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U.S. PRICE CONTROLS ON ENERGY AND THE INTERNATIONAL PETROCHEMICAL MARKET

Robert A. Levy
James M. Jondrow

The Public Research Institute
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U.S. PRICE CONTROLS ON ENERGY AND THE INTERNATIONAL PETROCHEMICAL MARKET

Robert A. Levy
James M. Jondrow

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The Public Research Institute
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ABSTRACT

During the last decade, most energy products--crude oil, natural gas, gasoline, and other refined products--have been subject to price controls. Though some of these controls have been lifted, the Common Market Countries have complained that the price controls subsidized U.S. exports of energy products, particularly petrochemicals. In this study, we have analyzed the effects of the price control programs to determine if they, in fact, subsidized U.S. petrochemical exports, and if so, what were the effects on world petrochemical prices and U.S. and foreign production levels?

We found that the controls on domestic crude oil prices did have some important effects: They reduced the marginal price paid by U.S. refiners; they reduced the domestic supply of crude oil; and they increased the demand for imports. It was not the price controls themselves that reduced the price of U.S. supplied crude oil, but the entitlements program, which equalized the cost of crude oil across refiners. Despite the subsidies, the effects on world petrochemical prices and U.S. and foreign production levels appear to have been relatively small. Our results indicate that the effects of the entitlements program were to increase U.S. production of petrochemicals by between 2 and 6.25 percent and to decrease foreign production by between 1 and 4.50 percent, depending upon the products studied and assumptions made.

Controls on natural gas were changed in 1978. Until then, however, by controlling prices in one large segment of the market, they gave U.S. producers access to cheaper energy feedstocks than were available to foreign competitors. The effects on trade in petrochemicals made from natural gas (e.g., urea) were small. U.S. production rose less than 4 percent due to the controls program in place for the pre-1978 period. Even this small effect was reduced, if not reversed, after the controls were changed in 1978.

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INTRODUCTION

During the last decade, most energy products have been subject to price controls: crude oil, gasoline, natural gas, and other refined products. Though these controls are being lifted, the Common Market countries have complained that the price controls subsidized U.S. exports of energy intensive products, particularly petrochemicals. This study is an analysis of whether the price controls did, in fact, subsidize petrochemical exports and, if so, by how much? Answers to these questions will help policymakers predict how markets will be affected by the removal of price controls and provide information in case price controls are considered again.

We begin with a brief description of the refining and petrochemical industries along with the types of products they produce. We then turn to the effects on the world petrochemical market of the U.S. energy controls program and focus on three issues. The first concerns whether the controls actually affected the U.S. supply of petrochemicals. To study the effects of the controls, we use graphical models to illustrate the direction of effects on the input markets (crude oil and natural gas) and the subsequent effects on the corresponding output market (the various petrochemical products).

The key issue concerns whether the controls affected the price of marginal units of crude oil and natural gas. It is the price of marginal units of an input (crude oil and natural gas) that determines the supply of an output (petrochemical). When the crude oil controls first began, they did not affect the marginal price of crude. The marginal price remained the world price. We conclude, nevertheless, that, after the entitlements program began, the controls did affect the marginal price of crude and, hence, the supply of petrochemicals. For natural gas, the price regulations that split the U.S. market into a controlled market and an uncontrolled market in the U.S. for at least part of the period also lowered prices from the uncontrolled equilibrium price.

A second issue is whether the controls affected trade in intermediate petrochemicals. If there is trade in intermediates, then any price advantage conferred on U.S. producers of final petrochemicals by crude oil price controls (and entitlements) will be shared by foreign producers. We examine trade in primary and intermediate petrochemicals, and conclude that the extent of trade varies by product. Some intermediates show a modest amount of trade (exports are 10-20 percent of production); others show virtually no trade. Thus, we regard the trade issue as unsettled. Nevertheless, we proceed on the assumption that trade does not negate the artificial comparative advantage and calculate whether, given this assumption, the induced comparative advantage is large or small.

Given that neither the marginal price issue nor the intermediate trade issue has completely negated the subsidy, U.S. producers will have received an artificial comparative advantage from the U.S. price controls on crude oil. The remaining issues are how large is this effect and how great is the impact on foreign production of specific petrochemicals. The graphical analysis of the input and output markets indicates only the direction of effects, not their size. To measure these effects, we construct an integrated model of the world petrochemical and energy input markets. The model includes equations representing the various supply and demand curves that were described graphically. The relevant parameters needed to calculate the effects of energy regulations are drawn from the empirical literature. The crucial parameters turn out to be supply and demand elasticities and the share of crude oil in the cost of producing petrochemicals. Using estimates of the different stages of processing, we then determine the effect of the crude oil price controls on foreign production of petrochemicals at different stages of processing.

In obtaining the effects of crude oil controls, we divide petrochemicals into three general categories--primary, intermediate, and final--each distinguished by a different stage of processing. Primary petrochemicals have the highest share of crude oil in total cost followed by intermediate and final petrochemicals. We find that U.S. petrochemical production increased about 4.8, 2.4, and 2.2 percent for primary, intermediate, and final petrochemicals, respectively, while foreign production decreased by 2.6, 2.9, and 1.2 percent. These findings, though based on specific values of relevant parameters, are robust. Alternative parameters do change the findings slightly, but it takes implausibly large changes to do so significantly.

The effect of the gas controls differ from those on crude oil in that advantages or disadvantages conferred on U.S. ammonia-based fertilizer producers (who use natural gas as an input) depend on the time period. The controls created two markets--one that was always regulated (the <u>interstate</u> market for natural gas) and one that was unregulated for most of the period (the <u>intrastate</u> gas market). Before 1978, the intrastate market was unregulated, and it turns out that the marginal price of gas was lower than it would have been had there been no controls at all. We estimate that U.S. urea production increased by almost 4 percent while foreign production decreased by almost .5 percent. After 1978, intrastate gas was regulated as well although the controls appeared to be binding only occasionally. When the controls were binding, however, curtailments of gas supplies forced U.S. urea producers to cease production or use a more expensive energy input. We estimate that if controlled intrastate prices were 25 percent below the uncontrolled price, then U.S. urea production would have fallen almost 6.8 percent because of the control program.

There were other effects of oil and gas regulation, less well known, but very important. The supply of natural gas liquids (NGLs) like ethane was affected since they are often found together with oil and natural gas. The gas regulations most likely raised their price, and so U.S. olefin production, which was largely based on NGLs as feedstocks, would have decreased because of the higher input prices. We estimate that, depending upon the extent of the rise in NGL price, much of the advantage conferred on U.S. petrochemical producers from oil regulations was offset by the controls on NGLs.

To summarize, we conclude that the price controls on crude oil and natural gas gave an advantage to the U.S. petrochemical industry, but the advantage was small; the removal of the price controls will not lead to a major long-term decline in our petrochemical industry.

TECHNOLOGY AND TRADE

THE REFINING AND PETROCHEMICAL INDUSTRIES

The refining industry uses crude oil and natural gas to manufacture gasoline, fuel oil, and other outputs, including feedstocks for petrochemicals: the natural gas liquids, ethane, propane, butane, and the light liquids, naphtha and gas oil. The feedstocks are used to produce primary petrochemical products such as ethylene, butadiene, and propylene, which are then processed into more finished petrochemicals.

At several stages of the petrochemical production process, beginning with the refinery, there are joint outputs. The mai. business of the refinery is to produce gasoline, but it also produces heating fuel, kerosene, distillate, residual fuel oil, the petrochemical feedstocks described earlier, and other products.* When crude oil first reaches the refinery, it is heated to separate its components, which have different boiling points. Of the components or "cuts" that result, one of the lightest, gasoline, is the most valuable. The incentive is to convert the heavier cuts to gasoline by means of cracking--reheating under pressure. In addition to producing more gasoline (and butane, for blending into gasoline), this process produces several gases and liquids that can be used for petrochemical feedstocks: methane, ethane, and propane. The methane is cycled back for use as a fuel for the refinery. Ethane is used only as a petrochemical feedstock. Propane is used for fuel (liquified petroleum gas) and as a petrochemical feedstock.

These petrochemical feedstocks are then piped into a petrochemical complex, often adjoining the refinery. One important type of complex is the olefin plant. Here the main output is ethylene, a primary petrochemical used later for synthetic rubber, plastics, and synthetic fiber. The other important olefins are butadiene (for rubber) and propylene (for polypropylene plastic). Aside from the olefins, the major primary petrochemicals are the aromatics, like xylene and benzene.

The olefins and aromatics are processed further into final petrochemicals. For example, butadiene and styrene are combined into styrene-butadiene rubber (SBR), as shown in figure 1.

<u>Natural Gas and the Natural Gas Liquids (NGL)</u>

There are also petrochemical products that are not part of this sequence, one of which we are studying: ammonia-based fertilizer.

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* A particularly interesting characteristic of both the refining and petrochemical industries is their ability to vary the proportions (within limits) of their outputs in response to changing economic conditions.

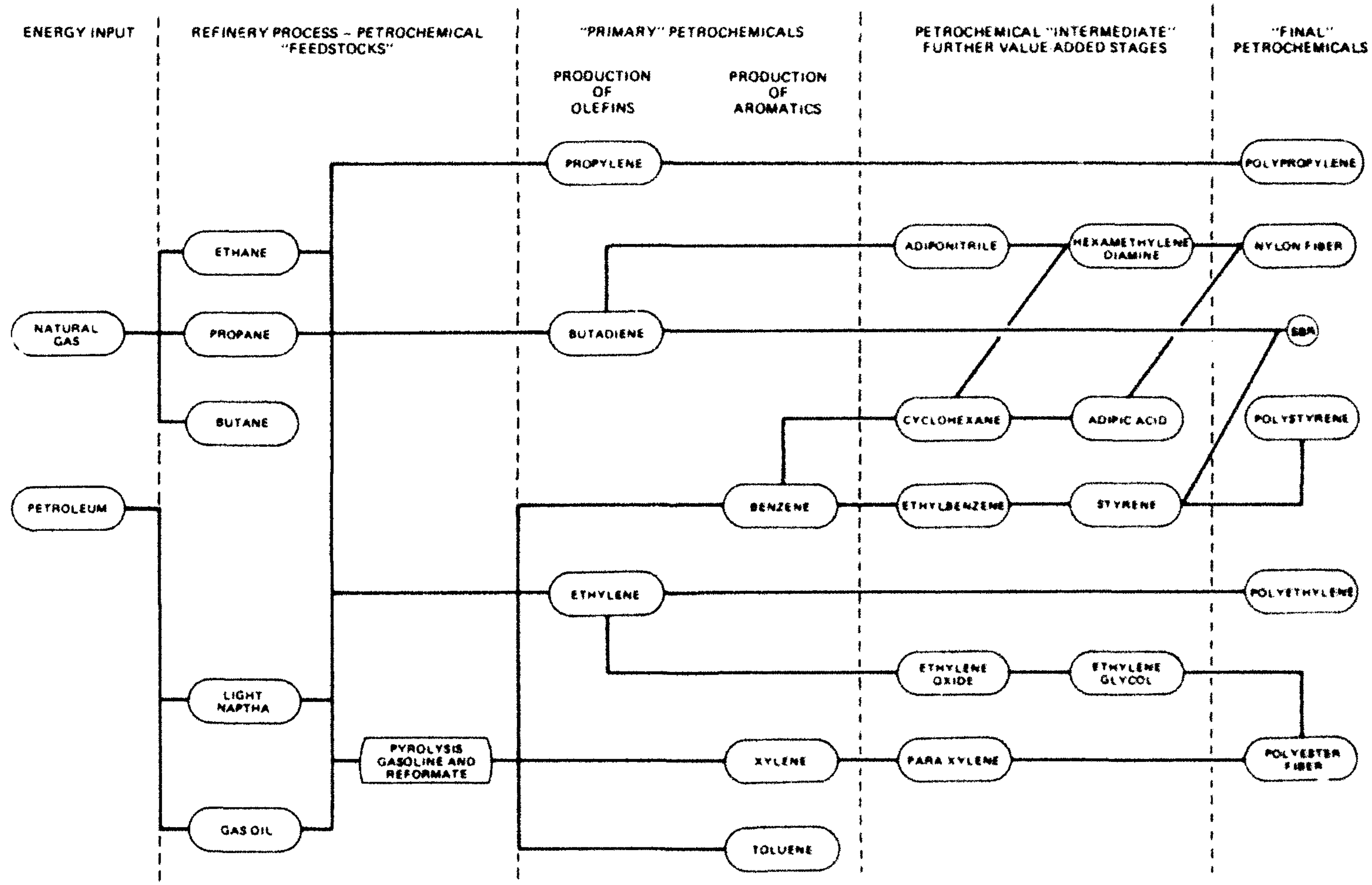

FIG. 1: STAGES OF PETROCHEMICAL PROCESSING

Ammonia can be made from natural gas directly. (It can also be made from the natural gas and feedstocks that come from the refinery.) This process is shown in figure 2.

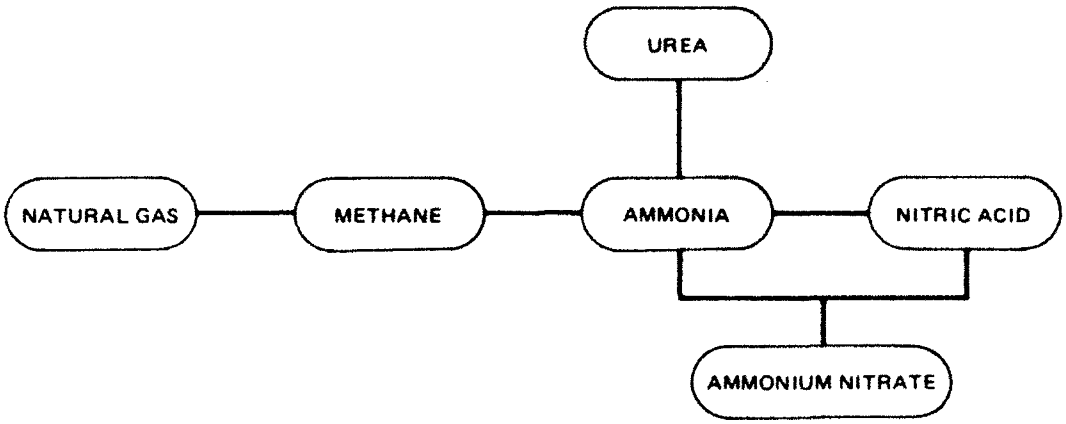

FIG. 2: STAGES OF AMMONIA-BASED FERTILIZER PROCESSING

In studying the regulatory effects on natural gas and ammonia-based fertilizer (e.g., urea), it is important to distinguish natural gas, by which we mean methane, from the natural gas liquids--ethane, propane, and butane. A gas field will typically contain gas and the three gas liquids in varying proportions, with methane being the largest component. A separation plant near the field separates the mixture into the individual components. The methane is then sent by pipeline* to utilities or industrial users or to a petrochemical plant for use as a feedstock (the use as a feedstock is about 2 to 3 percent of total methane use). The gas liquids are also used as fuel or feedstock, the latter use being particularly important in olefin production. Indeed, ethane is considered the preferred ethylene feedstock ([16], p. 88).

