THE NEOTECHNOLOGY ACCOUNT OF INTERNATIONAL TRADE: THE CASE OF PETROCHEMICALS*

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Since the publication of the Leontief paradox in 1953, there has been a proliferation of theories and studies intended to provide a better explanation of observed trade patterns than does the traditional factor proportions theory.[1]

Authors of the newer theories have relaxed some of the restrictive simplifications of the traditional factor proportions theory, as defined in the Heckscher-Ohlin-Samuelson model, such as two homogenous factors of production (capital and labor), constant returns-to-scale of production functions, international identity of production functions and factors, international similarity of preferences, and perfect competition.

Two of the newer theories have emphasized the dynamic aspects of international trade, one focusing on the production factors—the technological gap theory of Posner and Hufbauer[2]—and the other focusing on marketing factors—the product life cycle theory of Vernon.[3] These two theories have so many elements in common that any exact distinction between them is arbitrary.[4] Johnson combined them with a scale-economy

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1. These are summarized in G. C. Hufbauer, "The Impact of National Characteristics and Technology on the Commodity Composition of Trade in Manufacturing Goods," in *The Technology Factor in International Trade,* ed. by Raymond Vernon (New York: National Bureau of Economic Research, 1970), pp. 145-232.

2. M. V. Posner, "International Trade and Technological Change," *Oxford Economic Papers,* XIII (October 1961), pp. 323-41; and G. C. Hufbauer, *Synthetic Materials and the Theory of International Trade* (Cambridge: Harvard University Press, 1966).

3. Raymond Vernon, "International Investment and International Trade in the Product Life Cycle," *Quarterly Journal of Economics,* LXXX (May 1966), pp. 190-207.

4. Hufbauer, "The Impact of National Characteristics and Technology on the Commodity Composition of Trade in Manufactured Goods," p. 149.

theory into one "neotechnology" account of international trade, which he then includes as part of a modified factor proportions theory.[5]

The research described in this paper concerns world trade in petrochemicals and springs from Vernon's product life cycle theory; therefore, it also is part of Johnson's neotechnology account of international trade. In fact, after the early stage in the life of a petrochemical, product quality becomes standardized; then technological changes become a major determinant of economic behavior. Hence, the observed changes in economic behavior in the petrochemical industry could be referred to as a "technological life cycle" rather than a "product life cycle," but the latter term is used in this paper for consistency with other studies.

According to Vernon's exposition, the life cycle of products that save labor or appeal to high incomes can be divided into three parts, with certain specified international trade patterns.[6] Initially, in order to minimize communication costs during the time when a product is nonstandardized, a manufacturer makes the product in a high-income, large-market country—typically, the United States. This original producing country becomes an exporter to other consuming countires. Second, production begins in other major industrial nations, which begin exporting to the United States and third-country markets. Finally, during the third stage, when competition becomes keen, the product very standardized, and the technology standardized so that relatively unskilled labor can be used in the production process the less developed countries, because of their low labor costs, become exporters of the product; the United States becomes a net importer of the old product and shifts its resources into the manufacture of newer products.

The empirical studies to date have provided evidence consistent with this general line of reasoning: U.S. exports shift to newer products[7] and U.S. exports of high-income products hold up better than low-income products;[8] the exports of manufactured goods from Greece, Japan, and

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5. Harry G. Johnson, "The State of Theory in Relation to the Empirical Analysis," in *The Technology Factor in International Trade*, pp. 9-21; and Harry G. Johnson, "Comparative Cost and Commercial Policy Theory for a Developing World Economy," (Wicksell Lectures of 1968, mimeographed).

6. Raymond Vernon, "International Investment and International Trade in the Product Cycle," pp. 196-207.

7. Seev Hirsch, *Location of Industry and International Competitiveness* (Oxford, England: Clarendon Press, 1967); and Robert B. Stobaugh, "Systematic Bias and the Terms of Trade," *The Review of Economics and Statistics*, XLIX (November 1967), pp. 617-19.

8. Louis T. Wells, Jr., "Test of a Product Life Cycle Model of International Trade: U.S. Exports of Consumer Durables," *The Quarterly Journal of Economics*, LXXXIII (February 1969), pp. 152-62.

Central America tend to be standardized products originally developed elsewhere;[9] and, in general, the exports of manufactured goods from less developed countries tend to be from relatively mature industries although not necessarily labor-intensive ones.[10]

This paper shows the usefulness of the product life cycle model in explaining world trade in petrochemicals and presents refinements that are suggested by trade in petrochemicals. Some economic characteristics affecting trade in petrochemicals and bringing out the necessity of adding some refinements to the product life cycle theory are: Labor costs are relatively small compared with raw material costs, product quality is standardized at an early time in the product's life, and the production process has substantial economies of scale and requires a "lumpy" investment in which capacity can be added only in large steps.

