density of protein in the diet, and thus the needs for supplemental protein will increase accordingly.

TABLE I - Average 1960-1962 Cereal Consumption in Various Developing Countries in Relation to Total Calorie and Protein Intake

Country	Daily per caput consumption in gms				Total daily cereal consumption per caput gms	Calories from cereals in % of total calorie intake	Protein from cereals in % of total protein intake
	wheat and wheat flour	rice	corn	millet, sorghum and others			
Asia							
India	72.9	194.7	18.9	95.4	381.9	66.6	60.1
Iran	308.5	59.8	1.0	24.8	394.1	67.1	71.5
Iraq	258.9	47.2	0.5	48.2	354.8	55.6	60.1
Pakistan	120.0	276.1	10.4	25.6	423.1	72.2	68.8
Philippines	24.7	238.5	59.2	1.9	324.3	64.5	57.6
Syria	312.8	17.5	9.8	91.8	431.9	60.3	66.5
Africa							
UAR	228.7	83.7	165.7	65.8	543.9	71.7	68.7
Ethiopia	21.8	0.1	62.9	321.9	406.7	66.1	59.1
Libya	226.7	22.7	1.3	72.6	323.3	61.2	71.6
Madagascar	-	398.4	28.5	9.6	436.5	70.6	66.4
Sudan	22.4	1.3	2.6	283.3	310.1	52.5	47.8
Latin America							
Bolivia	104.2	20.6	119.1	23.4	267.3	52.2	53.7
Brazil	74.9	120.9	100.2	2.8	298.8	38.3	39.8
Chile	300.4	21.7	1.0	5.2	328.3	47.9	47.9
Guatemala	40.7	5.8	349.0	2.1	397.6	68.0	69.8
Mexiko	62.4	14.7	271.7	0.2	349.0	48.2	45.9
Peru	99.3	64.7	73.5	35.5	273.0	43.81	46.3

Source: Kaacht, U. Economic Aspects of the Supplementation of Cereals with Lysine FAO/WHO/UNICEF Protein Advisory Group, Document 2.20/5, 24 October 1969

Before we leave the subject of total dietary needs, it is relevant to the purpose of this report to review the argument leading to the conclusion that alternative (4) above, increased production of fish, is unlikely to be a significant source of the additional calories required in the next 30 years.

Fish production has increased at the rate of almost 10% per year in the last 10 years. It currently amounts to about 55 million tons. The most comprehensive investigation to date of the annual production of catchable fish in the sea is that given by Ryther (12). Ryther considers the primary rate at which carbon is fixed into living matter in various regions of the sea, the differing number of trophic levels required to convert this bio-mass into species usable by man, and concludes that the annual production of such species is 240 million tons per year. This is in general agreement with Schaefer's (13) earlier estimates of 200 million tons. From the same data, Chapman (14) argues that the catchable food production is as high as 2 billion tons. However, this appears to be based on an optimistic estimate of the number of trophic levels involved in the open ocean. Of course, man can extract only part of this production if the resource is going to be maintained at maximum sustainable levels. Furthermore, Ryther argues that much of the now unutilized fish are in the Antarctic and that most of the existing fisheries are at or near maximum sustainable levels. He argues for a maximum sustainable yield on the order of 100 million tons. This is in general agreement with Edwards (15) who extrapolates present fisheries experience to obtain an estimate of 125 million tons annually of fish harvestable by present technology. In general, most competent observers agree that without a breakthrough in harvesting technology, between 125 and 200 million tons could be economically harvested annually by the year 2000. A quick comparison between this figure and our projected needs reveals that fish can be expected to supply only a very small fraction of our caloric requirments. However, fish consists of about 20% protein. Thus, its contribution to our protein needs will have to be examined in much greater depth. For now, we simply note that expanded fish production alone cannot be expected to meet the world's gross dietary needs.

The Protein Problem

Our subject, FPC, is of course not aimed at the total world food problem, but rather at a particular sector of that problem: the needs of the human race for protein. Proteins are chains of nitrogen bearing acids (amino acids) which form the basic building blocks of human tissue. In addition, the hemoglobin of red blood cells, insulin and other hormones, the enzymes which digest our foods and those which transfer energy into muscle action, are all proteins or are composed primarily of proteins.

There are some twenty amino acids found in human tissues, of which all but eight can be synthesized by the human body, given sufficient dietary nitrogen and carbohydrates. These remaining eight amino acids must be consumed directly. Furthermore, they must be consumed in the proportions required by the body, or tissue generation will be curtailed. Thus, protein in foods containing these eight amino acids occurring in proportions close to those required will be more efficiently utilized than those proteins whose proportions are markedly different from human needs. In general, animal proteins fit into the first category and vegetable proteins into the second.

In short, the nutritional effect of the same quantity of protein can vary according to the proportions of amino acids in the protein. In order to place proteins on a comparable basis, the concept of reference protein has been introduced; the quality of any naturally occurring protein can be expressed in terms of this reference protein. The reference protein is protein in which the eight needed amino acids occur in just the proportion required by the human body. Thus, if a particular protein, say that occurring in soy meal, is 60% as effective as reference protein due to its relative composition of the eight needed amino acids, then 1.67 units of soy protein is said to be the equivalent of 1 unit of reference protein, or each gram of soymeal protein contains 3/5 of a gram of reference protein. In general, animal proteins are 70-80% as effective as reference protein, and vegetable proteins are about 50-60% as effective.

The FAO/WHO expert group on protein requirements has estimated the minimum amount of reference protein required per unit of body weight for all ages, from newborn infants to adults(10). The requirements of pregnant and lactating mothers are adjusted to reflect their special needs for protein. From these requirements, it has been estimated that the world's need for reference protein in 1965 amounted to 116,000 metric tons per day. In anticipation of the population growth rate, this need will increase to between 176,000 and 168,000 metric tons per day by 1985, approximately a 50% increase (8). It has also been estimated that the amount of protein available on the retail level in 1965 was 122,000 metric tons. More importantly, if we meet calorie needs in the future with a diet similar to that being consumed now in the industrialized countries, on the average, we will be meeting reference protein needs. For example, in 1985 if we supply sufficient calories of the present world diet, we will be supplying between 192,000 to 180,000 metric tons of reference protein, depending on the population; that is, some 10% more than the estimated requirements. This surplus is conservative in that it does not account for the improvement in the protein efficiency which results from combining one natural protein with another in the diet. However, we should not therefore jump to the conclusion that if we meet our caloric needs, everyone will receive all the protein he requires. Not only is the world diet likely to be more grain based in the future than it is now; but, more important, as we saw earlier with respect to calories, supplying needs on the average does not guarantee that everyone will receive adequate protein. We will also argue that the FAO recommendations will not be sufficient for a population with a heavy burden of parasitic and other infections. Despite these caveats, the basic fact remains, that,assuming caloric requirements are met, there is no average protein problem. There is rather a series of individual protein problems involving certain sectors of the population in certain localized areas. A large part of the world' population will meet its protein needs if it meets its calorie needs.

But important segments will not. The widespread prevalence of kwashiorkor and less severe forms of protein and calorie malnutrition demonstrate that certain segments of the population in developing countries are not receiving adequate protein. These include the child of the low income family from some time during weaning to about the age of five, and many pregnant and lactating mothers.

In Chapter III, we will discuss the amount of additional protein required by these groups under a number of assumptions concerning protein needs and basal diets. For now, we wish to consider briefly the possible sources of this additional protein:

1) Introduction of grains with genetically improved protein value.

2) Increased production of animal foods.

3) Increased production of milk.

4) Increased use of oilseeds.

5) Synthetic amino acid supplementation of foods.

6) Fish and fish protein concentrate.

Genetically Improved Grains

As noted earlier, the bulk of the developing world's diet consists of grains. Grains have a crude protein content of from 8-12%. About two thirds of the protein consumed in the developing countries is derived from grain. This percentage is likely to increase in the future. Unfortunately, the extent to which the human body can utilize the protein in grain is severely limited by the relative lack of the amino acid lysine in cereal proteins, and in the case of corn, the lack of the amino acid, tryptophan. Recently, work at Purdue University (17) has identified genes which produce a significantly higher concentration of these two amino acids than ordinary corn. Either of these genes, opaque -2 or floury -2 can be introduced into any local corn variety.
As a result of this breakthrough, the protein quality of corn can be improved without significantly affecting yield or other agronomic characteristics. Production of these varieties is already well advanced in Colombia and Mexico. Nutritional studies have noted that children fed this

corn as the sole protein source have shown normal growth patterns. The attractiveness of this genetic approach to the protein problem is obvious; one increases the protein quality of the diet with few or no economic or social problems. However, with the above exceptions, strains of high protein quality grains have been slow in coming, as agronomists have concentrated on yield. In sum, genetic improvement of grains is potentially a very attractive answer to the world's future protein needs. However, the development and widespread introduction of high quality grains for a variety of agricultural and social environments is at least some way off.

In the body of the report we have not attempted to compare investment in improved protein cereal against more conventional supplementation programs such as FPC. This will be an increasingly more serious omission as time passes and the characteristics of these grains become better known, and all our conclusions must be qualified by this omission.

Increased Animal Production

In the developed countries, there have been striking advances in the technology of animal production in the last twenty years. The time required to produce marketable beef animals has fallen to one year, with the requirement of about 8 to 9 pounds of feed for one pound of animal. In the developing countries, the production of the same animal may take 3.5 years and require 16 to 20 pounds of produce per pound of animal (18). In the last ten years, the time to produce a 3 pound broiler has dropped to six weeks and now requires two pounds of feed per pound of chicken, as opposed to at least three pounds per pound in the developing country (18). Thus, there seems to be some room for the advancement of production of land animal protein in the developing countries.

However, the above advances are achieved largely by increasing the quality of the diet of the animal which places these animals in direct competition for food with humans. Furthermore,it is clear that placing the animal in the food chain is inefficient in terms of total calories. Thus, in a world where caloric supplies are about as marginal as protein, increased animal production appears to be a relatively expensive alternative.

There are some exceptions. The ruminants, despite their relatively low conversion ratio, can utilize grasses and grains unsuitable for direct human consumption. In fact, experiments in Finland indicate that the ruminant may be used in the future to convert simple hydrocarbons including industrial by-products to nutritious, attractive foods (19).

In sum, however, there is little likelihood that land animal flesh will play a significantly larger role in the nutrition of the less developed countries than they do now.

Increased Production of Milk

Until recently, the great majority of present protein supplementation programs for developing countries have been based on dry skimmed milk. The production of milk, like all animal foods, is a relatively inefficient operation. The dairy cow converts 23% of the protein she consumes into milk and beef. Furthermore, use of milk is limited by the fact that the geographical distribution of milk is even further from the distribution of population than is the distribution of food in general. Three-fourths of the world's milk is produced in Europe, North America and Oceania, which area contains less than one-fourth of the world's population.

There appears to be considerable room for increased milk production,at least in those countries which are currently large producers. The United States produces some 5 to 7 billion pounds more than it consumes annually (20). The current annual production per cow is about 8,000 pounds per year, up from 6,000 pounds ten years ago, and many well managed herds average 16,000 pounds per cow per year (20).

Once again, this increase is in part a reflection of increased use of higher quality grains and fishmeal which could go directly to human consumption. Some progress has been made in developing cattle for milk production in tropical areas. Israel has demonstrated that with suitable modification, European and American breeds can be made to produce in hot countries at levels comparable to those in their native countries (21). Still, due to the basic inefficiency of cattle and the capital required for the introduction and upgrading of herds, as well as processing and distribution costs, progress in domestic milk production in the developing countries will be very slow indeed.

Of course, developing countries have the option of using some of their generally scarce foreign exchange and importing milk. Due to heavy subsidies of the butterfat industry in the producing countries, dry skimmed milk can be bought on the world market at 8-9 cents a pound, depending on the quantity purchased (22). In the last ten years, this price has varied between 5 and 18 cents a pound (22). At the lower end of this scale, milk is a very cheap source of protein and, as we shall see, at present prices, it is quite a respectable competitor to FPC even in countries which are fish rich and foreign exchange poor. Of course, any developing country which relies upon imported milk is taking considerable risk in the factors not under its control, because the internal policies of the producing countries may result in a substantial increase in price. Moreover, world shortages of dry skim milk may reoccur. Estimates of world price of dry skim milk without subsidy range up to 23 cents a pound (23).

Moreover, developing countries often opt to protect domestic milk industries. As a result the domestic price of milk can be far higher than the world price. In Central America it is currently about 40 cents a pound (24). Thus, if a nutrition program in a developing country is bound by these import restrictions, then the relevant milk price can be four or more times the world price. We intend to argue, however, that a country which does not allow itself the option of imported milk is almost always behaving irrationally. One might indeed argue that protection of inefficient domestic dairy industries by the developing countries is a contributory cause to their nutrition problems.

Not only does it result in the diminishment of national wealth which occurs with any inefficiency, but it also results in a price for milk which effectively removes it from the diet of the people who need it most. Some developing countries attempt to counter the latter effect by government subsidized milk distribution programs. We intend to argue that they would be better off to let the developed countries finance this subsidy for them.

Oilseeds

Oilseeds are the seeds of those plants from which the oil is extracted mainly for cooking purposes. The principle oilseeds are (1965 production figures) soybean (35 million tons), cottonseed (21 million tons), and sesame (1.5 million tons) (8). These seeds contain 25 to 40% protein and thus together constitute a potential source of protein equal in size to the present total of animal protein. In general, this protein is not used for human consumption. The soybean is a particularly attractive source for human nutrition, since it contains 42% protein (which is about 80% as efficient as reference protein). The production of soybeans is limited to temperate zones and, in fact, the United States produces about 65% of the world's crop; most of the remainder is produced in China where the soybean has been an important source of protein for humans for 5,000 years. The present price of defatted soy flour (the residue after the oil is pressed out), which is 50% protein, is 5 to 5.5 ¢ per pound in the United States (24 a). At present, almost all the non-Chinese production of soy flour is used as animal feed.

Cottonseeds contain less protein (30%) and that protein is of lower quality (56-58% reference protein). Furthermore, cottonseed must be processed in order to reduce or remove the toxic pigments known as gossypol.

On the plus side, the geographic distribution of the production of cotton is much closer to the distribution of protein-calorie malnutrition than that of soybean. Furthermore, many of the costs of producing the edible meal are shared jointly with the cotton lint used in apparel. Cottonseed flour is the basic source of protein in Incaparina, a high-protein mixture which has been successfully marketed in Guatemala and Colombia.

Human grade cottonseed flour containing about 50% protein is available in the United States at 11 cents per pound and has been sold in El Salvador at 5 cents per pound (24). The present source of Incaparina's cottonseed flour is in Nicaragua, and Incaparina's producer has recently purchased cottonseed flour from this mill at less than 5 cents per pound. Our later analyses indicate that, even at costs considerably above the latter, cottonseed flour is a very attractive protein source. Therefore, it is necessary to point out that this price history is based on a limited amount of data and that at present there is only one domestic and one foreign source of human grade cottonseed flour, and no one can be certain what the price will be under large scale demand. However, the present cotton production, 21 million tons of seed per year, could support any conceivable supplementation program. Furthermore, a gossypol-free cotton strain has recently been developed and introduced in Egypt. While it is too early to count on the widespread implementation of gossypol-free cotton, it does show considerable promise.

The third major oilseed, peanut, contains 27% protein of relatively low quality (34-54% reference protein). In addition, care must be taken to avoid spoilage because a toxic substance known as aflatoxin is produced in molding peanuts.* However, the relative abundance of peanuts in India, Senegal, and Nigeria and its low price --peanut flour containing 50% protein costs about 6 cents per pound--makes it an alternative worthy of consideration. (24)

* Aflatoxin can occur in any oilseed given improper handling and storage.

Supplementation With Synthetic Amino Acids

We have seen that 'protein needs' is a general term covering, more precisely, the requirements of the human for certain quantities of a number of amino acids and for nitrogen to synthesize the other amino acids. Often the natural diet is lacking only one or two of the amino acids rather than protein in general. The possibility thus arises of supplementing such diets with only those amino acids rather than with a whole natural protein. In terms of our earlier discussion of reference protein and protein quality, it may be possible to improve sufficiently the quality of the protein in a diet by adding small quantities of the amino acids lacking, so that the resulting mixture meets reference protein requirements.

Only three amino acids are likely to be critical in naturally occurring diets: lysine, methionine, and trytophan. Cereal grains in general are severely lacking in lysine. The efficiency of the protein in legumes, oilseeds, and animal protein is generally limited by methionine. These foods usually have more than enough lysine. Thus a diet combining wheat and beans may be limiting in either lysine or methionine, depending on the proportion of beans in the diet . Miller and Platt (25) have surveyed 42 diets, throughout the world and found that most of them were limiting in methionine. Corn is deficient in tryptophan as well as lysine. Thus, in areas which are heavily dependent on maize both these amino acids can be critical.

All these amino acids can and are being manufactured industrially either microbiologically or through chemical synthesis. However, only lysine and methionine are currently manufactured in commercial quantities. The current price of tryptophan is $41.00 a pound and that of threonine is $34.00, which limits these amino acids to clinical use (26).

On the other hand, human-grade lysine can currently be bought from the Japanese at $2.20 a kilo (27) and has been recently sold by American companies at $1.70 - $1.95 a pound (26). Feedgrade lysine and methionine can be bought for about 65-70¢ a pound (26). Methionine has proved to be a competitive supplement in animal feed, and the current world market is 25-30 million pounds a year, half of which is consumed in the United States, mainly by poultry. Food grade, methionine is presently sold in Japan for $2.50/kilo on $1.14/lb .(27)

American producers appear to be at a comparative disadvantage in the production of synthetic amino acids, and both Dow and Monsanto have recently shut down methionine plants in the face of foreign competition. In general, methionine appears to be easier to produce than lysine. For one thing, only one of the two enantiomorphs of lysine is useful in nutrition, which necessitates either microbiological production or resolution of the racemate obtained by chemical synthesis. With methionine, both forms are utilized, thus simplifying synthesis.

However, at very large scales, synthesis of lysine becomes more economic. At present, all lysine is produced biologically. The Dutch built a $10 million plant for lysine synthesis in 1966, but shut it down when they found there was no market. Mr. Esty of Merck Chemical Company estimates that an economical plant for lysine synthesis would require a market of ten million pounds a year. Our later analyses will indicate that 10 million pounds a year would adequately supplement the diet of several hundred million wheat eaters. Thus, achievement of economy for large-scale lysine synthesis would occur only with rather widespread adoption of lysine supplementation.

Given markets of this size, there is some evidence that the price of lysine could drop to the 70 cent level predicted for human grade methionine. The world market for human consumption of monosodium glutamate (MSG) is 40 million pounds (28). MSG for human consumption sells for 40 cents a pound wholesale and is produced microbiologically from the same sort of material from which lysine is made, mainly molasses. The stochiochemistry is such that about 50% more raw material is required per unit of output for lysine than for MSG, thus a cost figure in the area of 60 to 70 cents a pound does appear achievable, given large-scale production.

In our later analyses, we have chosen to be reasonably conservative and have applied a cost of $1.25 a pound to both lysine and methionine . We expect these prices to drop somewhat in the future. The base appears to be about 70¢/lb.

Fish and Fish Protein Concentrate

The remaining source of protein which has been suggested is fish, and more generally, aquatic animals. There is little doubt that the oceans in conjunction with even a pure grain-based diet produce enough protein to supply the needs of a population many times the present one. Using the aforementioned reasonably conservative estimateof 125 million tons of annual production of fish by the year 2000, results in an annual production of about 17 million tons of reference protein, which would be enough protein to supplement the diets of a population of about 19 billion people , assuming that the population received sufficient calories in rice, the cereal most lacking in protein.* However, demonstration that the ocean has more than enough catchable protein to meet even the most extravagant estimate of our present and future protein needs, assuming caloric requirements are met, is not a sufficient argument for recommending investment in fish as a protein supplement. It is only an indication that the idea should be carefully examined. In order to recommend investment, one must argue that fish are the least expensive feasible means of meeting a developing country's nutritional goals, which is a much tougher assignment indeed.

One of the primary difficulties in employing fish as a protein source in a developing country is that marine animals have perhaps the worst spoilage characteristics of any protein source. This problem has limited the consumption of fish to areas which are within a few miles of the landing site, or to areas which have a refrigerated or frozen distribution system. The developing countries in most need of protein often have little or no effective food distribution system , let alone facilities for refrigerated or frozen transport and storage. Thus, any attempt to market whole fish in developing areas not immediately adjacent to the landing areas is doomed to failure. Some success has been achieved in a few

* Assumes that all people eat the same diet according to their calorie requirements and the diet is supplemented to the ratio of reference protein to calories required if a one year old child is to obtain the FAO/WHO recommended levels of reference protein,given that he eats the diet according to his calorie requirements.

developing areas -notably Ghana- with smoking, however, the organoleptic properties of smoked fish are not particularly attractive in terms of our primary target group--the weaning child.

These two facts, the abundance of fish protein and the inability to distribute it in natural form, have led to the study of means of rendering the fish protein into a stable form which can be transported and stored for long periods of time without refrigeration. Improving the shelf life of fish involves two things:

1) extraction of the water which promotes bacterial growth,
2) extractions of the oils and lipids (fats) which oxidize and go rancid.

Since the oil contains the flavor of fish, this latter step has the advantage of removing, or at least reducing, the fish taste which can be a plus in cultures which are not accustomed to eating fish. Protein itself is almost tasteless.

The simplest means of accomplishing (1) and (2) above is to cook the fish in steam, press the oil out of the resulting product, and dry it. The result is called fishmeal. It usually has a protein content of about 65% and contains about 10% residual oil. At present fishmeal can be bought in Peru at about 7 cents per pound (29),and it is an important constituent of animal feeds in the developed countries. Over 30% of the fish caught worldwide becomes fishmeal (29). Fishmeal is not generally regarded as suitable for human consumption. For one thing, most fishmeal is made under conditions which are not sufficiently hygenic for human standards. More important,due to the remaining fats and oil, fishmeal quickly goes rancid and the tolerance of humans for rancid fat is considerable lower than that of animals. Furthermore, the flavor of rancid fish products is not universally appreciated. The rate at which fishmeal deteriorates under unfavorable conditions can be demonstrated by the fact that several vessels carrying South American fishmeal to the United States have caught fire due to spontaneous combustion, and this danger is reflected in special insurance rates for this cargo. Therefore, we will provisionally rule that untreated fishmeal does not come under our definition of fish protein concentrate on the grounds that it is not sufficiently stable, nor is it aimed at human consumption.

With this in mind, researchers have attempted to find ways of removing a higher proportion of the lipids from fish than can be accomplished with simple cooking and pressing. The resulting products we shall call fish protein concentrates. There are four main approaches to the production of FPC.

a) Solvent extraction.
b) Microbiological methods.
c) Precipitation in an aqueous solution of controlled pH.
d) Physical methods which can be used alone or in combination.

The solvent extraction systems basically use an organic solvent, generally an alcohol, to dissolve the lipids which are then separated from the insoluble protein by physical means.

The microbiological systems combine the ground fish with a microorganism which grows and produces enzymes (proteins which have the capability of breaking down other proteins into their constituent parts) which in turn reduce the proteins to water soluable peptides, which are then separated from the oily phase in a centrifuge. The aqueous phase is then dried.

The controlled pH systems make use of the fact that proteins become soluble in solutions of high acidity. The protein in this solution is then precipitated out by reducing the pH.

The most promising physical method involves mixing the commutated fish in a non-volatile liquid. The dispersion is heated in a vessel which is then quickly evacuated removing the water by flash evaporation. The dehydrated fish particles are then separated from the liquid by filtration or centrifugation and can then be extracted with solvent as desired. This processing method is still in very preliminary stages of development.

The most likely looking combinations of processes are aqueous extraction, followed by solvent extraction and the aforementioned combination of evaporation and solvent extraction.

Almost all the FPC made to date has been produced by solvent extraction. The resulting product is about 80% protein and contains less than .2% lipids. Taste runs from neutral to definitely fishy , depending on the raw material and processing details. Some solvent extracted FPC has been stored for as long as six years with little or no deterioration (30). The product is insoluble and has a definite tendency toward grittiness. The nutritional efficiency of the protein, assuming proper preparation, is quite high, being about 80% as effective as reference protein and about the same as the protein in milk. This nutritional effectiveness and the nontoxicity of the product have been established by extensive testing in both animals and humans.

Microbiological methods offer a far greater variety of end products, in terms of flavor and other functional qualities, than does solvent extraction. Solubility and the binding properties of natural fish protein can be preserved. At present, however, the development of these processes has not advanced to the stage where commercial economics can be predicted.

Two approaches to the pH adjustment route have been undertaken. The Dutch State Mines have had a pilot plant in operation for several years. The product is a pure, tasteless, white soluble powder. Nothing is known of the product's nutritional characteristics and people close to the method are not impressed by its economics. Recently, the Bureau of Commercial Fisheries has developed an aqueous extraction process, and the product is currently being tested. The cost of this process for commercial use cannot yet be predicted.

The Present Status of Fish Protein Concentrate

After pioneering efforts by Dr.Ezra Levin dating back to 1931 and some preliminary work in South Africa, modern attempts to produce and distribute fish protein concentrate began with the attempts in 1956 of UNESCO to establish an FPC plant in Quintero, Chile*. This plant had the capability of producing about a ton of FPC per day (seven tons per day input). This plant utilized extraction by ethyl alcohol of the local hake, a lean white fish. The initial output of this plant supplied the raw material for most of the acceptability studies of FPC that have been undertaken. No FPC has been produced at this location in the last six years.

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* Fermented fish products were known to the Romans and have been used as fish sauce in the Orient for at least four centuries.

Also in 1956, the Fishery Industry Research Institute of South Africa established a pilot plant based on ethanol extraction to produce fishmeal. Considerable research on various solvent mixtures has been undertaken by this group. This plant also supplies the FPC for the only successful example of commercial marketing of FPC, a relatively high protein (22%) food known as Pronutro, which for a while contained a small percentage of FPC, and is marketed for 28 cents a pound in South Africa. Sales of this product reached 1800 tons per year in 1964 (24). It is symptomatic of the problem that while this product was originally aimed at the undernourished black, it is being bought and consumed primarily by middle-class whites.

In 1957, the Fisheries Research Board of Canada began experimentation on solvent extraction of FPC using isopropanol preceded by an acidification step. This effort has culminated in the recent decision (May 1969) of Cardinal Proteins Inc. to build a 200 tons a day input (30 tons output) FPC plant based on this process in eastern Nova Scotia (31). Cardinal is now buying equipment and expects to be in operation in 1970. We will discuss this operation in more detail in Chapter IV.

In 1961, Congress appropriated funds to study the advisability of a research effort in FPC in the United States government. In 1963, an annual appropriation of $500,000 was granted to the Bureau of Commercial Fisheries for this purpose. Research was commissioned on a variety of production processes. However, in late 1964, BCF opted to concentrate completely on the development of a particular process, isopropanol extraction. The main motivation was to present concrete evidence to the Food and Drug Authority to induce them to remove the prohibition on FPC made from whole fish. By 1965, a pilot plant (100 lb/day) was in operation. Despite this initial success, industry showed no great enthusiasm for entering into the production of FPC, citing the risks. The decision was made to construct a demonstration plant of about 50 tons per day input. Congress was asked for one million dollars to build this plant in fiscal year 1968. However, after receiving the money it was discovered the plant would cost about $1.8 million and the BCF returned to Congress for the additional funds, which were supplied in late 1969. Construction is scheduled to begin in December 1969, with operation by late 1970.

In a parallel American effort, the Viobin Corporation in 1967 began modification of an existing animal grade fish concentrate extracted by ethylene dichloride. This product is made suitable for human consumption by the addition of an isopropanol wash to the process. In 1968 this plant, located in New Bedford, Mass., was sold to Alpine Corporation. This plant has the capability of producing 15 tons per day. Also in 1968, the Agency for International Development contracted with this organization for the delivery of 970 tons of hake based FPC at 42 cents/pound with which it intends to conduct worldwide market surveys. Delivery of the FPC was delayed by a multitude of problems, including the lack of availability of hake and problems in controlling bacteria count. In October 1969, the first 25 tons of this product were accepted by AID. However, subsequent difficulties in meeting specifications have forced cancellation of the contract.

In 1966 the FDA, in response to petitions from the BCF and Viobin and after a study by a committee of the National Academy of Sciences, ruled that FPC produced by either the BCF or Viobin process based on hake or hakelike fish could be distributed in the United States in clearly marked 1 lb. packages provided that the fluoride content was less than 100 ppm. As we shall see, while this ruling represented a considerable change in philosophy the provisos effectively bar FPC from domestic distribution. BCF is currently attempting to have the species and distribution restrictions lessened and it appears there is considerable sympathy with FDA for their requests.

A variety of other FPC efforts are currently in various stages of operation. Dutch Federal Mines has a pilot plant in Tijerlands, Netherlands, based on precipitation of the protein via the adjustment of the pH of an aqueous solution. Astra Products of Sweden has the capability of producing (12 tons a day of human grade FPC) based on ethanol extraction of fishmeal.(32) This product has been accepted by the Swedish Health authorities. In 1965, FAO and the

Moroccan government established a 3 ton a day plant in Agadir, Morocco based on extraction of fishmeal with hexane vapors. This plant produced 150 tons of FPC in 1966 but has not operated since. An attempt to resurrect the plant was made in the summer of 1969, but no significant recent production has been reported.

Several plants, one on a barge at Cape Flattery, Washington and number in Peru that currently produce a solvent-extracted fishmeal claim the ability to transfer to human grade FPC as soon as the market develops. (33) Given the difficulties of the Alpine Plant in achieving this conversion, it is not clear that the change over is all that easily accomplished. An American firm, Oceanic Development Corporation, has recently committed itself to the construction of a human grade FPC plant based on the Viobin process in Baja, California. They expect to be operating a 200 ton input per day plant by mid or late 1971, with planned expansion to 800 tons per day input over a four year period. We will discuss this effort in more detail in Chapter IV.

The Japanese, East Germans, Russians, and Poles have been reported to be experimenting with FPC production; the latter two appear to be envisioning the accomplishment of at least the first stages of processing at sea. However, no commerical production has been reported.

While it is fairly clear that raw fishmeal is not a suitable food for human consumption on a continuing basis, it is also unclear whether the high standards which have been adopted for FPC production by the developed countries and such international bodies as UNESCO and FAO are necessary. A number of installations are presently making a solvent extracted fishmeal which has a fat content on the order of 1%. This product is presently marketed as a high quality animal feed and for use in pet foods where the odor of raw fishmeal adversely effects marketability. Several authorities have suggested that this product be used for human consumption. This approach has been followed by Verrando S.A. in Peru which presently has a plant based on extraction of fishmeal with hexane vapors capable of producing 180 tons of FPC per month (34). The product is neither tasteless nor odorless and its storability is not well known. However, the product sells for 12 cents a pound which is less than half that of ordinary FPC which has fat contents of less than .2%. Varrando claims acceptance of his product for human consumption in Peru and plans a line of noodles and cereals fortified with this FPC. Verrando plans to expand to a capacity of 1000 tons per month. However, there has been little scientific study of the properties of this product and its acceptability. (One observer who has eaten a meal supplemented with Verrando FPC predicts that acceptability will be a real problem.) However, given the difference in costs, a careful study of lower quality FPC is certainly well deserved.

II. 2. Cost Benefit Analysis

Introduction and Potential Benefits of Increased Nutrition

Any protein supplementation plan necessarily involves a diversion of the developing country's limited resources. An increase in the consumption of protein will result in a decrease in expenditures on some other item. If the developing country is to behave rationally, the benefits which accrue from the investment in protein must be greater than the benefits which would accrue from the most beneficial alternative use of the resources required to make the protein available. In short, the protein needs of a developing country's population compete with many other valued uses of the country's resources.

The only point of stating this tautology is that it is often denied by nutritionists who attempt to place the satisfaction of human nutrition needs on a separate plane from other investments, claiming that such demands deserve absolute priority over other uses and that these demands by their very nature need no further justification. Not only does this attitude immediately raise problems with respect to just what level of nutrition deserves this kind of priority, but also it clearly is not shared by the planners and, more importantly, by the population of the developing country who often choose to begin to satisfy other needs before reaching the nutrition levels advanced by the nutritionists.

Given that protein needs properly compete with other demands for resources, how do we determine what level of protein nutrition the developing country should purchase? In order to answer this question, one must postulate an objective for the developing economy and rarely are the developing countries able to articulate an operationally useful objective. However, it is clear that the developing country must be concerned with two sets of questions in considering any investment in protein:

1) the overall efficiency of the economy, and
2) distributional considerations.

Efficiency considerations relate to the size of the pie available, while distribution relates to who gets what share. Efficiency is the motivation behind such goals as maximum gross national product and maximum real rate of growth. As Hierschliefer et al. (35) point out:

> "Someone may propose reducing income taxes in the upper brackets on the ground that the high rates now effective there seriously deter initiative and enterprise and so reduce national income; he is making an efficiency argument that the present taxes reduce the size of the national pie. Someone else may point out that such a change will help large taxpayers as against small-- a distributional consideration."