* There will often be some ethane and other liquids remaining in what is sent by pipeline; too much of the heavier liquids, however, may impede the flow through the pipeline.

The regulatory authorities controlled natural gas and natural gas liquids separately; gas liquids were thought of as petroleum-like products. Nevertheless, natural gas regulation affected the market for gas liquids and thereby the oil market. These interactions will be described later in the paper.

International Trade in Petrochemicals

The U.S. has been an important producer and exporter of petrochemicals. According to the Commerce Department, the value of U.S. petrochemical exports increased from $2.75 billion in 1973 to $11.80 billion in 1980--a growth rate of 23.1 percent per year. The 1980 value of petrochemical exports was 55.9 percent of all chemical exports and 5.4 percent of U.S. exports of all merchandise. The value of imports was much smaller than that of exports and was increasing at a slower rate.

The opportunity for trade in intermediate petrochemicals is important because trade would dilute any advantage that the controls conferred on U.S. petrochemical producers. The largest advantage accrues to producers of those petrochemicals for which the cost share of oil is the greatest. The primary petrochemicals--e.g., ethylene, propylene, and benzene--have crude oil cost shares that are approximately 50 percent. To the extent that these products are traded and foreign producers of petrochemicals at later stages of processing, like plastics and synthetic fibers, could buy the cheaper traded product, they, too, would benefit from U.S. controls. There would be no artificial comparative advantage conferred on U.S. producers of the final product.

There are limits, however, to the importance of trade as a means to spread the advantages to non-U.S. producers. Clearly, advantages are not spread to foreign producers who produce petrochemicals at the earliest stages and those who produce other petrochemicals at a later stage, but cannot get intermediate petrochemicals through trade. For some products like ethylene, and to a lesser extent, propylene, trade is negligible because of the high cost of transport (ethylene is volatile and must be shipped under pressure, much like liquified natural gas). Those U.S. producers of petrochemicals at the next stage would therefore gain an advantage over foreign producers of similar products. Furthermore, to really gain a significant advantage, port and distribution facilities needed to be built, production capacity added, and contractual arrangements broken all on the basis of what has turned out to be a temporary action by the U.S. government.

Table 1 provides values of production and trade for several final petrochemicals and table 2 does the same for some selected primary and intermediate petrochemicals.* These tables illustrate that trade is important for several products but not for most. We export over 20 percent of our urea and polypropylene production, but a much lower percentage of the other final products. Similarly, for intermediates, we export large quantities of cyclohexane and styrene, but little ethylene and propylene.

TABLE 1

U.S. PRODUCTION, EXPORTS, AND IMPORTS--1979[a]
(Final Petrochemicals)

Final products	Production Quantity	Exports Quantity	Exports As % of production	Exports ($) Value	Imports (c.i.f.) Quantity	Imports (c.i.f.) ($) Value
Styrene-Butadiene Rubber	3,086.62	233.59	7.57	98,837	110.05	46,258
Urea	14,054.00	3,005.80	21.39	181,358	--	--
Polypropylene	3,823.91	802.12	20.98	235,296	1.29	920
Polystyrene	3,846.85	199.99	5.20	86,517	20.56	9,814
Nylon fiber	2,720.40	171.69	6.31	212,289	10.14	12,817
Polyester fiber	4,117.80	523.76	12.7	399,036	11.79	13,875

[a]Quantity measure = millions of pounds
Value = thousands of dollars.

United Nations [23] data allow computation of U.S. apparent consumption (i.e., production plus imports minus exports) and production. In table 3, these are displayed as a percentage of the corresponding world magnitudes for individual petrochemicals in each category: primary, intermediate, and final. In all three categories, there are

* For both tables, the U.S. production data were obtained from the International Trade Commission, and U.S. export and import data were obtained from the U.S. Department of Commerce.

some products where consumption exceeds production (i.e., the U.S. is a net importer), some where trade is almost exactly balanced, and some where we are net exporters. In most cases, trade is unimportant. These figures demonstrate that most production is consumed at home and that small changes in trade patterns could be accommodated without great disruption.

TABLE 2

U.S. PRODUCTION, EXPORTS, AND IMPORTS--1979[a]
(Primary and Intermediate Petrochemicals)

Intermediate products	Production	Exports			Imports (c.i.f.)	
	Quantity	Quantity	As % of production	($) Value	Quantity	($) Value
Propane (mil. barrels)[b]	8,712.22	1.48	< 1	21,155	33.18	342,429
Ethylene[b]	28,666.53	5.63	< 1	2,500	84.63	14,449
Propylene	14,198.42	6.94	< 1	1,054	526.77	40,460
Toluene	7,214.80	751.17	10.41	112,025	362.23	46,108
Para-xylene	4,649.79	635.47	13.67	140,835	26.94	7,077
Cyclohexane	2,425.28	452.50	18.66	100,200	23.35	5,385
Ethylbenzene	8,448.36	97.88	1.16	25,875	--	--
Ethylene glycol	4,728.57	222.37	4.70	48,208	16.08	3,277
Styrene	7,484.23	960.91	12.84	279,769	38.07	8,522
Hexamethylene diamine	997.34	92.07	9.23	5,797	.55	425

[a]Quantity measure = millions of pounds
Value = thousands of dollars.
[b]1980 values.

TABLE 3

U.S. APPARENT CONSUMPTION AND PRODUCTION AS A PERCENTAGE OF WORLD CONSUMPTION AND PRODUCTION (1979)

	Apparent consumption (%)	Production (%)	Exports as a fraction of production
Primary Petrochemicals			
Ethylene	44.0	43.9	-.002[a]
Propylene	42.6	41.1	-.037
Benzene	43.4	42.1	-.031
Xylene	63.5	59.8	-.062
Butadiene[b]	85.2	83.5	-.012
Intermediate Petrochemicals			
Styrene Monomer	67.1	76.5	.123
Ethylene Oxide	63.1	63.9	.013
Ethylene Glycol	66.5	69.6	.045
Final Petrochemicals			
Polyethylene	36.8	41.9	.123
Polypropylene	34.9	44.1	.209
Polystyrene	51.0	53.1	.040
Urea	11.6	15.6	.256

[a]A negative number signifies that the U.S. is a net importer.
[b]1978 values.

From these tables, it is hard to conclude that the effect of U.S. controls on primary and intermediate petrochemicals were transmitted abroad. Though most goods are "traded," in the strict sense, trade is just not very important. Our conjecture as to why trade remained modest (10-20 percent of production) in the presence of controls was given earlier, that the controls were regarded as transitory and not a reliable basis for long-run changes in suppliers. Trade does seem to be more important in the "final petrochemical" stage. These products, including plastics and certain synthetic fibers, were the ones mentioned most often in foreign complaints of our energy "subsidies." Their complaints cannot be wholly refuted by reference to patterns of trade. Further evidence awaits our analytical work.

THE EFFECTS OF CRUDE OIL REGULATIONS

REGULATION OF CRUDE OIL

The recent controls on crude oil began in 1973 with the passage of the EPAA (Emergency Petroleum Allocation Act) of 1973. The central element of EPAA regulation was a two-tier system of price controls on domestically produced crude oil, with the tiers referring to either "old oil" or "new oil." Not surprisingly, oil was categorized as old or new depending upon its time of discovery and extraction.*

Figure 3 illustrates the oil market under controls. P_c is the controlled old oil price, and P_w is the world price, also the uncontrolled new oil price. In the absence of controls, the supply of domestically produced oil would be given by S. Since crude oil was a traded good, in the absence of any controls, the U.S. would import a quantity of oil equal to $X_d - X_s$. The marginal price of oil is the world price, P_w. Federal controls on crude oil, in effect, "created" two types of oil--old oil, of which there was a given quantity X_c and which was priced at P_c, and new oil, which would be priced at whatever the market would allow. To the extent that the supply curve for old oil fields was not perfectly vertical beyond the control price P_c (i.e., the supply elasticity for old oil was greater than zero), potential supplies from these fields were cut off. The supply of domestic crude in the absence of trade would have a "kink" as shown by the curve SAS'.** With trade, the effective supply curve to U.S. refiners would

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* Two kinds of oil were included in the "new oil" category. One was oil from properties that started producing after 1972. The other was oil from a property producing in 1972 but which exceeded the 1972 base production, the base period control level (BPCL). Each property had its own BPCL. If annual production fell below the BPCL, the property acquired a deficit, which had to be carried over. Production could not be classified as new oil until the deficit (current cumulation deficiency or CCD) had been worked off by cumulated production over and above the BPCL.

A new category--"stripper oil"--was also created. Stripper oil was oil from properties producing less than 12 barrels per day. The price of old stripper oil, from properties producing in 1972, was controlled at the levels of May 15, 1973 plus 35 cents per barrel, but then was released from controls in November 1973. New stripper oil and imported oil were not controlled. All other oil was classified as "old oil." The controlled price was $5.03 as of December 1973.

** Since old oil referred to oil discovered and extracted at some early date, we assume that its supply curve has a smaller intercept than the supply curve of new oil. Even with controls, some old oil was produced. At the controlled price, the supply elasticity becomes zero, which leads to a kink in total supply as shown in figure 3.

be SABD. The controls therefore decreased U.S. production to X_{c+n}, increased imports to $X_d - X_{c+n}$ but left the marginal price of oil unchanged at price P_w.

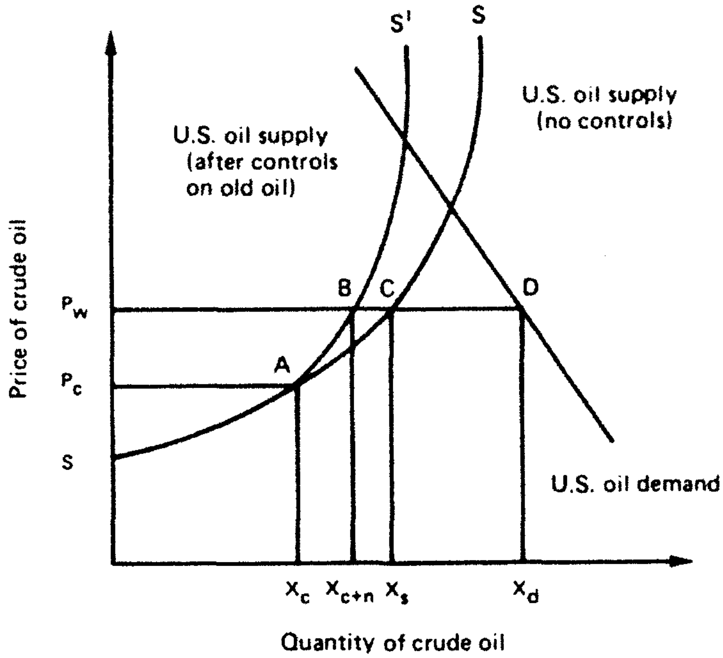

FIG. 3: THE U.S. CRUDE OIL MARKET

Since industries that used oil as an input, including the petrochemicals industry, would value crude at P_w, controls of this nature would have had no effect on final product prices. So far as we know, there is no dispute on this issue (see Kalt [11], p. 35, for a concurring view). What did affect refined product prices, however, was the November 1974 "old oil entitlements program." The entitlements program was meant to equalize the cost of crude oil across refiners. It was begun in response to complaints that under the EPAA pricing of crude oil, domestic refiners who were heavily dependent upon uncontrolled crude oil were placed at a competitive disadvantage.*

The premise of the program was that each refiner was only "entitled" to the cheaper old oil in the same proportion as his use of crude oil relative to total industry use. As the program was set up,

* It turns out that access to controlled oil led to windfall profits, but not a competitive advantage. See Kalt, p. 35, for a discussion of these issues.

the number of entitlements granted to a refiner in any given month was equal to the number of barrels refined in the previous month multiplied by the industry-wide average of controlled to uncontrolled oil. A refiner who wanted to use a proportion of controlled oil higher than the national average had to purchase entitlements (at a price calculated as the difference between P_w and P_c) from a refiner whose crude oil contained a lower fraction of controlled oil than the national average.

In addition, in 1973, all refined products (as distinct from crude) were brought under price controls. The controls allowed refiners to recover all increases in the petroleum or nonpetroleum costs of inputs (called "product" and "nonproduct" cost, respectively). Any eligible costs that were not recovered (perhaps, because of market forces) could be "banked" and used later, which made the refined product price ceilings more flexible than the crude oil ceilings.*

Most of the EPAA price regulations were due to expire in early 1975, but after much debate, controls were extended by the Energy Policy and Conservation Act (EPCA). The regulations under EPCA were similar to those under EPAA, except that they extended controls to new oil, bringing most domestic production under control. There were now three tiers: (1) lower-tier oil (pegged at prices set in 1973), (2) upper-tier oil (pegged at prices set in 1975), and (3) uncontrolled oil. The entitlements program was changed to "equalize access" to both types of controlled crude, upper-tier oil and lower-tier oil. Each barrel of upper-tier oil was granted a fraction of the entitlement given to lower-tier oil.

The Entitlements Program

As noted earlier, the simple fact of price controls on an input does not necessarily lower the supply price of an output.** Because the input will be subject to excess demand, the shadow price or marginal price will be set by whatever is purchased to fill the excess demand, in this case crude oil purchased from world markets.

The entitlements program, on the other hand, did affect the marginal price facing refiners of crude oil. The evidence from various economic studies of the program, including Friedman [6], Hall and

* Indeed, it appears that the controls were, for the most part, nonbinding. Both Kalt and Phelps-Smith [15] investigated this issue and found that except for early 1974 (during the Arab embargo) and again in 1979 (after the shutdowns of Iranian production), there was little evidence supporting binding price controls. In any event, most major products were made exempt from controls since mid-1976 (one exception being gasoline).