Most studies of the product life cycle have focused on *categories* of products; thus, there is the problem of a change in "mix" of products over time. The study presented here differs in that it examines world trade and investment of nine *individual* petrochemicals (in SITC 512). World production of these nine petrochemicals exceeds $4 billion and the value of U.S. exports exceeds $100 million; these petrochemicals are used in the manufacture of a variety of polymers and others organic chemicals which, in turn, are used primarily in the manufacture of synthetic materials—plastics, fibers, and rubbers. These petrochemicals are believed to be representative of petrochemical products, which account for about $20 billion of U.S. sales and $80 billion of world sales.**

The Birth of a Petrochemical

Market size is the major factor in determining the initial country of production of petrochemicals and the materials made from them. The United States and Germany, the countries that have the largest domestic markets (omitting the USSR), have accounted for most introductions of such products. All nine petrochemicals in this study initially were intro-

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**Appendix A contains information on the selection of petrochemicals for this study and on their relation to the remainder of the chemical industry.

9. Satoris Mousouris, "Export Horizons of Greek Industries" (Unpublished DBA Thesis, Harvard University Graduate School of Business Administration, 1967); Yoshi Tsurumi, "R & D Factor and Exports of Manufactured Good of Japan" (Unpublished DBA Thesis, Harvard University Graduate School of Business Administration, 1969); and Jose de la Torre, "Exports of Manufactured Goods from Developing Countries: Marketing Factors and the Role of Foreign Enterprise" (Unpublished DBA Thesis, Harvard Graduate School of Business Administration, 1971).
10. Hal B. Lary, *Imports of Manufactures from Less Developed Countries* (New York: National Bureau of Economic Research, 1968), p. 97.

duced commercially in the United States or Germany;[11] furthermore, 46 of the 53 most important plasics, man-made fibers, and rubbers were introduced commercially in either the United States or Germany with the United Kingdom and Italy accounting for the remainder.[12]

The marketing opportunities are more likely to be recognized in a country with a large market than in one with a small market. There are several reasons why the producer prefers to build his first commercial plant in a country with a large market.

First, there is a need for a considerable amount of communication between the customers and the personnel in the pilot plant producing samples for the customers. For chemical products there is usually a long and complex development process during which trial quantities of the product are made for the customers.[13] The pilot plant is located in a large-market country in order to minimize communication difficulties; there is an advantage in locating the initial commercial plant near the pilot plant so that the pilot plant operating personnel are available to form the nucleus of the commercial plant's work force, and so that the research and development personnel are available for consultation. Furthermore, although chemical products reach "standardized" quality more rapidly in their product life cycles than items such as radios, there is still much negotiation between the manufacturer and the customer over product quality for some time after the initial commercial plant has been built.[14] As a result, marketing costs for new chemical products are high compared with what they are when the product is mature, declining from about 23 percent of sales price of 2 percent of sales price as a product goes from introduction to maturity (Exhibit 1). Locating the initial commercial plant in a country with a large market minimizes these marketing costs.

A second reason for the producer's preferring a country with a large market results from the large economies of scale inherent in the production of chemicals. The producer wants to build a large plant and

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11. Chemical trade journals and private correspondence with manufacturers; for data see Robert B. Stobaugh, "The Product Life Cycle, U.S. Exports, and International Investment" (Unpublished DBA Thesis, Harvard University Graduate School of Business Administration, 1968), p. 71.

12. Hufbauer, *Synthetic Materials and the Theory of International Trade,* pp. 131-34.

13. A survey showed an *average* of six years and two months between the inception of the idea and the start of commercial production, with an average of 540 possibilities considered for every one commercialized. H. M. Corley, ed., *Successful Commercial Chemical Development* (New York: John Wiley & Sons, Inc., 1954), p. 137.

14. *Ibid.,* pp. 142, 237.

at the same time wants to avoid the risk of depending on the export market for a large percentage of the plant output. This risk results from the specialized nature of most plant's producing chemicals in large volumes—the plants could not be converted easily to the production of other chemicals if changes in trade barriers closed an export market.

EXHIBIT 1

SELLING EXPENSES FOR CHEMICAL PRODUCTS

Item	*Estimated Cost as a Percentage of Sales* *New Product*	*Old Product*
Customer technical service	8.0%	0.5%
Selling expense	15.0	1.5
TOTAL	23.0%	2.0%

Source: Roger Williams, Jr., "Why Cost Estimates Go Astray," *Chemical Engineering Progress,* LX (April 1964), p. 18.

Furthermore, the producer likely perceives that factor costs abroad are not radically different from those in his home country. And the producer is unlikely to make a major search for the location with the lowest factor costs because as a monopolist or near monopolist he faces a low price elasticity of demand.

Certain external economies are critical in the development of new chemical products; for example, scientists and engineers are needed[15] and are likely to be available in a country with a large market for chemicals. However, even though a supply of technical manpower is a necessary condition for the introduction of new chemicals, it is not a sufficient condition for the introduction of petrochemicals, which typically have large economies of scale in the production process. Countries such as

15. William Gruber, Dileep Mehta, and Raymond Vernon, "The R & D Factor in International Trade and International Investment of U.S. Industries," *Journal of Political Economy,* LXXV (February 1967), pp. 20-37; and Roger Williams, Jr., "Why Cost Estimates Go Astray," *Chemical Engineering Progress,* LX (April 1964), p. 18.

