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Economic Review

Federal Reserve Bank of Dallas
March 1986

Appreciation of the U.S. dollar contributed to downward pressure on the dollar price of oil during the first half of the 1980s. An econometric and simulation analysis suggests that had the dollar maintained its real 1980 value through fourth quarter 1984, the real dollar price of oil would have been more than 25 percent higher. The increase in the value of the dollar increased the foreign price of oil, contributing to decreased foreign demand and increased foreign supply. These changes in foreign demand and supply added to downward pressure on the dollar price of oil during the first half of the 1980s.

State government programs designed to increase employment will have greater success by encouraging high-technology equipment manufacturing rather than the manufacture of other types of producers' durable equipment. Because of the labor-intensive nature of manufacturing high-technology equipment, an expansion in this industry will produce a greater increase in employment than would an equal expansion in other capital goods industries. The average high-technology job, however, requires little skill and pays a relatively low wage. As a result, income gains will be less than employment gains.

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Exchange Rates and World Oil Prices

Stephen P. A. Brown

Senior Economist
Federal Reserve Bank of Dallas

Keith R. Phillips

Economic Analyst
Federal Reserve Bank of Dallas

Introduction

From fourth quarter 1980 through the end of 1984, the value of the U.S. dollar rose dramatically while real dollar prices of oil fell nearly as sharply (see Chart 1). Because world oil prices are denominated in dollars, appreciation of the dollar during this period likely contributed to the decline in world oil prices. The appreciation of the dollar increased the foreign price of oil, which decreased foreign demand and increased foreign supply, thus putting downward pressure on the dollar price of oil.[1]

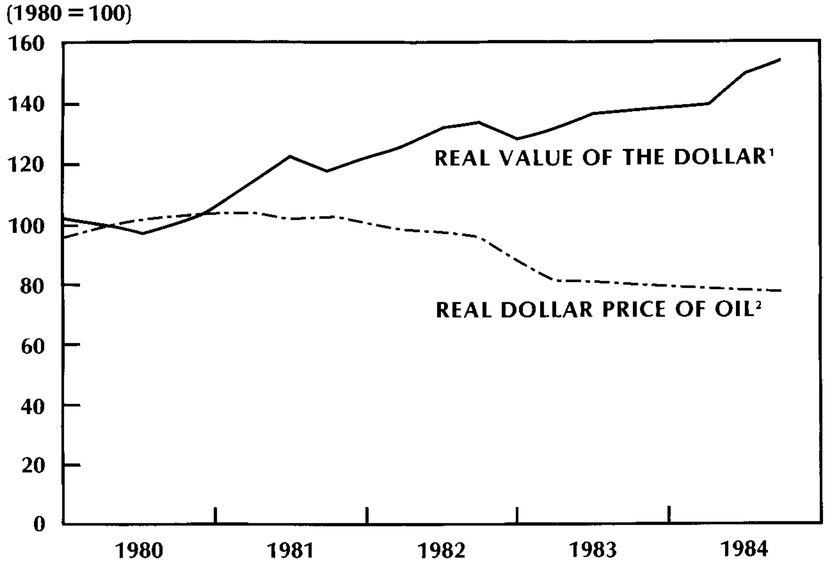
An econometric model was used to estimate the relationship between movements in the foreign value of the dollar and those in the official dollar price of Mideastern light crude oil. This estimated relationship was used in a simulation analysis to calculate the impact of recent exchange rate movements on the price of oil. In the analysis, the value of the dollar was held constant at its 1980 level through 1984. This simulated price of oil was then compared to the actual price of oil during the period.

Regression results showed that the official dollar price of Mideastern light crude has a strong and statistically significant response to changes in the foreign value of the dollar. Furthermore, the simulation suggested that the sharp appreciation of the dollar between 1980 and 1984 had a considerable impact on the dollar price of oil. Had the dollar maintained its 1980 value and not appreciated against foreign currencies, the real dollar price of oil might have been more than 25 percent higher in fourth quarter 1984.