** By supply price, we mean the vertical intercept of the supply curve at a given quantity.

Pindyck [9], Montgomery [13], Phelps and Smith, Cox and Wright [4], and Kalt, illustrates how apportioning to all domestic refiners equal access to controlled crude oil lowers the marginal price for U.S. refiners.* The buying and selling of entitlements allowed all domestic refiners to share in the windfall profits that previously had accrued to refiners having access to controlled, and therefore cheaper, oil. The price paid for an additional unit of crude oil no longer was the import price but rather a weighted average of controlled and uncontrolled prices.

This is illustrated in figure 4, which shows the supply and demand for crude oil under the entitlements program.** The profits of refiners purchasing old oil (A + B) are spread across all producers (B + C). The price that accomplishes this spread is P_e. Since P_e is below P_w, the quantity demanded is increased from X_d' to X_d while the quantity supplied is reduced from X_s' to X_s. Thus, uncontrolled production falls and imports rise.

What is relevant for the supply of refined products and petrochemicals is the amount by which P_e is reduced below P_w. The formula for this amount is the subject of the next section.

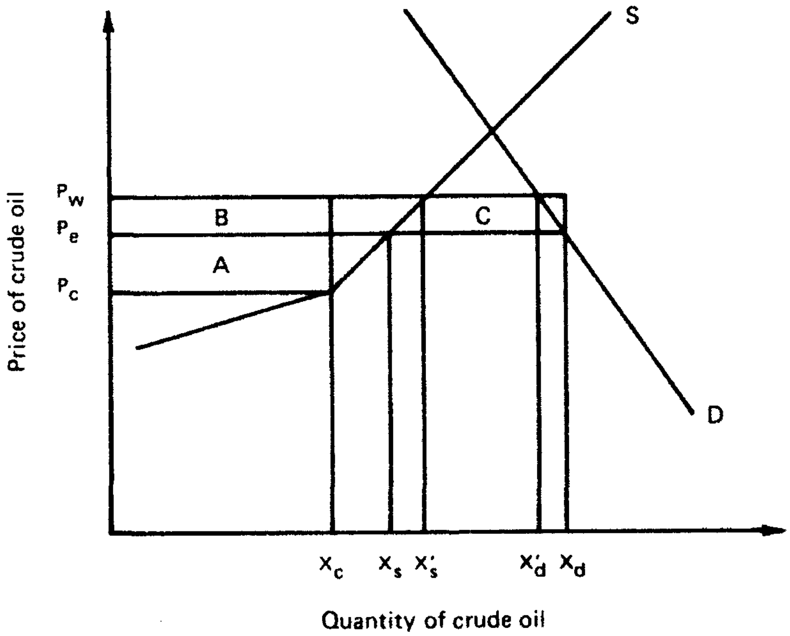

FIG. 4: THE U.S. CRUDE OIL MARKET AFTER ENTITLEMENTS

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* Appendix A presents in greater detail a description of the models as well as a comparison to the one to be provided in this section.

** For simplicity, we depict the two-tiered system of prices rather than the full three-tiered system.

The Marginal Price of Oil to U.S. Refiners

The price of oil to refiners, including the cost of the entitlement, is P_e. This price is determined by the equation below. The left-hand side of the equation is the total rents available from controlled domestic production. The right-hand side is the same rent, spread over all consumers of crude oil.

$$(P_w - P_c)\ X_c = (P_w - P_e)\ X_d \tag{1}$$

where

P_w is the world price

P_c is the controlled price

P_e is U.S. price of crude given the entitlements program

X_c is domestic production of controlled crude oil

X_d is domestic demand for crude oil.

Let $\lambda = X_c/X_d < 1$, and we can see how the entitlements price is a weighted average of controlled and uncontrolled oil prices:

$$P_e = (1 - \lambda)\ P_w + \lambda P_c \quad . \tag{2}$$

To illustrate the result in another way, we rearrange the equation and obtain

$$P_w - P_e = \lambda(P_w - P_c) \quad . \tag{3}$$

The difference between the world and U.S. price for crude oil is some proportion of the difference between the world and controlled prices. Controls on the price of old oil therefore had an effect on the marginal price of crude in the U.S. market. This was not true before the entitlements program began.

ECONOMIC EFFECTS

The central question concerning the effects of the regulations is whether the divergence they caused between the world price and the U.S. price shifted the U.S. supply of petrochemicals downward relative to the rest of the world supply. If so, U.S. production would displace foreign production.

The size of the decline depends on a number of factors, including, for example, the amount of crude relative to other inputs and the extent to which there is international trade in the product or in intermediate inputs. Of crucial importance are the elasticities of supply and demand.

Although studies of the entitlements program agree that crude prices were reduced, there is not equal agreement on whether refined product prices were reduced.* The primary source of the disagreement concerns differing assumptions on whether the U.S. refined market is isolated from world markets, thereby allowing an outward shift in U.S. supply of refined products to lead to lower domestic prices.

Several of the studies (e.g., Friedman, Hall and Pindyck, and Montgomery) claim, with little empirical evidence, that the entitlements program did reduce domestic refined product prices below the levels that would have prevailed without the program. An important assumption, however, was that the U.S. refining industry was essentially isolated from foreign markets and operated along a perfectly elastic supply curve for petrochemicals.

In contrast, the study by Phelps and Smith for the Rand Corporation concluded that there was little effect on domestic prices. This conclusion is based on the assumption that the U.S. was a price taker in world refined product markets and that there was a perfectly elastic supply curve for these products. The entitlements program increased U.S. supply and displaced foreign exports to this country, but left product prices unchanged. One major problem with this approach is the lack of an explanation concerning why our production would displace foreign production if our products were no cheaper.

Kalt also investigated the effects on refined product prices. In a model that assumes less than infinite supply elasticities for either the U.S. or foreign market, he concludes that the U.S. entitlements program may well have affected refined product prices. Indeed, for petrochemical feedstocks, he finds the reduction in price as a

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* Most studies investigated the effects on gasoline, heating oil, and kerosene, etc., or other products of high relative value. Few, if any, were concerned with individual petrochemical feedstocks or particular petrochemicals as is our study.

percentage of the entitlements subsidy of almost 75 percent in the long run.*

The Entitlements Program--Graphical Approach

The first effect of entitlements is on the crude oil market. The entitlements program increased the demand for crude oil by U.S. refiners. This could have increased world demand by a significant amount (in 1979, U.S. consumption as a proportion of total world consumption was almost 31 percent). Figure 5 shows the shift in world demand from D to D' and in the price of crude to P'_w. The extent of the price rise depends upon the elasticity of the supply curve--the smaller the elasticity, the greater the increase in price.

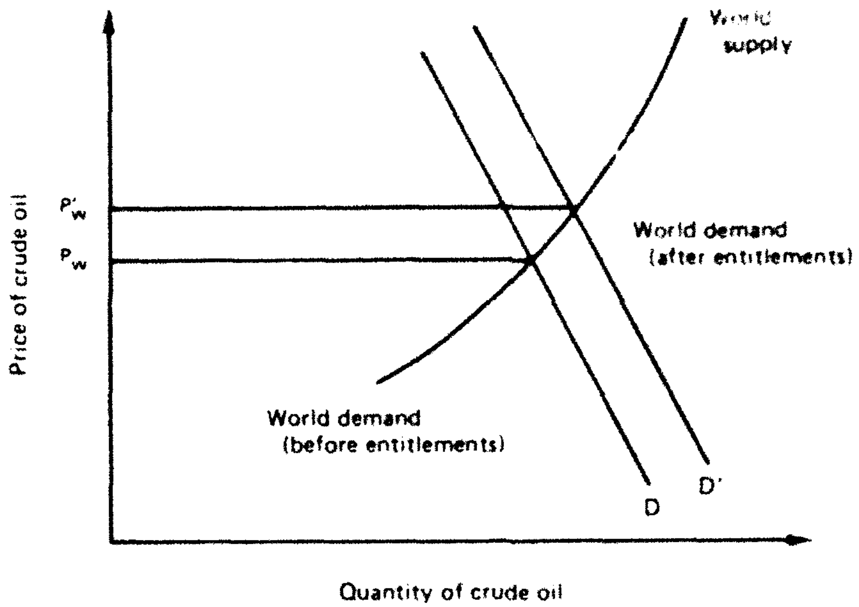

FIG. 5: THE WORLD CRUDE OIL MARKET

* This is assuming that because entitlements were not provided for oil used in products to be exported, the U.S. was removed as a participant in world markets. This really pertains to very early stage petrochemical feedstocks like naphtha.

Because crude oil is an input used in the production of petrochemicals, the change in its price will shift the supply curve of petrochemicals. Figure 6 shows supply and demand for petrochemicals under the assumption that the U.S. is a net exporter of petrochemicals.* In the absence of any controls and entitlements, the supply curves for refined products in the U.S., foreign, and world as a whole are given by $S_{U.S.}$, S_f, and S, respectively. The world price for these products is given by P_y (above the autarkic U.S. price and below the autarkic foreign price). U.S. exports to the rest of the world (= to foreign imports) are given by A(=B).

Now consider the situation in the presence of the entitlements program. The program decreases the price of crude to U.S. refiners but leads to increases in the price paid by foreign refiners. The U.S. supply curve shifts to $S'_{U.S.}$, foreign supply shifts to S'_f, and the total world supply expands to S'. The world price falls to P'_y. These changes in the refined product market mean that U.S. production has expanded and foreign production has fallen. We export more abroad (U.S. quantity demanded increases due to the lower price but not by as much as production), which is equal to foreign imports (given by B' and equal to A'). In sum, the entitlements program increased the output of our refiners and decreased the production of foreign refiners.

* The analysis where the U.S. is a net importer of petrochemicals is similar. If the entitlements program succeeds in reducing crude oil prices to the average U.S. refiner, our supply curve will shift and displace European production.

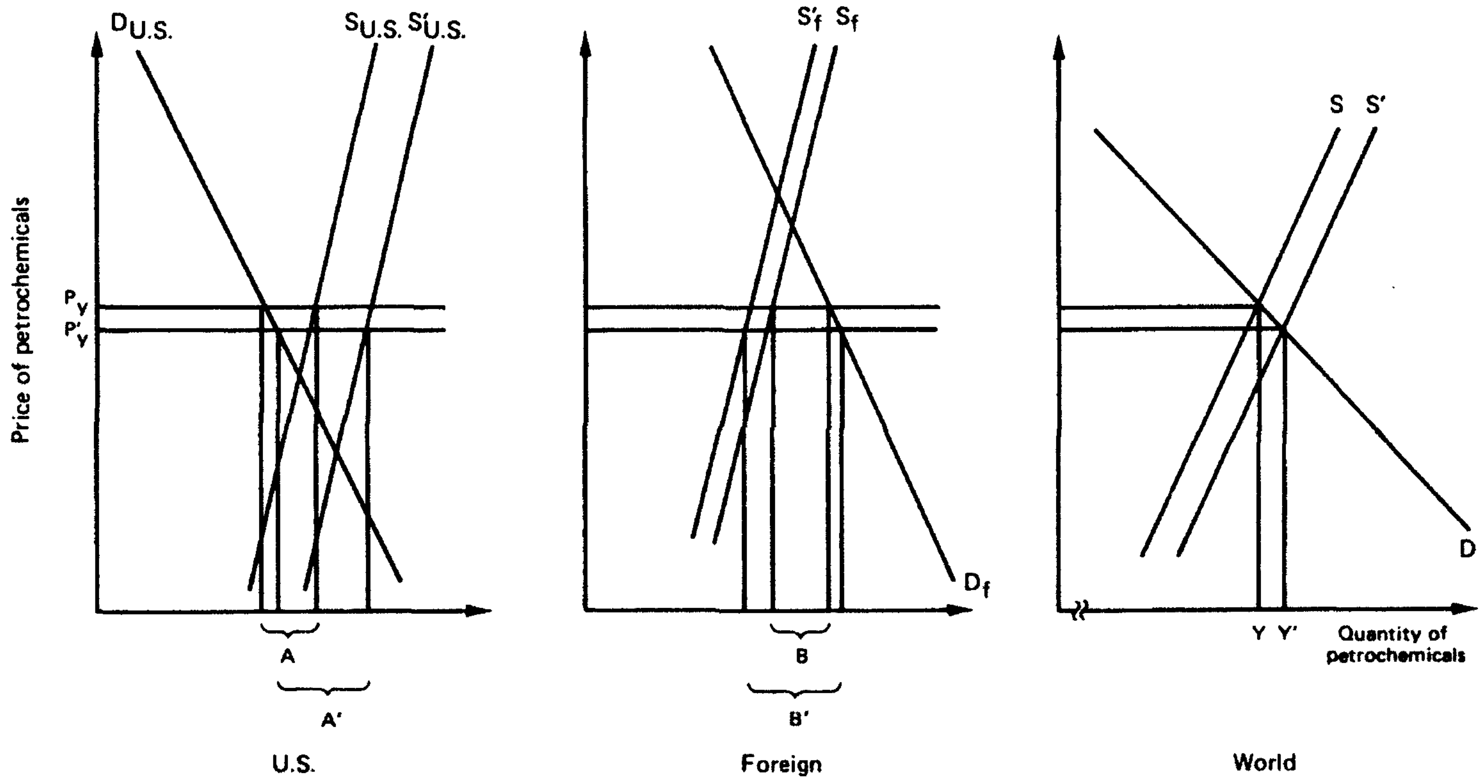

FIG. 6: THE U.S., FOREIGN, AND WORLD PETROCHEMICAL MARKETS

THE EFFECTS OF NATURAL GAS REGULATION

REGULATION OF NATURAL GAS

Natural gas regulation began with the passage of the Natural Gas Act of 1938 (NGA). The NGA gave the Federal Power Commission (FPC) the authority to regulate interstate pipeline rates and the terms and conditions of sale. The law exempted the production and gathering of natural gas from federal regulation, but in 1954, the U.S. Supreme Court interpreted the NGA to require FPC regulation of wellhead gas prices delivered into interstate markets.