Switzerland, with a supply of technical manpower but a relatively small market, have not been the kind of market in which new petrochemicals have been introduced.

To summarize, there are a number of relationships making it desirable to locate the first commercial plant in a large-market country: Close communication between the plant and customers is needed. Also, the producer does not want to depend on the export market for too large a share of plant output. Furthermore, because of a relatively low price elasticity of demand for the product, the producer has little incentive to search for a location with lower costs, especially as he probably expects them not to be radically different from those in his home country.

The Start of Exports

In those cases in which production begins initially in the United States, a market develops abroad some time later and exports begin. Consumption increases in the United States and in the foreign markets as a result of three factors: increases in market saturation due to the diffusion of knowledge about the product, increases in consumer income, and decreases in product price.[16] The American producer prefers expanding his U.S. plant in order to serve these markets abroad.[17] There is a relatively low incremental manufacturing cost of production from the existing plant; furthermore, the rapid growth of the U.S. market during the early stages of the product life cycle means that the producer, in addition to providing capacity for the home market, also can provide with a minimum of risk the capacity necessary to serve the foreign market. If the foreign markets eventually are lost, the producer knows that soon his expanded home market will be able to consume all of the output of his plant.

In those cases in which production begins initially outside the United States, the large American market induces an early production date in the United States; furthermore, the large market enables the American producer to expand rapidly and to lower his costs because of large economies of scale. However, as will be shown later, a relatively weaker export performance on the part of U.S. producers results because of competition in the world markets from the initial producing country; and,

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16. The steady increase in consumption and decline in price is shown in Robert B. Stobaugh, "Away from Market Concentration: The Case of Petrochemicals, "*Working Paper* (Cambridge, Mass.: Marketing Science Institute, 1971).

17 .For a typical expression of this preference, see statement by Lammot du Pont Copeland, President of du Pont, *The General Electric Forum,* April-June 1964, p. 16.

of course, the initial producing country has one important advantage: the longer experience of its manufacturers helps them to reduce production costs because of the "learning curve" effect of cumulative production experience.[18]

Regardless of whether production initially is started abroad or in the United States, there is a lag of several years and often as long as 20 years between the time commercial production begins in the United States and the time U.S. exports begin.[19] This lag results because the foreign markets are served very early by exports of end-producers rather than intermediate products—plastics, rubbers, and fibers, for example—rather than petrochemical intermediates such as styrene monomer. Eventually the individual foreign markets become large enough to justify construction of a plant to manufacture the end products. But since economies of scale relative to market size usually are larger for petrochemicals than for end products,[20] the erection of a plant to produce the end product in a given country typically precedes the erection of a petrochemical plant. During this lag in a given country between the time the plant to produce the end product goes onstream and the time the petrochemicals used as raw materials for these foreign plants making the end product.

Although the export performance of the United States is weaker when production initially commences abroad rather than in the United States, the time lag between commencement of U.S. production and commencement of U.S. exports seems to be the same regardless of whether the product is produced initially abroad or in the United States. For the

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18. For the application of the learning curve to a process industry, see W. B. Hirschman, "Profit from the Learning Curve," *Harvard Business Review*, XLII (January-February 1964), pp. 125-39.

19. First production dates were obtained from chemical trade journals and private correspondence with chemical manufacturers, and first dates of U.S. exports were obtained from chemical trade journals and from private files of a consulting firm. Of the nine products in this study, extensive export data are available only for seven—a relatively few observations from which to dray statistical conclusions; however, for a statistical analysis of such small samples, see Stobaugh, "The Product Life Cycle, U.S. Exports, and International Investment," p. 98.

20. As an illustration, there were 17 vinyl chloride monomer (intermediate product) plants compared with 29 polyvinyl chloride (end product) plants in the U.S. in 1965. Wickham Skinner and David C. D. Rogers, *Manufacturing Policy in the Plastics Industry* (Homewood, Illinois: Richard D. Irwin, Inc., 1970), p. 29.

products in this study, the lag for both classes averaged about 14 years.[21] Two countervailing forces apparently cancel one another. On the one hand, the development of markets abroad begins with the commencement of production in the initial producing country rather than with production in the United States. Therefore, by the time production commences in the United States, foreign markets already are available, thus encouraging American exports soon after American production has commenced. On the other hand, the U.S. plant initially has less experience than the initial producer abroad.

These exports to nonproducing countries often are referred to as "technological gap" exports; in fact, as consumption in individual foreign nations approaches a sufficient size to support an economic-sized plant, plants begin to be constructed in these countries. As the size of the market in the most important determinant of when production is begun in a country,[22] such gaps might better be referred to as a "market size gap" rather than a "technological gap."

As more manufacturers in more countries begin production, the American share of the total foreign market begins to decline. At the same time, U.S. exports begin to grow at a slower rate than American consumption, so U.S. exports *as a percentage of U.S. production* begin to decline. This decline has occurred for most products in this study (Exhibit 2). Under this model, once production starts abroad, it typically experiences a greater percentage growth than American exports. This pattern is illustrated in Exhibit 3 for low-density polyethylene, which is used in this illustration because data on world trade for the nine petrochemicals in this study were not available to the author. However, the trade patterns shown in Exhibit 3 are believed to apply to petrochemicals in general because low-density polyenthylene normally is classified as a petrochemical and has many of the economic characteristics of the nine petrochemicals in this study: Labor costs are relatively small compared with raw material costs and the production process has substantial economies of scale and requires a "lumpy" investment. The quality of low density polyethylene is changed more often than those of the petrochemicals in this study, but not to such an extent that a producer can gain a major competitive lead over other producers by continually changing the quality.