Most of what the existing body of economic thought has to say concerns the efficiency effects -the effects on the size of the pie- of alternate possible allocation of resources. However, there is an extremely important sense in which the enlargement of the size of the pie may be said to be good for all the eaters. This sense turns upon the possibility of dividing the enlarged pie in such a manner that everyone benefits. If this can be done, then clearly the larger the pie the better. This thought underlies and is the justification for the concentration of developing countries upon the maximization of their national product or more precisely, national product per capita. Unfortunately, as the above example points out, it is often the case that such redistribution of the enlarged pie is infeasible. In such situations, legal and ethical considerations must be weighted against economic on a case by case basis. Nonetheless, given the basic attractiveness of maximum GNP as an objective and, more to the point, government acceptance of this objective, nutritionists, if they hope to obtain a significant share of the developing country's resources, must be prepared to argue the effects of increased nutrition on national economic growth.

Dr. Allen Berg,(36), head of the AID nutrition program in India, for one, accepts this responsibility and has divided the potential effects of increased nutrition which relate to the economic welfare of the developing country into the following five categories:

1. Disease prevention.
2. More productive population distribution.
3. Higher productivity, mental and physical per person.
4. Easier population control.
5. Increased political stability.

Disease Prevention

It is well established that malnutrition increases the frequency and severity of infectious disease and further, that malnutrition and infectious disease react synergistically upon each other. There exists the possibility, therefore, that investment in improving protein nutrition will reduce the investment in curative medicine without reducing the overall health of the population. Certainly the total number of days of illness will be appreciably reduced. However, at present, it is impossible to quantitively predict the effect of a nutritional program on health. The few field studies which have been done to date have been somewhat disappointing reflecting, no doubt, the fact that health is a closely coupled product of sanitation, general level of medical care, and a number of cultural factors, as well as nutrition.

Two obvious, but sometimes overlooked, inferences which can be drawn from these experiences are (a) for maximum effectiveness, that investment in infant health should be allocated among the various causative factors according to their effectiveness at the margin, rather than giving absolute priority to one or two of the causes and (b) any nutritional program aimed at contributing to this effort must be designed to operate in the actual environment. We shall see that the latter has important implications in the choice of the target level of nutrition.

More Productive Population Distribution

Once the effect of protein deficiency on mortality has been isolated, it would be an easy matter to predict the effect of increased protein on the age distribution of the population. At present the developing countries are severely handicapped by the large percentage of children in the population. This is the result of the high child mortality rate which impels people to produce more children to ensure some living ones. In West Africa 45% of the population is less than 15 years old as compared to 25% in Europe. Table II compares the population distribution in the less developed with that in the developed world. The implication is clear. In the less developed country a much smaller proportion of the economy is productive which in turn implies slower economic growth. The less developed countries make a large investment in children who reach a productive age.*

However, until we are able to separate the effects of protein malnutrition from all the other environmental causes of child mortality, we cannot quantify this potential benefit of improved nutrition. At present all we can say is that it is undoubtedly important.

* Of course, the first effect of a decrease in infant mortality would be an even younger population. The crucial questions then become, how soon will people react to the new situation, and can the economy weather the interim period?

TABLE II

PERCENTAGE OF POPULATION UNDER 15 YEARS OF AGE IN DEVELOPED AND UNDERDEVELOPED COUNTRIES

DEVELOPED[a]	% OF POPULATION UNDER 15	UNDERDEVELOPED	% OF POPULATION UNDER 15
U.S.	30.7	Chile[b]	39.5
Canada	33.2	Peru[b]	43.2
Germany	22.6	Mexico[b]	44.3
France	25.2	Dahomey[c]	45.9
Sweden	21.0	Mauritania[c]	50.6
Japan	24.7	Cameroun[c]	48.6

a Basic statistics of the Community, Statistical Office of the European Communities, December 1967

b Statistical Abstract of Latin America, Latin American Center, University of California, Los Angeles, December 1968

c Yearbook of General Statistics 1966, Statistical Office of the European Communities

Higher Productivity Per Capita

One of the most striking differences between the population of the less developed countries and that of the developed is body size. And, in fact, these differences in body size are perhaps the second most often cited argument - next to kwashiorkor- for the existence of widespread protein malnutrition. An almost certain output of increased nutrition would be an increase in height and weight of the population. However, increased body size in itself is not necessarily a goal,and the economic effects of this increase are far from clear. There is no doubt that a larger man can do certain things a smaller man can not do; however, even in those jobs which are exclusively physical, it in unlikely that productivity rises linearly with height or weight, and yet the body's nutritional requirements rise almost as fast as body weight. This latter increase is an extremely important consideration in a typical developing economy which spends 60% of its income on food.Furthermore, the number of jobs in which physical strength is an important asset is small and declining. In the United States, small size is rarely a handicap in job performance. If one were to increase nutritional standards in a generally undernourished population, one would in time increase the size of the entire population as a whole, but reap benefits only in those few jobs where productivity increased faster with body weight than did nutritional requirements.

The primary effect of protein malnutrition on adult productivity is through childhood deficiency resulting in decreased mental capability. Cravioto and de Licardie (2) have demonstrated a clear correlation in poor segments of the population in Guatemala between height and ability to relate visual and kinesthetic identification of various shapes. In a sample of 296 lower income Guatemalan children from six to eleven years old, the lower quartile in height were two years behind the upper quartile in performance. Cravioto also noted that for these children there was no correlation between height of parents and height of children.

This is a general phenomenon for low income groups in developing countries which runs counter to the developed countries' experience. Environmental influences are more important than genetic developments in the growth of these children. Thus for these groups, height is a valid indicator of the child's former nutritional environment. The shorter children in this sample almost certainly suffered more nutritional deficiencies than the taller. Cravioto's findings do not prove that such pyscomotor deficiencies extend into adulthood; however, this is the clear implication.

It is important to recognize that many more children survive protein calorie malnutrition than die of it. In 1952 approximately 30% of the children who came to medical attention with severe protein-caloric malnutrition died, while less than 5% of those affected with equal severity died during the years 1962 to 1965 (2).

When malnourished children start to recover, they do so with great rapidity at first. However, some observations indicate the recovery rate is not excessive in terms of younger children who are the same size as the malnourished child. The weight gain appears to be size dependent. These higher than normal rates of growth on an age basis have important implications for any nutritional program, especially during its initial implementation. The few studies of malnourished children which have been carried to adolescence indicate that growth in length ceases at the same chronological age as it does in well nourished children due to closure of bone epiphyses; as a result these children never quite catch up in body size, thus the previously mentioned correlation between adult body size and prevalence of malnutrition.

The Russians have carried out some studies on the relationship between nutrition and higher nervous activity. Alekseeva and Kaplanskaya-Raiskaya (37) have reported that protein deficiency has a marked effect on the ability of young children to acquire conditioned reflexes. If this deficiency is continued, even previously well established reflexes may be depressed or abolished. These effects occur in advance of the clinical symptoms of severe malnutrition. Recovery of normal ability to elaborate these reflexes is reported to be slow.

Many investigators (38, 39, 40, 41) in the field have noted psychological disturbances in children suffering from kwashiorkor. Severely protein deficient children are universally characterized as apathetic, seeming to have little of the normal curiosity and desire for exploration that is natural in a young child. This condition of unresponsiveness is so marked that renewal of interest in the environment is considered one of the most reliable signs of improvement. Several investigators (42, 43, 44) have used electroencephalography as a method for measuring the effect of malnutrition on the nervous system. On admission, the EEG records of severe cases show very substantial abnormalities in form, frequency, and amplitude. However, with recovery patterns they became normal. In general, the abnormal features took no more than 40 days to disappear. Thus, it is clear that malnutrition has a substantial effect on the brain. The permanence of this effect, however, it still unknown.

Stoch and Smythe (45) tested two groups of 21 children in South Africa. Initially, these children were between the ages of 10 months and three years. Both groups came from the same low socio-economic background. One group was characterized as better nourished. These children attended an all-day nursery, allowing both parents to be employed. The I.Q. of the parents of the two groups as tested by the Raven Matrices Test was not significantly different. All the children were examined every six months for I.Q. by means of the Merrill-Palmer test. The results indicated that at all ages the mean intelligence quotient of the undernourished groups was well below that of the better nourished group. The disparity remained relatively constant throughout the period. The difference of 22 points found at the time of final testing is statistically significant at the .01 level. However, interpretation of these findings is obscured by the differences in social and economic background and in nursery school experience of the two groups.

It is of some interest that results indicate that newborn infants in preindustrial areas such as Uganda, Mexico and Guatemala have scores in pyschomotor tests which are generally higher and never below those obtained by North American and European children (46, 47, 48). This indicates that there appear to be few prenatal nutritional deficiencies. Soon after birth these children begin to develop relatively slowly compared to their industrial cousins, so that beyond the ages of 18 to 24 months their mean performance is below that of their European contemporaries.

Ramos-Galvan (49) has noted correlation between height and performance scores on the Terman-Merrill test among poor children in Mexico. He found that mental ages were better associated with height age than chronological age. This finding also suggests a concurrent deceleration of somatic and mental growth.

Barrere-Moncada (50) has explored the psychological behavior of severely malnourished children by the Gesell technique. Performance in all areas was lower in the malnourished than the standard for well nourished children of similar age and ethnic group. This is one of the few tests that attempted to test various psychological attributes separately. In general, motor development showed the least and language development the greatest retardation. In this test, the older the child the more marked the findings.

Cravioto and Robles (51) also tested a group of severely malnourished children according to the Gesell method. Serial information was taken on 20 hospitalized malnourished Mexican children ranging from six months to 42 months in age. Initial tests confirmed the previous reports. The children scored below the norms in all areas. As recovery from malnutrition occurred, the gap between normal age expectation and actual performance decreased for all except those children who were admitted to the hospital at less than six months. These children showed no tendency to catch up. In the older children speech, which in general was the function most affected, showed the slowest rate of return.

In Chile, Monckeberg (52) examined fourteen children who had suffered severe marasmic malnutrition during the first six months of life. Marasmus refers to the symptoms associated primarily with severe, general malnutrition. However, since a caloric deficiency almost certainly implies a lack of protein utilized in tissue generation, the findings are relevant to our present interest. The children were treated and after some time discharged. Their progress was followed and each patient received a total of 20 liters of free milk per month with a similar amount for all other infant and preschool children in the family. The children were later examined at ages three to six years. All appeared clinically normal. Weight in every case was past the third percentile of the Iowa standard population, but height in every case was below this level. For almost every child, the ratio of sitting height to total weight was more than two standard deviations below the average for Chilean children. Head circumferences were well below normal. The average intelligence quotient of the group was significantly less than that of the average Chilean preschool children of low socioeconomic state at the P = .001 level. The authors comment:

"The results of the physical and psychological tests have led us to conclude that brain damage in infancy is permanent at least up to the sixth year of life, despite improving nutritional conditions. . . It is recognized that brain growth takes place primarily during the first months of life and is largely a process of protein synthesis..."

They go on to suggest that the relative permanence of the effect as compared to some of the other I.Q. results is a result of the very early age at which the child suffered the malnutrition. They note that malnutrition at the age of less than six months is a relatively modern phenomenon due largely to the remarkable decrease in breast feeding during recent years in Chile. This latter phenomenon is associated with industrialization and urbanization.

In the more traditional cultures where breast feeding is prolonged, infant malnutrition is not significant until the latter half of the first and during the second year. Thus, the cultural effect of urbanization can be expected to have increasingly and perhaps critically important implications for infant nutrition in the future.

While it is impossible to quantify the effects of improved nutrition on productivity, several things are clear.

1) The improvement in per capita physical productivity as a result of increased body size is unlikely to be of great economic importance in itself, especially since it is necessarily connected with a significant increase in nutritional needs.

2) Protein-calorie malnutrition in the very young has a marked effect on mental growth and substantial evidence suggests that the severely malnourished child will have some mental disadvantage for his entire life. The younger the age at which this malnourishment occurs, the more permanent the effect.

3) With urbanization and the resultant shortening of the breast feeding period, there is a trend toward earlier malnourishment.

In short, protein calorie malnourishment in the very young is likely to be an extremely important factor in the mental productivity of the developing country's population.

Population Control

The effect of improved nutrition on the subject of size of the population is one of the most controversial and important aspects of protein programs in developing countries.

It is clear that if the program has any significant effect, the short term response will be a rise in the population growth rate due to decreased mortality. Since many of the developing countries are barely maintaining per capita income as it is, this can hardly be regarded as an unalloyed benefit. This fact has been seized upon by some national planners to argue against expenditures for improving nutrition. Others argue that not only will those who survive, who comprise the vast majority even under current nutrition standards be more productive, but also that the long term effect of decreased child mortality will be a decrease in the birth rate.

There is some evidence that lower class Indians, in deciding how many children to have, behave as if they are attempting to ensure the survival of an adult son. The average number of births per fertile Indian women is six which, at Indian mortality rates, yields a .95 probability of an adult son (36). Investigations of developing cultures have universally noted the importance of surviving children in determining the economic welfare of the parent in old age. If the survival of children to adulthood is the real motivation behind parental childbearing decisions, then cutting the death rate will result in a decrease in the birth rate. The much lower birth rates in the developed countries are cited in support of this argument.

While one can be reasonably confident that the decreased infant mortality rate will eventually result in a decrease in the birth rate, there is little concrete evidence on which to base an estimate of how soon this will happen. Once again, in this area, reliable relationships between nutritional programs and their socio-economic effects are lacking.

The Effect on Political Stability

Increased nutrition may have a very basic effect on the political stability of a developing country. Berg cites this aspect as one which is uppermost in the minds of some planners. (36) Once again, however, reliable estimates of this effect are lacking. We cannot even predict which direction the effect will take. People whose mental and psychological faculties have been dulled by malnutrition are hardly the stuff of which revolutionaries are made. On the other hand, the existence of malnutrition in others, especially in the young, is an eloquent argument against the status quo. At least among the Indian officials that Berg cites the opinion was that the net effect of improved nutrition would be to increase stability. The value of increased stability can, of course, be positive or negative, depending on one's political and social viewpoint.

Summary

Our survey of the state of knowledge regarding the relationships between improved nutrition and its socio-economic effects has, on the whole, been very disappointing. In the areas of population control and political stability, we were unable to postulate with any degree of confidence the direction of the effect. With respect to disease, it is clear that malnutrition is an important concomitant of infant disease in developing countries, but the quantitative knowledge is far from abundant. We were able to identify an important relationship between malnutrition and mental development, but the frequency and magnitude of this effect is unknown. In short, there can be no doubt that malnutrition is an important factor in the development lag of the pre-industrial countries. However, at present it is impossible to say just how important it is and to identify quantitatively all the mechanisms through which malnutrition affects the socio-economic characteristics of the developing country. Without such relationships, cost-benefit analysis is impossible. Therefore, we must move to a less comprehensive point of view in examining alternative protein supplementation programs.

A corollary of this is, that nutritionists are at a disadvantage with respect to proponents of capital projects in arguing for a share of a developing country's limited resources. Given the present and future magnitude of the nutrition problem, establishment of the relationship between nutrition and economic welfare should be a high priority research area.

II. 3. Cost Effectiveness Analysis

Introduction

Given his inability to value the benefit to a developing economy which will accrue from a protein supplementation program, the systems analyst is forced to fall back on cost-effectiveness analysis. That is, we must somehow postulate a level of nutrition and then search for that alternative which accomplishes this level using the minimum amount of the developing economy's limited resources.

This poses the conceptual problem of what level of nutrition we should choose. Perhaps the ideal cost-effectiveness analysis would involve the determination of the least cost alternative for a range of levels of nutrition, which analysis would generate curves such as those shown in Figure II. This relationship would then be presented to the developing country's decision makers, and they would choose the target level with full knowledge of the costs involved. However, to generate this relationship for even one developing country is beyond the scope of this report. Nonetheless, it is worth pointing out that, rationally, you cannot decide what level you are going to buy until you know how much it will cost you.

Figure II is also relevant to a common fallacy in the evaluation of alternative supplementation programs, which we might term the ratio test fallacy. Some people attempt to avoid the choice of a level of nutritional effeciency by postulating as an objective the minimization of a ratio such as cost per unit of protein nutrition, for example, dollars per pound of utilizable protein. Consider Table III, reproduced from Hegsted (53), which gives this ratio for a number of wheat-supplement alternatives. For the purposes of this paragraph, we need not concern ourselves with the price assumptions or the exact definition of utilizable protein. For the moment, it is sufficient to assume that utilizable protein is a good measure of nutritional effectiveness.

According to this Table, the alternative shown which minimizes this ratio is wheat plus 10% FPC. However, the last two lines are revealing. They indicate that this ratio decreases with increasing FPC and, in fact, according to the assumptions of this

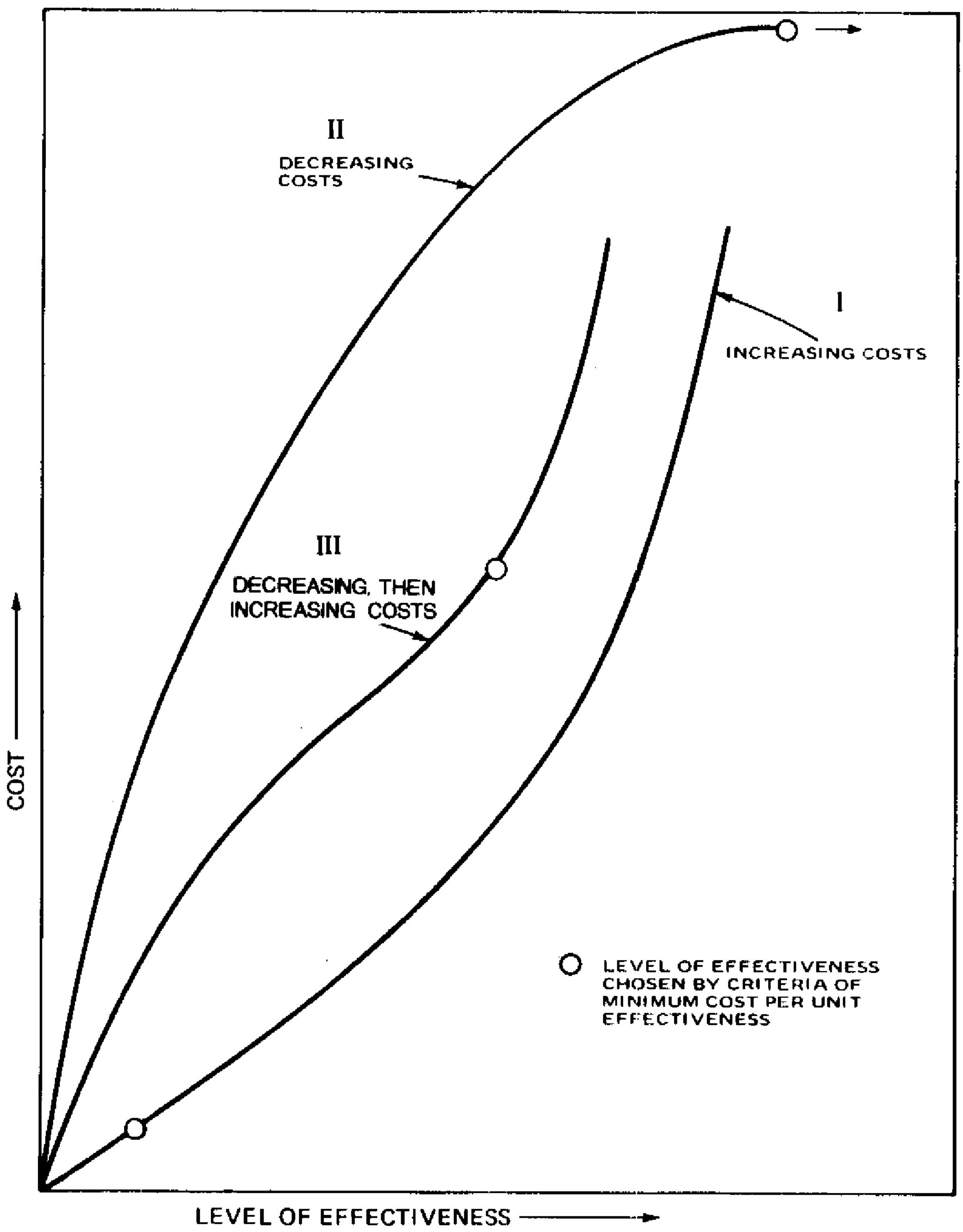

FIGURE II THREE POSSIBLE COST EFFECTIVENESS RELATIONS

TABLE III

EFFECT OF SUPPLEMENTATION OF WHEAT FLOUR UPON THE NUTRITIVE VALUE OF PROTEIN AND RELATIVE COSTS OF UTILIZABLE PROTEIN[a]

	% Protein Content	% Utilizable Protein	Cost $/100 lb.	Cost of Utilizable Proteins$/lb.
Wheat Flour	13.75	3.20	8.00	2.50
Wheat Flour + 0.2% lysine. HCl	13.94	5.30	8.20	1.55
Wheat Flour + 0.5% lysine. HCl	14.25	6.55	8.50	1.30
Wheat Flour + 0.5% lysine HCl + 0.3% Threonine	14.55	8.14	8.80	1.08
Wheat Flour +5% FPC	16.66	7.00	8.85	1.26
Wheat Flour + 10% FPC	21.26	10.68	9.70	0.91

a Hegsted, D.M. American Journal of Clinical Nutrition June, 1968.

table, 100% FPC would have a cost per lb. of utilizable protein of 31 cents. The point, of course, is that this ratio keeps decreasing with increasing levels of protein. Thus, in terms of Figure I, we have a situation like curve Number II. Yet, no one would recommend the extremely high level of protein which would minimize this ratio. In fact, as we shall see in Chapter IV if one accepts the FAO/WHO protein recommendations as the target level, usually the least expensive means of meeting this requirement results in a rather high cost per pound of utilizable protein.

The point is that, in accepting a ratio test such as cost per unit of nutrition as an objective to be extremized, we are implicitly selecting a level of nutrition. If the cost-effectiveness curve looks like Curve I in Figure I, then this ratio will pick out an unacceptably low level of nutrition. If the cost effectiveness curve looks like Curve II, it will point to an unrealistically high level of nutrition. If it looks like Curve III, it will pick out the knee in the curve, which may or may not make sense depending on where the knee is located. In sum, ratio tests can be dangerously misleading and should be avoided. There is no alternative to selecting a level of nutrition and then searching for the minimum cost means of meeting that level. Often the level that must be chosen is multi-dimensional. That is, one must specify more than a single nutritional quantity to characterize the nutritional effectiveness of a program. For example, at the very least one must specify both a protein and a calorie level.

Failure to do the latter and then evaluating competitive alternatives on the basis of cost to meet protein requirements will fail to consider differentials in the calories supplied by differing alternatives. A case in point is the General

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* It is easy to show that minimizing the cost per unit effectiveness leads to the point on the cost-effectiveness curve which minimizes the slope of the straight line between the point and the origin.

Oceanology study of FPC in Korea (53a) which after a series of assumptions calculated the cost of supplying a stated level of protein by a variety of different methods. Despite the fact that the alternatives considered supplied very different amounts of calories and the data exhibited showed that calorie supply was as marginal as protein, the report took no cognizance of this differential in calories. In short cost-effectiveness analysis which concentrates solely on one dimension of the problem, can like ratio tests, lead to misleading results. In actual practice, ratio tests and concentration on a single dimension are often combined.

Another ratio test which has sometimes been suggested as an objective is maximization of the ratio of weight gain to total protein consumed. This ratio is known as the Protein Efficiency Ratio, or P.E.R. It derives its popularity from the fact that it is a relatively easy quantity to measure. Given a particular supplement, maximizing P.E.R. does not lead to nonsensical protein levels, as minimum cost per unit protein can, for it will call for levels of protein in excess of those required to maintain nitrogen balance, otherwise the numerator of the Protein Efficiency Ratio is zero. At the same time, it will call for levels below those at which the target population is not utilizing the marginal increment of protein, for increasing protein above requirements will increase the denominator without changing the numerator. Thus, the indicated level will be high enough to support growth, but less than that at which additional protein cannot be utilized.

On the other hand, this objective takes no account of the cost of the protein. If one chooses to maximize P.E.R. when comparing various sources of protein, one will always pick the highest quality protein, although the requirements of the person may, and usually will, be satisfied by larger quantities of a less efficient but less expensive protein.

In short, the objective maximum P.E.R. has no economic foundation and cannot be used to compare alternative sources of protein.

Choice Level of Nutrition

With regard to the choice of target level of nutrition for a developing country, most nutritionists would agree with the goal enunciated by Call (54): "...The alteration of consumption patterns in such a manner that, for all segments of the population diet is no longer a limiting factor in development." Efficiency requires that we achieve this goal with a minimum of the developing country's limited resources.

The important word in this goal is consumption as distinguished from production. Production is a necessary, but not sufficient condition for consumption; and unless the protein is consumed, production is pointless. The costs of distributing and promoting a particular supplement are properly charged to that supplement. This is an obvious tautology. Nonetheless, it is worth repeating in view of the fact that federal protein programs appear to have emphasized production almost exclusively.

Despite the obvious importance of the demand side of the problem, little is known about the relationship between the functional qualities of the various alternative supplements, including FPC, and their acceptability to the target population.

Acceptability of Alternative Supplements

The acceptability of dry skimmed milk is, of course, well documented, although in some areas of Africa it is known as "the stuff that causes diarrhea." This is probably due to deficiencies which have been observed among some negros in the enzymes which digest the complex sugars in milk. The relative intolerance of black children for lactose poses a considerable problem for milk supplementation, especially since a symptom of protein-calorie malnutrition is diarrhea, which symptom may prompt the mother to cut off the child's milk supply just when the protein is needed most.

However, with the above important exception, dry skimmed milk's close relation to mother's milk, its versatility, flavor, and its enhancement of the functional qualities of most of the foods with which it is used rank it high on the list from the point of view of acceptability.

The acceptability of the oilseeds as a source of protein is also reasonably well documented. Incaparina, a high protein supplement made up of 38% cottonseed flour has been successfully marketed in several Central American and South American countries. In general, we are considerably further along in the manipulation of the characteristics of soy protein than we are in the modification of the attributes of FPC. Soy protein is available in forms ranging from highly flavored products of fermentation, used as sauces in the Orient, to an almost neutral, soluble flour through which a high protein soft drink has been successfully marketed in Hong Kong. With soy, some problems with respect to flatulence are encountered, but in general, present technology is such that soy protein can be put in a form acceptable to almost any culture.

Synthetic amino acid supplementation presents a relatively simple problem from the demand side; since the level of supplementation, generally about 1/4 of 1%, is so low that it has no effect on the qualities of the food supplemented. Synthetic supplementation is limited more by the need for careful control and central processing of food than by effects on the organoleptic characteristics of diet.

Acceptability of FPC

All the acceptability tests conducted on FPC to date have been based on the solvent-extracted product, which is not soluble and has a rather gritty or chalky feel. It has no binding properties. In this form it can be expected to add little to the attractiveness of the host food. Furthermore, for all practical purposes, its application is limited to solids, an extremely important consideration in infant feeding. Finally, some of the samples of solvent extracted FPC which we have examined retain a slight fishy flavor which, while not unpleasant and rarely noticeable in the final product, will rarely enhance its acceptability.

Most of the actual studies of FPC acceptability have been undertaken in Chile. The odor and taste of fish are generally disliked by Chileans, thus in this culture we are looking for a neutral product. Tests were conducted employing ethanol extracted FPC in both bread and pasta (55). Bread was prepared containing 0,3,6,9, and 12% by weight FPC. The authors comment:

"The addition considerably and progressively deteriorated the properties of the dough and the quality of the baked bread. By altering the standard fermentation and baking times and by the addition of sugar a suitable though darker bread was produced. Adults and school children were given the enriched bread. Three groups of 30 adults each were used: university students of both sexes, nursing mothers, and male manual workers. The test consisted of asking each to give two judgments:
1) on the normality (normal-different) of color, odor, and taste;
2) on the taste (good-indifferent-bad) of the samples . . . "

TABLE IV

Level of Enrichment (%)	Good			Indifferent			Bad		
	w	m	u	w	m	u	w	m	u
0	27	27	20	3	3	8	0	0	2
3	22	25	16	7	5	13	1	0	1
6	20	26	15	8	3	11	2	1	4
9	14	24	16	12	5	14	4	1	0
12	18	22	16	5	8	6	7	0	8

Total number of tasters = 30. W = workmen, M = mothers
U = university students

In general, there is a jump in the "poor quality" judgments at about the 6% level, and a general though hardly overwhelming trend for Bad and Indifferent ratings to increase with increasing FPC. The investigators continue:

"The acceptability of bread enriched at the 9% level was also tested on 175 school children of both sexes, seven to fourteen years old, from working class families. At lunchtime their normal bread was exchanged for the enriched bread. No bread was left over, every child said he liked it, and 140 of 175 said he expressed preference for the FPC-enriched bread."

Tests were also conducted using pasta enriched to the 10% level, which has considerable advantages over bread in storage properties as well as the fact that this food is more suited to central processing than bread is

"Acceptability studies were conducted with adults and children. Adults were hospital personnel (150, male and female) and hospital patients (300, male and female). They were given a ration of 300 g. of cooked FPC enriched spaghetti without knowledge of the actual compositions. In no case was there a refusal or suspicion of the real nature of the spaghetti. ...150 school girls six to fifteen years of age were subjects for testing. The children regularly attended a school of a benevolent society. They were given a ration of 300-400 g. of cooked spaghetti three times a week for three months. ...Acceptability was excellent. No cases of refusal, initial or acquired were reported. Also, no abnormal gastrointestinal complaints were reported by the girls in their medical checkup."

Roasted whole wheat meal is consumed by lower income rural groups in Chile in the form of gruel known as ulpo. Ulpo containing 10% of the Quintera FPC was given to 300 young children and 50 adult women at a community care center.

"Everyone accepted it readily and many asked for a second helping. The women were not aware that the product contained fish." (56)

Recently, AID officials have prepared pasta and doughnuts from the Viobin process FPC and have distributed these foods to several hundred children under a school lunch program. No refusals were recorded and comments were favorable despite the fact that the AID officials were able to detect a slight fish taste in the warm doughnuts.

All the above experiments were based on FPC made from hake. There is some recent evidence that FPC extracted from oily fish may not rank as highly from an acceptability point of view. Tables V,VI, and VII compare the results of a sensory evaluation of bread, cookies and pasta enriched by FPC made from various species. In general, the acceptability of oily fish ranked significantly lower in appearance than hake FPC and considerably lower in flavor. There was little difference in texture. We shall see later that a commercially viable FPC industry will have to rely heavily on oily fish supplies. The point here is that the relative acceptability of hake-FPC should not be extrapolated uncritically to other species.

Clearly, the above data are a far cry from a market study. However, a tenable conclusion is that at levels on the order of 5%, solvent-extracted hake FPC has little or no effect on the organoleptic attributes of wheat products as perceived by the consumer. Just as clearly, solvent-extracted FPC will not be able to be sold on its functional qualities. This implies either government subsidy of an FPC supplementation program, or education of the people in order to generate the demand for better nutrition. An even more obvious conclusion we can draw from the sparseness of the data on the marketability of solvent extracted FPC is that, at present, no firm analysis can be based on the Call criterion, for no one knows what the relationship is between protein consumption, the additional price of the protein, and its functional qualities.

Variation in Acceptability of FPC From Different Species

Recently, the Bureau of Commercial Fisheries (57) has undertaken an evaluation of the differences in acceptability of FPC as a function of the source of raw material. A number of subjects were given cookies, bread, and pasta supplemented to 10% with FPC made from a variety of fish and were asked to evaluate their reactions to the taste, appearance, and texture of the product by assigning a number from 1 to 5 to each product in each category. Hake based FPC was used as a control and the subjects were told that if they preferred the hake FPC to the other then a number less than three was to be assigned. The results are shown in Tables V,VI, and VII. They are far from conclusive, but they indicate that there is no reason to expect solvent-extracted FPC made from sources other than hake to be more attractive to the consumer.