At the same time there was an FPC regulated interstate market, there existed intrastate markets that were not subject to FPC jurisdiction (since the gas never left the producing state). During the late 1960s and early-to-mid-1970s, prices in those markets rose relative to the interstate market.* For producers, the unregulated intrastate markets were more attractive because, once reserves were committed to the interstate market, they had to remain there. Even if production from a well ceased temporarily, as soon as it resumed production, the gas was committed to the interstate market at FPC-regulated prices.

Not surprisingly, by late 1972, shortages occurred in the interstate market. The FPC realized its cost-oriented pricing regulations were a direct cause of the shortages and attempted to alleviate them by allowing higher gas prices through the issuance of Opinions 770 and 770-A. For post-January 1975 gas, the base rate was raised to $1.42 per mcf (thousand cubic feet), a 173-percent increase over the base rate established by the Commission in a prior area rate proceeding.

Though Opinions 770 and 770-A did move the interstate price closer to the intrastate price as well as to its true commodity value (as set by the price of energy alternatives), problems confronting the natural gas market remained. The next major regulatory development, the Natural Gas Policy Act of 1978 (NGPA), was intended to provide incentives for new production through higher prices while preventing sharply higher increases in prices for gas already in production. Table 4 presents the provisions of the NGPA, the provisions being classified into three major regulatory categories: supply incentives, consumer protection, and the intrastate market. The main effects of the act were:

- It immediately deregulated so-called "high-cost" gas (e.g., gas produced from fields 15,000 feet below the surface).

* This has changed in the more recent period, as we shall see later in the paper.

TABLE 4

OVERVIEW OF THE NATURAL GAS POLICY ACT OF 1978

Sections	Description	Price escalation formula	Status as of 1/1/85
Supply incentives			
102	New natural gas outside existing fields; new reservoirs; new outer continental shelf fields	Inflation real growth premium	Deregulated
103	New onshore wells within existing fields	Inflation	Deregulated
107	High-cost gas	Deregulated immediately	Deregulated
108	Stripper wells	Same as 102	Regulated
Consumer protection			
104	Interstate gas	Same as 103	Regulated
106a	Renegotiated interstate	Same as 103	Regulated
109	All other gas	Same as 103	Regulated
Intrastate market			
105	Intrastate gas	Tied to new gas prices	Deregulated
106b	Renegotiated intrastate contracts	Same as 103	Deregulated if contract price is greater than $1.00 per thousand cubic feet

Source: Congressional Budg· Office [4], p. 46.

- It controlled intrastate gas, tying price increases to those of new gas; both categories would be decontrolled as of 1-1-85.

- It allowed the price of interstate gas to rise at the rate of inflation; the price would remain regulated even beyond 1985.

A typical interstate customer (industrial, residential, or utility) draws upon gas arriving by pipeline after different vintages of gas have been mixed. The price paid by the consumer is a weighted average of the prices specified in different long-term contracts. Some of the gas is priced at or near oil prices, and some is priced far below oil prices.* The marginal price is therefore an average price and will only approximate oil prices if the greatest proportion of gas is priced near oil. Table 5 presents some Department of Energy estimates of the volume and average cost of the different gas categories.

An important feature of the NGPA was that it blurred the distinction between interstate and intrastate markets. New gas produced and sold to the pipelines, including interstate sales, could be priced at much higher levels than the old gas that was still rigidly controlled. As the cheaper old gas became proportionately less of the pipeline's total volume, the price could rise rapidly.

Though there are other regulations that potentially may affect the price of gas (e.g., the Power Plant and Industrial Fuel Use Act of 1977, which more or less prohibited utilities from building new gas-fueled power plants), the major regulatory actions have been outlined above. The next section begins the analysis of the effects of these regulations.

ECONOMIC EFFECTS

As in oil, the central question concerning the regulatory effects was whether they shifted the U.S. supply of petrochemicals downward relative to world supply. There is no equivalent to the entitlements program for natural gas. For at least part of the relevant time period, however, the controls on gas had much the same effect on petrochemical supply--they encouraged U.S. production at the expense of foreign competitors.

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* In fact, some gas may be priced far above alternative fuels. Because of "take or pay" provisions in long-term contracts, the pipeline is obliged to pay for high-priced gas even if it doesn't want it under current market conditions.

TABLE 5

AVERAGE ACQUISITION COSTS FOR SELECTED INTERSTATE PIPELINES BY TYPE OF GAS (Late 1981)

	Volume[a] (billion cubic feet)	Percent of purchase[b]	Average cost (dollars per thousand cubic feet	Percent of total costs[b]
Old gas[c]	6,036	59	$1.21	34
New gas[d]	3,588	35	2.89	48
High-cost gas[e]	583	6	6.49	18
Total	10,207	100	2.10	100

Source: Department of Energy

[a]Volumes shown on an annualized basis.
[b]Percentages may not add to 100 because of independent rounding.
[c]Gas covered by NGPA Sections 104 and 106.
[d]Gas covered by NGPA Sections 102, 103, 108, and 109.
[e]Gas Covered by NGPA Section 107.

Consider a simple model of the markets for natural gas. There is a regulated (interstate) market and an unregulated (intrastate) market. For American producers, natural gas (methane) is the refined energy input in the production of urea (an ammonia-based fertilizer). Foreign producers, lacking natural gas, use an alternative--more expensive--energy input: naphtha or coal.* Furthermore, though gas is almost always bought on long-term contracts and it includes many differently priced categories, we summarize these prices by their average.

The Gas Market

Figures 7a and 7b illustrate the effects of controls on the natural gas market in the U.S. In the market before controls (figure 7a), there is a supply curve for gas and demand curves representing the intrastate market (D_a), the interstate market (D_i), and total demand ($D_a + D_i$). At equilibrium (where supply = total demand), the price is P^*, and the

* Though this is changing over time, these assumptions are not unreasonable. Almost all U.S. ammonia production is based on methane, and almost all European production is based on naphtha or coal.

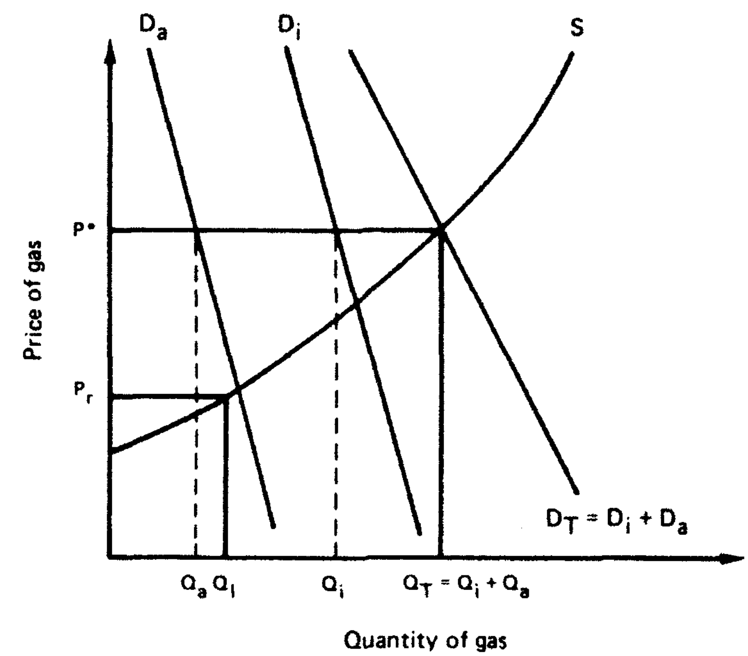

FIG. 7a: (BEFORE CONTROLS)

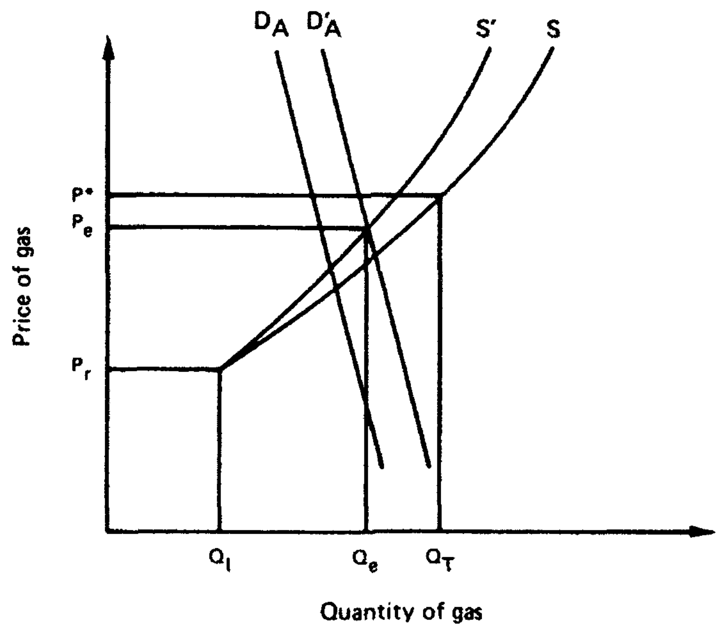

FIG. 7b: (AFTER CONTROLS)

FIG. 7: THE NATURAL GAS MARKET BEFORE AND AFTER CONTROLS

total quantity produced and sold is $Q_a + Q_i$, of which Q_a is sold in the intrastate market, and Q_i is sold in the interstate market.

Then, as shown in figure 7b, there is a price control placed on interstate sales of gas at price P_r. At this price, the quantity Q_I has been determined (by government regulations) as the amount that producers must sell. Producers would like to sell in the unregulated intrastate market but cannot. Supplies of gas from these producers would be cut back (assuming they had a nonzero supply elasticity before controls), and so the total supply curve becomes "kinked" beyond price P_r. This is analogous to the effects on the supply curve of domestic oil arising from the old oil price controls (see figure 3). As for the total demand for gas, this too will shift since it is made up of the quantity Q_I plus demand for gas in the intrastate market. Total demand is now given by D_A (= $Q_I + D_a$). To the extent that some of the unmet demand in the interstate market can move to the uncontrolled intrastate market (e.g., industrial users who can move their plants to Texas), demand would increase (from D_A to D_A'). The equilibrium point, representing the marginal unit in the gas market, is at price P_e and quantity Q_e (= $Q_I + Q_a$).

The Urea Market

The lower equilibrium price in the gas market affects the urea market in much the same way as the lower price for oil in the U.S. affected oil-based petrochemicals. In figure 8, the three graphs represent the supply of urea derived from natural gas (= U.S. urea supply), the supply from naphtha (= foreign urea supply), and the total world market. Note that the supply from naphtha has a higher intercept than the supply from methane since methane is the preferred feedstock.

We have represented two situations—before and after the control period on natural gas. The supply curve $S(P^*)$ represents the supply of urea when gas is uncontrolled and the equilibrium price of gas is P^* (as in 7a). Total supply is represented by $S_t(*)$, and world equilibrium of urea occurs at price P_1 and quantity Q_1. Of the total quantity produced and sold, G_1 is produced from natural gas and N_1 from naphtha.

The situation after controls begins with a lower price for gas and a downward shift in urea supply to $S(P_e)$. This leads to a shift in total supply to $S_t(e)$ and given the same demand curve for urea, a lower price P_2 and higher quantity produced Q_2. Of this higher total quantity, a larger proportion is produced from natural gas (G_2/Q_2), benefitting U.S. producers, and a smaller proportion is produced from naphtha (N_2/Q_2), hurting foreign producers.

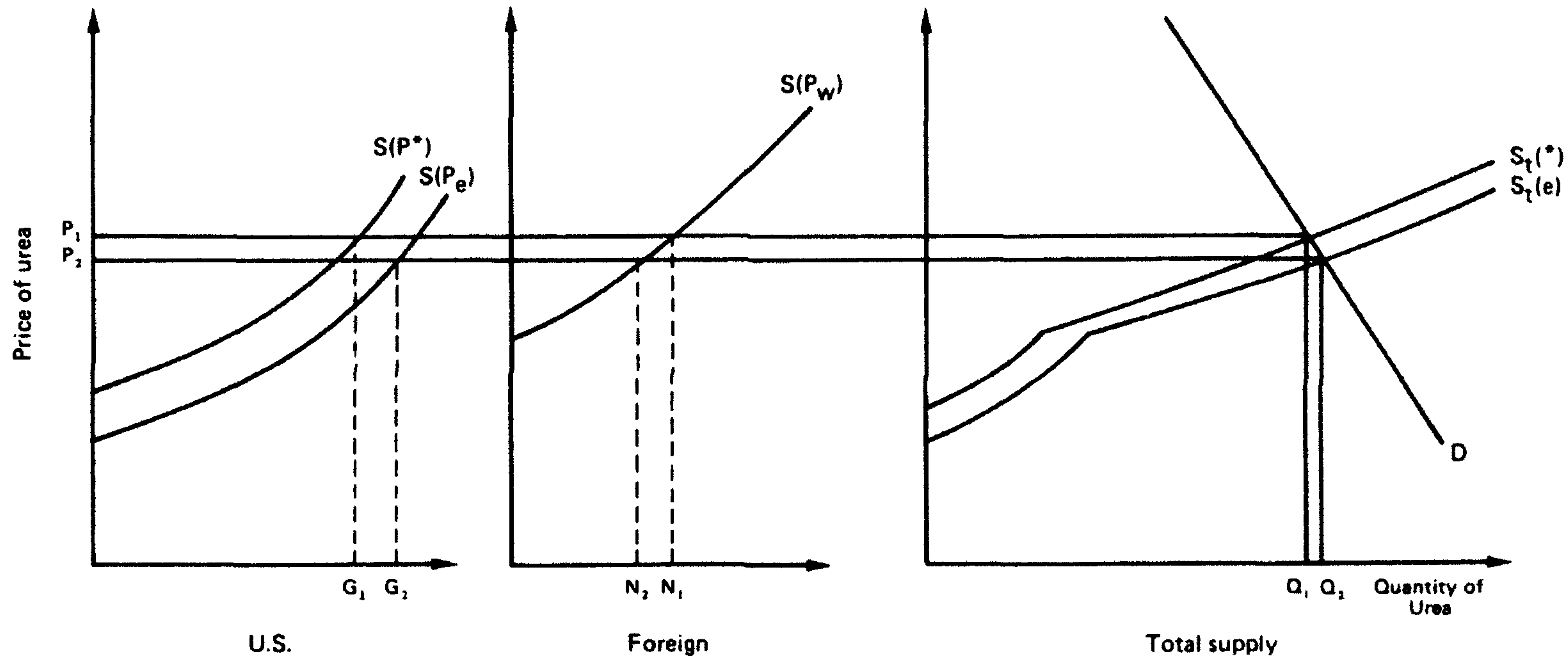

FIG. 8: THE UREA MARKET

The Markets After the NGPA

The situation was changed by the 1978 enactment of the NGPA, which allowed some increases in the interstate price (depending upon the type of gas sold in the pipeline) and imposed controls on the price of intrastate gas. The higher interstate price would increase supply there and thus increase overall gas supply.