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21. Stobaugh, "The Product Life Cycle," Chapter III.

22. Robert B. Stobaugh, "Where in the World Should We Put That Plant?" *Harvard Business Review*, XLVII (January-February 1969), pp. 129-36.

EXHIBIT 2

DECLINE IN U.S. EXPORTS AS A PERCENTAGE OF U.S. PRODUCTION, SEVEN PETROCHEMICALS, 1914 TO 1969

Products First Produced In United States	*Year of Export Peak*	*U.S. Exports as a Percentage of U.S. Production, Average for Products in Sample*	
		In Peak Year	*In 1969*
CH[a]	1967	47%	35%
OX	1960	87	70
PX	1965	25	22
Average		53%	42%
Products First Produced Abroad			
AN	1963	27%	24%
MN	1964	14	2
PN	1943	16	1
SM	1969[b]	18	18[b]
Average		19%	11%

[a]For descriptions of the individual products, see the Appendix.
[b]U.S. exports of SM had not yet reached a peak—exports during 1969 were an all-time high.

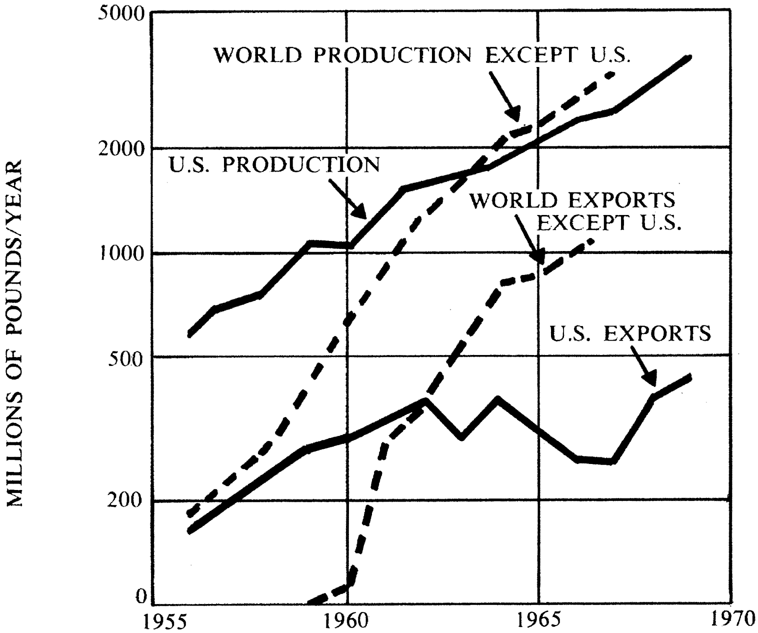
Sources: Production data from U.S. Tariff Commission, *Synthetic Organic Chemicals—U.S. Production and Sales.* Export data from Bureau of the Census, *U.S. Exports of Domestic and Foreign Merchandise, FT-410.* These sources were supplemented by data from files of a consulting firm and from chemical industry trade journals.

Note: Export data for the other two products in the study—IP and VC are not available.

Before the decline in the relative importance of U.S. exports begins, an export peak higher than the chemical industry average of about 4 percent of U.S. production[23] is reached. These export peaks expressed as a percent of U.S. output; for the products in this study, they averaged 53 percent compared with 19 percent for products first produced abroad (Exhibit 2). Further evidence of the effect of a production lead on exports is indicated by the significant negative correlation (R^{-2} = .69) between the imitation

EXHIBIT 3

LOW-DENSITY POLYETHYLENE PRODUCTION AND EXPORTS



Source: World-wide production and trade data are very difficult to obtain for individual products. These data came from United States Industries, Inc., and were reported in the Arthur D. Little, Inc., report in the Appendix of the Chemco Group's submittal to the Cabinet Task Force on Oil Import Control, 1969.

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23. The United States chemical industry exported $2.4 billion out of total sales of $36 billion in 1965, or 6.7%, according to *The Chemical Industry,* Organization for Economic Cooperation and Development, Paris, 1967, pp. 16, 143. The ratio of United States Chemical exports to total United States chemical industry sales for the years 1929, 1939, 1948, 1957, and 1961 varied from 4% to 6%. Jules Backman, *Foreign Competition in Chemicals and Allied Products* (Washington: Manufacturing Chemists' Association, 1965), p. 6. U.S. exports as a percentage of U.S. production would be less than these percentages because these are a percentage of industry sales, which are less than production because of captive uses by manufacturers.

lag of the United States and the peak that American exports reached as a percentage of American production (Exhibit 4).