TABLE V

AVERAGE RANKING BY SUBJECTS OF FPC PROPERTIES AS A FUNCTION OF FISH SPECIES. BASED ON A SENSORY EVALUATION OF COOKIES CONTAINING 10 PERCENT FPC MADE FROM VARIOUS SPECIES OF FISH

(5 point Hedonic scale)

	Appearance	Flavor	Texture
Hake-FPC	2.9±.23	2.8±.13	2.9±.18
Ocean pout-FPC	2.9±.23	3.1±.23	2.3±.39
Anchovy-FPC	1.6±.22 1/	2.6±.26	2.6±.36
Herring-FPC	2.2±.13	2.4±.26	2.8±.25
Atlantic menhaden-FPC	3.1±.38	2.7±.33	2.8±.36
Alewife	1.4±.16 1/	2.1±.23	2.7±.36
Gulf menhaden-FPC	2.3±.16	1.7±.30 1/	2.5±.16

1/ Tukey's w ($P < .05$)	.99	1.12	1.37

TABLE VI

AVERAGE RANKING BY SUBJECTS OF FPC PROPERTIES AS A FUNCTION OF FISH SPECIES. BASED ON A SENSORY EVALUATION OF BREAD SUPPLEMENTED WITH 10% FPC MADE FROM VARIOUS SPECIES OF FISH

(5 point Hedonic scale)

	Appearance	Flavor	Texture
Hake-FPC (control)	2.8±.13	3.0±.21	3.0± 26
Ocean pout-FPC	2.5±.22	2.5±.17	2.4±.48
Anchovy-FPC	1.5±.17[1]	2.4±.20	2.5±.27
Herring-FPC	2.3±.30	2.8±.33	3.0±.21
Atlantic menhaden-FPC	2.1±.18	2.5±.22	1.9±.23
Alewife-FPC	1.9±.07[1]	2.1±.23	2.3±.33
Gulf menhaden-FPC	2.5±.11	2.3±.30	3.0±.30
[1] Tukey's w ($P < .05$)	.77	1.12	1.33

TABLE VII

AVERAGE RANKING BY SUBJECTS OF FPC PROPERTIES AS A FUNCTION OF FISH SPECIES BASED ON A SENSORY EVALUATION OF COOKED PASTA WITH 10% FPC MADE FROM VARIOUS SPECIES OF FISH

(Appearance, flavor, odor on 6 point Hedonic scale - Texture on a 9 point Hedonic scale)

	Appearance	Texture	Flavor	Odor
Hake-FPC (control)	3.0±.00	6.1±.81	3.0±.41	2.8±.29
Ocean pout-FPC	3.1±.28	4.2±.49	2.8±.20	2.8±.30
Anchovy-FPC	1.0±.00[1]	5.6±.69	2.5±.25	2.5±.22
Herring-FPC	1.8±.13[1]	5.2±.59	2.9±.31	2.9±.23
Atlantic menhaden-FPC	2.6±.27	4.4±.62	3.0±.15	2.8±.32
Alewife-FPC	1.5±.22[1]	5.1±.48	2.7±.26	2.8±.24
Gulf menhaden-FPC	1.7±.21[1]	4.7±.52	2.6±.34	2.9±.23
[1] Tukey's w (P =.05)	.83	2.63	1.07	1.16

CHAPTER III

THE NUTRITIONAL EFFICIENCY OF FPC

Introduction

In brief, the argument so far has proceeded as follows. The ideal analysis would compare the total benefits to an economy of alternative means of upgrading diets with the costs of these alternatives. Unfortunately, this requires quantitative relationships between nutrition and its socio-economic effects, which do not yet exist. However, there is presumptive evidence that some investment to decrease protein-deficiency can be justified as part of a coherent attack on living standards in the developing country, not only on the basis of the human tragedy implied by widespread malnutrition, but also on narrower economic terms. The question then is how much, and what kind of investment?

At this point, the Call criterion was postulated and the problem of meeting that criterion at minimal cost considered. Since this criterion is predicated on consumption, it requires quantitative demand functions to be operationally useful. After a review of the existing demand data, it was concluded that, at present, construction of useful demand models is not feasible.

In this section, we fall back one more step and consider the following provisional problem:

Given a basal diet and a population by age and sex, what is the minimal cost means of supplying all sectors of that population with the quantity of calories and the quantity and quality of proteins required if diet is not to adversely limit health and performance?

The word provisional is used in describing this subproblem because we are for the moment going to ignore extremely important distributional and promotional considerations, and are also going to make a series of assumptions as to how protein quality is related to the chemical composition of the food. Also, in concentrating entirely on calories and protein, we are ignoring differentials in the mineral and vitamin values of the alternative supplements, the assumption being that adequate minerals and vitamins are being supplied. Clearly, then, any results of the analysis we are about to undertake will have to be examined very carefully. Even with all these qualifications, however, these analyses will allow us to focus the FPC discussion considerably.

Furthermore, in order to have a concrete problem to analyze, we will have to postulate a distributional scheme. Our analyses will be based on three conceptual programs:

(1) Universal supplementation in which a supplementation program is designed on the basis of a critical target group and then the resulting diet is fed to the entire population according to their caloric needs. This scheme has a certain inherent simplicity; however, it is necessarily wasteful in the sense that almost all the population will be receiving more protein than it can use.

(2) Perfectly selective supplementation is the other extreme. Under this program, each sector of the population receives exactly those calorie and protein requirements estimated for that sector. This is an imaginary construct, since no practical distributional program which implements this policy exists. However, this analysis will serve as a useful lower bound.

(3) Given that the primary target group is almost always the weaning child, an attractive distribution scheme involves the concoction of a baby food which, together with the ordinary diet, supplies the target group with the required protein.

We will undertake illustrative analyses under each of these distributional policies. While they hardly exhaust the set of all possible programs, they do constitute a representative subset.

III. 1. Nutritional Assumptions

The first assumption that we make in tackling this sub-problem is that the estimate of the FAO Expert Committee (58) gives daily calorie requirements for any individual, Table VIII. This is a fairly well accepted postulate. Clinical protein malnutrition is almost invariably coupled with some degree of calorie deficiency; and, unless caloric requirements are being met, it is generally inefficient for a developing country to embark on an expensive protein supplementation program, for the bulk of the protein supplied to the target group will be metabolized for energy, which energy could have been obtained more cheaply with conventional calories. Of course, due to variations in the level of nutrition within any real population, one can often usefully consider protein supplementation even though not all the population is meeting its caloric requirements.

TABLE VIII

FAO CALORIE REQUIREMENTS

AGE	Male	Female
0 - 1	Kg. x 115	Kg. x 115
1	1150	1150
2 - 3	1300	1300
4 - 6	1700	1700
7 - 9	2100	2100
10 - 12	2500	2400
13 - 15	3100	2600
16 - 19	3600	2400
20 - 29	3200	2300
30 - 39	3104	2231
40 - 49	3008	2162
50 - 59	2768	1990
60 - 69	2528	1817
70 +	2208	1587

Moreover, persons with chronically inadequate caloric intake by FAO standards have usually adapted to this situation by reducing activity. In cases such as these, statements as to the extent to which protein will be used to meet calorie needs when protein is also deficient must be made with considerable caution. Our analyses do not explicitly cover these situations, although we feel it would not be difficult to extrapolate our results to such cases.

The remaining assumptions concern the amount and quality of the protein required and the means of relating quality of protein to the chemical composition of the diet.

Assumptions Concerning Protein Requirements

We have seen that 'protein requirements' is a general term covering more precisely the human's need for quantities of certain amino acids and for nitrogen with which to synthesize other amino acids. Various protein sources differ both in the quantities of the required amino acids they contain and in the degree to which these amino acids can be digested by the human. As a result, the same amount of protein from two differing sources can vary markedly in nutritional value.

Attempts to measure the relative amounts of each of the amino acids which must be supplied externally have resulted in the publication of a number of reference patterns which attempt to represent the relative amounts of each of these amino acids required by man. The original reference pattern is that published by the Food and Agriculture Organization in 1957. (59) This is the pattern shown in Table IX, and the pattern used in our calculations.

The assumption is that this pattern reflects the needs of the human for the relative amount of each of the amino acids which must be supplied externally.

Given that this pattern reflects the relative amounts of each of the amino acids that must be supplied externally as well as the specific amount of nitrogen required for protein synthesis in man, the assumption is that if a protein containing the relative quantities of the amino acids shown in Table IX is consumed in a form in which these acids can be digested, at a level at or below requirements, then that protein would be

100% utilized by the body. The quantity of such 100% utilized or reference protein required by healthy humans of various ages and sizes has been estimated by the FAO/WHO Expert Group (60) by considering all the needs to which the utilized protein must be put: obligatory urinary and fecal nitrogen losses, integumental and minimal sweat losses, growth, stress of ordinary living, and, where applicable, for pregnancy and lactation. The result is the FAO reference protein requirements which specify reference protein per pound of body weight required as a function of age and sex, with provisions to reflect the special protein needs of pregnant and lactating mothers.

TABLE IX

1957 FAO AMINO ACID REFERENCE PATTERN

	Grams/100 Grams Protein
Lysine	4.2
Methionine	2.2
Total Sulphur Amino Acids	4.2
Threonine	2.8
Tryptophan	1.4
Valine	4.2
Phenylalanine	2.8
Leucine	4.8
Isoleucine	4.2

Tests to determine individual requirements for the various amino acids display rather large variances, and there is considerable evidence that different individuals can have rather different requirements for specific amino acids. With the uncertainties in mind, the FAO requirements are based on estimated mean requirements plus two standard deviations. Thus, theoretically the FAO estimates cover 97.5% of the population.

However, the FAO requirements are based on the needs of a healthy human being living under ordinary conditions. In the following section, we argue that the malnourished child, at whom a protein supplementation program is aimed, cannot be regarded as living under normal conditions and that as a result, requirements considerably in excess of the FAO standard are appropriate.

Adjusting the FAO Standards to Reflect the Protein Needs of the Target Group

There are several factors, particularly the multiple interactions between host and environment, which serve to increase the protein needs of underprivileged populations above those proposed for healthy, well nourished individuals living in a favorable environment and who are also relatively free of infectious disease. The most important factor, particularly among young children, is the frequency in which diarrhea and respiratory disease are superimposed on the common communicable diseases of childhood, which occur in more severe form in malnourished children. Recent studies in villages near Guatemala City (61) and near Calcutta, India (62) have clearly shown the high frequency of illness among preschool children. Most of these children suffer from acute infectious episodes for more than a quarter of their first few years and are, in addition, suffering from multiple intestinal parasites. Intestinal parasites in large numbers, along with altered gastro-intestinal functions resulting from a combination of multiple infectious insults and malnutrition, combine to reduce protein absorption. (63).

It has been demonstrated that acute infections, even those which are clinically mild (64, 65, 66), result in increased urinary nitrogen loss as a consequence of the generalized stress response, which brings about a mobilization of amino acids from skeletal muscles, and their subsequent diversion into the liver for gluconeogenesis. Once the acute episode is past, additional dietary protein is required to replace the loss of body nitrogen which occurred earlier. The losses are often aggravated by the anorexia associated with infection and also because the diet is generally changed to one lower in protein content as a therapeutic measure. If the infection is also associated with the intestine, absorption of nutrients may also be impaired to some degree. Finally, the situation is often made worse by the administration of strong purgatives (67).

The influence of infection extends far beyond the initial catabolic period of the acute stage into the longer anabolic period which follows. This latter period is likely to be at least twice as long as the catabolic phase, as suggested by metabolic measurements, and by growth data in various populations (68). The latter indicate that the effect on protein metabolism is sufficient to limit growth during both the anabolic and the catabolic phases. A number of studies have shown a highly significant negative correlation between morbidity from infection and rate of growth (70, 71). The effects of infection are, of course, not limited to young children but influence all age groups. The effects of frequent infectious illnesses were not taken into account in the factorial requirements given in the 1965 FAO/WHO report on protein requirements because they were intended for healthy infants. It is difficult to determine how much the FAO standards would be increased in dealing with a malnourished target group. Rose, after studying the requirements of young college men for each of the essential amino acids, suggests double the highest value found as a safe practical allowance (72). This value appears overly conservative. However, the increased nitrogen losses even in the mildest stress situation amount to 30% for some people (73), (74). Nitrogen losses in severe infections have been shown to amount to a considerable corresponding protein loss (75) (76). It would therefore seem reasonable to accept 50% above FAO/WHO recommended allowances for underprivileged persons in vulnerable groups.

The foregoing discussion refers to protein in the diet which is available for digestion at the time of consumption. Our later analyses are based on the protein composition of the various foods as tested in the laboratory through hydrolysis. Such tests take into account neither the destruction of some of the protein in cooking or, what is the same thing, the fact that some of the protein may become unavailable for digestion during cooking due to chemical reactions which may take place during processing or cooking. Given improper cooking or processing, these losses can be very substantial. Skimmed milk which has been dried at too high a temperature can suffer over a 50% decrease in nutritional efficiency (77). Similar losses have been noted in certain batches of FPC (78), and synthetic amino acids have shown themselves to be particularly sensitive to processing losses (79).

In our later analyses, we are going to assume that the protein in the food is 100% available and adjust the requirements to reflect processing losses.

(After completing the analyses, we will discuss differentials in availability among the alternative supplements.) It would be more logical to specify a processing loss directly and then account for that loss in designing the supplementation program rather than by upping the requirement. However, processing losses are at least as variable as the other unknowns in nutrition, and by incorporating this variable with the others in the level of reference protein, we can simplify the discussion considerably.

With the foregoing uncertainties about protein requirements, we have chosen to conduct all our analyses on the basis of supplying three different levels of reference protein to the target group, specifically 100%, 150% and 200% of the FAO requirements. Our basic purpose in this section is not to recommend a specific supplementation program, but rather to compare FPC with its alternatives in a number of interesting situations. Hence our use of a range of protein levels. However, as the discussion indicates, we feel that the 100% level is considerably low for a malnourished target group and that 200% is probably high for a properly prepared diet. Professor Scrimshaw feels that a reference protein level of 175% FAO/WHO requirements before processing losses would probably be appropriate to the typical target group. This corresponds to 150% FAO/WHO requirements if we assume an average loss in availability of 15%.

Choice of Target Group

Having accepted a level of reference protein or, in our case, a range of levels, the next problem is to choose a target group to whose requirements one is going to supplement the diet. This will, of course, depend on the problem at hand. For Chile, which is our sample problem,there is an increasing tendency towards malnutrition in younger infants due to decreased duration of breast feeding, especially in the urban areas. Monckeberg cites cases of severe infant malnutrition at ages of less than three months. Generally, the highest incidence of protein-calorie malnutrition occurs after the age of one, extending well into the second year of life in Chile,and lasts longer in countries where weaning in the second year of life is the rule. For our sample problem, we have arbitrarily picked an age of 10 months. For areas such as West Africa where prolonged breast feeding is the rule and little infant malnutrition is observed at ages less than 18 months, an older age would almost certainly be more appropriate. Figure III shows the decrease in FAO reference protein requirements with age (80).

Since we are going to compare FPC and its alternatives over a range of requirements, the exact definition of the target group need not concern us unduly here. In an actual application, the choice of the target group is extremely important, as we shall see, since the decrease in requirements per pound of body weight with age is quite sharp, as Figure III indicates, and the cost of the supplementation program increases three or four times as fast as the increase in the postulated level of reference protein.

Evaluation of Protein Quality in a Diet

In order to make whatever level of reference protein requirements we choose operational, we must have a means for relating the protein in an actual diet to the equivalent amount of reference protein. For the moment, let us assume that all of the protein in the diet is available; that is, 100% can be digested and absorbed. In general, the amino acid pattern of the protein in a diet will be different from that of the reference pattern. If one compares the amino acid pattern of the diet protein with the reference pattern, one of the required amino acids relative to the reference pattern will nearly always be in shorter supply than all the others. This amino acid is said to be the limiting amino acid in the diet.More precisely, one compares the concentration in the diet of each of the essential amino acids with the corresponding concentration in the reference pattern. The amino acid with the lowest concentration relative to the reference pattern is the limiting amino acid. Thus, if 100 grams of protein in a diet contain 5 grams of all the required amino acids except lysine and three grams of lysine then comparison with Table IX reveals that lysine is the limiting amino acid. Furthermore, one assumes that the relative concentrations of the required amino acids in the reference pattern must be strictly observed if tissue generation is to occur. Thus, in the case above, since lysine is limiting and there are only three grams of lysine per 100 grams of protein in this diet, but the requirements are for 4.2 grams, only 3/4.2 or 71% of this protein can be utilized for tissue generation.This assumes that it is impossible to retain more than a few hours an excess of a particular amino acid and use it later to correct deficiency in the diet. There is adequate experimental evidence for this. It also assumes that the unused protein is used for energy or discarded with no net effect on protein metabolism. Actually

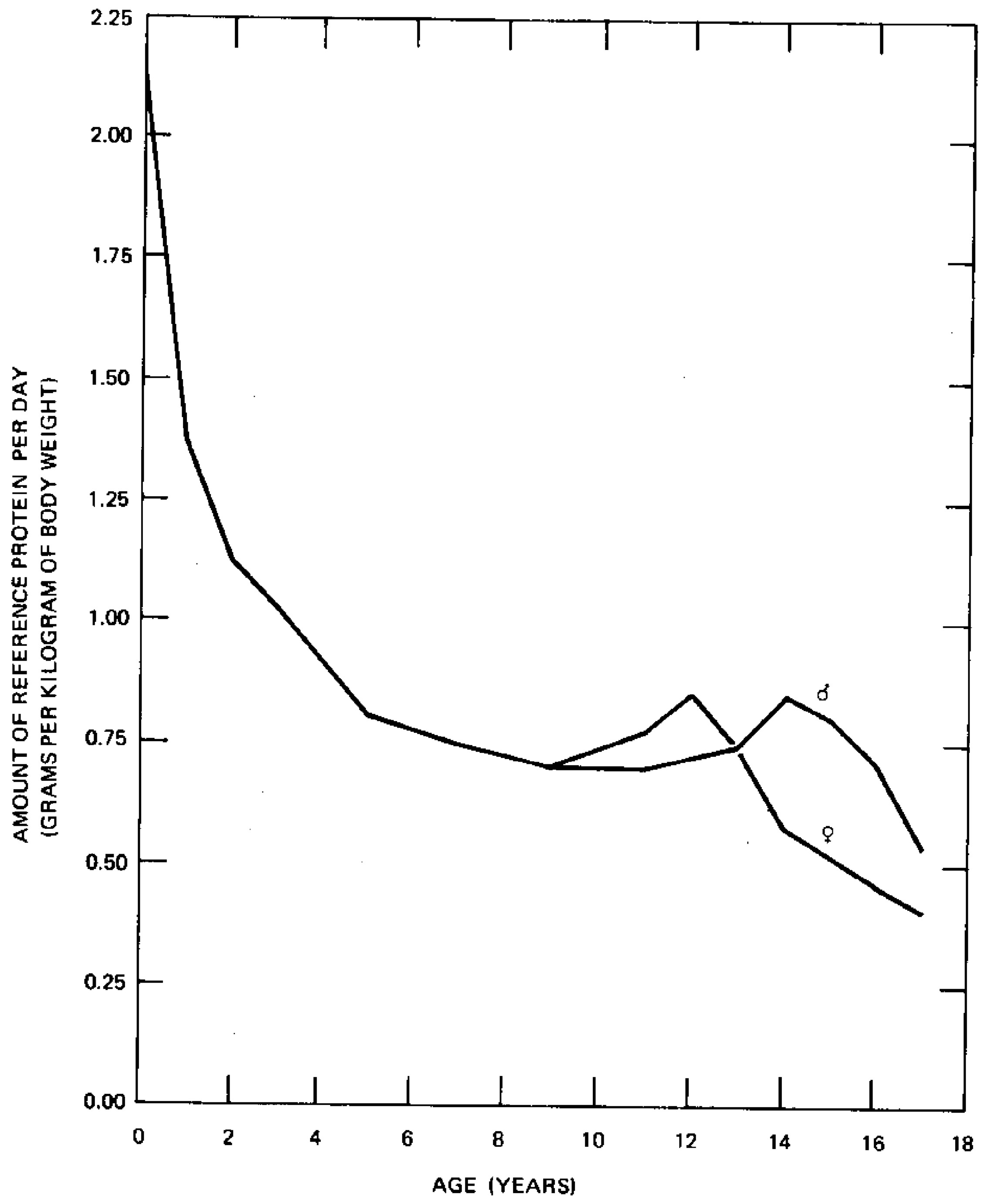

FIGURE III FAO MINIMAL REFERENCE PROTEIN REQUIREMENTS there is some evidence which indicates that large relative excesses of some amino acids have a detrimental effect on health. However, this need not concern us here because we are supplementing to correct imbalances rather than increase them.

The proportion of the limiting acid relative to the reference pattern is called the chemical score of the protein. The above set of assumptions leads to the acceptance of proportionality between protein utilized in tissue formation and chemical score, and an inverse relationship between chemical score and the amount of available protein required to meet reference protein requirements. If the score is 33%, and the requirement as reference protein is ten grams, then thirty grams would have to be supplied, and so on.

The first qualification we must put on this statement is that it is not true if calorie requirements are not being met, for the body will then metabolize part of the protein and use it to meet its energy requirements. Assuming that calorie requirements are being met, which will be the case in the diets we are analyzing in this section, it further has been observed that the efficiency with which the body utilizes protein depends on the level of intake of total protein in the diet. At intake levels above those required to replace the obligatory losses in nitrogen, protein utilization begins to decrease until the point is reached where the person is receiving more protein than he can utilize, after which additional protein is converted into fat or energy. The level at which further protein utilization ceases is that required to maintain nitrogen balance in the healthy stress-free adult, but must be considerably higher in children to allow for growth. In attempting to supply the target group's needs, we will always be operating with protein intakes at or above those required to maintain nitrogen balance.

If one measures the efficiency of protein utilization of a person receiving more protein than he can use in tissue generation, one will observe decreasing efficiency with increasing protein in the diet. If a person who needs 20 grams of reference protein is fed 60 grams of protein which has a score of 50%, he will utilize 40 grams of this protein at 50% efficiency and waste the rest as far as protein needs are concerned. The observed protein utilization will be (40/60) X 50 or 33%. If the same person is fed 80 grams of this protein, the observed protein efficiency will be (40/80) x 50 or 25%; and in general, the observed protein efficiency will fall off in a hyperbolic fashion at levels of reference protein higher than required. For a high quality protein, this decrease will begin at a lower level of total protein in the diet than for a low quality protein. See Figure IV.

The decrease in protein efficiency with increasing protein in the diet has been almost universally observed in both animal and human tests. Attempts to model this decrease have taken linear (81) and logarithmic (82, 83) forms, although recently Payne (84) has suggested fitting these data with hyperbolas. The point of this digression is that this decrease has been widely misinterpreted in nutrition circles with respect to predicting the effectiveness of a proposed nutrition protein. The argument has been made that if one is contemplating use of a diet which is, say 15% total protein, then one should not evaluate the protein at its maximum efficiency, but at the efficiency at which this protein has been observed to be utilized in diets which contain 15% protein in animals or humans which efficacy will be considerably less than the maximum. This approach will indicate that one needs considerably more reference protein to meet a specific requirement than if the protein in the diet were evaluated at its maximum efficiency.

This argument is circular. The reason that one is adding protein to the diet is that one has identified a target group which needs that protein. A person who needs protein will use it efficiently. If one is adding so much protein that this target group is utilizing protein at less than maximum efficiency, then one is wasting protein and the amount present can be reduced at no loss in nutritional effectiveness. Therefore, in deciding how much protein to add, one should evaluate the protein at its maximum efficiency. Given that the target group is the malnourished and often sick child under stress, it is true that almost everybody in the supplemented population is receiving more protein than he needs most of the time. Therefore, if one observed the average protein efficiency in this population after supplementation, one would obtain values considerably lower than the maximum efficiency with which this protein can be utilized. However, as

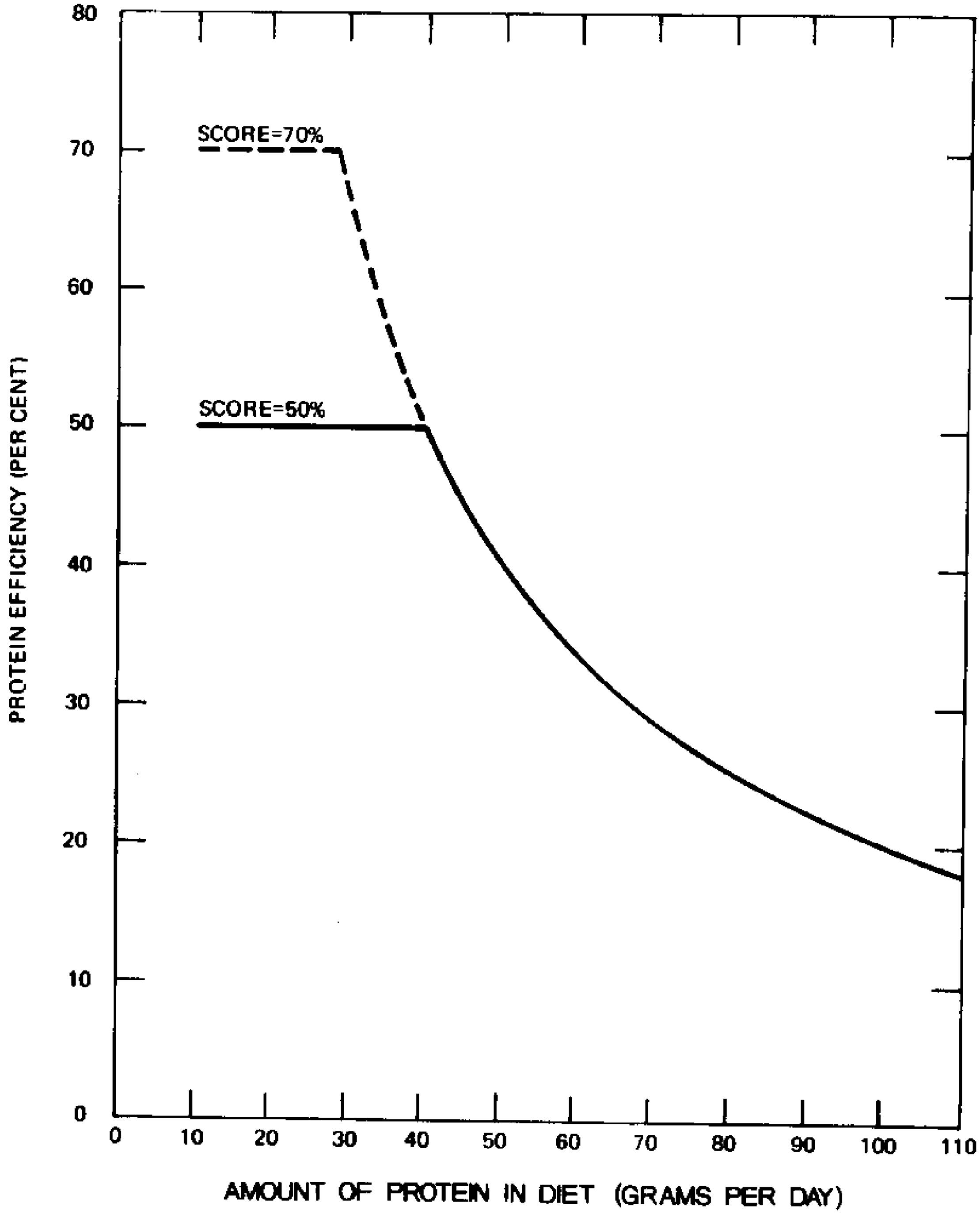

FIGURE IV DECREASE IN PROTEIN EFFICIENCY WITH INCREASING PROTEIN IN DIET
(ASSUMING A 20g REFERENCE PROTEIN REQUIREMENT)

TABLE X

COMPARISON OF SUPPLEMENT REQUIRED ACCORDING TO TWO DIFFERENT ASSUMPTIONS ABOUT PROTEIN UTILIZATION. AMOUNTS SHOWN SATISFY 150% FAO PROTEIN REQUIREMENTS FOR TEN MONTH OLD INFANTS

		WHEAT		CORN		RICE	
		Morrison	NPU_{st}	Morrison	NPU_{st}	Morrison	NPU_{st}
FPC							
Base	(grams)	200.4	204.7	202	205	209	210
Supp	"	9.2	4.2	7.4	3.3	6.2	3.86
Skim							
Base	"	183.8	197.3	159	185	193	203
Supp	"	24.5	10.9	48.8	23.0	21.1	10.1
Peanut							
Base	"	x	190.7	x	178	x	197
Supp	"	x	18.0	x	30.2	x	16.7
Cotton							
Base	"	179.7	198.3	177	195	191	204
Supp	"	39.5	13.8	43.7	18.4	30.6	12.75
Soy							
Base	"	181.3	201.3	190.3	200	195	204
Supp	"	37.3	9.7	18.0	7.9	19.04	9.03
Sunflower							
Base	"	167.9	192.0		195		199
Supp	"	52.0	20.9		17.1		19.3
Lysine							
Base	"	x	208.0	x	x	x	214
Supp	"	x	.38	x	x	x	.34
Lysine + Tryptophan							
Base	"			x	207		
Supp	"			x	.70		

x indicates that requirements could not be met by corresponding supplements.

We saw above, this is no argument for using this lower protein efficiency in deciding how much one should supplement the target group's diet.

The danger of this misinterpretation is demonstrated in Table X which compares the amount of various supplements in three basal diets which a ten month old child required, assuming 150% FAO/WHO requirements under: (a) the assumption that available protein is utilized according to the protein's score, (b) the assumption that protein utilization decreases with level of protein in the diet according to the formulation of Morrison _et al_. (83), which is the best validated description of this phenomenon in the literature.

As will be noted, the Morrison formulation requires from two to three times the supplement required by the standard formulation. The x's signify that it was impossible to meet the reference protein requirements with the corresponding basal diet-supplement combination. In this table, the total calorie content of the diet was kept constant by reducing the amount of basal diet as the supplement was added according to its caloric value. This method, assuming that the protein is going to be used inefficiently, can triple the cost of the supplementation program.

III. 2. Universal Supplementation

The first distribution scheme we will consider is universal supplementation. Under universal supplementation, the percentage of supplementation is based on the target group's needs and then the same diet is fed to the rest of the population according to their calorie requirements. This philosophy necessarily implies that almost all the population is receiving more protein then it can use. However, both its implementational and analytic simplicity recommend it as a starting point for our comparisons.

In order to perform this analysis, a computer program has been constructed which, given the basal diet and a supplement and their respective nutritional characteristics, determines the amount of the supplement required to supply the target group 100%, 150% and 200% of the FAO reference protein requirements, given that the target group eats enough of the combined diet to satisfy its calorie requirements. If the supplement also has calorie value, e.g. milk, the program adjusts the amount of the basal diet downward as the supplement is added, to keep the total calories at the FAO requirements for the target group.

The program works by trial and error. It starts with a very small amount of supplement, calculates the chemical score of the combined diet and determines whether this combination meets the prescribed reference protein requirements. If not, it adds another small increment of supplement and repeats this until the protein requirement is met.

After the ratio of supplement to basal diet required in order that the target group can simultaneously meet its calorie and protein requirements is determined, the program then feeds the resulting diet to the entire population according to their calorie needs, and computes the total cost of this diet for the population and the cost of the supplement in this diet.