Exchange rate movements and the world oil market

The historical record. During the 1981-84 period, the value of the U.S. dollar generally rose against other currencies. As is shown in Chart 2, appreciation of the dollar had a dramatic impact on the real prices for oil that other countries faced. In fact, for consumers in West Germany, France, the United Kingdom, and Italy, exchange rate movements more than offset declines in the dollar price of oil, causing the price paid for oil to be greater in the fourth quarter of 1984 than in the same period for 1980. For the six non-Communist countries other than the United States that consume the most oil—Canada,

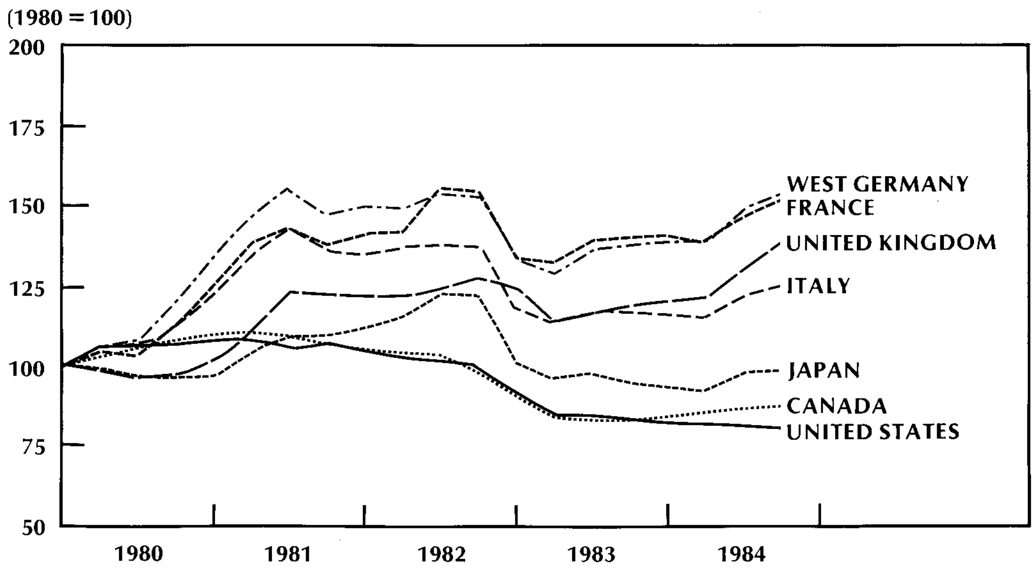
Chart 1
The Value of the Dollar and the Price of Oil



1. Weighted by oil consumption in big seven countries, excluding the United States.
2. Official price for Mideastern light crude oil, adjusted for inflation.

SOURCES OF PRIMARY DATA: International Monetary Fund.
U.S. Department of Energy.
Petroleum Intelligence Weekly.