EXHIBIT 4

IMITATION LAG AND U.S. EXPORT PEAK,
SEVEN PETROCHEMICALS, 1914 TO 1969

Products First Produced in United States	*Imitation Lag of U.S., Average for Products in Sample*	*U.S. Export Peak as a Percentage of U.S. Production, Average For Products in Sample*
OX	−15[a]	+87
CH	− 7	+47
PX	− 6	+25
Average	− 9	+53
Products First Produced Abroad		
AN	+ 7	+27
PN	+ 7	+16
SM	+ 4	+18
MN	+ 3	+14
Average	+ 5	+19

[a]This negative imitation lag of 15 years means that the U.S. started production 15 years before any other country.

Sources: Production data from U.S. Tariff Commission, *Synthetic Organic Chemicals—U.S. Production and Sales.* Export data from Bureau of the Census, *U.S. Exports of Domestic and Foreign Merchandise, FT-410.* These sources were supplemented by data from files of a consulting firm and from chemical industry trade journals.

Notes: 1. Export data for the other two products in this study—IP and VC—are not available.

2. The coefficient of correlation, r, between "imitation lag" and "U.S. export peak as a percentage of U.S. production" for these seven products is —0.86 ($R^2 = .74$ and $\bar{R}^2 = .69$). Although this coefficient is significant at greater than 95% confidence level, if the observation for OX is omitted the resulting coefficient would not be statistically significant.

U.S. Exports Later in the Product Life Cycle

Although U.S. exports decline in relative importance, their growth in absolute terms is a different story. The sizes of new plants continue to become larger, because consumption continues to grow tand there are very large economies of scale in the production process; to illustrate, if two petrochemical plants were built at the same time using similar technology with one having a capacity of 2x and the other a capacity of 1x, then when both plants operated at maximum capacity, the one with an output of 2x would have operating costs per pound of product about 30 to 40 percent lower than the plant with an output of 1x.[24] As a result, even though a foreign nation's market might eventually be large enough to support a plant of an economic size, this day is postponed by the continuing increase in the economic sizes of new plants. Therefore, the volume of the export market grows in absolute terms; albeit, the United States begins to share with other producing nations these markets in countries without production.

American exports continue because of a second phenomenon: American manufacturers export to some foreign countries that have already begun production of the product. There are several reasons for American exports to these producing countries: there may be only one source of supply in the foreign country but the local customers might desire several sources of supply, or a multinational enterprise might export to its subsidiary in the producing nation. Both are common situations in the chemical industry. Furthermore, new capacity in the chemical industry generally can be added only in fairly large lumps;[25] thus, as consumption rises steadily, periodic shortages and surplus exist in any given country. Because the producer in a foreign country does not want to depend on the export market for too large a share of the output of any plant, especially during the early and intermediate stages of the product life cycle before world trade has become large relative to the size of a typical plant, he is likely to build a new plant only when the domestic market can consume most of the plant output. This pattern is depicted in Exhibit 5. The case of styrene monomer (SM) in Germany supplies a specific example of this phenomenon. American exports of SM to Germany were negligible in the few years prior to 1964 and 1965; however, in 1964 and 1965 they approximated $10 million yearly. In 1966, they dropped off sharply as a new SM plant began production in Germany.[26] Other foreign markets

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24. Robert B. Stobaugh, "Away from Market Concentration: The Case of Petrochemicals."

25. For discussions of "lumpy production functions, see Jacob Viner, "Cost Curves and Supply Curves, *Zeitschrift fur Nationalekonomie,* III (1931), pp. 23-46; reprinted, with supplementary note, in American Economic Association, *Readings in Price Theory* (Homewood, Illinois: Richard D. Irwin, Inc., 1952), pp. 198-233; George Stigler, "Production and Distribution in the Short Run," *Journal of Political Economy,* XLVII (June 1939), pp. 305-27; Alan S. Manne, ed., *Investments for Capacity Expansion: Size, Location and Time Phasing* (London: Allen & Unwin Ltd., 1967), pp. 44-45; and John Haldi and David Whitcomb, "Economies of Scale in Industrial Plants," *Journal of Political Economy,* LXXV (August 1967), pp. 373-85.

26. A 440-million-pound/year styrene (SM) plant by Badische Anilin & Sodafabrik, *Oil, Paint and Drug Reporter,* April 18, 1966, p. 9.

replaced the German market so that total U.S. exports of SM were essentially the same in 1966 and in 1965.

These "balancing exports" become very important once many of the foreign countries with large markets commence production. In fact, after a petrochemical reaches a mature stage in its life cycle, these balancing exports exceed the so-called "technological gap" or "market size gap" exports (i.e., exports to non-producing countries). For the products in this study U.S. exports of individual products to countries producing the products at the time of the exports increased from 12 percent of total United States exports of the products during an early stage of the life cycle to 62 percent of total United States exports of the products during a mature stage of the life cycle.[27]

Primarily because of these balancing exports, the quantity of U.S. exports of individual petrochemicals typically does not decline to lower levels, at least in *absolute* terms. To be sure, in some years a shortage of the product in the United States results in a cutback in exports, since the U.S. producer typically gives priority to the domestic market. However, as soon as new plants are brought into production in the United States, exports resume in substantial quantities. For the products in this study, by 1969 only two had clearly passed their export peaks expressed in absolute terms. These two peaks had been reached in the early 1960's, after one product had been produced in the United States for 38 years and the other 46 years;[28] and for one of these products (synthetic methanol), a new export peak was being predicted for the early 1970's because of a technological innovation's being adopted in the United States prior to adoption by other countries; and by mid-1971 it appeared that these predictions might be realized at an early date.[29] For the remaining seven products in this study, export peaks expressed in absolute terms had not yet been reached by the late 1960's even though these seven products had been produced in the United States for periods of 20 to 40 years.