The new price controls on the intrastate market, however, changed the nature of the equilibrium in the gas and urea markets. In figure 9a, we have assumed a controlled price for intrastate gas of P_R, which is above P_r (the controlled interstate price), but below the uncontrolled intrastate price P_e. At this controlled price, curtailments of gas supplies occur, and the quantity of gas falls from Q_e to Q_R. Alternative supplies of an input in urea production can be obtained from only deep gas and imported gas (each of which is totally uncontrolled) or some petroleum-based alternative, like naphtha. The "shadow price" of the gas becomes P_s, which is the price of gas corresponding to quantity demanded Q_R. It is a measure of the true value of natural gas in the control situation.

Figure 9b shows what happens to the urea market. Assuming some gas-based urea producers have their gas supplies curtailed, they must either cease production or use naphtha as their energy input. Let us assume, as before, that in the absence of regulation all U.S. producers use natural gas as their input and foreign producers use naphtha. The controls on natural gas cause a shift in the urea supply curve to $S(P_R)$ signifying the switch to the naphtha input. There is a higher equilibrium price for urea, but more importantly a decrease in production from Q_1 to Q_2 and an even larger decline in the proportion of urea made from natural gas.*

The controls on intrastate gas seemed to be binding only part of the time. When the NGPA was first passed, it did not seem to affect the intrastate price though it greatly increased drilling activity, based both on higher new gas prices for interstate gas as well as on the eventual decontrol for new gas in 1985. Then in 1979, the Iranian Revolution greatly increased crude oil prices. The resulting increase in gas demand may well have made the intrastate gas price controls binding. Since then, crude oil prices have fallen dramatically, and there now seems to be a surplus of natural gas (industrial users have been switching from gas to residual oil). Thus, our analysis of the post-NGPA market pertains to an equilibrium toward which the market tended only briefly.

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* To obtain the quantities made from each input, we could assume representative supply curves as we did in figure 8 and then read off the respective quantities for the new equilibrium price.

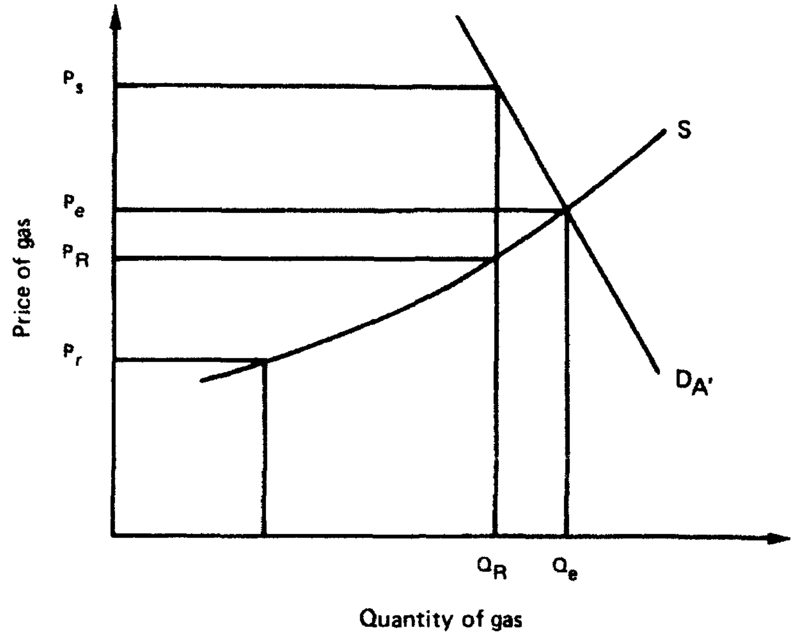

FIG. 9a: GAS MARKET

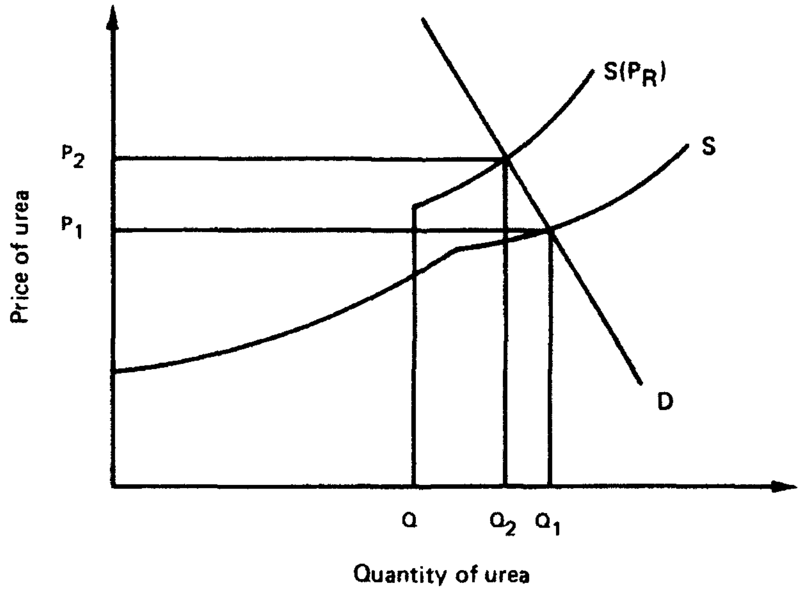

FIG. 9b: UREA MARKET

FIG. 9: THE GAS AND UREA MARKETS WHEN INTRASTATE CONTROLS ARE BINDING

REGULATION OF NATURAL GAS LIQUIDS

The natural gas liquids (NGLs) are important petrochemical feedstocks for primary petrochemicals like ethylene and propylene. Until the early 1970s, ethylene production was based on NGL feedstocks, primarily ethane and propane. Since 1973, almost all incremental U.S. ethylene capacity has been designed for naphtha and gas oil feed, a logical consequence of both gas and crude oil regulations.*

Regulations on natural gas affect the NGL markets by restricting the drilling of gas fields where NGLs are typically found. In figure 7b, the supply of methane was shown to fall to Q_e because of controls in the interstate market. The decrease in drilling activity and, consequently, supply causes a change in the NGL market. Specifically, the supply curve for NGLs becomes much more inelastic above the point corresponding to controlled supply for natural gas. The curtailment of gas supplies causes it to be more expensive to find and extract NGLs. This leads to a rise in the NGL price and a lower quantity demanded.

The NGLs and crude oil markets are related because they are substitute feedstocks for many petrochemicals. When the price of crude oil fell as a result of the entitlements program and the price of NGLs rose in response to gas regulations, there was a shift away from using NGLs as a feedstock.

This shift is shown in figure 10. We assume that before the imposition of any energy controls, NGLs were the preferred feedstock over some crude oil liquids--naphtha and gas oil. The original supply curves before energy regulations are $S_1(NGL) + S_1(0) = S_1$. The majority of supply is derived from NGL feedstocks. The controls, however, shift total supply to $S_2(NGL) + S_2(0) = S_2$. It is conceivable that the supply curves will cross (as drawn in the diagram) because the curves represent the supplies of olefins derived from NGLs and oil, respectively and shift in opposite directions. The price and total quantity of the petrochemical product has not changed very much, but feedstock use has shifted heavily against NGL feedstocks.

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* There is another regulatory policy concerning NGLs that we ignore. Like oil, propane's price was controlled until around 1980 when crude oil regulation was ended. The propane price controls were binding only occasionally during the 1970s, and so we do not attempt to measure the effects when they were.

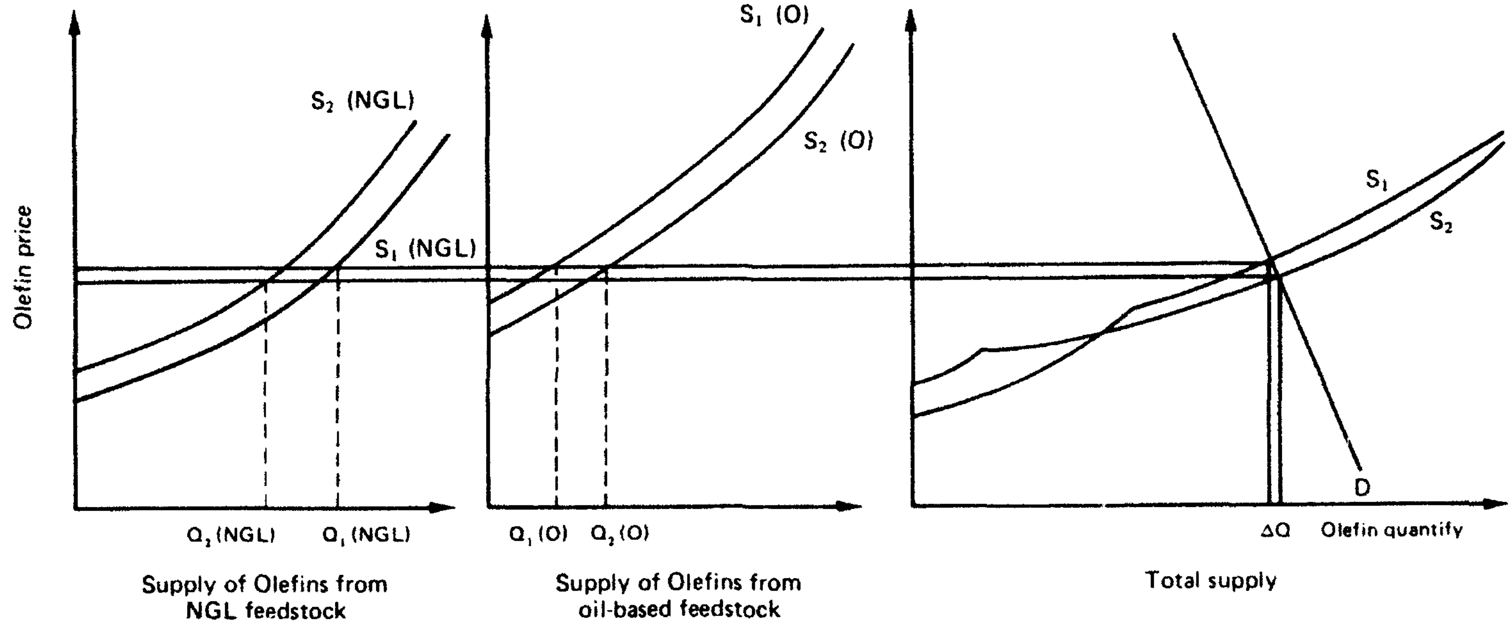

FIG. 10: THE OLEFIN MARKET

THE EFFECTS OF ENERGY REGULATIONS ON TRADE IN PETROCHEMICALS

Thus far, the analysis concerning the effects of energy controls on petrochemicals has been graphical. We need to translate the theory into mathematical models that allow us to measure the effects on U.S. and foreign production and price. We do this by developing equations representing the input and the output markets. The link between them is the price of oil or gas, inputs in the production of petrochemicals. Since the U.S. energy controls have created a differential between the U.S. and foreign energy input prices, we have conferred on our petrochemical producers a relative advantage in production. In the next few sections, we measure the extent of the advantage by determining how U.S. and foreign petrochemical markets would respond to alternative energy price changes.

The equations are developed fully in appendix B. We group oil-based petrochemical products into three major categories--primary, intermediate, and final petrochemicals. We analyze one natural gas-based petrochemical--urea, an ammonia-based fertilizer--and a representative primary petrochemical that uses natural gas liquids as an input.

THREE REPRESENTATIVE OIL-BASED PETROCHEMICALS

Having simulated the imposition of controls on crude, three separate runs of the model were made to find the effect of regulation on three markets--one representing a primary petrochemical (a cost share of crude oil of about 55 percent), one representing an intermediate petrochemical (40 percent cost share), and the last representing a final petrochemical (25 percent cost share). These three runs use as parameters the typical U.S. consumption and production in each category reported in table 3. The results are reported in table 6.

As expected, products having a higher cost share of oil are, in general, most affected by the controls. For primary petrochemicals, regulation increases U.S. production by about 4.8 percent and reduces foreign production by about 2.6 percent. World prices fall about 3 percent, so that total world demand rises by about 0.53 perc nt.

For intermediate and final petrochemical products, U.S. production increases by 2.4 percent and 2.1 percent, respectively, and prices fall by 4.5 percent and 1.4 percent, respectively. European production is reduced by 2.9 percent and 1.2 percent.

TABLE 6

RESPONSE OF ENDOGENOUS VARIABLES TO DECREASE IN P_c OF 55 PERCENT

Endogenous variable	Percent change in: Primary petrochemicals	Intermediate petrochemicals	Final petrochemicals
U.S. petrochemical demand	0.53	0.81	0.25
Foreign petrochemical demand	0.53	0.81	0.25
U.S. petrochemical supply	4.82	2.41	2.17
Foreign petrochemical supply	-2.57	-2.91	-1.20
Petrochemical price	-2.97	-4.51	-1.39
U.S. oil demand	15.80	13.81	13.39
Foreign oil demand	-4.29	-4.26	-3.10
U.S. oil supply	-7.87	-8.02	-7.85
Foreign oil supply	3.96	3.28	4.05
Old oil supply	-11.00	-11.00	-11.00
U.S. oil price	-22.93	-23.30	-22.88
World oil price	3.96	3.28	4.05

The estimated results for all three cases indicate large effects on the crude oil market. The U.S. price falls by about 23 percent. When this is coupled to an increase in the world price of about 4 percent, the difference between the price facing domestic and foreign refiners is about 27 percent.* The quantity of controlled oil produced in the U.S.