Tables XI, XII and XIII illustrate some of the diets produced by this process. These tables show for diets of pure wheat, rice and corn respectively, and for 100, 150, and 200% reference protein requirements for

TABLE XI

AMOUNTS OF SUPPLEMENT IN A BASAL DIET OF WHEAT REQUIRED TO MEET VARIOUS REFERENCE PROTEIN LEVELS ASSUMING TARGET CHILD IS A TEN MONTH OLD, 8.5 KG INFANT. TOTAL CALORIES KEPT CONSTANT AT 970

100% FAO/WHO PROTEIN REQUIREMENTS (1.5 g/kg body weight)

	WHEAT (grams)	SUPP. (grams)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	270	1.6	.6	13.7	38
COTTONSEED FLOUR	268	5.3	1.9	14.3	36
SKIM MILK POWDER	267	4.2	1.6	13.7	38
PEANUT FLOUR	265	6.9	2.6	14.5	36
SOY FLOUR	269	3.7	1.3	13.9	37
SINGLE CELL PROTEIN	270	2.9	1.1	13.8	37
SUNFLOWER SEED	265	8.0	2.9	14.3	36
LYSINE	271	.14	.05	13.4	40

150% FAO/WHO PROTEIN REQUIREMENTS (2.25 g/kg body weight)

	WHEAT (grams)	SUPP. (grams)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	267	5.5	2.1	14.8	52
COTTONSEED FLOUR	259	18.1	7.0	16.7	47
SKIM MILK POWDER	257	14.4	5.5	14.7	53
PEANUT FLOUR	248	23.7	9.5	17.5	45
SOY FLOUR	262	12.6	4.8	15.4	50
SINGLE CELL PROTEIN	255	10.1	3.7	15.2	51
SUNFLOWER SEED	250	27.4	10.9	16.6	47
LYSINE	271	.5	.18	13.4	59

200% FAO/WHO PROTEIN REQUIREMENTS (3.0 g/kg body weight)

	WHEAT (grams)	SUPP. (grams)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	264	9.3	3.5	15.9	65
COTTONSEED FLOUR	250	30.9	12.4	19.1	55
SKIM MILK POWDER	247	24.5	9.9	15.8	66
PEANUT FLOUR	229	45.2	17.5	21.3	51
SOY FLOUR	256	21.6	8.4	16.9	61
SINGLE CELL PROTEIN	254	26.8	10.6	18.4	56
SUNFLOWER SEED	236	46.8	19.9	19.0	55
LYSINE	X	X	X	X	X

TABLE XII

AMOUNTS OF SUPPLEMENT IN A BASAL DIET OF RICE REQUIRED TO MEET VARIOUS REFERENCE PROTEIN LEVELS ASSUMING TARGET CHILD IS A TEN MONTH OLD, 8.5 KG INFANT. TOTAL CALORIES KEPT CONSTANT AT 970

100% FAO/WHO PROTEIN REQUIREMENTS (1.5 g/kg body weight)

	RICE (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	278	1.1	.4	8.9	58
COTTONSEED FLOUR	277	3.8	1.4	9.3	56
SKIM MILK POWDER	277	3.1	1.1	8.9	58
PEANUT FLOUR	274	5.0	1.8	9.5	55
SOY FLOUR	277	2.7	1.0	9.0	57
SINGLE CELL PROTEIN	278	2.1	.7	9.0	54
SUNFLOWER SEED FLOUR	276	5.6	2.1	9.3	56
LYSINE	279	.12	.04	8.6	62

150% FAO/WHO PROTEIN REQUIREMENTS (2.25 g/kg body weight)

	RICE (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	275	5.0	1.8	10.0	77
COTTONSEED FLOUR	267	16.7	6.3	11.9	67
SKIM MILK POWDER	266	13.3	4.9	10.1	77
PEANUT FLOUR	257	21.9	8.5	12.8	63
SOY FLOUR	271	11.7	4.4	10.6	73
SINGLE CELL PROTEIN	273	9.3	3.4	10.4	71
SUNFLOWER SEED FLOUR	259	25.5	9.7	12.0	65
LYSINE	279	.5	.6	8.7	89

200% FAO/WHO PROTEIN REQUIREMENTS (3.0 g/kg body weight)

	RICE (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	272	8.9	3.3	11.2	92
COTTONSEED FLOUR	258	29.7	11.5	14.6	74
SKIM MILK POWDER	256	23.6	9.2	11.3	92
PEANUT FLOUR	241	38.8	16.1	16.0	68
SOY FLOUR	264	20.6	7.8	12.3	83
SINGLE CELL PROTEIN	268	16.5	6.2	11.9	87
SUNFLOWER SEED FLOUR	244	45.1	18.4	14.6	71
LYSINE	X	X	X	X	X

TABLE XIII

AMOUNTS OF SUPPLEMENT IN A BASAL DIET OF CORN REQUIRED TO MEET VARIOUS REFERENCE PROTEIN LEVELS ASSUMING TARGET CHILD IS A TEN MONTH OLD, 8.5 KG INFANT. TOTAL CALORIES KEPT CONSTANT AT 970

100% FAO/WHO PROTEIN REQUIREMENTS (1.5 g/kg. body weight)

	CORN (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	271	.5	.2	9.0	58
COTTON SEED FLOUR	265	8.5	3.2	10.6	50
SKIM MILK POWDER	261	10.7	4.0	10.1	51
SOY FLOUR	271	1.2	.4	9.1	57
SINGLE CELL PROTEIN	266	8.0	3.3	10.5	49
PEANUT FLOUR	258	14.0	5.4	11.5	46
SUNFLOWER SEED FLOUR	270	2.7	.9	9.2	56
LYSINE & TRYPTOPHAN *	271	.3	.1	9.0	59

150% FAO/WHO PROTEIN REQUIREMENTS (2.25 g/kg body weight)

	CORN (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	268	4.4	1.7	10.1	76
COTTON SEED FLOUR	254	24.1	9.4	13.7	58
SKIM MILK POWDER	241	30.2	12.4	12.3	63
SOY FLOUR	264	10.2	3.5	10.6	73
SINGLE CELL PROTEIN	256	22.8	8.8	13.5	56
PEANUT FLOUR	233	39.7	16.7	16.5	50
SUNFLOWER SEED FLOUR	254	22.4	8.8	11.9	66
LYSINE & TRYPTOPHAN *	271	.9	.3	9.15	85

200% FAO/WHO PROTEIN REQUIREMENTS (3.0 g/kg body weight)

	CORN (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN %CALORIES	PROTEIN EFFICIENCY
FPC	265	8.3	3.2	11.3	91
COTTON SEED FLOUR	252	39.7	16.2	16.9	64
SKIM MILK POWDER	222	49.6	22.4	14.7	71
SOY FLOUR	258	19.2	7.4	12.4	84
SINGLE CELL PROTEIN	245	37.4	15.3	16.5	63
PEANUT FLOUR	208	65.4	31.5	21.5	51
SUNFLOWER SEED FLOUR	239	42.2	17.7	14.5	71
LYSINE & TRYPTOPHAN *	X	X	X	X	X

$\frac{\text{Tryptophan}}{\text{Lysine}} = \frac{15}{85}$

the target group, the amount of the basal diet and the amount of each of a number of supplements which must be consumed per day by a target child in order to meet his calorie and protein requirement.

It will be noted that this child requires about 250 grams of the basal diet per day and that the percentage of supplementation can vary less than 6/100 of 1% to 16%, depending on the levels of requirement and the basal diet-supplement combination. We can also see that increasing the reference protein required by 50% may increase the amount of supplement required by a factor of three or more. This is to be expected since, at the 100% FAO/WHO level, the bulk of the reference protein is being supplied by the basal diet.

It will be noted that, even for the 150% FAO level, the percentage supplementation is considerably less than that usually encountered in the literature. If 10% FPC were added to an all wheat diet, one can be sure that at least 80% of this supplement would be wasted. Of course, if the diet is only 20% wheat and all the supplementation is to be accomplished through wheat, then higher percentages may be indicated. The fact still remains that even with pure grain diets and using 150% of FAO/WHO protein requirements calculated to cover nearly all of a usual population (mean plus 2 standard deviations), a daily dose of 4 grams of FPC is sufficient.

The ratio of the amounts of various supplements added is also worthy of comment. Consider 150% of normal FAO requirements and wheat. The program adds about 1.5 times as much cottonseed flour (7%) as it does soy flour (4.8%). It also calculates that approximately equal concentrations of soy (4.8%) and dried skimmed milk (5.5%) will improve the diet to meet the 150% protein requirements. This agrees with Bressani et al. (85), who achieved maximum weight gain in rats on a diet of whole wheat flour with cottonseed flour concentrations of 10%, or 1.7 times the optimum concentration of soyflour (6%) and dried skimmed milk. This indicates some empirical support for our predictions of the relative effectiveness of the various supplements. This agreement is merely a restatement of the reasonably well validated fact that chemical score equals protein efficiency as long as the subject can utilize the protein, at least in the case of young rats.

Breakeven Cost Analysis

In this section, we wish to indicate those statements which can be made about the relative nutritional efficiency of FPC independent of the actual prices of the competing supplements. These statements take the form of breakeven costs. The breakeven cost of a potential alternative to FPC is the unit cost relative to that of FPC at which nutritionally equivalent diets would require the same amount of the supplementing country's resources.

The breakeven costs may be calculated from information such as that shown in Tables XI, XII, and XIII by specifying a unit price for FPC and then asking how much more or less expensive a unit of the competing supplement must be before the diet based on it has the same cost as the diet based on FPC. In order to do this, one must make an assumption concerning the unit cost of the base relative to FPC. In Table XIV the results of this analysis are presented for wheat, rice, corn, assuming that the base is 1/5 as expensive as FPC per weight unit, respectively. These are believed to be representative ratios, assuming domestic FPC production in the developing country at 25¢/lb. We caution that the results of these three tables will be relatively sensitive to the relative price of the base. For, if the base is more expensive relative to the supplement, those supplements which supply calories as well as protein will become, relatively speaking, cheaper.

In order to demonstrate the use of this Table consider the combination of wheat and dry skim milk. The .49 is this position should be interpreted as follows. Given that one is going to supplement universally the diet of the Chilean population according to 150% the FAO/WHO requirements for the target group while supplying FAO/WHO calorie requirements to everybody, the total cost of performing this supplementation by FPC and the total costs of performing this supplementation by milk will be the same if the cost of milk is 49% of the cost of FPC on a unit weight basis. If milk costs more than this, the country should prefer FPC, if less, it should prefer milk. The relevant unit costs are the costs of the supplement in the hands of the target group.

TABLE XIV

RATIO OF ALTERNATE SUPPLEMENT PRICE TO FPC PRICE AT WHICH FPC & ALTERNATE ARE EQUALLY AS EXPENSIVE AT MEETING FAO CALORIE REQUIREMENT AND 150% FAO/WHO REFERENCE PROTEIN LEVEL FOR 10-MONTH-OLD TARGET GROUP ASSUMING UNIVERSAL SUPPLEMENTATION OF CHILEAN POPULATION

BASAL DIET

	WHEAT	RICE	CORN	CHILEAN DIET #1
DRY SKIM MILK	.49	.59	.24	.66
PEANUT FLOUR	.37	.46	.20	.54
COTTONSEED FLOUR	.37	.44	.24	.51
SOY FLOUR	.48	.63	.49	.48
SUNFLOWER SEED FLOUR	.29	.37	.26	.56
SINGLE CELL PROTEIN	.57	.96	.21	.44
LYSINE	10.8	10.9	X	X
LYSINE & TRYPTOPHAN	-	-	4.58	X
METHIONINE	X	X	X	22.3

The blanks in this table indicate that it is not possible to meet the postulated protein requirements with the corresponding basal diet-supplement combination. For example, it is impossible to add enough lysine to corn to make 150% FAO requirements for the target group. This is because another amino acid, tryptophan, becomes limiting before the postulated level is reached.

One notes that the breakeven ratios can change markedly with changes in the basal diet. Thus, while milk will be competitive with FPC in wheat if it is only half as expensive as FPC, it will not be competitive with FPC in corn unless it is one-quarter as expensive on a per pound basis. In general, FPC is most favored as a supplement to corn and least favored for rice.

Perhaps we can made Table XIV more meaningful if we postulate prices of the alternative supplements. Our best estimates of the world market prices (f.o.b. origin) for the alternatives are: dry skimmed milk, 8¢.lb; defatted soy flour, 7¢/lb; cottonseed flour, 5¢/lb; lysine and methionine, $1.14/lb; peanut flour, 5¢/lb (see Chapter II, pages 27-30). Combining these prices with the breakeven ratios in Table XIV leads to the following breakeven costs for FPC.

TABLE XIVa

BREAKEVEN COST OF FPC, UNIVERSAL SUPPLEMENTATION IN CHILE, TO 150% FAO/WHO REQUIREMENT FOR 10-MONTH-OLD CHILD, WORLD MARKET PRICES AS INDICATED (CENTS PER POUND)

	WHEAT	RICE	CORN	CHILEAN #1
DRY SKIM MILK @ 8¢/lb	16	14	33	12
PEANUT FLOUR @ 6¢/lb	17	13	30	11
COTTONSEED FLOUR @ 5¢/lb	14	11	21	10
SOY FLOUR @ 6¢/lb	13	10	12	13
LYSINE @ $1.14/lb	11	10	X	X
METHIONINE @ $1.14/lb	X	X	X	5

This is the price of FPC at which the cost of supplementation via FPC would be as inexpensive as the alternative shown in this situation (Chile and 150% FAO/WHO reference protein requirements) if there were no foreign exchange problem or shipping charges. These breakeven costs might be appropriate to a country which had to import all its protein supplements.

Of course, one can apply one's own price assumptions to Table XIV. For example, at present the price of dry skim milk is quite depressed. In view of the uncertainty about the price of this commodity, one might want to assume a price of, say, 10¢/lb for milk, in which case the breakeven costs for the first row become 20¢,18¢, 41¢, and 15¢, respectively, for the basal diets shown.

In particular in the Chilean case, all the supplements shown, with the exception of FPC, must be imported. It is argued in Chapter IV that the value of foreign exchange to the Chilean economy is 30% higher than indicated by the market exchange rate. Therefore, adding a 30% premium to the prices indicated above, plus 1¢/lb shipping charges leads to the following set of breakeven prices.

TABLE XIVb

BREAKEVEN COST OF FPC, UNIVERSAL SUPPLEMENTATION IN CHILE TO 150% FAO/WHO REQUIREMENTS, PRICES OF IMPORTS ADJUSTED FOR SCARCITY OF FOREIGN EXCHANGE AND TRANSPORTATION COSTS

	WHEAT	RICE	CORN	CHILEAN #1
DRY SKIM MILK @ 12¢/lb	24	21	50	18
PEANUT FLOUR @ 8¢/lb	23	17	40	15
COTTONSEED FLOUR @ 7.5¢/lb	21	16	32	15
SOY FLOUR @ 9¢/lb	20	15	18	20
LYSINE @ $1.48/lb	15	13	X	X
METHIONINE @ $1.48/lb	X	X	X	7

From the point of view of the Chilean situation, columns 1 and 4 of Table XIVb are the most interesting. They indicate that, if a pure wheat diet is being supplemented to 150% FAO/WHO requirements for the target group, then the cost of FPC to Chile adjusted for any effects on the foreign exchange position must approach 20¢/lb before FPC is competitive with the most cost-effective oilseeds and 15¢/lb before it is competitive with synthetic amino acid supplementation. If the diet being supplemented is Chilean #1 (developed in Chapter V) then the cost of FPC must approach 15¢/lb to compete with the oilseeds and to less than 10¢/lb to compete with synthetic amino acid supplementation. The difference with diets is due to the fact that wheat is limiting in lysine while Chilean #1 is limiting in methionine. This table does not include the alternatives of mixing oilseeds or augmenting the various alternatives with synthetic amino acids, both of which strategies can have attractive properties, as we shall see.

Notice that so far the analysis has been independent of the actual cost of FPC, except insofar as this cost affects the ratio of the cost of basal diet to the cost of FPC.

Absolute Costs of Universal Supplementation with a Basal Diet

If one can specify the unit costs of all of the supplements, then one can calculate from the information given in Tables XI, XII, and XIII and from the total amount of calories required daily by the target population, the total cost of supplying this population sufficient amounts of this diet to meet its energy needs.

As noted earlier, the relevant costs are the costs of the diet in the hands of the consumer in a form acceptable to him. That is, the costs of distribution and promotion are properly included in the supplementation program. Our goal is consumption, not production.

Nonetheless, in considering universal supplementation schemes, it is useful to make some comparisons of production costs or, more properly, costs before distribution. For, if we can show that a supplement which can be expected to have distribution and promotion costs as low as those of any of the other supplements is also the lowest cost alternative before distribution, then a fortiori it will be the most efficient supplement. The following are our best estimates of the unit costs of the various supplements, dockside in Chile. The costs of those supplements which have to be imported which include all the alternatives other than FPC and sunflower seed, have been adjusted to reflect the disparity between exchange rate (presently about 30% for Chile), according to the theory of Section II.5.

The following Table represents a very important specialization of our definition of FPC. Up to now the term fish protein concentrate referred to any product involving the removal of water and oil from fish aimed at human consumption. In the last section we did particularize to a product containing 80% fish protein. The following Table specializes still further to isopropanol extracted FPC using the Southwest Engineering Company's modification of the Bureau of Commercial Fisheries process. This is the definition of FPC which we use for the remainder of Section III. 4.

TABLE XV

SUPPLEMENT	UNIT COST IN CHILE	SOURCE
Dry Skimmed Milk*	12¢ /lb. 18 "	(See ch. II. p.27)
FPC	25 "	(See ch. V, Sect. 3)
Soy Flour*	9 "	(See ch. II, p.28)
Cottonseed Flour*	7.5"	(See ch. II, p.29)
Lysine*	$1.48 "	(See ch. II, p.30)
Peanut Flour*	8 "	(See ch. II, p.29)
Sunflowerseed Flour	8 "	

(asterisks indicate imported: unit costs increased 30%)

Two prices have been given for dry skim milk, reflecting our uncertainty about the future price of this commodity. The 12¢/lb. price corresponds to 8¢/lb. on the world market with a cent per pound for transportation charges* plus a 30% premium to account for the fact that the scarcity of foreign exchange in Chile is not properly reflected in the market exchange rate. Milk powder must be imported in Chile. This price can be regarded as a lower limit. The 18¢ figure corresponds to about 14¢/lb. on the world market and is about as high as the world market price of milk can be expected to go, given present subsidy policies.

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* One cent per pound transportation costs, which correspond to about $20 per measurement ton, is undoubtedly an overestimate of shipping costs if Chile obtains its transportation on the tramp charter market. A recent charter quote was $16 per measurement ton from Buenos Aires to Japan. However, this would require ship load shipments. This would be the case for all alternatives except lysine supplementation. Liner rates can run many times tramp rates for the same item.
However, lysine is so expensive on a unit basis that transportation costs will never be more than a small percentage of the overall cost of the material.

With these costs and the unit cost of the basal diet, we can derive the total daily cost of the diet and the cost of the supplement for each of the alternative protein sources for 100%, 150% and 200% FAO/WHO reference protein allowances. These figures are shown in the columns in Table XVI, labeled TOTAL and SUPP. respectively, for a basal diet of pure wheat at 4¢/lb. The total cost of all the diets are within ten percent of each other, reflecting the fact that the overwhelming proportion of the money spent on supplemented diets still goes to the basal diet. The cost of the supplement, however, can vary by a factor of three.

Total cost is a more meaningful measure than the cost of the supplement. The significance of the total cost is not that we expect this to be the amount actually spent in Chile on food, even at the wholesale level, but that this number accounts for the differences in caloric values of the various supplements. For example, compare FPC with milk at world market price of 8¢/lb. The cheaper alternative in terms of the total cost to the economy is dry skim milk. However, in terms of the cost of the supplement, the cheaper alternative is FPC. The reason for this is that when one buys a certain amount of protein in milk, one also buys considerably more calories.

Thus, supplementation with milk allows one to decrease the amount of wheat in the diet more than does supplementation with FPC. Total cost, then, is a better measure of the resources that the country must devote to nutrition under various supplementation alternatives than the cost of the supplement alone.

However, the relative magnitude of the TOTAL cost figures can be misleading. On the basis of TOTAL COST, FPC is 1% more expensive than skim milk at the lower milk price. We would be the last to claim that our cost figures are accurate to within 1%, and therefore at first glance it might appear that we can draw only the most limited conclusions from this analysis. However, the great bulk of TOTAL is made up of dietary costs, which are unaffected by our supplement. In column three, labeled NET, we have removed these costs and show only the costs of the supplement minus the basal costs which the supplement saves due to its caloric contribution to the diet. This is the

TABLE XVI

TOTAL & SUPPLEMENT COSTS OF WHEAT DIET IN CHILE AT SHADOW PRICE OF FOREIGN EXCHANGE

DAILY DOLLARS X 10^{-5}

100% FAO/WHO Requirements

	TOTAL	SUPP.	NET	%
FPC	4.95	.18	.23	4.9
SKIM MILK				
@ 8¢	4.91	.21	.19	4.0
@14¢	5.02	.33	.30	6.3
PEANUT FLOUR	4.90	.23	.18	3.8
COTTONFLOUR	4.89	.18	.17	3.6
SOY FLOUR	4.91	.18	.19	4.0
SUNFLOWER SEED FLOUR	4.96	.28	.24	5.1
SINGLE CELL PROTEIN	4.91	.16	.19	4.0
LYSINE- HCL	4.88	.11	.16	3.4

150% FAO/WHO Requirements

	TOTAL	SUPP.	NET	%
FPC	5.26	.61	.54	11.4
SKIM MILK				
@ 8¢	5.21	.73	.46	10.4
@14¢	5.65	1.14	.93	19.7
PEANUT FLOUR	5.16	.82	.44	9.3
COTTON FLOUR	5.14	.63	.42	8.[illegible]
SOY FLOUR	5.22	.64	.50	10.6
SUNFLOWER SEED FLOUR	5.32	.96	.60	12.7
SINGLE CELL PROTEIN	5.18	.57	.46	9.7
LYSINE - HCL	5.07	.35	.35	7.4

200% FAO/WHO Requirements

	TOTAL	SUPP.	NET	%
FPC	5.63	1.03	.91	19.3
SKIM MILK				
@ 8¢	5.56	1.25	.84	17.9
@14¢	6.48	2.19	1.88	29.0
PEANUT FLOUR	5.54	1.57	.82	17.4
COTTON FLOUR	5.42	1.07	.70	14.9
SOY FLOUR	5.56	1.10	.84	17.9
SUNFLOWER SEED FLOUR	5.74	1.64	1.02	21.7
SINGLE CELL PROTEIN	5.92	1.51	1.20	25.5
LYSINE - HCL	X	X	X	X

net cost of supplementation to the economy, the difference between the economy's expenditures on nutrition with and without supplementation. In the NET cost of supplementation, the analysis indicated differentials of 20% and up, and we believe the results to be significant at these differences. Of course, the rankings given by NET and TOTAL and their differences are identical.

In the fourth columns, we have shown the net cost of supplementation relative to the cost of the original diet on a percentage basis. As can be seen, accepting the 150% FAO/WHO requirements for our target group, universal supplementation in Chile will increase the costs of a pure wheat diet by at least seven percent. Accepting 200% FAO/WHO requirements for this group in this situation will increase total diet costs by about 15%. The costs of a supplementation program are not a linear function of the level of protein chosen.

The 1969 FAO/WHO/UNICEF Protein Advisory Group, Subcommittee on Amino Acid Fortification has recommended that the costs of supplementation programs be expressed in terms of annual costs per member of the target group. We have already noted the dangers of ratio tests, and this recommendation was aimed at correcting abuses with regard to the evaluation of universal supplementation with more specific programs. Universal supplementation programs have been characterized by cost per head receiving the diet, which is misleading, since only a small percentage of the population can expect to benefit significantly from the program.

Our approach is to avoid ratio tests altogether specifying rather, absolute costs to perform a stated nutritional function. However, in view of the universal popularity of per capita comparisons, we have shown this ratio for the alternatives of Table XVI and Table XVIII, assuming that the beneficiary group is all children under six years of age, a group of which numbers 1.2×10^6 and represents 15% of the Chilean population.

Examining Table XVII we note that, as might be expected, the attractiveness of milk is extremely dependent on its price. If the world price of milk were to rise to 14¢, its 1966 maximum level,

TABLE XVII

ANNUAL NET COSTS OF UNIVERSAL SUPPLEMENTATION BEFORE DISTRIBUTION IN CHILE PER CHILD AGED ONE TO SIX ASSUMING A PURE WHEAT DIET IN U.S. DOLLARS AT SHADOW PRICE OF FOREIGN EXCHANGE

	100%	150%	200%
FPC	6.9	16.2	$27.2
SMP @ 8¢	5.7	14.7	25.2
Peanut Flour	5.4	13.2	24.6
Cottonseed Flour	5.1	12.6	21.0
Soy Flour	5.7	15.0	25.2
Sunflowerseed Flour	7.2	18.0	30.6
SCP	5.7	13.8	36.0
Lysine	4.8	10.5	X

importation of milk would be the least attractive alternative of all and, in fact, a penny a pound increase in the present price would eliminate milk's present advantage over FPC. Thus, in comparing milk with FPC, Chile would do well to consider the probability of a rise in milk prices before committing herself to this alternative.

We note that the ranking of the various supplements with respect to both total and supplement cost does not vary with respect to level of reference protein postulated, between 100% and 150% FAO/WHO requirements. If any supplement is cheaper than another supplement in one case, it is cheaper in the other case as well. However, at the 200% level, methionine as well as lysine must be supplemented. Hence, pure lysine supplementation becomes infeasible. Moreover, since the single cell protein we have analyzed, Torula yeast, is relatively deficient in methionine, this alternative becomes very expensive.

Under the 100% and 150% sets of requirements, synthetic supplementation with lysine is the least costly in terms of both total and supplement costs. For the 150% requirement, universal lysine supplementation will cost Chile about twelve million dollars annually, about 2.4 million less than the next cheapest alternative, importation of cottonseed flour.

If the government is contemplating a fully subsidized program, then political considerations may dictate that it be more concerned with the cost of the supplement than with the total costs of the diet. From the point of view of the efficiency of the total economy, this is irrational. Nonetheless, such attitudes may be operating, in which case, lysine supplementation is still the cheapest alternative, where it is feasible. However, disregarding the not completely developed SCP, the second cheapest alternative is FPC. To put it another way, if the costs of the basal diet are negligible, FPC is the second cheapest alternative at 150% and the cheapest alternative at 200%.

If Chile limits itself to domestic supplements, then we note that FPC has approximately a 10% advantage over sunflower seed. (The price of domestic milk is in excess of 25 cents per pound.) According to our analysis, the decision to use only domestic supplements will cost Chile the equivalent of $7 million U.S. dollars a year at the shadow price (the true value) of foreign exchange, for which Chile should be willing to pay $10 million dollars worth of escudos at the market exchange rate, if she decides on universal supplementation based on 150% FAO requirements for the target group assuming a pure wheat diet. We note in passing that the decision to use FPC does not avoid foreign exchange losses, for not only will the processing equipment have to be imported, but assuming that the hake is already being fished at a maximum sustainable yield, some of this fish will be transfered from an export market to domestic consumption. Chapter IV discusses this in more detail.

We reiterate that our analyses are based on our estimates of the present costs of the alternative supplement, and that both the relative prices of the supplements and the value of foreign exchange may change in the future.

III.3. Costs on the World Market

Table XVIII, which is based on free market prices without a correction for the shadow price of foreign exchange, illustrates an interesting point. This is the situation which would confront a country whose foreign exchange situation was in balance. Here we note that peanut and cottonseed flour beecome as cheap as supplementation with synthetic lysine. This is because both lysine and these flours have had their price reduced relative to wheat, and thus the effect of the oilseed flours in reducing the requirement for wheat becomes more important. This phenomenon also demonstrates the sensitivity of our results to the price of the basal diet relative to the supplement.

In general, our analysis predicts a smaller advantage for synthetic amino acid supplementation compared to the arguments sometimes seen in the literature that synthetic lysine supplementation is anywhere from 200-700% cheaper than natural protein. This difference is a product of our use of the present selling price for lysine, the explicit realization that the world price does not measure the value of foreign exchange for a country with a balance of payments problem, the realization that lysine for human supplementation is not lysine, but lysine monochloride, which is only 80% lysine, and most importantly, the realization that minimum cost per unit of utilizable protein is not the appropriate objective. Since one can reasonably expect some decrease in the price of lysine (see Section II.2) and since the introduction and distribution costs of universal synthetic supplementation should be as low as either of the other alternatives, we feel that the analysis values synthetic lysine supplementation conservatively, with the possible exception of differentials in availability, which are discussed in the following section.

Table XVIII also demonstrates that, under the assumptions of this analysis, FPC is unlikely to be an economic supplement for a country which has to import it. Under these conditions, even at the relatively low Chilean price, FPC ranks behind all the supplements except dried skim milk, at prices higher than about 12 cents per pound.

TABLE XVIII

TOTAL & SUPPLEMENT COSTS OF SUPPLEMENTATION OF WHEAT AT WORLD MARKET PRICES USING THE CHILEAN POPULATION

DAILY DOLLARS X 10^{-5}

100% FAO/WHO REQUIREMENT

	TOTAL	SUPP.	NET	%
FPC	4.89	.18	.17	3.6
SKIM MILK				
@ 8¢	4.86	.16	.14	3.0
@14¢	4.94	.25	.22	4.7
PEANUT FLOUR	4.85	.18	.13	2.8
COTTONSEED FLOUR	4.85	.14	.13	2.8
SOY FLOUR	4.87	.14	.15	3.2
SUNFLOWER SEED FLOUR	4.91	.28	.19	4.0
SINGLE CELL PROTEIN	4.87	.12	.15	3.2
LYSINE - HCL	4.85	.08	.13	2.8

150% FAO/WHO REQUIREMENT

	TOTAL	SUPP.	NET	%
FPC	5.26	.61	.54	11.5
SKIM MILK				
@ 8¢	5.03	.56	.31	6.6
@14¢	5.35	.88	.63	13.4
PEANUT FLOUR	4.96	.63	.24	5.1
COTTONSEED FLOUR	4.96	.48	.24	5.1
SOY FLOUR	5.04	.48	.32	6.8
SUNFLOWER SEED FLOUR	5.32	.96	.60	12.7
SINGLE CELL PROTEIN	5.05	.44	.33	7.0
LYSINE - HCL	4.99	.27	.27	5.7

200% FAO/WHO REQUIREMENT

	TOTAL	SUPP.	NET	%
FPC	5.63	1.03	.91	19.2
SKIM MILK				
@ 8¢	5.27	.96	.55	11.6
@14¢	5.99	1.68	1.27	26.9
PEANUT FLOUR	5.18	1.21	.46	8.7
COTTONSEED FLOUR	5.17	.82	.45	9.5
SOY FLOUR	5.31	.85	.59	12.5
SUNFLOWER SEED FLOUR	5.74	1.64	1.02	21.6
SINGLE CELL PROTEIN	5.57	1.16	.85	18.0
LYSINE - HCL	X	X	X	X

III. 4. Objections to Synthetic Fortification

Our analysis indicates that synthetic fortification with lysine should be examined very carefully in the Chilean situation. An important question, then, is will synthetic amino acid fortification work to anything like the degree predicted? There are three possible sets of reasons why it may not:

1) Our use of chemical score in evaluating protein efficiency is based primarily on rat feeding data. Lysine is more clearly limiting in cereal diets for the rapidly growing young rat than it is for human adults or children.
2) Even the Chilean diet, which relatively speaking is very dependent on wheat, consists of a mixture of foods that may contain sufficient lysine, or may or not be deficient to nearly the degree of a pure bread mixture.
3) As mentioned earlier, considerable processing losses in availability can occur during baking. In some cases, synthetic fortification may be relatively more sensitive to these losses than are its competitors.

There are other reasons why amino acid fortification may not be as effective as we predict. The most common is that the calorie requirements are not being met, and any additional protein is largely metabolized for energy. However, such objections apply equally well to all supplements. In this section we will consider only those objections which are specifically weighted against synthetic amino acid fortification.

Problems with Chemical Score

As noted earlier, the great majority of tests of the validity of the concept of chemical score are based on tests on young rats. In addition, extensive tests with humans on the natural protein supplements such as FPC indicate that properly prepared, these proteins have protein efficiencies equal to or greater than those calculated from chemical score data, provided that protein intake is restricted to levels below the person's total protein requirements. Unfortunately, the same statement cannot be made for synthetic supplementation. Carefully controlled tests of the supplementation of human diets with lysine are few in number and practical applications have sometimes been disappointing.* Furthermore, rats grow much more rapidly than humans, so that while tests indicate somewhat similar amino acid balance requirements, we can expect differences between the response of rats and that of humans.

The earliest test on the effect of lysine supplementation of wheat on humans was conducted by Bressani et al. (86) on a very small sample of six children recently recovered from protein malnutrition. The six boys were fed varying diets over a two-week period. Nitrogen retention on the fortified diets was far above the nitrogen retention on the basal wheat diet and approached that achieved on milk. No systematic changes in weight were recorded, but this is to be expected, considering the very short period (3 days) the subjects were on each diet. The authors conclude, "The nitrogen balance data presented show that the nutritive value of wheat protein can be improved markedly by the addition of lysine alone."

In a second article, (87) these authors discuss the results of similar experiments on seven more children The differences in nitrogen retention were statistically significant at the.01 level. That is, the probability that these differences could have arisen by chance is less than .01. The authors conclude:

> "The nitrogen retention results of the first experiment confirm the previous report of Bressani et al.(see above) that in young children the addition of lysine to a basal wheat diet brings about a marked increase in nitrogen retention. Nevertheless, the increase is lower than that observed from feeding isonitrogenous amounts of tryptophan, methionine, isoleucine, valine, and threonine to the wheat basal diet in amounts called for by the FAO reference pattern (FAO '57) results in nitrogen retention values as high as those obtained with milk or higher."

The most recent set of studies on lysine fortification of wheat in the human diet was that undertaken by Pereira et al.(88) on 52 children ages 2 to 5, in

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*In general, the results of protein supplementation are difficult to demonstrate in the field, no matter what the supplement, including milk.

India. The trials took place over a period of six months, during which time the children were maintained on a basal diet which supplied 100 cal/kg of body weight and 2 grams per kg of vegetable protein. After three months on the pure basal diet, the wheat diet of the children in the experimental group was supplemented to the .25% level with lysine. The wheat used in the diets of both the control and experimental groups supplied 54% of the daily calories and 85% of the daily protein. No animal foods were consumed. The cereal eaten by the control group contained .68 g/lysine, while the supplemented diet contained 1.05 grams.