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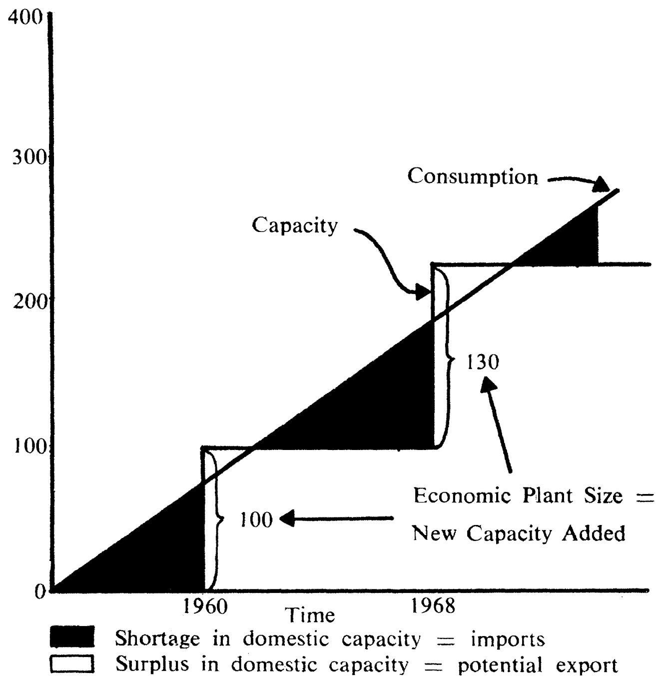
27. A Gompertz-type curve, "smoothed by eye," was used to classify the products' growth into stages of a product life cycle. For further details, see Robert B. Stobaugh, "The Product Life Cycle, U.S. Exports, and International Investment," Chapter II.

28. Synthetic phenol was first produced in the United States in 1913 and reached an export peak in absolute quantity in 1960, and synthetic methanol was wirst produced in the United States in 1926 and reached an export peak in absolute quantity in 1964. *Ibid.*, Chapter III.

29. Barry Hedley, Walter Powers, and Robert B. Stobaugh, "Methanol: How, Where, Who—Future," *Hydrocarbon Processing,* XLIX (July 1970), 135; and "How Will They Close the Gap?" *Chemical Week,* CVIII (May 19, 1971), p. 47.

EXHIBIT 5

IDEALIZED RELATIONSHIP OF CAPACITY AND CONSUMPTION FOR ONE PRODUCT IN ONE FOREIGN COUNTRY



The lack of recognition of the existence of balancing exports by managers of U.S. chemical companies has contributed to a belief that after reaching a peak, U.S. exports would experience a permanent decline, approach zero, and stay there. This belief has contributed to a shortage of chemical products in the United States and abroad—at times chemicals have been rationed by the U.S. producers in both the U.S. and the export markets.[30]

The general belief that the United States will lose most of its export market for an individual product is not restricted to the chemical industry; international executives in a variety of industries feel that "most markets

30. Hufbauer, *Synthetic Materials and the Theory of International Trade*, pp. 101-2; and Robert B. Stobaugh, "Effects of Proposed 'ASP Package' on U.S. Chemical Exports and Imports," *Foreign Trade and Tariff Proposals, Hearings*, before the Committee on Ways and Means, House of Representatives, Ninetieth Congress, July 1, 1968, p. 4686.

will eventually be closed to exports [because of high tariffs or the erection of a competing plant]."[31]

The Future

The product life cycle model suggests that late in the life of the product, after product quality has been standardized and competition has become severe, less developed countries—with low production costs—would export to the advanced countries. In addition to standardized product quality and keen competition, another factor should encourage the development of export plants in less developed countries: technology for the production of mature products often is readily available for purchase.[32]

Under these conditions any country with lower production costs than other nations for the production of certain products should become a major exporter of such products. In electronics this has happened in mature products in nations such as Taiwan, with low labor costs who, have become major exporters to developed nations. However, few such developments have taken place in the petrochemical industry. For example, only one of the 350 plants in the world that manufacture any one of the nine petrochemicals in this study was built in a less developed country without a large domestic market for the consumption of the product.[33] In this case the less developed country was one that had low raw material costs rather than low labor costs—the potential labor savings were not sufficiently large to offset the capital risk of building a plant solely for exports.

Looking to the future, however, there is evidence that the nations having low-cost raw materials because of large oil and gas supplies might become major exporters of mature petrochemicals. If this trend develops, two criteria will determine which products are produced initially for exports and in which nations they will be produced.