* The difference between $22.93 and $17.05 (the U.S. price after entitlements) is just over 26 percent, and so we seem to be simulating the market fairly well.

falls by 11 percent, but domestic demand for oil increases by between 13.4 and 15.8 percent. New oil supplies (uncontrolled domestic supplies) make up some of the difference, but imports must make up the rest (imports rise by almost 50 percent).*

Results With Alternative Parameters

Our study relies on the published literature for estimates of many of the elasticities. Though these seem to be the best available estimates, our conclusions might change if we used different estimates or assumptions. To better understand the implications of our model as well as the robustness of our solution values, we have solved the system under alternative assumptions concerning the elasticities of demand and supply of petrochemicals.

Table 7 provides solution values for a few selected endogenous variables in the intermediate petrochemicals model. The results assume a 40 percent crude oil share, representing the crude oil share of an intermediate petrochemical. We have solved the model for a number of alternative demand and supply elasticities. Originally, we assumed a demand elaticity (ε_y) equal to -0.18 and a supply elasticity (η_y) equal to 0.50. As our first comparison, we change these to $\varepsilon_y = -1.0$ and $\eta_y = 1.0$. The results differ in that U.S. output increases 6.25 percent while foreign production decreases by 4.4 percent.

The next four cases are informative in that they assume a wide range of elasticity estimates. Demand and supply elasticities range from .1 to 10 and so both very elastic and inelastic curves are simulated. The results have some interesting implications. If there is little competition in world markets so that U.S. and foreign producers essentially meet home demand, given at some (more or less) fixed amount, the effects are even less than those found earlier: U.S. producers supply a little more, foreign producers supply a bit less, and the total net change is just over 1 percent.

On the other hand, alternative assumptions can generate huge changes in the market for petrochemical products. Increasing the supply elasticity confers advantage in production (e.g., obtaining a cheap input) that translates into large relative changes in the amount supplied by U.S. producers. In one case ($\varepsilon_y = 10$, $\eta_y = 10$), the U.S.

* This is obtained from the relationship:

$$X_u^d = X_u^s + \left(X_u^d - X_u^s\right)$$

where X_u^d and X_u^s represent U.S. demand for and supply of oil, respectively, and Imports = $X_u^d - X_u^s$. The actual calculation is performed in terms of percentage changes (see appendices B and C, respectively, for the general approach and actual values of X_u^d and X_u^s).

production would rise by almost 65 percent, while foreign production would fall by over 36 percent. In effect, the entitlements program alone would have wiped out much of the U.S. producers' foreign competition.

TABLE 7

RESPONSE OF KEY ENDOGENOUS VARIABLES
UNDER ALTERNATIVE PARAMETER VALUES
(For an Intermediate Petrochemical)

$S_x = .40$		Percent change in U.S. petrochemical supply	Percent change in Foreign petrochemical supply	Percent change in Petrochemical price
$\varepsilon_y = -1.0$	$\eta_y = 1.0$	6.25	-4.40	-3.05
$= -0.1$	$= 0.1$	0.62	-0.46	-2.96
$= -0.1$	$= 10.0$	22.96	-49.90	-11.01
$= -10.0$	$= 0.1$	0.90	-0.18	-0.06
$= -10.0$	$= 10.0$	64.84	-36.31	-3.45

The supply elasticities needed to produce such large effects on relative production levels are extreme. For example, a supply elasticity of 10.0, coupled with a demand elasticity of 0.10 is associated with a fall in the petrochemical price of over 11 percent. This is an implausibly large price reduction, simply in response to a fall in one input price paid by certain producers. Perhaps even more implausible is the case where the demand and supply elasticities are -10.0 and 10.0, respectively. The increase in U.S. production of almost 65 percent would lead to an increase in crude oil demand of almost 71 percent.* Given a fall in U.S. oil production (because of the lower U.S. oil price), we calculate that crude oil imports would have to rise by almost 200 percent just to meet petrochemical demand. Since petrochemical production uses only a fraction of all U.S. oil consumption, increases of this magnitude do not seem possible. A more acceptable upper bound on demand and supply elasticities is -1.0 and 1.0, respectively (even these are twice the supply elasticity and over five times the demand elasticity used in table 7). The change in U.S. and foreign production is then about double those found earlier. We conclude, therefore, that

* See equation B-11 in appendix B for the relationship between changes in output supply and input demand.

an acceptable range for the advantage provided U.S. producers, given the parameters assumed for energy share, relative U.S. demand and supply share, etc., leads to a range of increased production of 2.4 percent to 6.25 percent, the lower end being more likely.

UREA

The Pre-NGPA Period

The values of parameters needed to simulate the urea market are similar to those needed for the oil-based petrochemical market: supply and demand elasticities, the relative share of U.S. production and consumption, and the share in total cost of the energy input--in this case natural gas. The values used are discussed in detail in appendix C.

One very important parameter is the change in the price of gas due to the regulations. These regulations have been around for a long time and have changed many times. In [19], Ott and Tatom estimate that decontrol will cause gas prices to rise by 9.3 to 27.5 percent, a wide range that certainly depends upon the time period and assumptions made concerning the supply of alternate energy inputs.

For simulation purposes, we have assumed that the regulations led to a decrease in marginal gas prices of 25 percent, a value at the upper end of their estimate. This was then used in our model of the pre-NGPA period when intrastate prices were uncontrolled and so the price in the intrastate market was the marginal price confronting a U.S. urea producer.

The results of the simulation are shown in table 8. Assuming a 36 percent gas share, the price of urea fell by just over 1 percent while consumption increased by just 0.2 percent. U.S. producers, who had access to a cheaper energy input, increased production by almost 4 percent while foreign production fell only marginally, by about 0.5 percent.

TABLE 8

RESPONSE OF ENDOGENOUS VARIABLES IN THE UREA MARKET
TO DECREASE IN GAS PRICE OF 25 PERCENT

Endogenous variable	Percent change
U.S. urea demand	0.20
Foreign urea demand	0.20
U.S. urea supply	3.97
Foreign urea supply	-0.48
Urea price	-1.06

The Post-NGPA Period

The results are different after the NGPA was passed in 1978. We assume that the new controls on intrastate gas were binding, as is likely in the 1979-80 period when oil prices increased sharply. The increase in oil prices would have naturally caused gas prices to rise as well, but controls on intrastate prices may well have stopped this causing curtailments of gas supplies to urea producers and others. The exact model is described in appendix B; for now, we describe the assumptions and results.

The controls are introduced as a forced decrease in the gas price of 25 percent below the uncontrolled equilibrium. This leads to decreased supplies of gas of 25 percent below equilibrium. Effects on other variables are presented in table 9. Urea prices rise by 1.64 percent, and demand falls by about 0.3 percent. U.S. urea production falls by almost 7 percent, of which only 0.74 percent is made up by foreign producers. The last item in the table, the shadow price, requires some explanation. The shadow price is the price that would lead to the reduced quantity of gas now demanded by users. In our case, the quantity demanded has decreased by 25 percent. The corresponding price of gas is almost 39 percent above the equilibrium value before the binding control was imposed. The conclusion is that U.S. gas users, including urea producers, are substantially hurt by the imposition of controls on an energy input.

TABLE 9

RESPONSE OF ENDOGENOUS VARIABLES IN THE UREA MARKET TO A BINDING CONTROL ON INTRASTATE PRICES

Variable	Percent change
U.S. urea demand	-0.30
Foreign urea demand	-0.30
U.S. urea supply	-6.78
Foreign urea supply	0.74
Urea price	1.64
Shadow price of gas	38.88

The Olefin Market with NGLs Included as Inputs

Incorporating the restrictions on supply of the NGLs means that the price of one possible input in the production of ethylene and of other olefins production will rise. Since there is little information concerning the actual effects of gas regulation in inhibiting supply, we will assume two different price increases--10 and 20 percent--to illustrate the expected effects in the petrochemical market. The regulations on oil benefit U.S. petrochemical producers, but the gas regulations raise the price of NGLs, hurting those U.S. producers who use them as an input.

Table 10 presents the simulation results. We now have two exogenous changes: the decrease in P_c of 55 percent (as before) and a change in P_b of either 10 or 20 percent. When the price of an NGL increases by 10 percent, we find that olefin production using NGLs falls by almost 3 percent. This means that, given a 6.2-percent increase in production of olefins due to crude oil controls, the net effect on U.S. olefin production is an increase of only 1.6 percent. This is smaller than the nearly 4.7-percent increase we reported in table 6 before we considered the effects of NGLs. The effect on foreign producers is also smaller. Their production falls by only 1.2 percent as opposed to the 2.7-percent drop earlier. Most of the decrease in the price of olefins has been negated as well; it falls by only 0.31 percent, compared to 3.3 percent earlier.

TABLE 10

RESPONSE OF ENDOGENOUS VARIABLES IN THE OLEFIN MARKET

	Percent change	
Variable	$P_b \uparrow$ 10%	$P_b \uparrow$ 20%
U. S. olefin demand	0.06	-0.11
Foreign olefin demand	0.06	-0.11
U.S. olefin supply derived from oil	6.16	6.61
U.S. olefin supply derived from NGL	-2.90	-5.19
Total U.S. olefin supply	1.63	0.71
Foreign olefin supply	-1.23	-0.78
Olefin price	-0.31	0.61

An increase in NGL prices of 20 percent almost entirely offsets the increased production due to U.S. oil regulations. Slightly more olefin production will use oil as the input, but much less comes from using NGLs. The increase in overall U.S. production is only 0.7 percent while foreign production decreases by 0.78 percent. The prices of olefins now rise despite the lower crude oil prices, and so the demand for olefins falls. The two types of energy controls have helped one type of U.S. olefin producer but hurt another with the overall advantage to U.S. production being greatly decreased.

CONCLUDING REMARKS

The U.S. controls program on domestic crude oil prices did have several important effects: It reduced the marginal price faced by U.S. refiners; it reduced the domestic supply of crude oil; and it increased the demand for imports. However, the effects on petrochemical prices and U.S. and foreign production levels appear to be much smaller. The results of our model for three petrochemicals indicate that the decrease in the crude oil price to domestic refiners had about a 5- to 10-percent effect on relative supplies. This assumes values of the U.S. and foreign elasticities of supply and demand used in other studies. Sensitivity analysis on these parameters illustrate, not unexpectedly, the importance of the supply elasticity in these calculations. But only when it is increased to implausible values do U.S. producers displace significant amounts of foreign production.

There are similar effects in the natural gas market. U.S. petrochemical producers of urea or other ammonia-based fertilizers had access to cheaper energy feedstocks, and so they were able to displace some foreign production. We found relatively small effects (i.e., U.S. production rose less than 4 percent) when prices were controlled only in the interstate market. Even this small effect could have been reversed in the post-1978 period if controls on intrastate prices were binding.

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APPENDIX A

MODELING THE ENTITLEMENTS PROGRAM FOR THE REPRESENTATIVE FIRM

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MODELING THE ENTITLEMENTS PROGRAM FOR THE REPRESENTATIVE FIRM

In the main body of this report, we analyzed the effect of the entitlements program on the aggregate domestic refining industry's demand for crude oil. It was shown that the effective price facing refiners was a weighted average of controlled and uncontrolled prices. Previous researchers have analyzed the program for the "representative" refiner. Though the models may all appear to differ, it turns out that they are essentially equivalent. To illustrate this, we will look at two of the models, by Cox and Wright (C - W) and Kalt.*

C - W define total cost as:

$$TC = p_m q_m + p_c q_c + p_\varepsilon q_c - p_\varepsilon q X_c / Q \tag{A-1}$$

where

p_m = uncontrolled (market) price of crude

p_c = controlled price of crude

p_ε = price paid for entitlement (= $p_m - p_c$)

q_c = quantity of old oil used by firm

q_m = quantity of uncontrolled oil used by firm

q = $q_c + q_m$ = total oil throughput (demand) by firm

X_c = total number of entitlements issued to all refiners and equal to total quantity of old oil supplies

Q = total crude oil throughput (demand) of the domestic refining industry.

* In all three cases, we are referring to the two-tier entitlements program. Though the program became more complicated, the general conclusions do not change very much.

The first two terms of (A-1) are the simple costs of controlled and uncontrolled oil. For controlled oil, however, the refiner had to pay p_ε to be able to refine it. At the same time, his allotment of entitlements was equal to $(q/Q)X_c$, also priced at p_ε, and so his entitlements reduced his total crude costs by the amount $p_\varepsilon(q/Q)X_c$. Since $q = q_c + q_m$, for the refiner to increase his throughput, regardless of whether it came from controlled or uncontrolled sources, his marginal cost for the additional amount is obtained by differentiating TC with respect to q, or

$$MC = p_m - p_\varepsilon \frac{X_c}{Q} . \qquad \text{(A-2)}$$

The expression $p_\varepsilon \frac{X_c}{Q}$ is greater than zero and so MC is less than p_m. Furthermore, if we substitute $p_m - p_c$ for p_ε and rearrange, we obtain

$$\begin{aligned} MC &= p_m - (p_m - p_c) \frac{X_c}{Q} \\ &= \left(1 - \frac{X_c}{Q}\right) p_m + \frac{X_c}{Q} p_c \quad . \end{aligned}$$

Thus, the marginal cost of crude oil is the same weighted average of the controlled and uncontrolled price as given by equation (2) in the text. Thus, the model in the text is equivalent to C - W. We now turn to the Kalt model.

The Kalt model defines total cost as follows:

$$TC = p_0 C_0^i + p_w C_w^i + (p_w - p_0)(a^i - A)\left(C_0^i + C_w^i\right) \qquad \text{(A-3)}$$

where the notation is related to C - W as follows:

Kalt		C - W
p_0	=	p_c
p_w	=	p_m

$$p_w - p_0 = p_\varepsilon$$

$$C_0^i = q_c$$

$$C_w^i = q_m$$

$$C_0^i + C_w^i = q$$

$$a^i = q_c/q$$

$$A^i = X_c/Q$$

The first two terms in (A-3) are the same as in (A-1). As for $(a^i - A)\left(C_0^i + C_w^i\right)$, it can be easily shown that it is equal to $q_c - qX_c/Q$ in the C - W terminology. Thus, all three models lead to equivalent U.S crude oil prices after accounting for the entitlements program.

APPENDIX B

THE EFFECT ON PETROCHEMICAL PRODUCTION AND PRICES: THE GENERAL EQUILIBRIUM MODEL

APPENDIX B

THE EFFECT ON PETROCHEMICAL PRODUCTION AND PRICES: THE GENERAL EQUILIBRIUM MODEL

In the following sections, we extend our analysis of the energy input and petrochemical markets by connecting the two markets in a simple general equilibrium system. For oil, the model is based on the graphical analysis and describes how a change in P_c, the controlled price, leads to changes in the output and input markets. We concentrate our discussion on a system describing the effects on a single aggregate petrochemical product Y. We will then turn to the equations for natural gas, the NGLs, and urea markets, specifying those equations that may differ from those for oil.