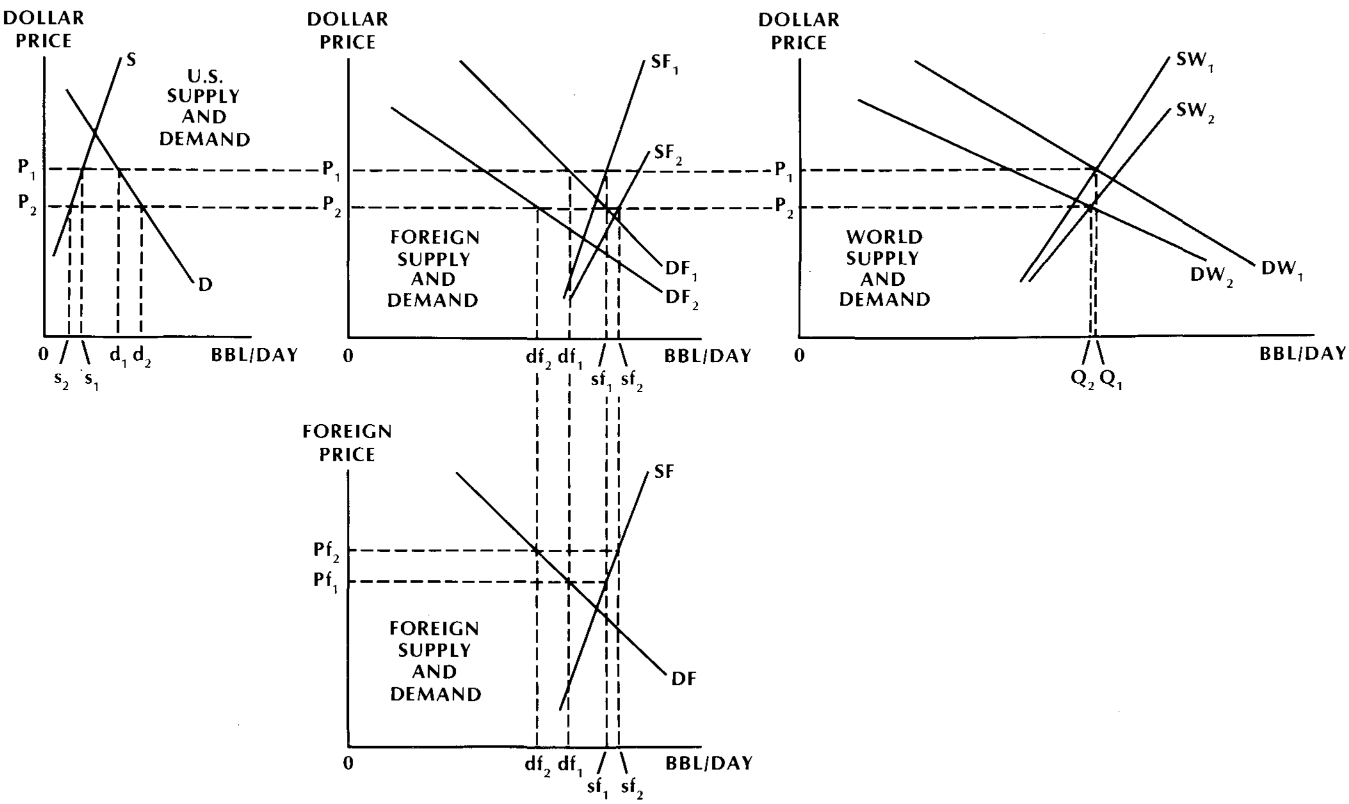
Chart 2
Real Foreign Oil Prices



NOTE: Each entry is the official price of Mideastern light crude oil, converted to each country's currency and then deflated with that country's implicit price deflator for the appropriate period.

SOURCES OF PRIMARY DATA: International Monetary Fund.
Petroleum Intelligence Weekly.

Figure 1
Effect of an Appreciating Dollar on the World Oil Market



France, Italy, Japan, the United Kingdom, and West Germany—the average real price of oil in local currency rose 16 percent (from fourth quarter 1980 to fourth quarter 1984) while the real price of oil in U.S. dollars fell 25 percent.

Higher foreign oil prices were one factor contributing to reduced world oil demand. In major non-Communist industrialized countries other than the United States, 1984 oil consumption was 7 percent lower than it was in 1980.[2] Previous research indicates that a number of factors contributed to changes in world oil consumption during the first half of the 1980s. These factors include a lagged oil-conservation response to the sharp oil price increase in 1979, fluctuations in worldwide aggregate economic activity, changes in government regulations, and changes in the value of the U.S. dollar. In addition, rising oil production in non-OPEC countries contributed to downward pressures on the price of oil.[3]

The theory. As illustrated in Figure 1, appreciation of the dollar affects the world oil market by increasing world oil supply but reducing demand—leading to a reduced dollar price of oil. But the reduction in the dollar price is not sufficient to prevent an increase in the foreign price of oil.