Analysis of samples of the cooked foods indicated that the children in the experimental group have a lysine intake of .73 grams per day and those in the control group .54 grams per day. Thus, losses in cooking were 30% in the experimental group and 21% in the control group. The final results are based on 24 children in the experimental group and 22 in the control group. 60% of the children in each group were female. Table XIX gives the means and the experimental standard deviations for the increases in height and weight of the control groups. Perhaps the most striking fact about these numbers is the size of the standard deviations relative to the means. Under field conditions, humans are notoriously irregular subjects, as these data bring out.

TABLE XIX

AVERAGES OF HEIGHTS AND WEIGHTS OF CHILDREN IN THE CONTROL GROUP AND THE LYSINE SUPPLEMENTED GROUP

	Height		Weight	
	Initial	Increase	Initial	Increase
Experimental	91.4±8.2	3.26±1.19	12.25±2.23	0.75±0.68
Control	91.4+8.0	2.61±0.99	12.45±0.99	0.58±0.81

The second item of interest is that the ratio of the standard deviation to the mean for height increase (.36 and .26) is much smaller than the corresponding ratio for weight increases (.91 and 1.4). Change in height appears to be a much more stable statistic than change in weight. This is not very surprising. Common experience reveals that weight responds much more rapidly than height to changes in the body's environment. This is true both externally (the last month of the experiment, May, is the hottest in Southern India and the bulk of the children were losing weight in this period while height continued to increase) and internally (weight responds rapidly to various infections, 20 episodes of diarrhea were recorded during the tests).

Applying the T-test to the above data and making the standard assumptions of statistical theory, we find that the probability that the difference in the height means could have arisen by chance is less than .05. However, the difference in the weight means could easily have arisen by chance (Pr = .6). One can take the latter fact as evidence that the supplementation was ineffective or that the weight was responding to other changes in the environment. We feel the latter is the more likely explanation.

There can be little doubt that more testing of lysine supplementation is indicated. However, our present best judgment is that these tests will indicate that available lysine will be as effective as the chemical score theory suggests.

This conclusion is based in part on the fact that there can be no doubt that the basic human protein needs are for nitrogen and certain amino acids, and not for milk or meat or any particular class of foodstuff. Thus, the only possible reason why available synthetic amino acids would not be utilized in the same manner as the same compound received in the form of, say, meat protein, is that the digestive mechanizm depends on the rate at which the amino acids are liberated from the structure of the food within the limits of a single meal. There is not any evidence that this matters. In reviewing the literature, one finds that the more carefully controlled the experiment, the more likely one is to find that both animal and human subjects made full use of the available synthetic amino acids that they required.

The Effects of a Mixed Diet

This brings us to the second set of possible objectives to synthetic fortification. These revolve around the fact that no culture subsists entirely on a single grain diet,and that the other components of that diet may go a long way towards correcting amino acid imbalances.

In order to investigate the effects of a mixed diet on the relative attractiveness of various supplementation alternatives,two mixed diets have been derived which are believed to be representative of the diet received by young children in Chilean homes from the lowest five percentile of the Chilean income distribution. The derivation of these diets is given in Chapter V and their relative composition is given below.

TABLE XX

CHILEAN MIXED DIET I	%
Bread	26.9
Vegetables	11.7
Sugar	7.7
Spaghetti	3.6
Flour	3.2
Fruit	6.6
Oil	3.8
Potatoes	7.8
Milk	28.7

CHILEAN MIXED DIET II	%
Bread	38.1
Vegetables	8.8
Sugar	2.7
Farinas	10.6
Legumes	.9
Fruit	8.8
Oil	3.5
Potatoes	26.6

The universal supplementation computer program was applied to Mixed Diet I, with the results shown in Table XXI. Despite the fact that this diet is 35% wheat, the limiting amino acid is methionine. Considerable natural supplementation occurs, and as a result, this diet will meet the FAO requirements for a 10 month old child, provided that the child receives sufficient calories, and even at 150% the FAO requirements, very little supplementation is required - little more than two grams of FPC, for example. This diet has a caloric density which is a good deal less than that of a pure wheat diet, which may mitigate against the small child's receiving sufficient calories. At 200%, the percentage supplements become substantial.

TABLE XXI

POOR CHILEAN DIET #I

CALCULATED BASE-SUPPLEMENT COMBINATIONS FOR TARGET GROUP*
150% FAO PROTEIN REQUIREMENTS

	BASE	SUPP.	% SUPP.	PROTEIN %CALORIES	% PROTEIN UTILIZED
FPC	461	2.8$	.6	10.3	75
SKIM MILK	451	8.3	1.8	10.5	75
PEANUT FLOUR	430	21.3	4.9	13.5	50
COTTONSEED FLOUR	453	10.2	2.2	11.5	69
SOY FLOUR	452	10.9	2.4	11.4	68
SUNFLOWER SEED FLOUR	450	11.5	2.5	11.0	71
SINGLE CELL PROTEIN	450	13.4	2.9	12.2	64
LYSINE & METHIONINE**	465	.4	.2	9.6	81

200% FAO PROTEIN REQUIREMENTS

	BASE	SUPP.	% SUPP.	PROTEIN %CALORIES	% PROTEIN UTILIZED
FPC	453	9.3	2.0	12.2	85
SKIM MILK	419	27.3	6.5	12.6	83
PEANUT FLOUR	349	69.6	19.9	22.8	49
COTTONSEED FLOUR	426	33.3	7.8	16.1	67
SOY FLOUR	422	35.8	8.5	15.9	65
SUNFLOWER SEED FLOUR	423	32.0	7.6	13.7	77
SINGLE CELL PROTEIN	414	43.8	12.6	18.3	57
LYSINE & METHIONINE**	461	3.0	.6	10.4	100

* Lysine of bread assumed to be only 50% available.

** $\frac{\text{Lysine-HCL}}{\text{Methionine}} = \frac{1}{1}$

TABLE XXII

COSTS OF UNIVERSAL SUPPLEMENTATION OF MIXED DIET I*
(CHILEAN COSTS AND POPULATION, 150% FAO REQUIREMENTS)

DAILY DOLLARS X 10^{-5}

	TOTAL	SUPP.	NET	%
FPC	16.4	.3	.1	.6
SKIM MILK POWDER	16.1	.4	-.2	1.2
PEANUT FLOUR	15.7	.7	-.6	3.8
COTTONSEED FLOUR	16.1	.3	-.2	1.2
SOY FLOUR	16.3	.5	0.0	0.0
SUNFLOWER SEED FLOUR	16.1	.4	-.2	1.2
SINGLE CELL PROTEIN	16.3	.7	0.0	0.0
LYSINE & METHIONINE	16.6	.3	.3	1.8

(CHILEAN COSTS AND POPULATION, 200% FAO REQUIREMENTS)

	TOTAL	SUPP.	NET	%
FPC	16.8	1.0	.5	3.1
SKIM MILK POWDER	16.0	1.4	-.3	1.8
PEANUT FLOUR	14.6	2.4	-1.7	10.4
COTTONSEED FLOUR	15.9	1.1	-.4	2.5
SOY FLOUR	16.5	1.8	.2	1.2
SUNFLOWER SEED FLOUR	15.8	1.1	-.5	3.1
SINGLE CELL PROTEIN	16.9	2.5	.6	3.7
LYSINE & METHIONINE	18.3	2.2	2.2	13.5

*All import costs adjusted for scarcity of foreign exchange and shipping charges.

Table XXII indicates the total and supplement cost for this diet at the 150 and 200% levels, assuming that it is fed to the entire Chilean population according to caloric needs. The average wholesale cost of this diet is about 7¢ per pound, which is approximately the cost of the oilseed flours on a weight basis, and is more expensive than the cheapest oilseeds on a calorie basis. Thus, supplementation with these flours can actually reduce the total cost of the diet under the 'constant calorie' assumption, for the supplement is not only a source of protein, but also a source of calories which is cheaper than the basal diet.

At first this might appear to be a highly anomalous situation. On the other hand, it could be quite common. People simply are not nutritional economizers when it comes to eating. In cases such as these, substituting a supplement for part of the natural diet, if possible, can reduce the cost of food while, at the same time, increasing the level of nutrition. This is more a statement about the inefficiencies of eating habits than the efficiency of supplement. In any event, in a situation such as this, the more supplement, the better by our standards. Thus, a low quality protein such as peanut flour, which requires large quantities of supplement, results in corresponding large decreases in total diet costs or large negative net costs.

This raises some important questions of both acceptability and distribution cost. How much would it cost to convince Chileans that 20% of their diet should be peanut flour? Is it possible at any price? There will almost certainly be important differentials in distribution costs between, say, a diet consisting of 20% imported peanut flour and a larger diet in total bulk, but consisting of only 2.9% FPC. Importing $100,000,000 worth of peanut flour per year will certainly change the shadow price, the marginal value of foreign exchange.

This is clearly a case where our concentration on cost ex-factory and our disregard for the demand side severely limits the conclusions we can draw. However, it does appear that: (a) at least some of the oilseeds maintain their advantage over FPC; (b) Primarily because of the phenomenon outlined above and the fact that sunflower seed is relatively rich in methionine, sunflower seed flour is a much more attractive alternative in this case than it was on a pure wheat diet;(c) since this diet requires supplementation with both methionine and lysine, synthetic amino acid supplementation not only is no longer the cheapest alternative, but also, it becomes the most expensive.

Thus, it appears that the objection against synthetic amino acid fortification on the grounds that nobody eats a pure grain should be given considerable weight. However, the validity of this objection appears to do little to improve the competitive position of FPC vis a vis the oilseeds in this situation,;although, once again, it exhibits a relatively low cost of supplement.

The second mixed diet we examined was derived from a Chilean urban middle class diet, given in reference 104, by removing all meat and dairy products on the grounds that the target group child rarely receives such foods.

The results are displayed in Tables XXIII and Table XXIV. In general, the results are the same as in the first diet, with the exception that methionine alone needs to be supplemented in order to meet even the 200% level of reference protein to make this a viable alternative.

In general, we have found that when there is a unique limiting amino acid in the target group's diet and this amino acid can be identified, supplementation with that acid will be quite attractive, even if it must be imported. However, if, due to variation in diet within the target group or variations in individual amino acid requirements, there exists no single limiting amino acid, or if that acid cannot be identified, then supplementation with more than one synthetic amino acid to ensure covering everybody's need will be rather expensive.

When one invests in a natural protein, one purchases this insurance automatically. Thus, when one makes this multiple amino acid requirement explicit, the cost of the natural protein alternative is almost unaffected.

TABLE XXIII

POOR CHILEAN DIET # II

CALCULATED BASE SUPPLEMENT COMBINATIONS FOR TARGET GROUP

150% FAO PROTEIN REQUIREMENTS

	BASE	SUPP.	% SUPP.	PROTEIN %CALORIES	PROTEIN %UTILIZED
FPC	410	3.5	.8	14.5	54
SKIM MILK	401	12.4	2.5	14.5	54
PEANUT FLOUR	399	10.2	6.6	18.0	45
COTTONSEED FLOUR	400	13.3	3.0	15.85	50
SOY FLOUR	397	16.3	3.3	15.76	49
SINGLE CELL PROTEIN	376	25.7	4.0	16.6	49
SUNFLOWERSEED FLOUR	401	11.4	2.8	14.0	52
METHIONINE	414	.2	.02	13.6	58

200% FAO PROTEIN REQUIREMENTS

	BASE	SUPP.	% SUPP.	PROTEIN %CALORIES	PROTEIN %UTILIZED
FPC	401	9.9	2.5	16.3	63
SKIM MILK	371	29.0	7.8	16.4	64
PEANUT FLOUR	307	73.1	23.9	26.4	42
COTTONSEED FLOUR	376	35.4	9.4	20.2	53
SOY FLOUR	374	38.0	10.2	19.9	52
SINGLE CELL PROTEIN	366	46.5	12.7	22.4	46
SUNFLOWER SEED FLOUR	376	32.7	8.7	17.5	59
METHIONINE	414	.5	.1	13.7	76

TABLE XXIV

COSTS OF UNIVERSAL SUPPLEMENTATION OF MIXED DIET II
(CHILEAN COSTS AND POPULATION, 150% FAO REQUIREMENTS)

DAILY DOLLARS X 10^{-5}

	TOTAL	SUPP.	NET	%
FPC	14.7	.4	.2	1.4
SKIM MILK POWDER	14.5	.5	.0	.0
PEANUT FLOUR	14.0	.8	-.5	3.4
COTTONSEED FLOUR	14.5	.4	.0	.0
SOY FLOUR	14.6	.7	.1	.7
SUNFLOWER SEED FLOUR	14.4	.4	.3	.7
SINGLE CELL PROTEIN	14.8	.9	.3	2.0
METHIONINE	14.5	.1	.0	.0

(CHILEAN COSTS AND POPULATION, 200% FAO REQUIREMENTS)

	TOTAL	SUPP.	NET	%
FPC	15.1	1.1	.6	4.1
SKIM MILK POWDER	14.4	1.5	-.1	.7
PEANUT FLOUR	13.2	2.5	-1.3	9.0
COTTONSEED FLOUR	14.4	1.2	- .1	.7
SOY FLOUR	15.0	1.9	.5	3.5
SUNFLOWER SEED FLOUR	14.3	1.1	- .2	1.4
SINGLE CELL PROTEIN	15.4	2.6	.9	6.1
METHIONINE	14.8	.4	.3	2.0

In summary, if one is unable to identify precisely the target group's basal diet, or if the target group is expected to have a range of diets differing in the limiting amino acids, then one is led away from synthetic supplementation toward natural supplementation. The Chilean analysis suggests that it will rarely be efficient to supplement with more than one synthetic amino acid.

Differentials in Availability

The final set of objectives against our analysis of universal supplementation is our rather cavalier treatment of availability, where we have assumed 100% availability and then recommended increasing the reference protein levels to cover differentials in availability which may exist among the alternative supplements.

This problem of availability of amino acids is particularly severe in the case of bread, where baking may reduce the availability of lysine in wheat flour by 10 to 30%, and in the case of roller dried milk, where lysine availability losses have been found as high as 70% (80). The mechanism used to explain the loss of availability is the Maillard reaction, in which a sufficient amount of heat can cause an amino acid and a reducing sugar, such as glucose, to form a chemical bond which is resistant to the activity of the digestive enzymes. This reaction most often involves lysine.

Although high temperatures are used during the industrial processing of the protein concentrates, available lysine is usually a high percentage of the total amount present. The Bureau of Commercial Fisheries (89) found the lysine of solvent-extracted FPC to be 93% available. Although some FPC samples examined by Morrison and Sabry (78) showed extreme availabilities of 61% and 100% of total lysine, most samples were between 83% and 95%. Stott and Smith (90) have developed a microbiological assay for distinguishing and measuring available amino acids. Their experiments on samples of soy and peanut flour suggest that lysine availabilities are within 85% to 95% of the total lysine. These results were similar to those they obtained using a method of Carpenter (91). They indicated a low (50%) availability of lysine in cottonseed flour, but the sample material was high in gossypol, a substance which is common in cottonseeds and which, if not removed, will bind lysine and render it unavailable. Baliga and Lyman (92) found that lysine in a commercial cottonseed meal was only 55% available when bound gossypol decreased to .49% and .37% respectively. An Italian firm, Vaccarino, manufactures a human grade cottonseed flour with lysine availability similar to the other concentrates (93). And, according to Bressani et al.(94), production of cottonseed flour with high lysine availability is entirely feasible.

Studies by Ebersdobler and Zucker (77) on roller dried skim milk showed lysine availabilities ranging from 62 to 91% of the total lysine present. The lower availabilities, however, were found to occur primarily in samples which had been dried on older rollers. On the basis of rat PER responses when non-fat dry milk was added to bread before and after baking, Jansen et al.(96) estimated that 36% of the lysine of milk protein was rendered nutritionally unavailable by the baking. Since milk has a higher content of reducing sugars, these baking losses are probably greater than would occur with FPC and the oilseed flours, although these are also likely to lose some available lysine. There are numerous ways of incorporating dried milk into the diet so that baking losses need not be a factor.

Most of the studies on the availability of synthetic lysine monohydrochloride have been concerned with losses of lysine supplements from wheat flour during baking. Mathews et al. (97) determined losses of L. lysine -HCL in two types of supplemental breads. A common unleavened Indian bread made of atta, a long extraction wheat flour, was susceptible to losses of only 1 to 4% of the added lysine. This bread is baked for only 40 seconds, however. Average decreases in availability of lysine were 25% in yeast leavened breads, which require 30 minutes of baking time. Jansen et al. (96) conducted PER experiments on rats to measure nutritional losses of lysine added to a standard white bread containing non-fat dry milk, and they indicated that losses in availability may run as high as 30%. Bread which did not contain dry skim milk lost 15% of the added lysine. In both cases the losses were progressive with increased baking time. Ericson et al.(98) using a microbiological assay, found 15% losses in white bread. Experience in Japan has shown losses during baking time to be about 10% (79).

In the orphanage study of Peirera *et al.*, described earlier in this report, losses of total lysine through cooking were 21% in the control diet and 30% in the supplemented diet. If losses of native lysine of the latter are assumed to be equivalent to the lysine loss of the former, then losses of synthetic lysine HCL amounted to 48% of the supplement. These large losses are probably due to the fact that the wheat flour was often prepared by boiling or frying. Similar losses (50-60%) of added lysine will occur on boiling of fortified noodles (79). Rinse resistent coatings are applied to enriched rice kernels, so that cooking losses are greatly reduced (99).

In summary, then, under proper processing conditions the natural sources can expect to have availabilities on the order of 85%, and there appear to be no significant differentials in susceptibility to processing losses among them. However, although the evidence is fragmentary, it does appear that considerably more care may have to be exercised to maintain the availability of synthetic lysine. However, at present, there is no reason to expect that with proper processing the availability of lysine cannot be maintained. An obvious exception to this statement is pasta cooked in excess water. Synthetic lysine is quite soluble whereas the lysine in a natural protein such as FPC is not.

Once again, the susceptability of synthetic lysine to processing losses will not improve FPC's position relative to the other natural protein sources. It is a factor, however, in determining what kind of cost decrease will be required of FPC in order to make it competitive in situations where synthetic lysine supplementation is currently the most attractive alternative.

III. 5. Analysis of a Number of Non-Chilean Diets

We have performed a less detailed analysis of the comparative economics of FPC on three non-Chilean basal diets: pure rice, pure corn, and cassava. Table XXV shows the results of the analysis of a pure rice diet supplemented with the now-familiar set of alternatives. As Table XIV intimated, FPC fares less well on rice than it does on wheat. The prices used in this Table are based on domestic production of FPC at the estimated Chilean production costs, and importation of all the other alternatives at a 30% surcharge, a shadow price that is typical of the currency scarcities of developing countries. This is a relatively favorable export/import situation for FPC. Despite this, FPC is the most expensive alternative. This analysis may be more than a little unfair, for the costs of preparing a supplement so that it can be used in a rice diet, generally through the manufacture of a synthetic grain, can be condiderably more than the costs of the material. (79) In terms of basic nutrition, however, FPC is at a considerable disadvantage on a pure rice diet.

Table XXVI shows the similar analysis of corn. Here we note that the situation is more favorable to FPC. Corn is short in tryptophan, which is currently available only at $41.00 per pound (26). Even if it were available at the current price of lysine, however, FPC would remain the cheaper alternative. This effectively rules out unaided synthetic supplementation at 150% FAO levels until tryptophan prices come down. At the 200% level yet another amino acid becomes limiting.

Furthermore, corn is cheap, about 3¢ per pound, which decreases the value of the less concentrated supplements' caloric content. As a result even if FPC has no foreign exchange advantage, it is second only to soy flour in both total supplement costs. If FPC can be produced domestically while soy flour cannot (the typical case in the tropics) and the shadow price of foreign exchange is 30% higher than the market rate, then soy flour's advantage is reduced to:

TABLE XXV

RICE-SUPPLEMENT COMBINATIONS UNIVERSAL SUPPLEMENTATION
TYPICAL DEVELOPING COUNTRY POPULATION. ALL SUPPLEMENTS EXCEPT FPC
IMPORTED AT 30% SURCHARGE

DAILY DOLLARS X 10^{-3}

100% FAO	TOTAL	SUPP.	NET	%
FPC @ 25¢	110.0	1.5	1.5	1.4
SKIM MILK POWDER				
@ 8¢	109.9	2.0	0.5	.46
@14¢	110.0	3.0	1.5	1.4
SOY FLOUR	109.0	1.5	0.5	.46
COTTONSEED FLOUR	109.0	1.5	0.5	.46
PEANUT FLOUR	109.0	2.0	0.5	.46
SINGLE CELL PROTEIN	109.0	1.0	0.5	.46
LYSINE	109.0	0.8	0.5	.46

150% FAO	TOTAL	SUPP.	NET	%
FPC	114.0	7.0	5.5	5.0
SKIM MILK POWDER				
@ 8¢	110.0	7.0	1.5	1.4
@14¢	114.0	11.0	5.5	5.0
SOY FLOUR	112.0	7.0	3.5	3.2
COTTONSEED FLOUR	111.0	7.0	2.5	2.3
PEANUT FLOUR	109.0	9.0	0.5	.46
SINGLE CELL PROTEIN	112.0	6.0	3.5	3.2
LYSINE	112.0	4.0	3.5	3.2

200% FAO	TOTAL	SUPP.	NET	%
FPC	117.0	12.0	8.5	7.8
SKIM MILK POWDER				
@ 8¢	113.0	14.0	4.5	4.1
@14¢	123.0	24.0	4.5	13.9
SOY FLOUR	115.0	12.0	6.5	6.0
COTTONSEED FLOUR	112.0	12.0	3.5	3.2
PEANUT FLOUR	109.0	16.0	0.5	.46
SINGLE CELL PROTEIN	115.0	11.0	6.5	6.0
LYSINE	X	X	X	X

TABLE XXVI

CORN SUPPLEMENT COMBINATIONS UNIVERSAL SUPPLEMENTATION TYPICAL DEVELOPING COUNTRY POPULATION. ALL SUPPLEMENTS AT WORLD MARKET PRICES

DAILY DOLLARS X 10^{-4}

100% FAO

	TOTAL	SUPP.	NET	%
FPC	.62	.07	.07	2.0
SKIM MILK POWDER @ 8¢	3.92	.50	.37	10.4
SOY FLOUR	3.60	.05	.05	1.4
COTTONSEED FLOUR	3.75	27	.20	5.6
PEANUT FLOUR	3.82	.44	.27	7.6
SINGLE CELL PROTEIN	3.90	.41	.35	9.8
LYSINE & TRYPTOPHAN				
@ $1.25/lb.	3.77	.22	.22	6.2
@ $35.00/lb.*	9.70	6.15	6.15	173.0

150% FAO

	TOTAL	SUPP.	NET	%
FPC	4.09	.58	.54	15.2
SKIM MILK POWDER @ 8¢	4.57	1.41	1.02	29.0
SOY FLOUR	3.93	.47	.38	10.5
COTTONSEED FLOUR	4.10	.77	.55	15.5
PEANUT FLOUR	4.32	1.26	.77	21.7
SINGLE CELL PROTEIN	4.52	1.16	.97	27.3
LYSINE & TRYPTOPHAN				
@ $1.25/lb.	4.13	.58	.58	16.4
@ $35.00/lb.*	19.75	16.20	16.20	58.0

200% FAO

	TOTAL	SUPP.	NET	%
FPC	4.54	1.08	.99	28.7
SKIM MILK POWDER @ 8¢	5.22	2.29	1.76	49.5
SOY FLOUR	4.27	.89	.72	20.3
COTTONSEED FLOUR	4.43	1.25	.97	28.1
PEANUT FLOUR	4.78	2.06	1.32	38.2
SINGLE CELL PROTEIN	5.15	1.93	1.60	45.1
LYSINE & TRYPTOPHAN	X	X	X	X

* Price of Lysine - Tryptophan combination based on current price of $41/lb. for tryptophan

TABLE XXVII
Daily Dollars X 10^{-4}

	TOTAL	SUPP.	NET	%
		100% FAO		
FPC	3.62	.07	.07	2.0
SOY FLOUR	3.62	.07	.07	2.0
		150% FAO		
FPC	4.09	.58	.54	15.2
SOY FLOUR	4.07	.59	.52	14.7
		200% FAO		
FPC	4.54	1.08	.99	27.9
SOY FLOUR	4.53	1.15	.98	27.6

Thus, a slight decrease in the price of FPC could make it the economic alternative in a fish rich, foreign exchange poor, corn eating country.

The final diet which we have analyzed under universal supplementation is that of a cassava as a basal diet. The diet of a cassava eating population on Madagascar (100) during the five months in which animal foods are scarce was analyzed in the usual manner. This diet, which consists of approximately equal amounts of honey, beans, corn and cassava, was found to be severely limited in methionine; threonine was the second limiting amino acid. Required amounts of base and supplement are shown in Table XXVIII.

As shown in Table XXIX, cottonseed flour performs rather well on this diet. Sunflower meal and peanut flour are no longer the cheapest supplements, as they were with the solely methionine limiting mixed Chilean diets.

Sunflower seed is now considered an import, (whereas in Chile it was a domestic product) and as such, it becomes more expensive relative to the other supplements. Peanut flour does not increase the caloric density of this high calorie diet as it did in the Chilean diet sample, and therefore it acts only through its methionine content, which is the poorest of all the supplements with the exception of single-cell protein. SCP is the most expensive supplement, due to a very low level of methionine. The synthetic supplements are the cheapest only if threonine is considered to cost the same as lysine does at present.

TABLE XXVIII

CASSAVA

BASE SUPPLEMENT COMBINATIONS WHICH SATISFY PROTEIN REQUIREMENTS FOR 10 MONTH OLD INFANT

100% FAO

	BASE (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN % CALORIES	SCORE
FPC	268	4.5	1.7	10.1	51
SKIM MILK POWDER	261	10.2	3.9	9.9	52
PEANUT FLOUR	260	12.1	4.7	11.1	48
COTTON FLOUR	265	9.2	3.5	10.6	50
SOY FLOUR	265	8.6	3.2	10.3	50
SUNFLOWER SEED FLOUR	263	10.6	4.0	10.2	51
SINGLE CELL PROTEIN	266	8.36	3.1	10.4	50
THREONINE AND METHIONINE*	272	.08	.29	8.9	59

150% FAO

	BASE (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN % CALORIES	SCORE
FPC	264	10.0	3.8	11.6	66
SKIM MILK POWDER	240	32.2	13.4	12.5	63
PEANUT FLOUR	222	51.0	23.0	18.6	44
COTTON FLOUR	253	26.4	10.4	14.1	57
SOY FLOUR	252	28.2	11.2	13.8	56
SUNFLOWER SEED FLOUR	253	24.2	9.5	12.0	65
SINGLE CELL PROTEIN	240	45.9	19.3	18.0	43
THREONINE AND METHIONINE*	272	.44	.16	8.9	88

200% FAO

	BASE (GRAMS)	SUPP. (GRAMS)	% SUPP.	PROTEIN % CALORIES	SCORE
FPC	256	18.6	7.3	14.1	73
SKIM MILK POWDER	212	59.1	27.9	15.7	67
PEANUT FLOUR	180	94.5	52.5	27.0	41
COTTON FLOUR	236	48.8	20.7	18.6	58
SOY FLOUR	234	52.3	22.3	18.2	56
SUNFLOWER SEED FLOUR	237	44.9	18.9	14.8	70
SINGLE CELL PROTEIN	213	84.5	39.7	25.9	40
THREONINE AND METHIONINE*	X	X	X	X	X

* $\frac{\text{Threonine}}{\text{Methionine}} = \frac{1}{3}$

TABLE XXIX

CASSAVA DIET

COST OF SUPPLEMENTS FOR POPULATION OF ONE MILLION
DAILY DOLLARS X 10^{-4}

100% FAO

	TOTAL	SUPP.	NET	%
FPC	6.09	.59	.53	9.5
SKIM MILK POWDER @ 8¢/lb	5.98	.61	.42	7.5
PEANUT FLOUR	5.84	.50	.28	5.0
COTTON FLOUR	5.82	.38	.26	4.7
SOY FLOUR	5.96	.51	.40	7.2
SUNFLOWER SEED FLOUR	5.98	.52	.42	7.6
SINGLE CELL PROTEIN	6.02	.56	.46	8.3
METHIONINE & THREONINE @$1.25/lb.	5.65	.07	.09	1.6
@$12.25/lb.*	6.27	.69	71	20.0

150% FAO

	TOTAL	SUPP.	NET	%
FPC	6.71	1.31	1.15	20.7
SKIM MILK POWDER@8¢/lb	6.85	1.93	1.29	23.2
PEANUT FLOUR	6.65	2.09	1.09	19.6
COTTON FLOUR	6.27	1.08	.71	12.7
SOY FLOUR	6.85	1.69	1.29	23.2
SUNFLOWER SEED FLOUR	6.49	1.30	.93	16.7
SINGLE CELL PROTEIN	7.98	3.06	2.42	43.5
METHIONINE & THREONINE @ 1.25/lb.	5.94	.37	.38	7.0
@12.25/lb.*	8.46	2.89	2.90	52.0

200% FAO

	TOTAL	SUPP.	NET	%
FPC	7.67	2.42	2.11	38.0
SKIM MILK POWDER @ 8¢/lb	7.91	3.55	2.35	42.3
PEANUT FLOUR	7.56	3.87	2.00	36.0
COTTON FLOUR	6.86	2.00	1.30	23.4
SOY FLOUR	7.94	3.14	2.38	42.8
SUNFLOWER SEED FLOUR	7.26	2.40	1.70	30.6
SINGLE CELL PROTEIN	10.01	5.64	4.45	80.0
METHIONINE & THREONINE	X	X	X	X

* Price of methionine and threonine combination based on current cost of $34.00/lb. for threonine.

This is not the case however, as threonine now sells for $34 a pound (26). FPC suffers much the same fate on Madagascar as it did in other cases. In contrast to other supplements, less FPC is required to make a diet adequate in protein, but this efficiency acts as a disadvantage in that it causes only a slight reduction in the amount of basal diet required. This, along with the high unit cost of FPC, makes it uncompetitive despite the fact that Table XXIX considers all supplements but FPC to be imports, and charges them with a 30% premium representing a typical differential between the market exchange rate and the true value of foreign exchange.

III. 6. Perfectly Selective Supplementation

It is clear that, distribution and promotion costs aside, universal amino acid supplementation is a nutritionally inefficient scheme in that in order to meet the minimum protein requirements for everybody, it is necessary to overfeed the great majority of the population. In order to obtain an upper limit on the costs incurred by limiting ourselves to universal supplementation, we have investigated the ex-factory/vessel cost of perfectly selective supplementation under which each nutritionally distinctive population sector is theoretically supplied exactly its protein and calorie requirements. It is obvious, from a practical view, that this is a hypothetical distribution scheme. However, it will serve to point out the maximum differential between the costs of universal supplementation and more selective programs.

We have analyzed only one diet under perfectly selective supplementation and that is a pure wheat diet in Chile. Table XXX shows the results. The four left hand columns assume that persons up to age 12 receive 150% of their FAO reference protein requirements, and persons above this age receive 100% of their requirements. In the righthand column, all age groups receive 150% FAO requirements.

If one compares the results with Table XVI representing universal supplementation, one notes that the supplement costs for 150% requirements for universal supplementation are in every case about 4.4 times their corresponding values in the lefthand side of Table XXX. Similarly, comparing the supplement figures results in a difference of 3.7 for all supplements. This suggests a near linear relationship between universal and perfectly selective supplementation costs.

As a result, the earlier rankings are preserved. However, synthetic amino acid supplementation is less practical for selective schemes than it is for universal application. One may not be able to effect the careful control required by synthetic lysine supplementation at the household or neighborhood clinic level.

Thus, the operative comparison may be between universal supplementation via synthetic lysine and non-synthetic selective supplementation, the most economical of which is cottonseed flour, if we regard SCP as not yet available. For 150% FAO requirements, the comparison thus becomes:

	TOTAL COST x 10^{-5}/DAY	NET COST x 10^{-5}/DAY
UNIVERSAL-LYSINE-HC.	5.07	.35
SELECTIVE-COTTON	4.85	.15

These numbers must be interpreted with some caution. Even in a highly developed economy with a sophisticated distribution system, the costs of distribution of processed foods run to 30% of the total costs. In a developing country with an inefficient distribution system, costs can be expected to be much higher. The costs of promoting and maintaining demand for even a well established product run to 10-15% of the food processor's budget. As far as universal versus selective distribution is concerned, there will be considerable differences in these promotion and distribution costs which will favor universal supplementation, especially if the government subsidizes universal supplementation, since then no promotion costs need be incurred.

Consider transport costs. The physical bulk of the supplement under universal synthetic lysine supplementation will be one-fifth that of selective supplementation with cottonseed flour, and no separate packaging will be required. In short, the costs of distributing synthetically supplemented wheat will be almost the same as the costs of distributing unsupplemented wheat, while any kind of selective supplementation will incur significant distribution costs over those incurred for the distribution of the basal diet. Of course, in general there will be large segments in any population outside the reach of centrally processed staples. These people must be reached by a form of selective supplementation.