THE MODEL FOR A SINGLE AGGREGATE OIL-BASED PETROCHEMICAL

We begin with the market for petrochemical Y. Its demand (both foreign and domestic) is a function of its price P_y, or

$$Y^d = f(P_y),\ f' < 0 .$$

To determine how the variables in our system respond to changes in oil regulations, we take the total differential (in logarithmic terms) of the relevant equations, since this approximates a percentage change. Beginning with foreign demand, we would have

$$\begin{aligned} d\ln Y_f^d &= \frac{\partial \ln f}{\partial \ln P_y}\, d\ln P_y \qquad \text{(B-1)} \\ &= \varepsilon_y d\ln P_y \end{aligned}$$

where ε_y is the elasticity of demand for petrochemicals. Equation (B-1) relates percentage changes in foreign petrochemical demand to percentage changes in its price, the extent of the relationship being measured by the demand elasticity. A similar equation describes changes in domestic demand. Note that we are holding constant (i.e., not including a term for) variables that affect demand, such as GNP, but that are not affected by the changes in regulations that we are analyzing.

The cost function for producing Y turns out to be a useful starting point both for deriving the supply relationship for Y as well as the demand for inputs like crude oil. Cost is assumed to be a function of the level of Y and input prices. For foreign production, cost is represented by

$$C_f = C_f(Y_f, P_w, P_{zf}) \tag{B-2}$$

where

C_f = minimum cost of producing Y_f

P_{zf} = vector of prices of all other inputs used to produce Y_f.

For domestic production, we have

$$C_u = C_u(Y_u, P_e, P_{zu}) \quad . \tag{B-3}$$

Foreign output supply is derived from the marginal cost relationship, which is obtained by differentiating equation (B-2) with respect to Y_f, or

$$MC(Y_f, P_w, P_{zf}) = \frac{\partial C_f(Y_f, P_w, P_{zf})}{\partial Y_f} \quad . \tag{B-4}$$

Under marginal cost pricing, marginal cost is equal to the output price (equal in the two markets) and so the nondecreasing portion of the marginal cost curve is the supply curve.* Changes in supply are then obtained by differentiating equation (B-4):

$$d\ln MC = \frac{\partial \ln MC}{\partial \ln Y_f} d\ln Y_f + \frac{\partial \ln MC}{\partial \ln P_w} d\ln P_w \quad . \tag{B-5}$$

We need to obtain values for $\partial \ln MC/\partial \ln Y_f$ and $\partial \ln MC/\partial \ln P_w$. To do this, we write the marginal cost relationship in a slightly different form,

$$MC = \frac{C_f}{Y_f} V_{yf} \quad , \tag{B-6}$$

* Under constant returns to scale, MC (and supply) is perfectly horizontal. Thus, our definition of supply includes the possibility of horizontal supply curves.

where $V_{yf} = \partial \ln C_f / \partial \ln Y_f$ is a measure of returns to scale. First, we hold all exogenous variables but Y_f constant and differentiate, obtaining

$$\frac{\partial \ln MC}{\partial \ln Y_f} = \frac{\partial \ln C_f}{\partial \ln Y_f} - 1 + \frac{\partial \ln V_{yf}}{\partial \ln Y_f}$$

$$= V_{yf} - 1 + \frac{\partial \ln V_{yf}}{\partial \ln Y_f} \quad . \tag{B-7}$$

The interpretation of (B-7) is straightforward. It is the inverse of the supply elasticity (since $MC = P_y$) and shows how this elasticity depends upon the degree of scale economies and the change in scale economies arising from changes in output supplied. Under constant returns to scale, $V_{yf} = 1$ and $\partial \ln V_{yf} / \partial \ln Y_f = 0$. Then $\partial \ln MC / \partial \ln Y_f = 0$ and the supply elasticity would be infinite.

We do not want to assume that returns are constant. At the same time, we do not want scale economies dependent upon the level of output. A less restrictive assumption, but one that still leads to the independence of scale economies from output, is that the production technology is homogeneous. It turns out that this is also a useful assumption when we differentiate MC with respect to P_w (holding all other variables constant) and obtain

$$\frac{\partial \ln MC}{\partial \ln P_w} = \frac{\partial \ln C_f}{\partial \ln P_w} + \frac{\partial \ln V_y}{\partial \ln P_w}$$

$$= S_{xf} + \frac{\partial \ln V_y}{\partial \ln P_w} \ . \tag{B-8}$$

The first term on the right-hand side (S_{xf}) is the cost share of crude oil in the total foreign production cost of petrochemicals, and the second term represents the degree to which scale is affected by changes in the price of oil. The latter is nonzero only when the cost function is nonhomothetic. For a single output, a homogeneous function is homothetic as well. This means that equation (B-5) may be rewritten as

$$dlnMC = (V_{yf} - 1)\ dlnY_f + S_{xf} dlnP_w \tag{B-9}$$

in the foreign market and

$$dlnMC = (V_{yu} - 1)\ dlnY_u + S_{xu} dlnP_e \tag{B-10}$$

in the domestic market.*

For equilibrium in the market for Y, we have the simple sum of the U.S. and foreign supply equal to world demand, or

$$Y_u^d + Y_f^d = Y_u^s + Y_f^s\ .$$

Differentiating this expression in the logarithmic form, we have

$$k_{uy} dlnY_u^d + k_{fy} dlnY_f^d = q_{uy} dlnY_u^s + q_{fy} dlnY_f^s \tag{B-11}$$

where

$$k_{uy} = Y_u^d / \left(Y_u^d + Y_f^d\right)$$

$$k_{fy} = 1 - k_{uy} = Y_f^d / \left(Y_u^d + Y_f^d\right)$$

$$q_{uy} = Y_u^s / \left(Y_u^s + Y_f^s\right)$$

$$q_{fy} = 1 - q_{uy} = Y_f^s / \left(Y_u^s + Y_f^s\right)\ .$$

This equation completes the output market for the single petrochemical product Y.

* It should be pointed out that the U.S. and foreign crude oil shares may differ both because of the production methods used, including different technologies, as well as the different input prices facing producers: Controlled prices in the U.S. and uncontrolled prices in the foreign market.

Turning to the crude oil market, we again make use of the cost function provided in equations (B-2) and (B-3). For the input market, differentiating the cost function with respect to the oil price yields the optimal quantity of oil demanded:*

$$X_f(Y_f, P_w, P_{zf}) = \frac{\partial C_f(Y_f, P_w, P_{zf})}{\partial P_w} \qquad \text{(B-12)}$$

and

$$X_u(Y_u, P_e, P_{zu}) = \frac{\partial C_u(Y_u, P_e, P_{zu})}{\partial P_e} \qquad \text{(B-13)}$$

Differentiating equations (B-12) and (B-13) leads to expressions for percentage changes in foreign and domestic crude demand:

$$d\ln X_f = \varepsilon_{xy} d\ln Y_f + \varepsilon_w d\ln P_w.^{**} \qquad \text{(B-14)}$$

and

$$d\ln X_u = \varepsilon_{xy} d\ln Y_u + \varepsilon_e d\ln P_e \qquad \text{(B-15)}$$

where

$$\varepsilon_{xy} = \partial \ln X/\partial \ln Y^{***}$$

$$\varepsilon_w = \partial \ln X_f/\partial \ln P_w$$

$$\varepsilon_e = \partial \ln X_u/\partial \ln P_e.$$

* This is Shephard's Lemma (see [3]).
** One pleasing characteristic of this equation is that we do not have to obtain specific parameters from other studies but instead can use elasticities, which are far easier to find in the economic literature.
*** The percentage change in the demand for crude oil is assumed to represent changes in total demand. Therefore, this elasticity is meant to represent the added use of oil when petrochemicals in the aggregate change, not just product Y.

For supply, there are also two components, U.S. and foreign, but because of U.S. price controls, the markets are somewhat different. First, for the foreign crude oil supply, we assume a simple relationship where supply depends positively on the world price, P_w, or

$$X_f^s = h(P_w), \quad h' > 0$$

and

$$d\ln X_f^s = \frac{\partial \ln h}{\partial \ln P_w} d\ln P_w$$

$$= \eta_{xf} d\ln P_w \qquad \text{(B-16)}$$

where η_{xf} is the elasticity (foreign) of supply for crude oil.

For the U.S. market, the supply curve was described earlier (see figure 3) as being composed of two components--old oil, dependent upon price P_c, and new oil, dependent upon price P_w. In functional notation, we have:

$$X_u^s = X_c(P_c) + X_n(P_w) = h(P_c, P_w) \; .$$

Differentiating and then rearranging leads to the following:

$$d\ln X_u^s = \frac{X_c}{X_u^s} \frac{\partial \ln X_c}{\partial \ln P_c} d\ln P_c + \frac{X_n}{X_u^s} \frac{\partial \ln X_n}{\partial \ln P_w} d\ln P_w \; . \qquad \text{(B-17)}$$

Substituting $\delta = X_c/X_u^s$, the proportion of total U.S. supplies from old oil, and denoting η_{cu} and η_{nu} for the supply elasticities of old and new oil, respectively, equation (B-17) may be rewritten as

$$d\ln X_u^s = \delta \eta_{cu} d\ln P_c + (1 - \delta) \, \eta_{nu} d\ln P_w \; . \qquad \text{(B-18)}$$

Equilibrium in the crude market equates demand and supply:

$$X_u^d + X_f^d = X_u^s + X_f^s$$

or in total differential form:

$$k_{ux}d\ln X_u^d + k_{fx}d\ln X_f^d = q_{ux}d\ln X_u^s + q_{fx}d\ln X_f^s \tag{B-19}$$

where

$$k_{ux} = X_u^d/\left(X_u^d + X_f^d\right)$$

$$k_{fx} = 1 - k_{ux}$$

$$q_{ux} = X_u^s/\left(X_u^s + X_f^s\right)$$

$$q_{fx} = 1 - q_{ux} \text{ .}$$

One equation that is crucial to the analysis has not yet been discussed. This is the equation relating changes in the controlled U.S. price to changes in the U.S. entitlements price and world price. To investigate the relationship of P_e, P_c, and P_w, we repeat equation (2) from the main text,

$$P_e = \left(1 - \frac{X_c}{X_u^d}\right)P_w + \frac{X_c}{X_u^d}P_c \text{ .}$$

This is differentiated and rearranged leading to equation (B-20):

$$d\ln P_e = \frac{P_w\left(X_u^d - X_c\right)}{P_eX_u^d}\,d\ln P_w + \frac{P_cX_c}{P_eX_u^d}\,d\ln P_c + \frac{\left(P_w - P_c\right)X_c}{P_eX_u^d}\left(d\ln X^d - d\ln X_c\right) \tag{B-20}$$

Equation (B-20) says that the change in the entitlements price is composed of changes in the world price, the controlled price, and the difference between changes in the demand and supply of crude, each of which is weighted by some proportion of the value of crude demanded. To provide the intuition behind equation (B-20) we refer to figure 4, which was used to describe the workings of the entitlements program and is repeated here in a slightly different form.

The weight on the first term, the percentage change in the world price, is $P_w\left(X_u^d - X_c\right)/P_e X_u^d$. The denominator, $P_e X_u^d$, is the same for all three terms. It is equal to the refiner's total costs of acquiring crude oil in the U.S. market.* It is given by boxes A + D + E in figure B-1. The numerator, $P_w\left(X_u^d - X_c\right)$, represents the value of oil in the U.S. market that came from uncontrolled sources. In other words, the quantity represents either imported oil or "new" U.S. oil, both of which command price P_w. It is given by boxes C + D.

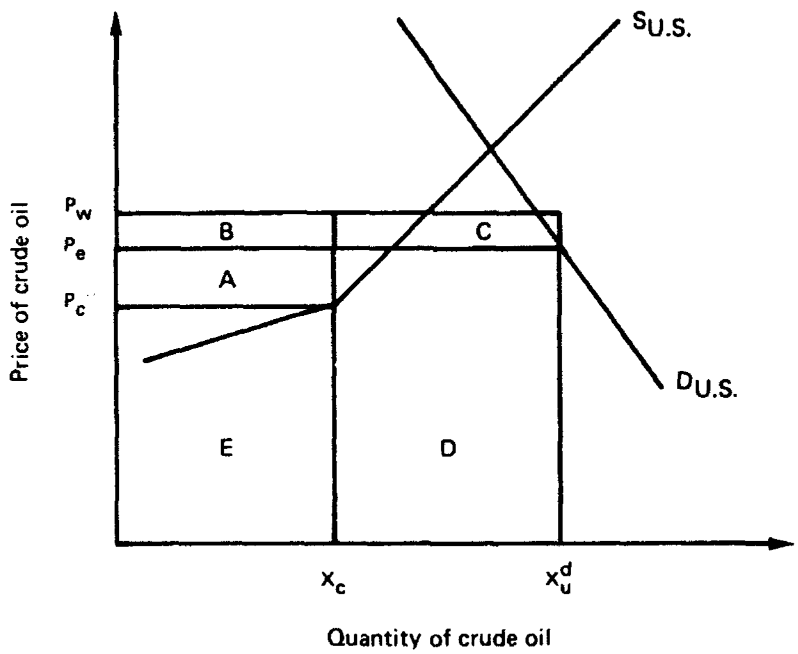

FIG. B-1: THE U.S. ENTITLEMENT PROGRAM

For the second term, which is the coefficient on the percentage change in the controlled price, the numerator, $P_c X_c$, represents the value of controlled (i.e., old) oil. It is given by box E.

* It is therefore also equivalent to revenue accruing to oil producers.

The third term may appear to be more complicated but was discussed earlier in the explanation of the entitlements program. When P_c changes and therefore changes P_e, both X_c and X_u^d change. The U.S. quantity supplied is dependent upon P_c, and the U.S. quantity demanded is dependent upon P_e. The weight on their percentage difference is equal to the quantity of controlled oil multiplied by the difference between the world price and the U.S. controlled price. It is equal to the implicit profits of petrochemical producers who were able to buy old oil at price P_c but which should have been valued at P_w. This is given by boxes A + B.