Appreciation of the dollar changes the relationship between the foreign-currency-denominated foreign supply of oil and the U.S.-dollar-denominated foreign supply of oil. Foreign producers are willing to accept a lower dollar price at every level of production. The supply increase is shown as the shift from SF_1 to SF_2.

Appreciation of the dollar also changes the relationship between the foreign-currency-denominated foreign demand for oil and the U.S.-dollar-denominated foreign demand for oil. Foreign consumers choose a lower level of consumption at every dollar price. The decrease in U.S.-dollar-denominated foreign demand is shown as the shift from DF_1 to DF_2.

Together, the increase in foreign supply, which increases total world supply, and the decrease in foreign demand, which reduces total world oil demand, establish a lower dollar price. In Figure 1, these changes are shown as an increase from SW_1 to SW_2, a decrease from DW_1 to DW_2, and a reduction from P_1 to P_2.

As indicated previously, the reduction in the dollar price of oil cannot be sufficient to prevent a net increase in the foreign price of oil. The decrease in the dollar price of oil leads to decreased U.S. oil production (from s_1 to s_2) and increased U.S. oil consumption (from d_1 to d_2). To balance these changes, foreign oil production must be increased (from sf_1 to sf_2) and/or foreign consumption reduced (from df_1 to df_2). This increase in foreign production and/or reduction in foreign oil consumption can be accomplished only if the foreign currency price of oil is higher after the dollar appreciates and the dollar price of oil falls. In Figure 1, this price increase is shown as a movement from Pf_1 to Pf_2.[4]

If, as is shown in Figure 1, the increase in foreign supply is smaller than the decrease in foreign demand, the equilibrium quantity of oil will be reduced. If, however, foreign supply increases more than foreign demand decreases, the equilibrium quantity of oil will be increased. Thus, as a result of appreciation of the dollar, the total quantity of oil produced and consumed worldwide may increase, decrease, or remain the same.

Estimating the relationship between exchange rate movements and the price of oil

An equation based on supply and demand conditions in the world oil market was developed for estimating the relationship between the inflation-adjusted foreign value of the dollar and the inflation-adjusted official price of Mideastern light crude oil. Econometric analysis with this equation showed that the official dollar price of Mideastern light crude oil has a strong and statistically significant response to changes in the foreign value of the dollar. The long-run elasticity of the official price of Mideastern light crude oil with respect to the value of the dollar was estimated at -0.74.

The estimating equation. The estimating equation was developed from underlying supply and demand conditions. The quantity of world oil consumption is a function of its price, the value of the dollar, and worldwide aggregate economic activity. The quantity of oil supplied is a function of its price and the value of the dollar. These demand and supply relationships are expressed in general terms as follows:

$$Q = D(P, X, Y) \tag{1}$$

$$Q = S(P, X) \tag{2}$$

where

Q = the quantity of oil demanded and supplied.
P = the price of oil.
X = the foreign currency value of the dollar.
Y = worldwide aggregate economic activity.

In addition to exchange rates, other exogenous factors—such as military conflict, property rights, market structure, technology, and perceptions of user costs—can have a major role in determining the supply of oil. Because these factors are difficult to quantify, they have been omitted from the present analysis. To the extent that any systematic changes in these factors occurred during the sample period, the estimates in the regression analysis may reflect some bias and inconsistency.

Although it is generally indicative of the market price of oil, the official price of Mideastern light crude oil does not adjust to clear the market in any short period of time such as a quarter. Empirical evidence suggests that although the price is set administratively, it generally reflects recent market conditions.[5] This dependence can be captured by including lagged values of the dependent and independent variables in the estimating equation. With these lags included, the estimating equation is consistent with the reduced form of either a lagged-adjustment model or an adaptive-expectations model. The estimating equation is as follows:

$$(3)\quad \ln(P_t) = \alpha + \sum_{i=1}^{m}\beta_i \ln(P_{t-i}) + \sum_{i=0}^{n}\gamma_i \ln(X_{t-i}) + \sum_{i=0}^{n}\delta_i \ln(Y_{t-i}) + \sum_{i=1}^{n}\lambda_i \ln(Q_{t-i}) + e_t$$

where

P_{t-i} = the official price of Mideastern light crude oil at time $t-i$.