This very cursory analysis serves to suggest that there do exist distribution programs which are considerably cheaper than universal supplementation, even if the more selective scheme rules out the use of synthetic amino acid supplementation. However, any comparison of a particular distribution scheme against universal supplementation must carefully consider distribution and promotion costs, which analysis is not undertaken in this report. We can note, however, that unless FPC offers distributional or promotional advantages over the oilseed flour, the mere fact that we go to a selective distribution scheme will not improve its competitive position.

III. 7 Nutritional Improvement Via An Infant Food

Introduction

Given that the members of the primary target group are preschool children, several countries have shown active interest in selective supplementation via an infant food.

In many cases, especially those with a reasonably well developed food processing and distribution system, this approach will be very attractive and indeed almost all the protein supplementation programs which have been successful fall into this general category.

For our analysis of infant foods, we will use the same basic nutritional assumptions which were employed earlier:

(1) the nutritional requirement is for amino acids and non-specific nitrogen according to the FAO reference pattern.

(2) the target group to whose requirements the infant food will be designed is a one year old child.

As before, we will analyze three levels of reference protein for this group: 100, 150, and 200% the FAO/WHO estimated minimal requirements. Processing losses will be ignored.

In addition, in order to design an infant food, one must make an assumption about how much of the infant food, and how much of the natural diet the target group will eat. Consistent with our earlier philosophy, we will assume that the combined diet will supply the target group with the FAO calorie requirements. Given that the quantity of baby food is specified, this requirement will determine how much of the natural diet the target group will eat.

With respect to the quantity of baby food in Chile, our sample situation, primary interest seems to be in a supplemented roast wheat gruel roughly similar to ulpo, the present infant diet. Thus, for the moment let us consider a liquid infant food based on wheat. Based on the Incaparina experience, Dr. Scrimshaw feels that it is reasonable to expect most of the target group -one year old children- to receive two glasses of the infant food per day, diluted in such a fashion as to supply about 20 grams of dry weight of infant food per glass. Incaparina's designers aimed at 75grams/child/day in three glasses of beverage. In practice this amount was rarely received and the dilution was usually into four rather than three glasses.

In this regard, we have arbitrarily assumed that, after designing the infant food in such a manner, 40 grams of the food plus sufficient calories from the basal diet meets both calorie and reference protein requirements of the one-year-old, then age groups up to age 6 receive their calorie requirements from a diet which combines the basal diet and the infant food in the same percentage as that used for the target group. Finally, we assumed that none of the infant food is consumed by population groups older than six.

Linear Programming Formulation

In designing an infant food, one would like to be able to consider combining the various alternative supplements in the same diet to make use of their varying amino acid patterns. The problem of designing a supplemental food which, together with a specified basal diet, meets stipulated calorie, essential amino acid and nitrogen levels at minimum cost can be expressed as a linear program (113)

We have adopted the Mathematical Programming System implemented in the IBM/360 system at the M.I.T. Computation Center for this purpose. The input to this program is shown in Table XXXI and Table XXXII. Table XXX indicates the calorie and amino acid concentrations of the various basal diets and supplements. These latter are the same figures that were used in our earlier analyses in determining the chemical score of the various diets. These concentrations form the activity coefficients in the linear program. Table XXXI shows the daily requirements for the target group under the assumption of 100%, 150%, and 200% FAO/WHO reference protein levels. These requirements form the constraint levels of the linear program. The unit costs used are those of page 88 which purport to represent the opportunity costs to Chile of employing the various alternatives.

A Pure Wheat Diet

The first basal diet we analyzed in this manner is the pure wheat regimen. Since we are using a wheat-based infant food, there is no essential nutritional difference between this problem and the analysis of universal supplementation of a pure wheat diet. Therefore, this analysis was primarily a check with the old.

The results did agree for the 100% and 150% FAO/WHO requirements. This is because at these levels there are only two operative constraints and a basic result of linear programming is that the number of different alternatives in the minimal cost solution will be no larger than the number of operational.

TABLE XXX

CONCENTRATIONS OF VARIOUS NUTRIENTS IN VARIOUS FOODS (THE MATRIX OF ACTIVITY COEFFICIENTS IN THE LINEAR PROGRAM)

Nutrient	Corn	Wheat	Rice	FPC	Milk	Peanut	Cotton.	Soy	Sunfl.	Lys	Meth.	Trypt.
Cals/kg.	.035	.036	.035	.031	.036	.035	.026	.026	.028	0	0	0
Lysine(gr/gr.)	.002	.002	.002	.070	.028	.017	.022	.031	.015	.78	0	0
Meth. "	.002	.002	.002	.023	.009	.004	.007	.007	.008	0	1.00	0
Tot.S. "	.004	.004	.004	.018	.034	.012	.011	.015	.015	0	1.00	0
Threon. "	.003	.003	.030	.036	.016	.014	.018	.019	.016	0	0	0
Trypt. "	.001	.002	.001	.008	.005	.004	.006	.007	.006	0	0	1.00
Nitrogen "	.012	.019	.013	.128	.056	.080	.082	.082	.062	.125	.16	.16

TABLE XXXI

DAILY REQUIREMENTS OF VARIOUS NUTRIENTS AS A FUNCTION OF REFERENCE PROTEIN LEVEL AND AGE (THE LEVEL OF CONTRAINT VECTORS IN THE LINEAR PROGRAM)

	100% FAO/WHO REFERENCE PROTEIN LEVEL			150% FAO/WHO REFERENCE PROTEIN LEVEL			200% FAO/WHO REFERENCE PROTEIN LEVEL		
Age Groups	1	2-3	4-6	1	2-3	4-6	1	2-3	4-6
Nutrients									
Calories	1150	1300	1600	1150	1300	1600	1150	1300	1650
Lysine (grs)	.52	.59	.70	.79	.88	1.04	1.05	1.17	1.39
Meth. "	.27	.31	.37	.41	.46	.55	.55	.62	.73
Tot. S. "	.52	.59	.70	.79	.88	1.04	1.05	1.17	1.39
Threon. "	.35	.39	.46	.53	.59	.69	.70	.78	.92
Trypt. "	.17	.20	.23	.26	.29	.34	.35	.39	.46
Nitrogen."	2.00	2.22	2.66	3.00	3.34	4.00	4.00	4.48	5.27

TABLE XXX II

COMPOSITION OF TWO COMPONENT INFANT FOODS MEETING REQUIREMENTS OF TARGET GROUP UNDER 100,150,200% FAO/WHO REFERENCE PROTEIN REQUIREMENTS

	COMPOSITION OF INFANT FOOD	
	%WHEAT	% PROTEIN CONCENTRATE
100% FAO PROTEIN REQUIREMENTS		
FPC	96.0	4.0
SKIM MILK POWDER	89.5	10.5
PEANUT FLOUR	82.7	17.3
COTTONSEED FLOUR	86.7	13.3
SOY FLOUR	90.5	9.5
SUNFLOWER SEED FLOUR	80	20
SINGLE CELL PROTEIN	92.8	7.2
LYSINE	99.65	.35
150% FAO PROTEIN REQUIREMENTS		
FPC	86	14
SKIM MILK POWDER	64	36
PEANUT FLOUR	40	60
COTTONSEED FLOUR	55	45
SOY FLOUR	69	21
SUNFLOWER SEED FLOUR	32	68
SINGLE CELL PROTEIN	75	25
LYSINE	98.75	1.25
200% FAO PROTEIN REQUIREMENTS		
FPC	78	22.
SKIM	39	61.
PEANUT FLOUR		
COTTONSEED FLOUR	23	77.
SOY FLOUR	46.0	54.0
SUNFLOWER SEED FLOUR		
SINGLE CELL PROTEIN	33	67
LYSINE	X	X

However, at the 200% level, methionine also becomes limiting, thus a three-part diet becomes the cost minimizing solution. In this case, the minimal cost supplementation program involves 39.4 grams of peanut flour and .28 grams of soy flour per target person/day. The cost advantage of this diet over the minimum cost alternative of those examined by the other program (30.9 grams of cottonseed flour) is quite small. However, this does illustrate how a relatively low quality supplement (peanut flour) can have its position improved if we allowed it to be fortified by small amounts of a higher quality supplement. This option was not among those analyzed in the earlier analysis. As pointed out above, there is no advantage to this option unless more than two constraints are operational.

There is one other major difference between the pure wheat-universal supplementation and pure wheat-infant food problems. That is, while the total amount of supplement in the diet remains small, the percentage of supplement in the infant food can be large. Table XXXII shows a variety of two component infant foods (wheat plus supplement) which meets the target group's requirements given a pure wheat diet and a number of specified levels of reference protein requirements. As will be noted, the percentage of supplement in the infant food can become quite large. For example, consider the 200% level and FPC, or this level and cottonseed flour. In the first case, the indicated solution requires 22% FPC in the baby food. It is extremely doubtful whether a liquid baby food based on this level would be accepted, especially in view of FPC's present insolubility. We noted earlier that there was some evidence of rejection at approximately 10% levels. Similarly, infant food based on 77% cottonseed flour can also be expected to encounter acceptability problems. Incaparina found it desirable to incorporate synthetic lysine in their formula rather than increase the cottonseed level above 38% although Peruvita, a high-protein food being marketed in Peru contains 50% and 56% cottonseed flour in its two varieties (112).

Thus, one conclusion we can obtain from this analysis is that designers of infant food will have to pay much closer attention to acceptability considerations than designers of universal supplementation programs.

Infant Food and Chilean Mixed Diet No. 1

We also analyzed Chilean Mixed Diet No. 1, as outlined in Chapter IV, as the basal diet. With this diet, under our assumptions, no supplementation was required at the 100% and 150% reference protein levels, hence the infant food would be pure wheat. The results for the 200% levels are shown in Table XXXIII and the corresponding costs are shown in Table XXXIV . With respect to composition, it is interesting to note that at 200% on this diet we require 23% FPC, and no FPC at 150%. While on the wheat diet, we required 14% FPC at

TABLE XXXIII

COMPOSITION OF REPRESENTATIVE
WHEAT BASED INFANT FOODS: CHILEAN DIET #1,
200% FAO/WHO REFERENCE PROTEIN FOR ONE YEAR
OLD REQUIREMENTS, TOTAL INFANT FOOD: 40 GRAMS.

	% OF WHEAT	% OF FIRST NAMED SUPPLEMENT	% OF SECOND NAMED SUPPLEMENT
PEANUT & SOY FLOURS*	82.	13	5.0
FPC & METHIONINE	94.	5.5	.5
SOY FLOUR	87.	13.	
FPC	82.	18.	
SKIM MILK POWDER	46.	54.	
SUNFLOWERSEED FLOUR	40.	60.	
COTTONSEED FLOUR	35.	65.	
METHIONINE & LYSINE	99.	.2	.8

TABLE XXXIV

COST OF REPRESENTATIVE WHEAT BASED INFANT FOODS.
CHILEAN PRICES

	Daily Dollars x 10^5		
	TOTAL	SUPP.	NET
PEANUT & SOY FLOURS*	1.62	.08	-.14
FPC& METHIONINE	1.63	.09	-.13
SOY FLOUR	1.63	.08	-.13
FPC	1.66	.11	-.10
SKIM MILK POWDER	1.66	.13	-.10
SUNFLOWERSEED FLOUR	1.67	.10	-.09
COTTONSEED FLOUR	1.69	.10	-.07
METHIONINE & LYSINE	1.71	.07	-.05

* MINIMUM COST COMBINATION

150%, but only 22% FPC at 200%. This is because the mixed diet, when it becomes deficient, is limiting in methionine and FPC is less rich in methionine than it is in lysine. Also, it is important to note that due to the low caloric density of this diet a one-year-old child must consume approximately 530 grams per day to receive sufficient calories. It is doubtful whether a child of this age can consume this much bulk. This, of course, is not the fault of the various supplements, but of the diet itself. One result of this low caloric density is that FPC becomes a cheap supplement alternative under our set of ground rules. First of all, the negative signs in the net column indicate that, on a per calorie basis, the infant foods are cheaper than the basal diet. The supplement which takes the largest advantage of this fact is FPC, for the corresponding infant food is approximately 8 grams FPC to 32 grams of wheat and wheat has a high caloric density. In comparison, the baby food from cottonseed flour is almost all cottonseed flour, and cottonseed flour has a caloric density of approximately half that of wheat. This is the first situation we have seen where FPC's concentration is in itself an advantage. That is, the fact that under our assumption FPC gets more wheat into the diet than the other alternatives (with the exception of synthetic amino acid supplementation which suffers from the fact that more than one amino acid needs to be supplemented) is to its advantage, given wheat's advantage over the natural diet on a cost per calorie basis.

Whether or not this can be expected to be a general phenomenon is still a matter of conjecture.

In any event, the minimal cost alternative in this situation is a combination of peanut and soy flour containing about 17% supplement. FPC fortified with a small amount of methionine is tied for second with soy flour. Both are about 10% more expensive than the cheapest possible combination but the FPC-methionine food has a possibly important acceptability, an advantage in that it requires only 5% supplement. FPC alone is about 30% more costly than FPC with methionine and tied with milk. Pure cottonseed and pure sunflower seed drop into the more expensive categories due to their poor methionine content. Once again, in a situation where two amino acids are limiting, synthetic amino acid supplementation is relatively expensive.

In sum, in this case, several alternatives appear nutritionally viable and a final decision would almost certainly depend on relative acceptability. However, this situation is an important exception to our general finding that cost reductions of the order of 25% or more from the 25¢/lb figure will be required before FPC is competitive.

III.8. Summary of Nutritional Analysis

In the foregoing sections we have analyzed a handful of the myriad different situations and alternatives which can arise in protein supplementation. Out of the multitude of different distribution systems possible, we have touched on only three, and those three have been examined in terms of predistribution costs. We have rather arbitrarily selected a target group and have made some rather sweeping nutritional assumptions. Our cost data is based on our estimates of the Chilean situation and, however accurate it is, we can be sure that different cost situations exist elsewhere. With all these caveats, it is certainly a matter of judgment as to how far one can extrapolate from these analyses.

It is our view that the analysis is a fairly solid indication that considerable reduction in costs will be required if FPC is to have a large role in world nutrition. Certainly, some of the more extravagant claims which have been made for FPC are unjustified. In many cases, the differential in net costs of supplementation between FPC and the least expensive alternative was in the order of 50% or more, and usually the differential between FPC and the cheapest natural protein source was greater than 25%. We believe our figures are significant within this range.

We certainly feel that any specific situation must be analyzed at a much greater level of detail before an actual investment is undertaken and that FPC should often be considered in this analysis. However, the analyses do indicate that even in fish-rich, currency-poor countries with very few alternative domestic protein sources, FPC is unlikely to be the least expensive alternative at opportunity costs in excess of 20¢/lb. At present, FPC appears to have no non-nutritional properties which would mitigate this cost differential.

The fact that FPC is either too expensive or presently lacks the functional qualities required to make it an important nutritional supplement now is certainly not an argument for not undertaking a research and development effort in FPC. As we saw earlier, the world's protein requirements are rapidly increasing; this shift in demand may make FPC competitive in the future, even with no further decrease in cost or increase in functionality. Furthermore, we think it is clear that there is a substantial probability that the cost of FPC can be reduced, and/or its functionality increased given a proper research program. In the Chilean situation, the opportunity cost of the raw material at dockside was about 8.7 cents per pound of FPC. Comparing this figure with our estimate of the final cost, 25 cents per pound, we see that there is considerable room for improvement. Our analyses indicate that even a moderate reduction in the price of FPC could make a substantial change in its attractiveness, especially in a corn-eating country. Furthermore, these are processing alternatives, which promise substantially improved functional qualities.

On the other hand, we are not sanguine about further refinement of solvent extraction as a likely approach toward obtaining reduced cost or improved functionality. The analysis does say something about the type of research and development that should be undertaken. In our view it points toward investigation of lower quality FPC and nonsolvent extraction processes, or combinations of these processes with solvent extraction, and away from refinement and demonstration of the present product which is, at best, marginally competitive.

CHAPTER IV

SOME PROBLEMS IN THE EVALUATION OF COSTS

Introduction

Before attacking the problem of the most efficient protein supplementation program in a particular developing country, we must discuss some of the problems which can arise in determining the true cost to the economy of employing a particular resource in the production of FPC, or for that matter in any supplementation program. This true cost is the value of the opportunities foregone by the particular use of this resource. The value of the opportunities foregone, in turn, is the maximum that the economy or somebody in it would be willing to pay to put this resource to some other use.

In a properly functioning competitive market, the market price properly values the cost to the economy of a particular use of a resource, for the fact that the resource can be bought for $100 means that no one is willing to pay more for that resource and, in fact if no one other than the successful bidder is willing to pay more than $90, competition would drive the price of this good down to this level. Thus, if the market of the resource which we contemplate using in the production of FPC is reasonably competitive, we can without further ado accept the market price as a true measure of the cost to the economy of our use of this resource.

Unfortunately, this is not always the case. The important exceptions are in regard to the following three resources: (1) Foreign exchange, (2) Capital, and (3) Labor.

IV. 1. The Value of Foreign Currency

Consider foreign exchange. The market price of foreign exchange is the exchange rate. If the exchange rate between two countries' currencies were free to seek its own level, it would move to that value at which the demand of one country for the goods of the other equaled the demand of the latter for the goods of the former. At this level, from the viewpoint of economic efficiency there is no reason to distinguish between domestic and foreign purchases. In the terms of Section II. 3., it can be shown that the size of the economic pie will be maximized by buying an article from the least expensive supplier.

However, in the real world, exchange rates are not free to respond to supply and demand in this manner. For a variety of reasons, governments attempt to stabilize their exchange rates. Given a fixed exchange rate, it is possible for one country's currency to become overvalued relative to another's. That is, at the exchange rate, the citizens of the overvalued currency country desire to spend or invest more of their money in another country than the citizens of the latter country wish to spend in the former. In this case, a scarcity of the latter country's currency will develop in the overvalued currency's country, and that country will find it will have to ration its foreign expenditures,for at the exchange rate, there will be more bidders for the available supply of foreign exchange than there is foreign exchange. Such a country is said to have a balance of payments problem. What has happened is that the true cost to the economy of utilizing a unit of foreign exchange is greater than the market price. In this situation, to evaluate this country's exchange transactions, whether they be for FPC processing equipment or the importation of milk at the exchange rate, is to seriously underestimate the value of the opportunities foregone due to these purchases.

There are a variety of ways in which a country can maintain an overvalued exchange rate: import quotas, travel restrictions, tariffs, restrictions against the export of capital, etc. Another hypothetical, if implementable, strategy is for the government to announce that henceforth all foreign exchange transactions must be evaluated at an exchange rate which makes foreign currency more expensive than the market exchange rate. The higher the government makes this purely legal exchange rate, the lower the level of imports will be and the more attractive the country's exports will become to holders of foreign currency. At some level of this promulgated exchange rate, the demand for foreign currency would equal the supply and the system would be in balance. We shall call this level the shadow price of foreign exchange. It is precisely the level at which the foreign exchange market would equilibrate in the absence of controls.

The advantage to the foreign-currency-poor country of using the shadow price rather than more conventional controls is that the use of the shadow price guarantees that the scarce foreign exchange will be allocated to the highest set of uses. Only those uses of the foreign currency which are valued higher than the shadow price will obtain the use of the foreign exchange; for only these uses will find it worthwhile to bid for the foreign exchange at the shadow price. In short, if all possible foreign currency transactions are evaluated at the shadow price, we will be maximizing the value-in-use of this foreign exchange to the economy. The use of the shadow price restores the natural efficiency of the competitive market to the foreign exchange problem. Thus, if Chile finds that at the shadow price of foreign exchange, which currently is about 30% higher than the market exchange rate (101), the importation of the dry skim milk is cheaper than a nutritionally equivalent quantity of domestically produced FPC, then she will be operating efficiently if she uses some of her scarce foreign exchange to buy the milk. That is, in this case, if the cost of milk is less than 70% of the cost of FPC at the exchange rate, Chile should import milk. If not, she would be better off producing FPC.

Note that from Chile's point of view, the fact that the foreign milk production is heavily subsidized is irrelevant. If foreigners wish to contribute to Chile's protein consumption, she should take advantage of the fact that - by their generosity- milk becomes cheaper than its domestic alternatives at the shadow price. From the point of view of the world economy, however, the milk subsidies will result in an inefficient allocation of the world's resources. In the above argument, we are assuming that Chile is interested only in her own welfare.

It may be worthwhile to say a few words about how economists attempt to estimate the true value of foreign exchange. Shadow prices should be close approximations to marginal social costs and benefits. There are two basic ways of calculating them: (a) in an economy which is relatively competitive, an attempt can be made to estimate what the free market price for some commodity would be were it not controlled. For example, in the U.S., it is possible to estimate the price of the dollar which would restore the balance of payments equilibrium by studying the effects of price and income changes on imports and exports (101a). (b) In an economy in which the entire price structure is distorted -say, due to price controls- a large model of the economy can be set up that takes only the resources of the economy and its technological relationships as a basis and computes the shadow prices. An "objective function" for the economy -sometimes called a "social welfare function"- is used. Most practical models are linear programs for which the objective function takes the form $\sum W_i C_i$ where C_i represents the quantities of various goods produced, and W_i represents the weights placed on outputs of these goods.

To use a very simplified example, consider an economy in which there are only two goods- wheat and steel- the objective function might be C_1+2C_2, where C_1 is the consumption of wheat and C_2 the combination of steel. Such an objective function would be used in a country which emphasizes the production of capital goods rather than consumer goods.

Continuing with the simplified example +, the technological relationships might be given in the form of an input-output matrix where the amount of inputs needed by each industry are read down the columns.

TABLE XXXIV

	Wheat	Steel	Initial Endowment
Wheat (bushels)	0	0.5	0
Steel (tons)	0.2	0.4	0
Labor (man days)	3	1	100 million
Foreign Exchange (dollars)	1	2	80 million

+ This example is given in Bruno, "The Optimal Selections of Export-Promoting and Import Substituting Projects," United Nations Dept. of Econ. & Social Affairs, ISDP. 1/A/R.3.

Our simplified economy begins life with no wheat and no steel, but it has labor and it has foreign exchange. We will assume it takes no wheat to produce a bushel of wheat (in actuality, of course, a small amount of wheat for seed is required to produce wheat). Furthermore, assume it takes 0.2 tons of steel, 3 man days, and one dollar of foreign exchange (perhaps as machinery) to produce a bushel of wheat.

Given these technical relationships and the quantities of labor and machines available, the objective function is to be maximized. Let X_1 and X_2 be the <u>total</u> outputs of wheat and steel respectively (including intermediate outputs): then

(1) $0X_1 + 0.5X_2 + C_1 = X_1$

(2) $0.2X_1 + 0.4X_2 + C_2 = X_2.$

Equation (1) states that the quantity of wheat used in producing wheat (0), plus the quantity of wheat used in producing steel ($0.5X_2$), plus the quantity of wheat consumed, is equal to the total wheat output. The equation for (2) results from a similar argument and our input-output mating.

In addition, the economy cannot use more labor or foreign exchange than it has:

(3) $3X_1 + 1X_2 \leq 100.10^6$

(4) $1X_1 + 2X_2 \leq 80.10^6$

Examining (3): $3X_1$ is the amount of labor used in producing wheat and $1X_2$ is the amount of labor used in producing steel. This total must be less than the total supply of labor.

There are standard techniques for solving such linear programming models. These solutions give the production plan for the economy which maximized the objective function. By solving a closely related problem, one obtains the amount by which the value of this maximum would change if one extra man-hour or one extra dollar or foreign exchange, respectively, became available to the economy. These variables are shadow prices of labor and foreign exchange, respectively. Those readers who are familiar with mathematical programming will recognize that the shadow price of foreign exchange is the dual of the foreign exchange constraint. To restate the point: from such a model one can calculate the value of an extra unit of some resource -say, foreign exchange- to the economy, and this is the shadow price of that resource. (Of course, shadow prices can also be calculated via non-linear models.)

In practice, much larger models are used in planning. These are more realistic in two directions: (a) they increase the number of sectors and break up resources into finer divisions; (b) they can be made dynamic, and the course of the economy through time projected to some terminal date. This latter method gives a time path of shadow prices.

A detailed dynamic model for India exists (101b) and somewhat less detailed models have been set up for many developing countries.

The Indian model indicates that the shadow price of foreign exchange in India is 50% higher than the exchange rate.

At present, work is proceeding in Chile on three separate models: a model of type (a) above which is not an optimizing model,but will attempt to estimate the free market price of foreign exchange; a static optimizing model of type (b), where the development of the economy through time is ignored; and (c) a short run dynamic model which projects the growth of the economy. All of these models point to a shadow price in Chile 30% in excess of the exchange rate. This figure is accepted by government planners.

IV. 2. The Shadow Price of Capital - The Interest Rate

In order to evaluate any investment in nutrition, we will have to make intertemporal comparisons. We will have to compare a cost incurred now with costs incurred and benefits received in the future. Furthermore, we will have to compare benefits received ten years from now with benefits received twenty years from now. It is an established fact that people prefer goods received now to goods received later. This is the reason a person will spend a dollar now rather than invest it and receive a dollar and six cents a year from now. It is also known that opportunities exist in which a dollar invested now can be made to be worth more than a dollar in the future. In a free economy, the interplay of people's attitudes toward dollars now and dollars received in the future, and the opportunities for businessmento turn some of their present resources into a more highly valued resource in the future determines the interest rate. People's time preferences determine the amount of savings, and opportunities for investment at a profit determine the amount of investment. At equilibrium, savings must equal investment and together the two determine the interest rate. In this situation, a businessman will invest in a project only if the rate of return is at least as high as the rate which he could obtain from the bank. As long as he can make more money, he will keep borrowing from the bank until the interest reaches the level at which he has no investment opportunities with a higher return than the interest rate. At this point, the interest rate measures the opportunity cost of a dollar; that is, if the interest rate is 5%, the value of the opportunities foregone by employing a dollar a year in a particular use is 5 cents. Furthermore, those people who prefer \$1.05 a year from now to \$1.00 now would increase their savings to a point where they preferred to spend the next dollar now rather than receive \$1.05 a year from now. Similarly, those who preferred \$1.00 now to \$1.05 a year from now would borrow money up to the point where \$1.00 now is worth exactly \$1.05 a year from now.

In this situation, a businessman would invest only in those projects which had a return on his investment of greater than 5 cents per dollar-year of capital invested. We assert without proof that the profit maximizing businessman would determine such projects by calculating the present value of the investment, which is given by:

$$V = \sum_{n=0}^{N} \frac{1}{(1 + i)} \quad (R_n - C_n)$$

where R_n is the revenue received in year n and C_n is the costs incurred in year n exclusive of interest charges, i is the interest rate, and N is the lifetime of the project. Proof can be found in any economics textbook. Those investments which have a positive present value, V, have a higher return on capital than the interest rate and should be undertaken with borrowed money if necessary. Those investments which have a negative present value have a lower return on investment than the interest rate and should not be undertaken. If a businessman has only opportunities with negative present value, he maximizes his return by putting his money in a bank.

We are now going to assert that if an economy wishes to operate efficiently -that is, maximize the size of the economic pie, then it should behave in exactly the same manner in evaluating its public investment. That is, it should evaluate future costs and benefits of each alternative and determine each alternative's net present value using the opportunity cost of capital as the interest rate. In other words, government should undertake those projects and only those projects where the present value of the benefit is greater than the present value of the costs. The reason is that such projects are more highly valued than the output that could be received from some other use of the same resources.

We note in passing that this argument implies the use of the same interest rate in determining the present value of public investment as of private investment. If a higher interest rate is used by government than is used by private projects, projects will fail to be adopted which are more highly valued by the citizens than private projects which will be undertaken. Conversely, if an interest rate lower than the private interest rate is used in evaluating public investment, then government will undertake projects whose capital could be put to more highly valued uses in the private market.

IV. 3. Difficulties in Choosing an Interest Rate

The above argument assumes no inflation, no risks and no interference in the capital market. In actuality, inflation, uncertainty and government capital controls are the order of the day in the developing economy. For all these reasons the market interest rate may not reflect either the opportunity cost of capital or the citizenry's time preference. Assuming that we are going to use present value in evaluation of public expenditures, the problem then becomes how do we determine the true opportunity cost of capital in the face of these three problems or, in the words of the last section, how do we determine the shadow price of capital?

Inflation presents no real problem, provided the rate of inflation can be estimated. One can either then deduct the inflationary rate from the market interest rate, obtaining the inflation free interest rate, and evaluate costs and benefits at present prices, or one can escalate the future costs and benefits according to the inflationary rate, and leave the inflationary rate in the interest rate, which will wipe out automatically the escalation in cost and benefits. The results are identical. Generally, it is simplest to value costs and benefits at their present prices and use the inflation free interest rate. This is the approach we shall use in the next chapter.

In the market when one makes a loan or pursues an investment, one is not certain of getting repaid in exactly the manner that one expects. Therefore, banks and businessmen in general demand a higher rate of return the more risky an investment. The subject of investment under risk is a whole area in itself which we cannot go into here. Suffice it to say that the interest rate to which we were referring above is the riskless interest rate which, in a market economy, economists gage by the rate charged very well established customers whose repayment is almost a certainty, the so-called prime rate.

In general, the governments of developing countries have seen fit to establish a number of restrictions over the capital market that effectively interfere with the borrowing and lending process and which make even the prime rate an unreliable indicator of the opportunity cost of capital. In such cases, economists have recourse to large-scale planning models similar to the ones described in the discussion of the shadow price of foreign exchange, through which they estimate the net productivity of capital given an allocation of resources that would maximize the country's, or at least the model's, objective function.

Investigation of the Chilean economy through models such as these indicate points to an inflation free opportunity cost of capital of about 12%, and this figure is generally accepted by Chile's planners. Hence, this is the interest rate we will use in evaluating the present value of possible investments in FPC in Chile.

IV. 4. Unemployment and the Shadow Price of Labor

Labor may be the one other resource to which it is necessary to apply a shadow price. If some of the labor used for the production of FPC would not otherwise be employed, then the cost to the economy of utilizing this resource will be less than his wage. Under competitive full employment, if one must pay a person $2.00 an hour, it is because he would be worth $2.00 an hour in some other use. The wage rate and the shadow price are the same; unemployment, however, is the situation where, at the market wage rate, the supply is greater than the demand. In this situation, given free competition the wage rate would decrease. However, for a variety of reasons it may not do so in an actual economy. If this is the case, when one hires a person, one has to pay the market rate, yet the opportunity cost to the economy of this person's employment is the wage rate that would exist under free competition, which may be considerably lower. From the point of view of efficiency, of maximizing the size of the economic pie, it is this opportunity cost or shadow price which should be used in evaluating a project's cost. This is the proper way to handle unemployment. In extreme cases, the shadow price of labor may be close to zero.

As in the case of foreign exchange and capital, the shadow price of labor can be estimated by either attempting to measure what the wage rate would be under free competition (relevant to close-to-free-market economies), or by calculating the dual of the labor constraint in planning models of highly controlled economies.

In evaluating unemployment and the shadow price of labor, one must avoid confusing a declining industry with unemployment. The New England fishing industry is not a healthy industry. Yet, there is little or no unemployment in this industry. In fact, the New England fisheries are suffering from a rather severe labor shortage. Three out of five Boston trawlermen are over 55. Attempts to entice ghetto unemployed to sea have been unsuccessful. The Boston boats average 280 days at sea and the average fisherman logs 267 days at sea (102). In comparison, a full time U.S. worker averages 245 days per year on the job. The difference in hours worked would be still greater. In this sector of the fishing industry, the demand for labor is higher than the supply.

Similarly, we shall see that the major labor resources which would be used in the production of FPC in Chile are currently fully employed. Since our analysis concentrates on the New England and Chilean situations, we shall not be faced with the problem of unemployment, and thus the problem of estimating the shadow price of labor given unemployment, in this report. However, it may be relevant to the analysis of FPC production in places other than New England or Chile, or it may be relevant to either of these areas. It appears that such a situation may exist on the West Coast, where immigrants and first generation Yugoslavs and Portugese who formerly fished the now defunct California sardine have few alternative employment opportunities due to the lack of cultural assimilation.

IV. 5. Unemployment of Capital

One sometimes hears the term unemployment of capital referring to, for example, fishing boats which are laid up for lack of work. This is certainly a form of unemployment, the supply is greater than the demand, but there is a very important differference between this situation and labor unemployment. In the case of labor, a market wage rate exists which is different from the opportunity cost of labor, which difference supplies misinformation as to the rest of the economy,which values labor at the wage rate and not at its opportunity costs. Thus, misinformation will in general result in inefficient resource allocations by the market. Hence, there is a valid size-of-the-economic-pie reason for government intervention in this market to correct the inefficiency.