The first criterion is that products made from natural gas, such as amonia and methanol, will be the first made in oil-producing nations for export, as natural gas is produced with crude oil and is flared in some oil-producing nations. Hence, the opportunity cost of this gas

31. Yair Aharoni, *The Foreign Investment Decision Process (Boston)* Harvard University Graduate School of Business Administration, 1966), p. 183.

32. Robert B. Stobaugh, "Using Technical Know-How in a Foreign Investment and Licensing Program," *Proceedings of the Chemical Marketing Research Association,* (Houston, February 1970).

33. This was a CH plant in Trinidad: see Robert B. Stobaugh, "The Product Life Cycle, U.S. Exports, and International Investment," Chapter IV.

is zero ((although at times some benefit can be obtained by reinjecting the gas into the ground). Still, the production of mature chemicals for exports will not be limited to those made from natural gas, because officials of oil-producing nations with nominal oil-producing costs and with 40 or so years of reserves will place a very low value on a barrel of oil used in petrochemical production.

A second criterion that affects the products for which export plants will be constructed is the ratio of world trade in that product to the output of one economic sized plant: the higher this ratio the less risk the owner of one economic-sized plant takes in depending to a large extent on the export market for his sales. In other words, a large world trade in a product relative to the capacity of a given plant presents more opportunities for the output of this plant to be absorbed in the export market than if world trade were relatively small compared with the plant capacity. Thus, given two products made from natural gas, such as amonia and methanol, export plants will be constructed first for amonia, because world trade in relation to the capacity of one economic-sized plant to make amonia is much larger than that in the case of methanol.

Sketchy evidence and speculation suggest that this pattern is evolving as several plants to manufacture amonia primarily for the export market are either under construction or nearing completion in the oil-rich nations,[34] and it is clear that sales are being made on the basis of low price (India claims to have obtained the lowest priced amonia in the world from Iran).[35]

Summary

The product life cycle theory, as part of a broader neotechnology account of world trade, provides an explanation for certain production and trade patterns observed for petrochemicals.

The plants to manufacture commercial quantities of petrochemicals initially are built in a country with a large domestic market, such as the United States or Germany.

Exhibit 6, based on the patterns described in this article, tells the story of United States exports. These exports begin some years after U.S.

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34. Earl V. Anderson, "Arabs and Their Oil," *Chemical and Engineering News*, XLVIII (November 16, 1970), pp. 58-72.

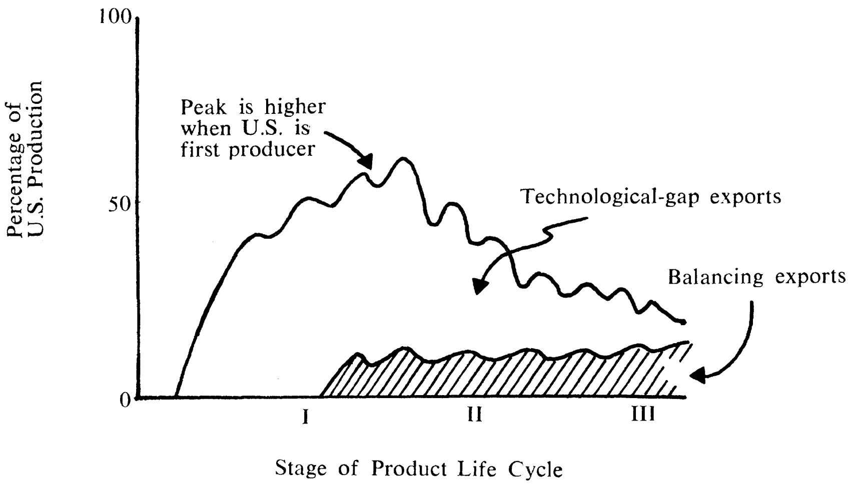
35. "Iran Gets NH_3 Order from India," *European Chemical News*, XVIII (February 27, 1970), p. 8.

production and *as a percentage of U.S. production* reach a peak substantially higher than the average for the U.S. chemical industry. The decline from the peak begins as more nations commence the manufacture and export of petrochemicals. However, the time required for the U.S. export peak to be reached is relatively long—some 25 years after the commencement of U.S. production.