Rewriting equation (B-20) with the weights measured by our imaginary boxes, we have

$$d\ln P_e = \frac{C + D}{A + D + E} d\ln P_w + \frac{E}{A + D + E} d\ln P_c + \frac{A + B}{A + D + E} \left(d\ln X_u^d - d\ln X_c\right). \tag{B-21}$$

Notice that the weights do not add to one but rather to a value greater than one. Specifically, they add to the world price of oil relative to the entitlements price, P_w/P_e.

Equation (B-20) completes our system. Changes in P_c, the cause of the system moving off its steady-state path, affect P_e through equation (2), which then affects P_w through equations (B-15), (B-17), and (B-20). As the system settles down to a new steady-state equilibrium, the endogenous variables will approach a new equilibrium. We measure the difference in these equilibrium levels resulting from the regulations.

Summary Of The Model

We can summarize the system in 12 equations. They are repeated below for convenience:

(a) $d\ln Y_f^d = \varepsilon_{yf} d\ln P_y$

(b) $d\ln Y_u^d = \varepsilon_{yu} d\ln P_y$

(c) $d\ln P_y = (V_{yf} - 1)\, d\ln Y_f^s + S_{xf} d\ln P_w$

(d) $d\ln P_y = (V_{yu} - 1)\, d\ln Y_u^s + S_{xu} d\ln P_e$

(e) $k_{uy} d\ln Y_u^d + k_{fy} d\ln Y_f^d = q_{uy} d\ln Y_u^s + q_{fy} d\ln Y_f^s$

(f) $d\ln X_f^d = \varepsilon_{xy} d\ln Y_f^s + \varepsilon_w d\ln P_w$

(g) $d\ln X_u^d = \varepsilon_{xy} d\ln Y_u^s + \varepsilon_e d\ln P_e$

(h) $d\ln X_f^s = \eta_{xf} d\ln P_w$

(i) $d\ln X_u^s = \delta\eta_{cu} d\ln P_c + (1 - \delta)\ \eta_{nu} d\ln P_w$

(j) $d\ln X_c = \eta_{cu} d\ln P_c$

(k) $k_{ux} d\ln X_u^d + k_{fx} d\ln X_f^d = q_{ux} d\ln X_u^s + q_{fx} d\ln X_f^s$

(l) $$d\ln P_e = P_w \frac{\left(X_u^d - X_c\right)}{P_e X_u^d} d\ln P_w + \frac{P_c X_c}{P_e X_u^d} d\ln P_c \quad .$$

THE MODEL FOR THE GAS-BASED UREA MARKET

Many of the equations used to describe the natural gas and urea markets are directly analogous to those of the previous section. There are some differences, however. In the urea market, we assume that foreign producers use naphtha as their energy feedstock, and so the world oil price continues to be the appropriate input price. In contrast, U.S. producers use natural gas as their energy input, an input whose regulations differ from those on oil. As we stated in the main text, the change in regulations from pre- to post-NGPA may have created two distinct sets of effects. The first is the situation with a controlled interstate market and an uncontrolled intrastate market. The marginal price of gas is the price in the intrastate market. Next, we model the situation in the post-NGPA period, where there are also controls on intrastate prices. We assume prices are forced below current prices, leading to curtailment of gas supplies.

Model I - The Pre-NGPA Period

We will begin with the cost functions for U.S. and foreign production of urea:

$$C_f = C_f(A_f, P_w, P_{zf}) \qquad \text{(B-22)}$$

where A_f = foreign production of urea, and

$$C_u = C_u(A_u, P_g, P_{zu}) \qquad \text{(B-23)}$$

where

A_u = U.S. production of urea

P_g = equilibrium price of gas. This is the price we will lower to simulate the actions of the regulations.

The change in price (marginal cost) is given by (see equations (B-9) and (B-10)):

$$d\ln P_A = (V_{af} - 1)\ d\ln A_f + S_{xf} d\ln P_w \tag{B-24}$$

and

$$d\ln P_A = (V_{au} - 1)\ d\ln A_u + S_{gu} d\ln P_g \tag{B-25}$$

for foreign and U.S. producers, respectively. S_{xf} and S_{gu} refer, respectively, to the cost share of naphtha and natural gas in foreign and U.S. urea costs. Other equations for the output market are similar in form to earlier equations for petrochemicals.

The final equation is an equilibrium relationship for the urea market and is given by

$$k_{uA} d\ln A_u^d + k_{fA}\ d\ln A_f^d = q_{uA}\ d\ln\ A_u^s + q_{fA}\ d\ln\ A_f^s \tag{B-26}$$

where

$$k_{uA} = A_u^d / \left(A_u^d + A_f^d\right)$$

$$k_{fA} = 1 - k_{uA}$$

$$q_{uA} = A_u^s / \left(A_u^s + A_f^s\right)$$

$$q_{fA} = 1 - q_{uA}.$$

Given an exogenous change in the market resulting from regulations imposed on gas, the system of equation may be solved. Unlike oil, we do not include the input (gas) market in the model since the change in price we assume has already incorporated the important changes that have occurred there. The equations summarizing the model for urea are:

(a) $d\ln A_f^d = \varepsilon_{Af} d\ln P_A$

(b) $d\ln A_u^d = \varepsilon_{Au} d\ln P_A$

(c) $d\ln P_A = (V_{Af} - 1)\, d\ln A_f^s + S_{xf} d\ln P_w$

(d) $d\ln P_A = (V_{Au} - 1) d\ln A_u^s + S_{gu} d\ln P_e$

(e) $k_{uA} d\ln A_u^d + k_{fA} d\ln A_f^d = q_{uA} d\ln A_u^s + q_{fA} d\ln A_f^s$.

Model II--the Post-NGPA Period

To model the period after the NGPA, we assume that intrastate controls are binding and so all U.S. producers cease production beyond some specified quantity (given by $\bar{Q}$ in figure 9b). As shown earlier, the controls benefit foreign producers who gain at the expense of U.S. producers.

This becomes a more complicated situation to model since we have a constrained system. Earlier, we said that before the controls were imposed on the intrastate market, U.S. urea producers were producing Q_1 units of urea at the world market price P_1. After the controls caused a curtailment of gas supplies, U.S. urea production decreased to $\bar{Q}$ at which point the supply elasticity becomes zero (increased supplies of urea can be produced only by foreign producers). The price rises to P_2, and so U.S. urea producers who are able to get the gas make large windfall profits, but many others are forced out of business.*

We will approximate this constrained system by proceeding in stages. First, we approximate the curtailment in gas supplies by lowering the gas price by $P_e - P_R$ (see figure 9a), which together with the positive supply elasticity yields a negative value for $d\ln G_u^s$. Changes in demand must equal changes in supply so that there is less demanded as well. In our system, this really means that less urea is produced and/or the price of gas rises (reflecting the shadow price due to the control). We would expect both to occur once we solve the system. Thus, we begin with an exogenous change in P_g, obtain $d\ln G_u^s$, which is equal to $d\ln G_u^d$, and then solve for the change in P_s (the shadow price), A_u^s, A_f^s, and other endogenous variables.

* This is similar to the situation for oil before the entitlements program. Refiners with access to controlled old oil reaped large profits.

THE MODEL WHEN NGLS ARE INCLUDED

The natural gas liquids are an alternative input for some oil-based petrochemical products. The regulations on oil and gas affect relative input prices (i.e., NGLs versus oil), which change the composition of U.S. supplies derived from each input. The effect on world markets depends upon the position of the total U.S. supply curve.

In our model, we will assume that only U.S. producers use NGLs as feedstock inputs and that there is a higher marginal price due to regulations on natural gas. As we have shown graphically, this should negate some of the benefits occurring to U.S. petrochemical producers from regulations on crude oil.

We include NGLs by specifying a separate cost function for petrochemical Y_u where one of the inputs is an NGL like butane (denoted by b), or

$$C_u^b = C_u^b(Y_{ub}, P_b, P_{zu}) \qquad \text{(B-27)}$$

where Y_{ub} = production of Y_u using butane

P_b = price of butane.

As before, we obtain the change in petrochemical Y's price as

$$d\ln P_y = (V_{yu} - 1)\, d\ln Y_{ub}^s + S_b d\ln P_b \;. \qquad \text{(B-28)}$$

This means there are three equations representing the equivalent change in output price (the other two corresponsing to U.S. and foreign producers who use oil as their input).

For the total U.S. supply of Y, some portion is made from oil and some from butane, or

$$Y^s = Y_{ub}^s + Y_{ux}^s$$

The change in total U.S. supply is given by the following equation:

$$d\ln Y_u^s = \frac{Y_{ub}^s}{Y_{ub}^s + Y_{ux}^s} d\ln Y_{ub}^s + \frac{Y_{us}^s}{Y_{ub}^s + Y_{ux}^s} d\ln Y_{ux}^s . \qquad (B\text{-}29)$$

The complete model for petrochemical Y would therefore have two exogenous changes occurring simultaneously. First, a higher price for butane results from gas regulations. Second, the entitlements program lowers the price of oil from an equilibrium world price to the entitlements price. Solving the model will yield new values for the endogenous variables, including the change in relative output supplied and output price.

APPENDIX C

QUANTITIES AND ELASTICITIES USED IN OUR MODEL

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QUANTITIES AND ELASTICITIES USED IN OUR MODEL

The model we have developed needs a number of variables and elasticities as inputs if we are to solve for values of the endogenous variables. We report on these variables and elasticities in this appendix.* Some are constant across all products (e.g., values for crude oil quantities and prices and certain elasticities) while others are not (e.g., world production of individual petrochemicals). This section provides the numbers we have used.

We begin with the values for U.S. crude oil prices. From data in Kalt, we calculated the U.S. controlled price (P_c) as a weighted average of lower tier (P_0), upper tier (P_u), and Alaskan oil prices (P_a):

$$P_c = .365\ P_o + .44\ P_u + .195\ P_a$$

$$= .365(\$5.95) + .44(\$13.20) + .195(\$10.57)$$

$$= \$10.04$$

where the weights were the shares of domestic production. The stripper price was used as the measure of world uncontrolled prices and was equal to $22.93 in 1979.

The quantity of U.S. oil supplied and demanded was obtained from the <u>Statistical Abstract</u>, and world production was obtained from the <u>International Petroleum Encyclopedia</u>. Total domestic production was equal to 3,121,480,000 barrels of which 79.1 percent came from controlled sources (Kalt). Apparent consumption (= production + inputs - exports) was equal to 5,415,140,000 barrels. Assuming total world consumption was equal to world production, we could then infer values for foreign production and consumption. Specifically, the values used in the calculation were:

$$X_c = 2{,}469{,}090{,}600 \text{ barrels}$$

$$X_f^d = 12{,}268{,}380{,}000$$

$$X_f^s = 14{,}562{,}040{,}000.$$

From equation (2), we could also determine that the U.S. price of crude oil was equal to $17.05.

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* All quantities provided are 1979 values.

The exogenous variable in our oil-based petrochemical model is a change in the price of controlled crude oil. We describe the effect of controls by measuring the effects of introducing the old oil controls (with entitlements) on a market that was initially free from controls of any kind. Where base periods are required for the calculation, we use actual 1979 values for production, consumption, and prices.

For example, before the control program was begun, all three oil prices in our system were equal (i.e., $P_c = P_w = P_e$). Putting the control program in place means that equation (B-15) should be written as

$$d\ln P_e = \left(\frac{X_u^d - X_c}{X_u^d}\right) d\ln P_w + \frac{X_c}{X_u^d}\, d\ln P_c$$

where in 1979, X_c/X_u^d was about .456. Though we do not adjust the ratio, we do adjust the world price of crude, which in 1979 was $22.93 per barrel. In our model, the U.S. controls can affect the world market price of crude. This means the observed uncontrolled price may be higher than it would have been in the absence of controls. Based on some preliminary runs of the model, we therefore adjusted it downward by approximately 4 percent to $22.00. This, in turn, implies that $d\ln P_c$ should be equal to about -.55 (a decrease in the oil price from $22.00 to $10.04).

The quantities of U.S. production of petrochemicals came from the ITC (International Trade Commission). These were given in table 2 of the text as were exports and imports (from the Commerce Department). Foreign production is difficult to obtain and our figures must be considered approximate. At the same time, the ratio of U.S. to total consumption and production is used in our model, and small differences probably do not matter very much. Quantities and sources were given in tables 2, 3, and 4 of the text. As representative values for the primary, intermediate, and final petrochemical, we have used the following numbers (table C-1), all drawn from [13].

The share of energy input cost as a proportion of total cost is an important variable and one that is difficult to obtain. For the oil-based petrochemicals (including those made from NGLs), we have indicated how we grouped them into the primary, intermediate, and final petrochemical categories. Chemsystems, a subcontractor on the project, provided estimates of the cost shares for each grouping. They felt ranges of 50 to 60 percent, 30 to 45 percent, and 20 to 30 percent were appropriate, respectively, and so we used 55, 40, and 25 percent in our models. For urea, we used a 36 percent energy (natural gas) share. This was obtained by the energy cost share of ammonia being about 60 percent (in 1979) and urea being about 60 percent ammonia.

Finally, for the necessary elasticities, table C-2 reports the values and sources that we used in our calculations.

TABLE C-1

PROPORTION OF U.S. CONSUMPTION AND PRODUCTION FOR VARIOUS PETROCHEMICALS

	U.S. apparent consumption (%)	U.S. production %
Primary petrochemical	.43	.42
Intermediate petrochemical	.65	.70
Final petrochemical	.35	.43
Urea	.12	.15

TABLE C-2

PARAMETERS AND ELASTICITIES USED IN THE MODEL

Elasticity	Value	Source
ε_{yu}[a]	-0.18	Kalt, p. 151
ε_{yf}	-0.18	Same as domestic value
V_{yu}[b]	3.00	Kalt, p. 151
V_{yf}	3.00	Same as domestic value
ε_{xy}	0.90	Estimate
ε_{e}	-0.50	Kalt, p. 190
ε_{w}	-0.50	Same as domestic value
η_{cu}	0.20	Kalt, p. 97
η_{nu}	1.00	Kalt, pp. 97-98, 204
η_{xf}	1.00	Same as domestic new oil

[a]Value provided for the product "petrochemical feedstock."
[b]Calculated from value provided for the long-run supply elasticity of petrochemical feedstock.

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