In the case of unutilized capital, such as a laid up fishing boat, no such misinformation exists. The fisherman is well aware of the marginal costs of taking his boat to sea and will do so as soon as the revenues from so doing are greater than the cost . There is little or no difference between perceived costs and opportunity costs,and no need for government action to correct inefficiencies. Of course any analysis of possible uses of presently unemployed boats (for example, the calculation of the cost of raw material for FPC) should use only the marginal costs associated with the boats'employment. The original construction costs and other past outlays are irrelevant to such an analysis.

CHAPTER V

THE ECONOMICS OF FPC IN A DEVELOPING COUNTRY -CHILE

Introduction

This chapter deals with the specifics of a particular developing country, Chile. It was clear at the outset that we could not properly analyze the value of FPC for all, or even a representative spectrum, of developing countries. We have decided, instead, to select a particular country and use it as an example of how one should evaluate the economic feasibility of FPC in any developing country. Chile was selected because it is the country for which the most complete cost data are available, for which the relevant shadow prices have been reliably estimated, and where almost all of the few market studies of FPC which have been completed were undertaken.

In addition, Chile is a country which appears to be rather well suited to the implementation of FPC. It has a large supply of conveniently available fish while almost any other supplement would have to be imported with scarce foreign exchange. It has an ongoing government food distribution plan, an effective government interest in FPC, and government concern about overcoming protein deficiency. The native diet is wheat based, which is deficient in lysine, an amino acid which FPC has in abundance.

V.1. The Need for Protein in Chile

In 1961, the Interdepartmental Committee on Nutrition for National Defense (101c) conducted an extensive survey of the nutritional status of Chile. Its report indicated that 2900-3000 calories and 80 grams of crude protein per person were available per day for consumption (at retail outlets) in Chile in 1961. This was well in excess of FAO requirements. However, a careful survey of the actual diets of 4300 non-commissioned military personnel and 5300 lower and middle income civilians indicated that 25% of this food was not actually consumed. The civilian population was averaging 2200 calories per capita a day. The intake varied geographically, but the most significant variations were with reference to socio-economic status. The report stated that 37% of the families were getting less than 2000 calories per day and 28% were receiving less than 54 grams of protein, with an average protein efficiency of .48. This is about 3 grams per person less than the FAO/WHO estimated requirements.*

Figure V shows the 1965 income distribution in Chile according to reference (103). If we define our target family to be in the lowest 5 percentile with respect to income, we see that this family is earning about 100 escudos per month.** The average number of people per family in this income group is about 5. Figure VI shows the expenditure on each category of foodstuff. There appear to be some inconsistencies in this data, for according to them our 100 escudo per month family is spending 120 escudos per month on food. However, assuming that relative values are correct, a combination of these data with the average prices of the various foodstuffs results in a diet made up of:

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* This statement is overly pessimistic in that it does not account for the increase in protein efficiency which results from mixing various food in the diet.

** Ideally, the choice of target family would depend on a cost benefit analysis.

Bread	26.9%
Vegetables	11.7
Sugar	7.7
Spaghetti	3.6
Flour	3.2
Oil	3.8
Fruit	6.6
Potatoes	7.8
Milk	28.7

This is Chilean Mixed Diet No. I used in Chapter III. As noted there, if an infant obtains his recommended number of calories from this diet, he will obtain not only the FAO/WHO estimated reference protein requirements, at least before processing losses, but 50% more than these requirements.

An alternate Chilean diet was obtained from reference (104) where the average Chilean diet was described. We arbitrarily left out the meat and dairy products from this diet, obtaining the following diet, which is Chilean Mixed Diet No. II in the Chapter III analyses:

Bread	38.1%
Vegetables	8.8
Sugar	2.7
Farinas	10.6
Legumes	.9
Fruit	8.8
Oil	3.5
Potatoes	26.6

Obviously, neither of these approaches to determination of the diet of the target group is satisfactory, one being based on inconsistent data and the other on a heroic assumption. They are meant to be exemplary rather than substantive estimates of the target group's diet.

We cannot emphasize too strongly that if investment in FPC or in any other protein supplement is being contemplated, the diet and the variation in diet of the target group must be determined with a great deal of care. It is quite possible that the group with which one is concerned is lacking in calories rather than protein, or is lacking in protein only because it is not receiving sufficient calories from its usual diet. Also, careful determination of the limiting amino acid must be made before any judgment with

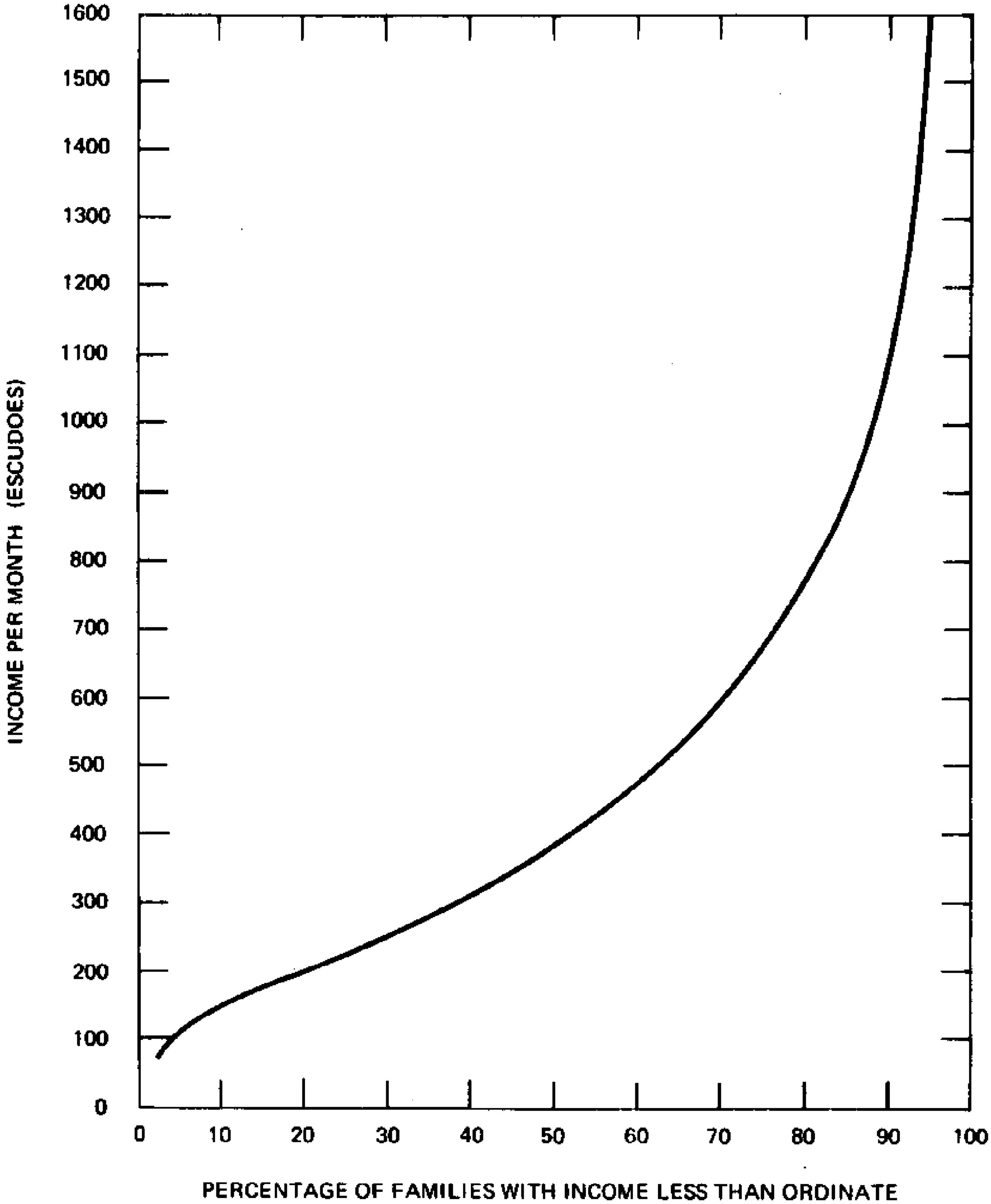

FIGURE V INCOME DISTRIBUTION AMONG SANTIAGO AREA FAMILIES JULY, 1965

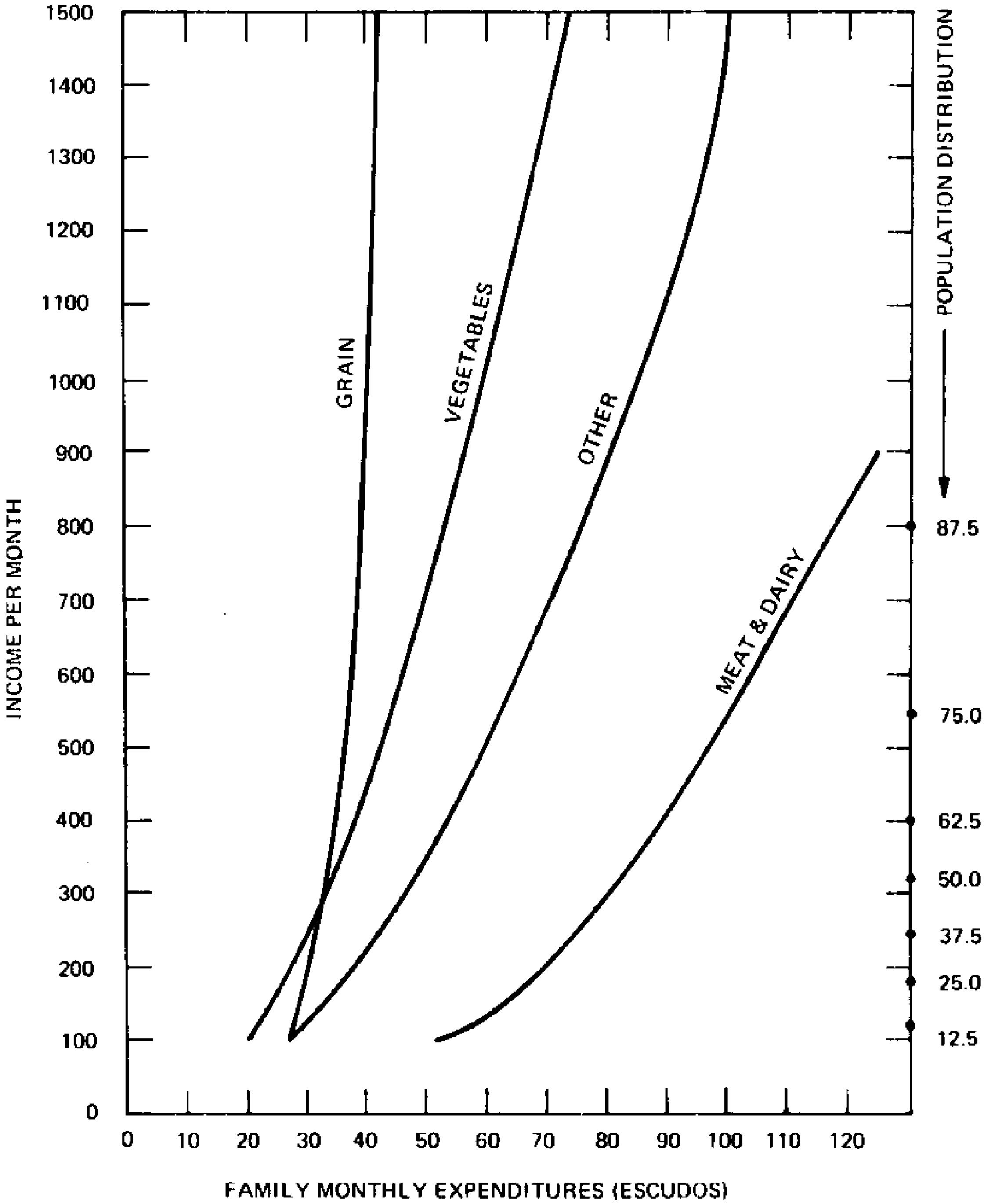

FIGURE VI CHILEAN FAMILY FOOD EXPENDITURES VS. INCOME respect to synthetic fortification can be made. Finally, even discarding synthetic amino acid fortification for the moment, the attractiveness of the other alternatives will depend on the basal diet. In Chapter III, we saw that sunflower seed flour showed up very poorly on an all-wheat diet but was quite competitive on Chilean Mixed Diet I.

V. 2. The Demand for FPC in Chile

The acceptability of deodorized FPC in Chile has already been reviewed in Section II.3. In addition, in Chapter III we saw that supplementation of either of the Chilean diets to 200% of the FAO requirements for a 10 month old child would require only about 5% FPC in the wheat in the diet. (The lower income Chilean consumes about half his calories in wheat.) As detailed in Chapter III, FPC in these quantities appears to have little effect on the acceptability of bread and pasta. Supplementation of pasta alone, which would have the advantage of avoiding some of the processing losses in bread, would be more income specific, since expenditures on pasta decrease as income increases. There is also the added advantage that the wheat in pasta, which would be replaced by FPC, is imported semolina, which is over twice as expensive as the wheat in bread. However, levels of supplementation in excess of 15% would be required due to the low percentage of pasta in the diet. The tests to date indicate it is unlikely that this level of supplementation could be maintained without significant decreases in acceptability to the consumer.

An alternative worthy of consideration is to supplement pasta to the maximum level possible with no significant decrease in acceptibility, perhaps 7 to 10%, and make up the difference through bread supplementation. It is worth noting that this is a situation in which FPC's lack of solubility may be an advantage. If a soluable supplement such as synthetic lysine is added to pasta, which is cooked in excess water, then very significant processing losses can occur.

Experiments in Korea with a synthetic supplementation of macaroni indicated that 60% of the lysine added was lost in the cooking water (104a).

The fact that Chileans will eat products supplemented with FPC without complaint is a necessary but not sufficient condition for successful distribution of FPC. The real question is: How much will they pay for it?

Since FPC adds little or nothing to the functional qualities of the food, the target group Chilean will pay a positive amount for FPC only if: a) he is convinced the additional nutrition is worth it, and b) he has no other choice.

The first consideration is relevant to the consideration of commerical marketing of FPC under competition. At present, there are only a handful of cases of the successful marketing of a nutritional food in a developing country. They are:

Pronutro in South Africa - Although this is the most profitable of our examples, it hardly qualifies, since only black South Africa can be described as developing, and the bulk of the sales are going to middle income whites. Initial attempts to market directly to blacks ended in failure, although after acceptance by the whites, the product is beginning to achieve significant sales to blacks.

Incaparina in Guatemala and Colombia - Incaparina has been successfully introduced in Guatemala with the help of a widespread government-aided educational program. This example points out that with sufficient promotion and careful preparation of the supplement in view of local economics and tastes, successful introduction of protein supplementation can be accomplished through the free market. However, less government cooperation (non-financial) was received in attempts to introduce Incaparina in surrounding Central American countries and they have not succeeded. Quaker Oats was successful in pilot marketing in a single area in South America, although this effort received little cooperation from the government. While now moderately successful, it has yet to return a profit to its originator.

These examples indicate that with proper promotion, free market supplements can, with considerable difficulty, succeed. However, since education and advertising programs are expensive, (U.S. food processors spend 10% of the retail price maintaining an already established demand for a product) the alternative of making protein supplementation a legal requirement suggests itself. The next question becomes: If supplementation is legally required, should the program be subsidized by the government or should the cost be carried forward to the consumer ? If the target group's price elasticity for the supplemented product is low (a change in the price of wheat results in little or no change in the amount of wheat purchased by the target group), then the only differences between the two alternatives involves distributional considerations: who pays the costs? However, if the price elasticity of wheat is high for the target group, the alternative of letting the user pay the costs will be less effective nutritionally, for the change in price will result in a decrease in the amount consumed by the target group.

Figure VI indicates that the income elasticity of bread of the 100 escudo a month family is .2; that is, a 1% increase in income will increase the amount of bread purchased by .2%. This is a lower limit on the price elasticity, for clearly the amount of bread purchased will respond more rapidly to a change in the price of bread than it will to a change in income. We expect that in a single grain country like Chile, even a poor man would be unlikely to decrease his total expenditures on wheat with a rise in the price of wheat. Even if he kept his expenditure the same, decreasing the amount bought in exactly the same proportion as the rise in price, required protein supplementation might be better than doing nothing at all, provided the population was receiving enough calories For example, supplementation of wheat to meet the 100% FAO reference requirements outlined in Chapter II would imply about an 8% increase in the retail price of bread which, assuming that the target Chilean operated so as to keep his bread expenditures unchanged, would imply an 8% increase in the amount of wheat consumed. Thus, the net effect of this alternative would be:

a) at least the low income portions of the population would have their caloric intakes cut by 4% since wheat constitutes about half the calories in the diet.
b) the target group would have its utilizable protein increased, assuming that this group was receiving sufficient calories (even after the change in wheat consumption.)

If prior to the price rise, the target group is receiving only marginally sufficient amounts of calories, then this alternative makes very little sense, because the bulk of the added protein will simply be converted into calories. If more than sufficient calories are being consumed, this alternative may be politically attractive in that it requires no additional investment in food by the economy and no additional revenue for the government. Our judgment, however, is that since protein deficiency is almost always coupled with marginal or less than marginal caloric intake, this alternative will almost always be less attractive than the alternative of government subsidy of supplementation which we are about to discuss. In particular, in Chile the surveys indicate that calorie deficiency is as prevalent as protein deficiency.

Both the expense of an educational and promotional campaign and the deleterious effects of the consumers' altering their purchases away from the supplemented foods can be avoided if the government decides to subsidize protein supplementation. This has the political disadvantage of requiring revenue which in general will be raised almost entirely from people who will not benefit from the program. This alternative implies a redistribution of income towards the malnourished child which however ethically pleasing, may not be politically implementable.

If it is, it is almost certainly to be preferred nutritionally to the alternatives of user costs.

As we saw in Chapter III, the country might be able to do still better with some form of selective supplementation, of which the most attractive policy, in our minds, is government subsidized supplementation of baby food.

V. 3. The Costs of FPC Produced in Chile

The purpose of this section is to substantiate the FPC price used in Chapter II and III and to indicate how a developing country should go about evaluating the costs of domestic FPC production.

Our Chilean FPC prices are based on a 200 tons-per-day input plant using the Bureau of Commercial Fisheries' solvent extraction process as modified by Southwest Engineering Company. The cost figures are based on Southwest Engineering's quoted prices for processing equipment, and the Chilean costs are based on a study by H. Briones y Cia, S.A.C.I., in support of General Oceanology's study of FPC in Chile for the Agency for International Development (104b). The plant that Briones costed was to be located at San Vincente in the Talcahuano region, 200 miles south of Santiago. In this area there is a seasonal abundance of the local hake which is now converted into fishmeal and exported at about 5 cents a pound, or 1 cent a pound for raw material. Thus, this fish earns foreign exchange. This 1 cent per pound is based on the market exchange rate. The shadow price of foreign exchange in Chile is about 30% higher than the market exchange rate.

Assuming that this resource is currently being harvested at or close to its maximum sustainable yield, the true cost to Chile of transferring the fish from fishmeal to FPC is the loss in foreign exchange, about 1.3 cents per pound at the shadow price of foreign currency, minus the savings in fishmeal processing costs, plus any additional costs associated with landing the fish in condition to be made into human-grade material rather than fishmeal. We judge the savings in fishmeal processing costs to be less than 1/2 cents per pound of input, and that the additional costs associated with more careful handling will be of roughly the same order of magnitude, but still smaller. General Oceanology estimates the latter costs at about $6 per ton. Therefore, for our purpose, we have considered the latter two effects a wash and the loss in foreign exchange as the opportunity cost of the raw material in Chile. This may be slightly pessimistic.

Briones' estimate of the variable costs of FPC are given in Table XXXV. We indicate variable costs of $285 per metric ton, or 13 cents per pound. Table XXXV also gives the salary costs. These are all local currency expenditures and thus have been evaluated at the exchange rates. Note that full employment has been assumed. Salary costs are based on a 12-month year. However, the fish are in the locality only during the spring and summer. Therefore, output is predicated on a 150-day year.

The capital investment for this FPC plant is given in Table XXXVI. One of the things which is often overlooked in discussions of domestic versus foreign supplements is that domestic production often implies a substantial expenditure in foreign exchange in order to import processing equipment, etc. In Table XXXVII these foreign exchange transactions are marked with asterisks, and the corresponding expenditure increased by 30% to reflect the price of foreign exchange. In this case, capital investment at the market exchange rate is estimated to be about $3.3 million. Two thirds of the investment requires expenditures in dollars and has been adjusted accordingly. With these adjustments, the true capital cost of the Chilean plant is about $4 million.

Both the annual costs of the plant will be incurred and the output will be received throughout the life installation . Therefore, according to the discussion of Chapter IV. 3., we must discount both future costs and benefits according to the shadow price of capital, the interest rate. This present value analysis requires three things: the interest rate, the life of the facility, and the salvage value of the plant at the end of its useful life. All three of these quantities are unknown. Therefore, it is comforting that the unit cost of the FPC is not particularly sensitive to them over a wide range of reasonable choices.

TABLE XXXV

PRODUCTION COSTS
VARIABLE COSTS

$/Metric Ton = (1.1 U.S. Tons)

Raw Fish (Hake)	$191.00
Solvent Loss	12.94
Electrical Power	19.50
Fuel Oil	47.50
Water	2.20
Bags (Polyethylene Lined)	4.00
Production Loss & Contingency	8.40
	$285.54

FIXED COSTS
$/Month

Supervision	$ 4,350
Office	2,210
Lab Technicians	1,200
Maintenance Personnel	1,900
Others	2,300
14 Productions Workers @ $60/mo. plus benefits	4,540
Maintenance Expenses	2,000
Property Tax	4,700
Insurance	2,350
	$ 30,200
Total fixed costs per year	$362,400

TABLE XXXVI

BREAKDOWN CAPITAL INVESTMENT X 1,000

Equipment

Process Equip.	$ 1500	x foreign
Electrical "	83	x
Boiler & Steam "	141	
Spare parts	86	x
Electrical	49	
Freight -Foreign	207	x
Local	68	
Bldg. Ventilation	6	
	$2,140*	

*(foreign 2,017
Local 123)

Constructions

Brine Storage Basin	$ 15	
Pavements for Bldgs.	20	
Building-Plant	36	
Lab	5	
Warehouse	34	
Boiler House	12	
Electrical Bldg.	4	
Guard House	4	
Lockers, Rest Rooms	7	
	$ 134	all local

Industrial Services

Water Tanks, Pipes	$ 14	
Sewage	5	
Process Piping	24	
	$ 43	all local

Erections

Industrial Equip.	$ 60	
Boilers & Steam Equip.	19	
Electrical Equip.	31	
	$ 110	local

Structures & Foundations

Fish Conveyor	$ 1	
Pipe Bridge	3	
Fish Comminution	8	
Process Equip.	19	
Solvent Recovery Founds.	2	
Boiler House	9	
Tanks	56	
	$ 98	local

Technical Services

Local Engineering	50	
Foreign Engineering	15	x
	$ 60	

Pre-Start Up Expenses

Company Expenses (Legal)	$ 15	
Construction Control Ofc.	32	
Operation Crew Payroll	25	
Personnel Training in USA	100	x
Start-Up Expenses	86	
Interest on Construction	140	
	$ 398	

TABLE XXXVII

CAPITAL INVESTMENT - FOREIGN AND LOCAL CURRENCY

x 1,000

	Local Currency	Foreign Currency
Site Prep	$ 63	-
Equipment	55	$ 1,810
Construction	134	-
Industrial Services	43	-
Erection	110	-
Structures & Foundations	98	-
Technical Services	50	15
Pre-Start Up	298	100
Contingency	126	107
Freight	68	207
	$ 1,045	$ 2,239

Investment at Shadow Price of Foreign Exchange (x 1,000)

Local Currency	$1,035
Foreign Currency	2,239
30% Shadow	671
	$3,955

Table XXXVIII gives the unit price of FPC at which the present value of the FPC operation is zero for a number of interest rates and life spans,under the assumption that the salvage value of the plant at the end of its life is zero. This latter assumption is certainly conservative, but shouldn't be critically so. Only about 300,000 dollars would be spent on the site, which can be expected to be worth something at the end of ten or twenty years. All the other capital investment, primarily the processing equipment, can be expected to be worth little more than its scrap value, which after discounting, will be insignificant. Thus, our results should not be sensitive to salvage value.

TABLE XXXVIII

UNIT COST OF FPC
AS A FUNCTION OF INTEREST RATE
AND INVESTMENT LIFE

	0	5	8	12
20 Years	19.8¢	21.1¢	22.2¢	23.5
10 Years	21.8¢	23.3¢	24.2¢	25.4

With respect to the other two variables, as Table XXXVIII shows, there is not a great deal of variation. As noted earlier, our estimate of the present opportunity cost of capital in Chile is 12%. We feel that a 10-year life span on most of the equipment is reasonable. Hence, we have chosen to use 25 cents per pound as the estimated opportunity cost of domestic production of FPC in Chile.

V. 4. Summary of Chapter V

The purpose of this chapter was to survey the nutritional situation in Chile, to point out some of the acceptability, distributional and financial considerations which must be considered with respect to protein implementation in a particular national context, and to estimate the opportunity cost of domestic production of FPC in Chile.

We noted that the basic nutrition problem in Chile is one of inequitable and inefficient distribution rather than lack of resources, that the price elasticity of the target group family for the supplemented product should be an important consideration in government versus market financing, and argued that the opportunity cost of FPC in Chile will be about 25 cents per pound when foreign exchange transactions are valued at the shadow price of foreign currency.

Given this price, the analysis of Chapter III indicates that at present in Chile, FPC is at best marginally competitive with other protein sources in terms of nutritional efficiency and, under most distribution schemes, is considerably more expensive than the most efficient alternative. This conclusion is based on production and processing costs and ignores promotional and distributional considerations. It also assumes that Chile attempts to maximize social welfare in deciding on the use of her foreign exchange.

If Chile arbitrarily decides to use only domestic protein sources in her supplementation programs, then FPC is, in most situations examined, more efficient than sunflower seed flour, the other alternative, even when the foreign currency transactions implied by domestic production of FPC are valued at the shadow price of foreign exchange.

CHAPTER VI

THE ECONOMICS OF FPC IN A DEVELOPED COUNTRY

VI.1 The Demand for FPC in Canada and the United States

The size and characteristics of the market for FPC in the United States is generally regarded as the key to the domestic FPC problem. There can be no doubt that the market for FPC is by far the single most important set of unknowns in determining the profitability of domestic FPC operation. There appear to have been three serious studies of the demand for FPC in the United States. Two are proprietary and the third is incomplete.

The two proprietary studies have been conducted by Cardinal Proteins, Inc. and by Oceanic Development Corporation. Apparently, in the view of these organizations, the results of both of these studies were positive, for Cardinal is firmly committed to a substantial investment in FPC at Canso Nova Scotia; and Oceanic Development claims it has decided to build a 200 ton per day input plant in Baja, California in 1970, adding 200 tons per day capacity in each of the three succeeding years. This implies that Oceanic foresees a market for more than 25,000 tons of FPC by 1974. Both these plants will produce FPC by solvent extraction; Cardinal via a modified isopropanol process, and Oceanic by the Viobin Process.

Cardinal is presently estimating its price at about 35 cents per pound and Oceanic envisions a price of 25 cents per pound. We must emphasize that the Cardinal operation is much closer to fruition than the Oceanic, the latter presently exists only in the minds of its promoters.

The non-proprietary study is being conducted by the University of Cornell under Bureau of Commercial Fisheries sponsorship and results will not be available until Spring of 1970.

There can be no doubt that there is a tremendous market for protein in the United States and that a very small penetration of this market percentage-wise would support a rather large FPC industry. However, it is more than a little difficult to foresee just where this penetration will occur given the present functional qualities of solvent extracted FPC. FPC is a cheap source of animal protein for nutritional purposes. However, the United States is presently producing four times its protein requirements from a nutritional standpoint. This is not to say that everybody is receiving sufficient protein, but rather that those groups who are not receiving their nutritional requirements are deficient for institutional reasons. Furthermore, it is not clear that FPC has any properties which will allow it to overcome these distributional problems more easily than already existing protein sources:

Nonetheless, several of the suggested markets for FPC are based on its nutritional charcteristics. They include: 1) pet foods, 2) institutional diets, 3) geriatric and reducing diets, and 4) high protein snacks.

Producers of pet foods have found it profitable to include animal proteins in some of their products. Fishmeal is regarded as unsuitable for this purpose because of its smell , and therefore an extracted fish product is preferred.

Furthermore, there is evidence that a significant portion of canned pet foods is consumed by humans in this country, perhaps as high as 25% (105). Thus, canned pet food generally has to meet human standards with regard to sanitation and toxicity. Hence, the argument for a market for human-grade FPC in pet foods.

Institutions such as nursing homes,which operate under severe budgetary restrictions may be able to use FPC's nutritional characteristics in concocting diets which maximize nutritional effectiveness subject to these financial constraints. It should be noted that FPC will be in direct competition with oilseed flours in this market and on the basis of our earlier nutritional analysis, we are not sanguine about the outcome unless the institution in question arbitrarily rules out non-animal sources.

Some diets require a very high percentage of protein to calories. These include geriatric regimens and weight loss diets. FPC's reference protein density is practically unmatched. However, there are a number of other protein sources, specifically the oilseed flours, whose reference protein to calories ratios qualify them for this purpose. Thus, unless the producer could convince consumers there is something special about FPC's reference protein, we would have something similar to the above institutional diet situation with the important exception that we are dealing with people whose incomes allow them the luxury of consuming FPC when they could obtain the same nutritional effect from non-animal sources. Also, FPC's concentration may be an important advantage in concocting an acceptable high protein diet, for more of the bulk of the product can be devoted to components which enhance the product's taste and appearance.

The high protein snack market would be strictly a Madison Avenue approach, in which the producer would attempt to convince the consumer that he should pay more for an FPC supplemented snack, such as a potato chip, because of the additional protein it would supply. FPC's concentration and its relatively exotic name may make this a profitable venture.

It has also been suggested that FPC might find a substantial market in the processed meat field such as sausages and meat patties. In this regard, it is interesting to note that the sausage industry distinguishes between functional protein and filler protein. Functional protein is required to have texture, binding power, and taste, and presently is comprised of meats for which the industry pays 40 cents per pound of protein and more. Filler protein is expected to supply little more than bulk. Currently, the industry uses by-products associated with the packing industry which are available at about 3 cents per pound or about 10 cents per pound of protein. Presently, FPC cannot compete with functional protein on the basis of its properties nor with filler protein on the basis of its costs (106). If, however, FPC's functional properties, particularly with respect to binding power, which natural fish protein has, could be improved, it would open up a tremendous market for the product*

In short, as best we can summarize the present state of the knowledge with respect to the domestic marketability of FPC:

(a) There is at least one and probably two groups of inventors who are prepared to risk several million dollars on the existence of at least a small market for present solvent extracted FPC at a price between 25 and 35 cents per pound;

(b) However, it appears that FPC's nutritional qualities do not necessarily guarantee it a domestic market in a country where overnutrition is as big a problem as under-nutrition;

(c) Furthermore, present solvent extracted FPC's organoleptic qualities or lack of same severely handicap its abilities to substitute for expensive protein sources in processed foods; and

(d) On the other hand, with improvement in functional properties such that FPC can begin to compete with meat products, rather large markets will become available.

* Very recently, the Federation of Hokkaido Fisheries Cooperative Associations in Japan announced plans to sell FPC made from Alaskan pollack as an additive to artificial meat made from soybeans, in which market it will be in competition with surimi, a minced meat made from whale or pollack flesh. This appears to be an attempt to compete with a functional protein over which FPC has a considerable cost advantage.

These non-conclusions illustrate the present state of knowledge,and we look forward to the results of the Cornell study and the Cardinal effort with considerable interest. Fortunately, for the purposes of this study, our uncertainties about the domestic market are not particularly relevant to the question of what role the government should play in the development of FPC. This point will be argued in Chapter VI.3. First, we shall survey the state of knowledge with respect to the costs of domestic production of FPC.

VI. 2. The Cost of Producing FPC in a Developed Country

Solvent Extracted FPC

At present what little experience that exists with respect to producing FPC in a developed country is based on solvent extraction. A.I.D. was able to contract with Alpine Geophysical Associates, Inc. in 1968 for 1000 tons of hake based FPC produced by the Viobin method at 42 cents a pound. The company was unable to supply the material and the contract has been terminated. Cardinal Proteins, the Canadian firm which is presently building a 200-ton per day input plant in Nova Scotia, claims that it will charge 35 cents a pound for its product but has no firm commitment to do so. Oceanic Development Corporation, which regards itself as firmly committed to construction of a 200ton/day plant based on the Viobin process and the California anchovy in Baja, California, during 1970, estimates its price at 25 cents per pound (105b). This figure is even more problematical than the Cardinal quote, which is based on a Canadian Federal grant covering almost 20% of the capital costs.

There have been four relatively recent non-proprietary studies of the cost of producing FPC in developed countries.