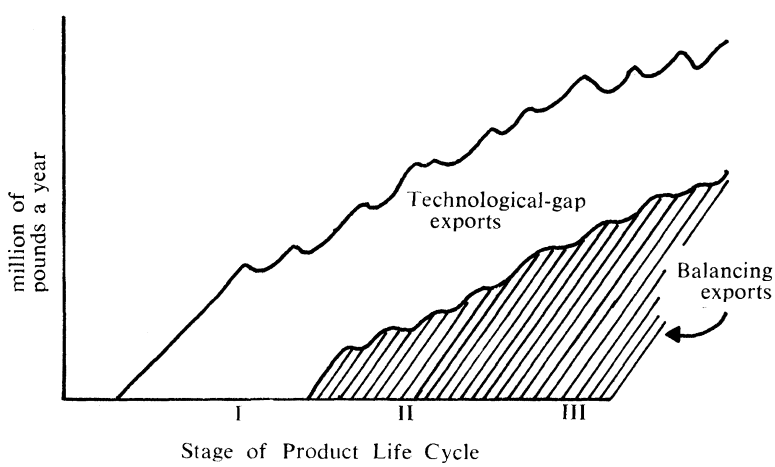
EXHIBIT 6

TYPICAL PATTERN OF UNITED STATES EXPORTS OF PETROCHEMICALS

RELATIVE TO U.S. PRODUCTION



ABSOLUTE QUANTITY



On the other hand it is not clear that U.S. exports decline in terms of *absolute quantity*—only two of the nine products in this study have experienced a clear descent from a peak; these descents occurred in the early 1960's after some 30 to 40 years of U.S. production. And for one of these two products a new peak is being predicted in the early 1970's as new technology is being adopted now (1971) in the United States prior to being adopted abroad. This continual increase in the absolute level of U.S. exports for so many years is a result of sales to countries in which production of the product has already commenced. One factor encouraging these countries to import from time to time is the need to balance supply with consumption, since local supply can be added only in "lumps," while consumption proceeds smoothly. These shifts in trade depend not on shifts in factor costs but on lumpiness in the production process.

Late in the product life cycle the relative costs of the factors of production begin to exert a major influence on trade patterns as scale lumpiness, uncertainty and communications become less important. Evidence suggests that for petrochemicals low-cost raw materials rather than low-cost labor will be an important factor affecting trade and that countries with low-cost raw materials will become exporters of petrochemicals to countries with high-cost raw materials, regardless of the sizes of the respective markets of the two countries.

APPENDIX A

Information Concerning Products in This Study

Selection of Products for the Study

Five criteria were used in the selection of individual chemicals: (1) the author would be expected to be knowledgeable about the product because of past experience; (2) the manufacture of the product would not be tied to a national resource that could not be easily transported, i.e., the products would be "foot-loose" manufactured goods; (3) the product would have characteristics that enable it to be traded internationally; (4) there would be a sufficient number of producing facilities in the world to allow a test of the model; (5) adequate data would be available on the location and timing of world production facilities.

Some 12 "foot-loose" manufactured chemical products were chosen from a list appearing in a series of journal articles written by the author and from a booklet published by the author's former employer.[1] From this list of 12 products two were deleted because freight costs for transport between continents were so high relative to value of product that international trade had been negligible and one was deleted because adequate data could not be obtained on world production facilities.

Description of Products

The nine products studied are:

Abbreviation	*Name*	*Principal Use*
AN	Acrylonitrile	Fiber
CH	Cyclohexane	Fiber
IP	Isoprene	Rubber
MN	Synthetic Methanol	Plastics
OX	Ortho-xylene	Plastics
PN	Synthetic Phenol	Plastics
PX	Para-xylene	Fiber
SM	Styrene monomer	Plastics
VC	Vinly chloride monomer	Plastics

The abbreviations are used in the text to refer to the individual products.

The nine products are organic chemicals produced in the United States in large volumes—greater than 100 million pounds per year. Each product is commonly referred to as a "petrochemical" because each can be manufactured by using petroleum as a basic raw material though they can also be manufactured from other raw materials. While these products are used principally in the manufacture of plastics, synthetic rubbers, and synthetic fibers, as shown above they also have a number of miscellaneous industrial uses.[2]

The number of years that had passed since their commercialization varied from 21 years for the "youngest" to 62 years for the "oldest" as of 1969.

Relationship of Products in This Study to Remainder of Chemical Industry

The products in this study were produced in about 100 plants in the United States in 1969. The total U.S. production of these products in 1969 was valued at $1 billion or about 5% of the total petrochemical

1. A series of 14 journal articles appeared in *Hydrocarbon Processing* between September 1965 and August 1967 as a Petrochemical Guide series. The booklet reference is Monsanto Company, *Facts about Monsanto and the Hydrocarbon Division,* not dated, but published about 1964.

industry sales of more than $20 billion. This compares with total U.S. chemical industry sales of about $50 billion in 1969.

The total number of plants world-wide manufacturing these products totaled about 350 in 1966. This compares with a world total of some 1,100 petrochemical plants,[3] many of which manufacture other products in addition to those in this study. The total world production of these nine petrochemicals was valued at $4 billion or about 5 percent of the total world sales of petrochemicals of about $80 billion.[4]

U.S. exports of these nine petrochemicals were about 5 percent of total U.S. exports of petrochemicals, or slightly over $100 million. World trade in these nine petrochemicals has not been estimated.

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2. More details concerning markets and manufacturing are presented for AN, CH, IP, OX, PN, PX, SM, and VC in my *Petrochemical Manufacturing and Marketing Guide,* Vols. I and II (Houston: Gulf Publishing Company 1966 and 1968); and MN in *Hydrocarbon Processing* (June, July, August, September, 1970).

3. "Focus on Naphtha," *Petroleum Press Service,* XXXIV (December 1967), p. 447.

4. For industry estimates see the Arthur D. Little, Inc., and the Stanford Research Institute estimates in the submittals to the Cabinet Task Force on Oil Import Control, 1969.