1) The Bureau of Commerical Fisheries original study in 1966 (91) of a plant similar to the proposed Aberdeen installation.

2) A study by a Canadian group, Resources Engineering, in 1967 authored by Holder, Kidd, Mayar and Ross (107).

3) A study conducted by Southwest Engineering as part of their effort to sell FPC processing equipment (108).

4) A study by a Montreal Consulting Firm (Surveyor, Nenniger, and Chenervert) in 1968 of the potential of FPC plants in eastern Quebec for the provincial government (19).

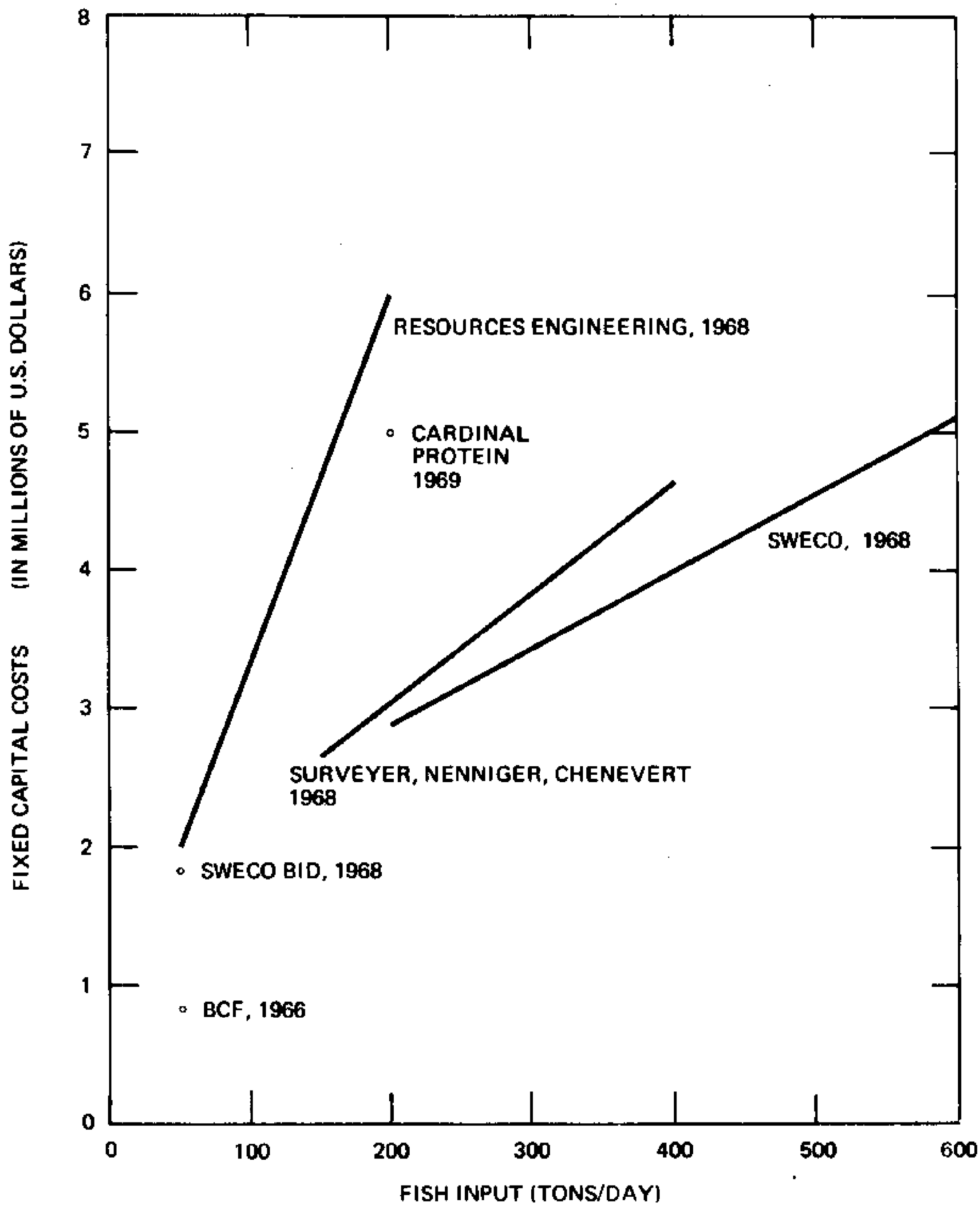

FIGURE VII ESTIMATE OF CAPITAL COSTS AS A FUNCTION OF CAPACITY

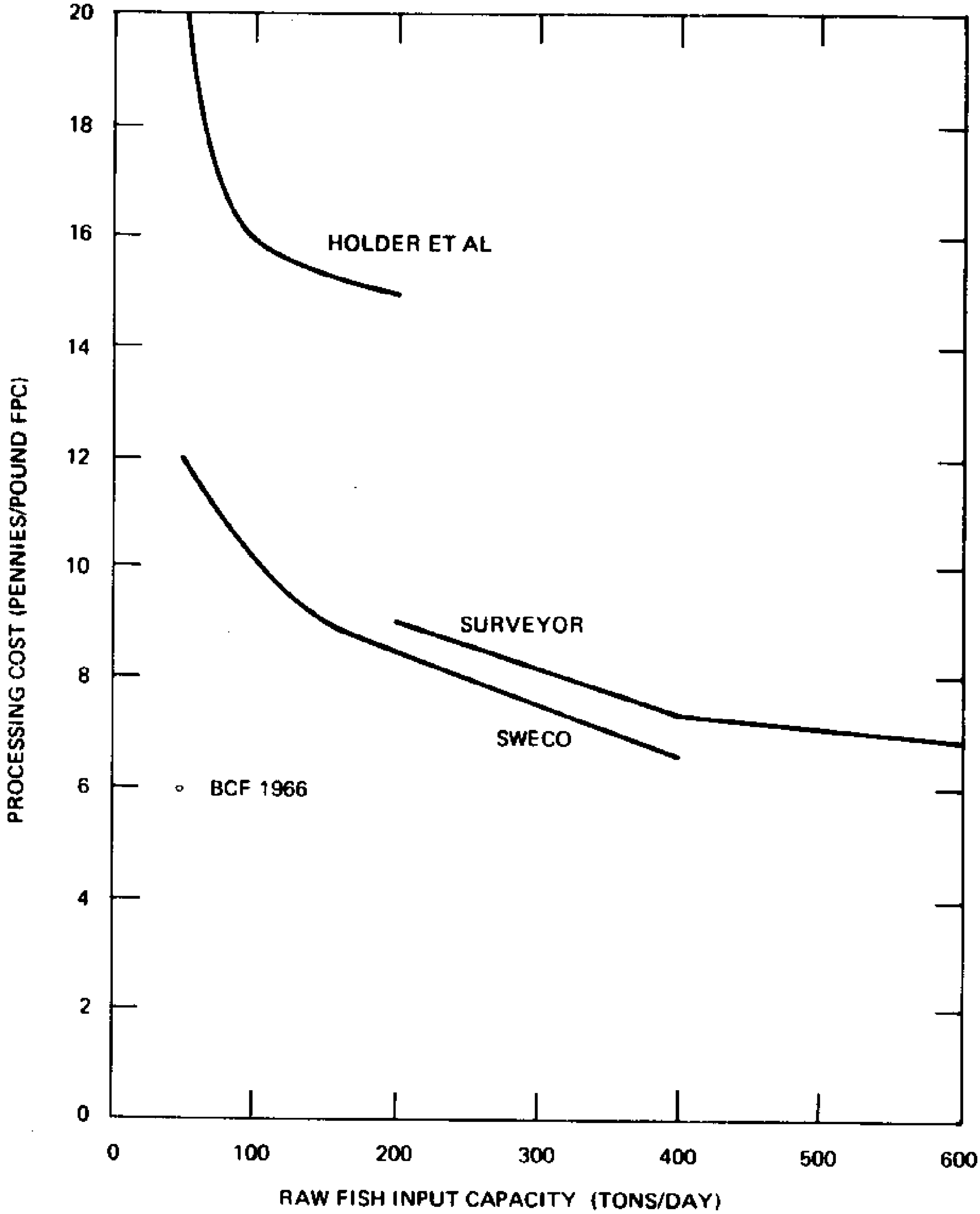

FIGURE VIII PROCESSING COSTS VS. INPUT CAPACITY

The capital costs from these four reports are compared in Figure VII. The Bureau of Commercial Fisheries study (91) is somewhat out of date. This report predicted a capital cost (not including land) of $900,000 for a 50 ton per day input plant. The actual construction bid on the 50 ton per day Aberdeen installation was twice that amount.

In 1969, Cardinal Proteins, after signing processing equipment contracts, reported a capital cost of close to $5 million on its 200 ton per day input plant at Canso, Nova Scotia. Thus, it appears that both the Surveyor and SWECO capital costs are optimistic. Holder *et al*. are less sanguine than the cost reported by Cardinal Protein. Their estimate includes a 35% allowance for management and interest and contingencies during construction which, while perhaps prudent, almost certainly makes their estimates overly pessimistic in terms of 1968 prices.

For our analyses of a 200 ton per day input plant, we will use the $5 million figure. Assuming a ten year equipment life time, a 5% inflation free interest rate, that the plant operates an equivalent of 260 full capacity days, which the Canso operation hopes to obtain, present value analysis indicated that the capital costs equal 4 cents per pound of output. This is less than 20% of the total cost of the product so that errors in capital costs are unlikely to be critical in the final analysis. We note, however, that since these costs are not independent of output, the assumption of 260 full capacity days is important and in fact the unit capital costs will vary inversely with the throughput.

Figure VIII shows the processing costs as a function of scale of input. Once again Surveyor and Sweco are in general agreement, the BCF figures are quite low, and Holder *et al*. are pessimistic. Holder *et al*.point out that most of the processing costs, maintenance, administration, et cetera will not vary with short term variations in output. In fact, only fuel, solvent, waste disposal and

TABLE XXXIX

VALUE OF ATLANTIC COAST GROUNDFISH*

Species	Year	Cents per pound: Landed Value	Marketed Value
Hake	1962	2.4	3.3
	1963	2.8	4.6
	1964	3.1	6.5
	1965	2.8	---
	1966	3.3	---
Cod	1962	3.2	6.8
	1963	3.4	7.9
	1964	3.9	8.2
	1965	4.1	---
	1966	4.4	---
Haddock	1962	4.2	10.3
	1963	5.4	13.6
	1964	5.9	14.6
	1965	6.5	----
	1966	7.1	----

*Derived from Dominion Bureau of Statistics data; 1966 data are preliminary.

packaging costs can be changed with short term variations in the output. These amount to about four cents per pound. Examining the various analyses we felt that production cost of about 12 cents per pound, assuming 260 day operation, in 1970 prices would be within 2 or 3 cents of the actual cost realized. Once again the bulk of these unit costs will vary inversely with the actual throughput.

Raw Material Costs

Perhaps the most basic fact of life with respect to FPC production is that it takes about 6.6 pounds of whole fish to produce 1 pound of FPC. As a result, raw material costs are the most important variable in the production of FPC. Given a 200 ton plant and our estimates of unit capital and processing costs, the following Table indicates the variation in cost of the output with raw material costs

COST OF FISH	1¢/lb.	2¢/lb.	3¢/lb.	4¢/lb.
COST OF FPC	23 "	29 "	36 "	43 "

The Cost of East Coast Hake

Table XXXIX shows the landed value of three Atlantic Coast groundfish in Canada for the years 1962-1966. It should be clear that the value of hake is rising rapidly. As Chapman has pointed out, hake is regarded as a first class food fish in Europe and has been extensively fished in the last five years. It can hardly be called an unutilized resource anymore. Thus, if FPC is to be based on hake, FPC must compete for this raw material with a variety of other uses. Furthermore, hake is a demersal fish and as such must almost always be caught by trawling. Trawling is an expensive business. Holder et al. estimate that on the East Coast a modern trawler can land groundfish such as hake at 3.7 cents a pound before profit and at 5 cents a pound given a ten percent profit after taxes.

We tend to agree with Holder who comments that "It is difficult to see the landed cost of groundfish species in Canada at less than 3 cents per pound." Presently East Coast American fisherman are not competitive with their Canadian counterparts, so that this figure may be regarded as a lower bound on New England costs. In sum, we do not see the production of hake based FPC on the East coast at less than 35 cents per pound, assuming relatively continuous operation.

The important phrase here is relatively continuous operation. According to BCF reports, Alpine never paid more than $46/ton for hake for its A.I.D. FPC contract and sometimes considerably less. Yet it was unable to make money at 42 cents per pound of FPC. Even allowing for severe management problems, this example points out the importance of regular supply. In order to ensure a regular supply, one will have to be willing to pay the bulk of the costs of supporting a fishing fleet rather than something approaching the opportunity costs of an already operating fisherman who happens across a school of hake. In other words, one can almost always get the price that one wants for fish if one is prepared to wait, but one can also go broke waiting.

The Cost of West Coast Hake

The situation appears to be considerably different on the West Coast. A recent survey under the direction of Professor James Crutchfield at the University of Washington (109) indicates that, assuming an optimally organized West Coast hake fishing, the price for hake at the processors can be expected to be about $22/ton with substantial profit to the fisherman. Professor Crutchfield also indicates that a considerably more regular catch can be expected on the West Coast than on the East Coast.

This report assumes both the employment of an efficient boat and that the industry is somehow regulated so that the fishing activities of one boat do not affect the profitability of the others. This is not presently the case and would require forthright government intervention to achieve in view of the rather large economic rents involved. (Professor Crutchfield indicates a marginal cost of $16/ton.) Unregulated fishermen observing the differences between price and marginal costs would attempt to overfish the resource with the now-familier inefficiencies.

This scenario is relevant to another argument relating to FPC. Government support of FPC is sometimes justified on the grounds that a domestic FPC industry would correct some of the inefficiencies prevalent in the existing fishing industry. Domestic FPC production by itself, however, would merely place another demand on our fish resources, which demand would be subject to the same economic problems, principally the fact that fish is not private property until caught, which give rise to inefficiencies in other sectors of the industry. If one wishes to correct misallocation of resources within the fishing industry, certainly a worthwhile aim, one should do so directly by economically rational regulation, license fees, taxation, etc. rather than through the support of a research program, which, if successful, will create another fishing regulation problem, and which, if not successful, will have no effect on the industry at all.

In any event, given efficient government regulation, it appears that the cost of FPC on the West Coast hake may go as low as 20 cents per pound assuming 300-day operation at capacity. A more conservative estimate assuming 240 day operation at capacity might be 25 cents per pound. Note that even if the former price were achieved, this does not mean that Chile should import FPC from the U.S.; for Chile would have to expend foreign exchange on the purchase and then the 20 cents per pound figure should be modified according to the 30% premium Chile should be willing to pay to avoid foreign currency losses. In terms of the analyses of Chapter II, in this case, the true cost to Chile of importing 20 cents per pound FPC is 20 X 1.3 or 26 cents per pound, which is more than our estimate of the true cost to Chile of domestic production, 25 cents per pound.

The Cost of New England Herring

Herring, mackerel and capelin, an oily, herring like fish that is found off Nova Scotia during certain parts of the year, present a somewhat different problem from East Coast hake. New England fishmeal producers are presently offering \$17-\$20 per ton for herring and mackerel for fishmeal to American fishermen with almost no takers. This is a little less than a penny a pound. The producers therefore receive their raw material irregularly from foreign fishermen at sea for which they pay \$16/ton to the fishermen, and they estimate the transfer and subsequent transportation of the fish to shore costs \$3/ton.* In short, oily school fish is available on an opportunity basis at about a penny a pound.

However, these fish are caught by purse seining. Seining is a much more weather sensitive operation then trawling. It becomes marginal in sea state 3. Furthermore, the coefficient of variation in the catch is much larger. A seiner can only fish tightly schooled fish and spends an average of 20 hours hunting to one hour fishing. The catch per net set can vary from nothing (20% of all net sets) to 100 tons (110) (10% of all net sets) with an average of about 25 tons. As a result, landings of fish caught by seining present a much more irregular pattern than trawler landings with consequent strains on the processing plant's storage capabilities.

Furthermore, this penny a pound fish usually arrives at dockside in rather poor condition. During the summers, it can be decomposed to a soup. In order to make human grade FPC from this fish, considerably more care in handling, shorter trips and more careful sanitation would be required. This will add substantially to the cost of the fish. We feel that a cent and a half per pound is a reasonable lower bound on the estimate of the cost of East Coast herring and other pelagic fish at dockside in condition for the manufacture of human grade FPC.

* Illegal direct landings are not unheard of.

West Coast Anchovy

Another domestic resource which has received some attention is the California anchovy. The University of Washington estimates that this fish could be landed at about $16 per ton by day boats operating out of the United States. Once again, this figure assumes a rationally organized industry.

This is the resource which Oceanic Development Corporation hopes to exploit operating out of Baja California. Oceanic Development is currently estimating that the final price of its product will be about 25 cents per pound. This is somewhat more than the unit costs we would predict if the University of Washington analysis is correct, especially in view of the lower labor costs associated with Mexican operation. Presumably, Oceanic's estimated price includes a prudent margin for uncertainties and takes cognizance of the fact that, if Oceanic Development's market analysis is correct, it will be operating in a seller's market for some time.

In summary, a price of a penny per pound for West Coast pelagics seems a reasonable estimate provided the industry is economically regulated. This would lead to an FPC cost of about 20 cents per pound. Thus, it appears that a West Coast based FPC industry will have substantial advantages over an East Coast operation. Time restraints on our study did not allow us to investigate the Gulf Coast situation.

Other Sources of Raw Material

The Cardinal Proteins plant in Canso will be located next door to a presently established fish processing plant. Cardinal expects to meet one third of its daily requirement for raw material by fluming trimmings directly from the processing plant. Presently, these trimmings are used in fishmeal production and thus have a market value equivalent to the herring and other oily fish above. Therefore, Cardinal Proteins will be able to bid them away from the fishmeal producers at about a penny a pound. However, this material is considerably superior to fishmeal fish from the point of view of the FPC producers, having been handled under sanitary conditions, being non-oily, non-bony, and white. Therefore, it would behoove Cardinal Proteins to obtain a long term committment from the suppliers of the trimmings before production starts, lest it find itself buying one third its input from a monopolist who could extract from it a considerably higher price than that paid by fishmeal producers.

In our opinion the ability to obtain fish trimmings is one key to the expected profitability of the Cardinal Proteins operation at the 35 cent per pound price, the other key being the availability of a market for its product. Fish trimmings will allow Cardinal to produce one third of its output at an average cost in the order of 23 cents per pound including capital costs. Cardinal expects to obtain the rest of its input from a combination of trawlers and seiners. We do not expect it to make a great deal of money on its trawling operation. The profitability of the seining operation will depend on the regularity with which it can furnish fish.

From this cursory study of the cost of the production of solvent extracted FPC three things are clear:

a) the cost of FPC is primarily a function of the cost of the raw material, and regularity with which it can be supplied.

b) the cost of hake based FPC will be considerably higher than the cost of FPC based on pelagic fish on both the East and West Coast. This differential will be prohibitively large on the East Coast.

c) A crucial point which is missing from all the analyses that we have reviewed is that they don't take into account, the fact that in general the raw material will not be available on a steady basis throughout the fishing year.

This last point is especially true on the East Coast. A large herring seiner on the East Coast can catch 200 tons a day, but its average catch will be one fifth that amount. Thus, a 200 tons a day plant would require an average of five seiners to support it. Such a system must be able to cope with receiving several days' raw material inventory in a few hours. This implies storage costs and intermittent periods when the plant is unable to operate at full capacity. The total effect of this variation in the catch has not been treated by past analyses and seems to have been underemphasized in the Canso operation which is allowing only 200 tons storage capacity. As a first guess, we believe it is conservative to estimate that the costs due to variability in the catch will add at least 20% to the above East Coast figures. The penalty for variability appears to be considerably less on the West Coast. Means are being developed to analyze this problem properly. The fisheries simulation program being developed by the Instrumentation Laboratory at M.I.T. will allow detailed study of the effect of the variability in the catch on total system costs. Unfortunately, this valuable tool was not operational in time for this study.

The Cost of Solubilizing Solvent Extracted FPC

Several investigators have studied the problem of producing a soluble product from solvent extracted FPC. The most advanced of these efforts is that undertaken by Tannenbaum and Wang at M.I.T. This involves hydrolysing the FPC with an enzyme. Prof. Tannebaum estimates that the final cost of this process will be about 5 cents per pound of output.

VI. 3. The Role of the Federal Government in the Domestic Production of FPC

We have seen that it is impossible to make any firm conclusion about the present domestic marketability of FPC; and further,that our estimates of the costs of FPC are extremely sensitive to the costs of the raw material, another variable which exhibits considerable variation. As a result, any prediction about how soon a domestic FPC industry will become economically viable would at best be an educated guess.

At this point, it is necessary to return to the basic purpose of this report namely, to apply economic direction as an input to the determination of what form federal support of FPC should take,if any. We wish to argue that we can make certain statements about this question without an answer to the profitability of a domestic FPC industry, which answer we presently do not have. We shall do so by assuming that the properties of FPC are such that it can be made to be a competitive product on the domestic market.

Let us for the moment assume that FPC is likely to be a competitive product on the domestic market. This fact in itself is not sufficient grounds for government support of fish protein concentrate. In order for a government attempt to accelerate the rate of development of FPC above that which would occur under ordinary market pressures to be justified, there must exist benefits which would accrue from this earlier development of FPC which are not properly reflected in the market processes.

Several such benefits have been suggested in the past. It is the purpose of the remainder of this section to distinguish between economically valid and economically invalid rationales for government support of FPC either directly or indirectly through support of research and development of FPC.

The Effect of FPC on the Domestic Fishing Industry

Perhaps the most commonly stated non-market benefit of domestic production of FPC is the effect that an FPC industry would have on the domestic fishing industry. We note that this point has to be made very carefully and, as it is usually stated,it is invalid. In a full employment situation, which generally obtains in the American economy, the effects of government investment on the suppliers of the inputs to that investment cannot be counted as a benefit of the government program. In cost-benefit language, these are secondary benefits and, in the national accounts, they wash out. If one pays a fisherman $3.00/hour for FPC raw material, then presumably he was worth $3.00/hour in some other use which he can no longer perform. Put another way, given full employment, there is no reason to distinguish between the benefits of government FPC investment to fishermen and the benefits which will accrue to processing equipment manufacturers.

Now, it is possible for structural unemployment in the fishing industry to exist even though the economy as a whole is at or close to full employment. This does not appear to be the case in the New England fishing industry where a recent study (109a) was unable to distinguish any significant differences between employment in fishing and any other weather sensitive occupation, and where there is a government sponsored program aimed at supplying more fishermen. On the West Coast, some structural unemployment exists due to lack of cultural assimilation of Yugoslav and Portugese fishermen, combined with the decline of the sardine industry. This implies that as far as efficient operation of the economy is concerned, the employment of these fishermen should be valued at the opportunity costs, which will be lower than the wage rate, and government programs which make these costs of hiring a fisherman to the operation equal to these opportunity costs are indicated. However, support of FPC is an exceedingly indirect means of attempting to achieve this equalization of wage rate and opportunity costs.

We feel that more direct and more effective means of tackling specific unemployment problems in the fishing industry exist than the support of research on FPC. Of course, if research on FPC does result in an earlier development of an FPC industry, and if this earlier development does result in a reduction in the costs of a government program aimed at tackling this unemployment, then this differential in costs is properly accounted a benefit of the research program. This is the tenuous argument upon which those who link FPC research and domestic fishing unemployment depend. We have made no attempt to quantitively evaluate the expected magnitude of this effect, but we believe that the reasoning outlined above indicates that frequently it may have been given too much weight.

A similar line of reasoning relating FPC research and development to the fishing industry arises from the fact that there may be valid reasons for government support of fishermen above that resulting from free market forces. For example, the country may judge it desirable to maintain a certain level of activity in certain international fisheries so that we can maintain influence on the agreements through which these fisheries are regulated. Such agreements are necessary in view of the fact that, since private property rights cannot be established on fish until they are caught, unregulated competition results in overfishing.

Suppose this is the case and the country wishes to maintain a certain level of fishing activity. This in itself is not an argument for government investment in FPC, for it is not difficult to show that, if fishing activity is the true objective, it is always at least as efficient to support that activity directly than by supporting an industry which uses that activity as an input and legally tying that industry to the fishing activity. Once again, direct solutions to a particular problem, in this case fishing activity, are preferred to indirect support.

However, once again, if the government supported FPC development program results in competitive FPC production earlier than would result without government investment; and if, without aid or legal protection, the American fisherman can successfully compete with foreigners in supplying raw material to this FPC industry; and if we assume that we would have subsidized the fishing activity anyway for the non-market benefits associated with fishing activity; then the extent to which the earlier development of the FPC industry reduces the costs of the fishing subsidy program is properly a benefit of the government effort. Once again, this argument is clearly a good deal different from that ordinarily offered in relating the domestic fisheries and FPC promotion, and requires much more careful reasoning.

The extent to which a going domestic FPC industry would reduce the subsidy of domestic fishermen in this situation is not at all clear. We have seen that to be economic FPC must be based on non-food fish and, with few exceptions (the highly seasonal menhaden industry) American fishermen have shown themselves to be unable to compete with foreign fishermen in supplying this type of fish. Furthermore, as fishermen are quick to point out, the amount to which the country has been willing to subsidize fishermen for whatever reasons is not large, therefore any reduction of subsidy payments which would result will necessarily be small. Finally, a domestic FPC industry will see little point in paying more for fish than the domestic fishmeal industry is presently willing to pay. The fishing subsidies payments with an FPC industry will differ from what they would be without this industry, but with the existing fishmeal industry(which would exist on a much higher scale if the country were willing to subsidize fishermen to the point where they could regularly supply this industry with fish at say $20 per ton). In summary, we do not believe the marginal effect on fishing subsidies resulting from a a domestic FPC industry will be large unless the country decides to support its domestic fishing industry at levels markedly higher than the present.

In sum, the arguments for government acceleration of the development of FPC on the grounds of its effects on the fishing industry are not particularly persuasive from an economist's point of view.

Support of FPC on the Grounds That Competitors Are Supported

The United States federal government offers large scale support to almost all the potential competitors of FPC, and in particular to milk. This support takes the form of not only purchasing programs and basic research, but also in recent years the Department of Agriculture has played a major role in new product development for the food processing industry. Given the widespread support of the food industry, it is argued that it would be inconsistent for the government not to support the development of FPC, including product development and demonstration of its marketability.

There are two possible lines of reasoning here and it is necessary to distinguish them, for one is economically invalid and one is economically valid. The economically invalid argument is the one from precedent. The fact that the government makes diseconomic investments in one area is no argument for a similar investment in another area. To be consistently wrong is not be be preferred to being inconsistently wrong. At the same time, the authors cannot help noting that, if at least certain agricultural support programs are a disbenefit on net (a proposition which we have not argued but our bias is clear) then this disbenefit is of far greater magnitude than any which would occur from a slightly off-target FPC program. The argument which we used against supporting fishermen through FPC obviously applies equally well to supporting dairy farmers through butterfat subsidies and to other agricultural sectors as well. The only difference is that in the latter cases it involves hundreds of millions of dollars, but in the former at most several million. In this report, we are appl analyses to the government FPC program which have not been applied elsewhere. Our guess is that, if they were so applied, some of these other programs would show up much worse than the FPC effort.

The second and more economically valid line of reasoning is that, given that government support of all of FPC's domestic competitors is an incontestable and probably unchangeable fact, a possible means of correcting the misallocation of resources that results from this support is to also support FPC. That is, one imagines what the allocation would be with no support programs, convinces oneself that FPC would be competitive in such a sitution, and then supports FPC to the level required to restore FPC to the position it would have under pure competition without government interference. This is a valid argument. The burden of proof on its advocate is to demonstrate that a) FPC would be competitive in a free market at the prices that would then prevail, and that b) the benefits from correcting the misallocation outweigh the disbenefits of moving still further from the market process, and that c) the support program one argues for will indeed achieve the competitive market allocation efficiently.

This would be an extremely difficult argument to make quantitatively and we have not attempted it. Nonetheless, its possible validity must be kept in mind in making policy decisions with respect to FPC.

Removal of the FDA Restrictions on FPC

A more direct means by which the government can interfere with an efficient allocation of resources is by legislating against a product which would have a place in that allocation. Given that such legislation exists, it is clearly economic for government to take action to remove that restriction. If FPC is to find a domestic market in human foods, it will be as an additive to highly processed products. The FDA prohibition against domestic distribution in less than one pound packages effectively removes FPC from its only possible human food market. Furthermore, the restriction to hake and hake-like fish can increase the unit cost of FPC by over 50%, as we have seen. The requirement with respect to fluoride content increases the costs still further, but it is of considerably less importance. Both the non-toxicity and the nutritional value of FPC have been amply demonstrated, and the fact that FDA allows any kind of marketing implies that it accepts these facts. The argument for the one pound restriction then rests on the idea that without this restriction, even if the product was labeled as containing FPC, the consumer would not always know what he is eating; and, if he did, he would not consume it. This argument is necessarily based on the fact that the FDA has the responsibility of preventing people from eating voluntarily unknown, beneficial ingredients. It would be difficult for the FDA to accept this responsibility, for the consumer often chooses to be unaware of what processed foods are comprised. Rather he relies on the FDA and similar agencies to make sure that these foods contain nothing harmful, and then judges the product on its final appearance to him rather than its composition. If he is interested in the composition, he reads the label or asks the waiter.

Even given that the FDA has this responsibility which it so rarely chooses to fulfill, the FDA's argument must also rely on the fact that the consumer who chooses not to read the label would not eat FPC were it explained to him that he is eating a product containing 80% high quality protein, 15% minerals with substantial vitamin content, 5% water, a very low percentage of fats and an extremely low number of bacteria, made from whole fish. This is perhaps possible but the burden of proof would seem to be on the FDA and as yet they have presented no evidence speaking to this point. It would be easy to test this proposition in the market place.

The FDA argues by analogy that if they were to accept FPC as an additive they would have to accept a bacteria free, stable, nutritious supplement made out of say, whole rat. We suggest that with suitable labeling this is indeed the case. Whether or not people found such a product distasteful would be made quickly evident in the market place. A restaranteur who attempted to mislead his customers would take the same kind of risks and face the same kind of laws which he faces whenever he misrepresents his product. We suggest that if these laws are inadequate, then make them better; but the final test of acceptability should be left to the people.

Arguing against the FDA regulation is not a very interesting exercise. The point is that if the FDA ruling is diseconomic, that is, inconsistent with public's utilities, then government action to correct this situation is patently valid. We believe this to be the case, and support further action by the BCF to remove the remaining restrictions which, we reiterate, are as economically restrictive as direct prohibition. Recent indications are that the FDA is becoming increasingly sympathetic to this view, and we look forward to the lifting of the restrictions. This action will be doubly beneficial in that it will-

a) allow a potentially economic commodity to fend for itself in the market place;
b) remove an artificiality which has cast a less than benign influence on a well intentioned and potentially exceedingly fruitful research and development effort.

Government Support of Basic FPC Research as a Public Good

Information is a public or collective good. That is, one man's consumption of a piece of information does not prevent another man from consuming it*. It is both well known and easy to demonstrate that the private market will allocate less than the optimal (sometimes much less) amount of resources to a public good, for a particular private investor can enjoy only a small portion of the possible benefits of the information he produces. On this fact rests the most basic and, in our view, the most persuasive grounds for government support of research into fish protein concentrate. We have seen that if the price of FPC can be reduced or its functional properties improved, it could play an important role in world nutrition or find a place in the competitive market place in the developed countries. No private investor would be expected to invest in the development of the technology required to make these improvements possible, for he would find that he could enjoy only an extremely small part of the benefits of this investment, should it prove fruitful. There is a clear-cut and, in view of the world nutritional situation, urgent need for government investment in the development of this basic technology. We feel that there exists a substantial probability of achieving the improvements necessary to make FPC a positive contributor to the welfare of the citizens of the developed as well as the undeveloped countries. Expenditures on a reasoned, broad-based research program would be one of the better investments this country could make. For example, research into microbiological processes in which the microorganisms utilize the fish oil as the source of carbon and energy as in Demain (110) is clearly warrented. Furthermore, research into aqueous extraction processes is certainly indicated. Means of stabilizing not completely fat free fish products should receive high priority.

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* There are several definitions of the term public good in use in the literature. This sentence will serve as our definition in this report.

The product of this research, the public good, is basic information on possible processes, not FPC itself. A research program based on this argument would concentrate on generating the basic information pertinent to FPC processes and disseminating this information to industry to do with as they will. If this information base leads to a competitive product, then industry and the developing countries will not be long in discovering this fact.

We feel that in toto this public good argument points toward and supports a well funded government research and development effort in FPC. However, considerable care must be exercised to avoid investments which are better left to the private market. Any pilot plant operations should carefully weight the increased realism associated with larger scale against the concomitent increase in cost and inflexibility.

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