X_{t-i} = the value of the dollar at time $t-i$.

Y_{t-i} = worldwide aggregate economic activity at time $t-i$.

Q_{t-i} = the equilibrium quantity of oil at time $t-i$.

e_t = a random error that has a zero mean and is normally distributed.

This estimating equation expresses the real official price of Mideastern light crude oil during any period in time as a function of its own history, coincident and prior values of the dollar, coincident and prior general economic activity, and prior equilibrium quantities. Using natural logs of the variables allows the estimated coefficients to be interpreted as elasticities.

The expected degree of multicollinearity between coincident and lagged values of the independent variables makes it difficult to place prior expectations on the signs of individual variables. Nevertheless, estimated long-run elasticities of price with respect to the exogenous variables can be computed by combining the appropriate estimated coefficients. For the model to be acceptable, the estimates of these long-run elasticities should be consistent with the first-order conditions in the supply and demand equations.

For the demand equation, the first-order conditions for price are $\partial P_d/\partial X < 0$, $\partial P_d/\partial Y > 0$, $\partial P_d/\partial Q < 0$. For the supply equation, the first-order conditions for price are $\partial P_s/\partial X < 0$, $\partial P_s/\partial Q > 0$.

The long-run elasticity of price with respect to an independent variable is estimated as follows:

$$(4)\quad \hat{\eta}_j = \sum_{i=a_j}^{n}\hat{z}_i \Big/ \left(1 - \sum_{i=1}^{m}\hat{\beta}_i\right)$$

where

$\hat{\eta}_j$ = the estimated long-run elasticity of price with respect to variable j.

$\hat{z}_i$ = the estimated coefficient for the natural log of the ith lag of variable j.

a_j = a summation variable having a value of zero or one; it has a zero value if a coefficient was estimated for the natural log of the coincident value of variable j.

$\hat{\beta}_i$ = the estimated coefficient for the natural log of the ith P.

The long-run elasticity of the dollar price of oil with respect to the value of the dollar should be negative. An increase in the value of the dollar decreases both the demand price and supply price of oil ($\partial P_d/\partial X < 0$ and $\partial P_s/\partial X < 0$).

In addition to being negative to conform to theory, the long-run elasticity of the dollar price of oil with respect to value of the dollar must be greater than -1.0. The estimated long-run elasticity of the foreign price of oil with respect to the value of the dollar equals $1 + \hat{\eta}_X$. If $\hat{\eta}_X$ is less than -1.0, the estimate will indicate an inverse relationship between the foreign price of oil and the value of the dollar, which is contrary to theory.

The long-run elasticity of the price of oil with respect to worldwide aggregate economic activity should be positive. An increase in aggregate economic activity will increase the demand price for oil ($\partial P_d/\partial Y > 0$), and aggregate economic activity will have no effect on the supply price of oil.

Theory places no prior expectations on the long-run elasticity of the price of oil with respect to quantity. An increase in the quantity decreases the demand price for oil ($\partial P_d/\partial Q < 0$). On the other hand, an increase in quantity increases the supply price of oil ($\partial P_s/\partial Q > 0$).

In a lagged-adjustment model, however, positive coefficients for the quantity variables would be consistent with demand adjusting more slowly to changes in prices than does supply. Similarly, negative coefficients would be consistent with supply adjusting more slowly to changes in price than does demand.

Estimation. Equation 3 was used for an econometric analysis of the relationship between the real value of the dollar and the real official dollar price of Mideastern light crude oil. This analysis revealed that the relationship is statistically significant and placed the long-run elasticity of the dollar price of oil with respect to the value of the dollar at -0.74.

For the econometric analysis, data for the big seven countries were used to represent the influences of exchange rate movements and aggregate economic activity on world oil prices. Of the free-world countries, these seven—which have the largest national products and consume the most oil—represent nearly 75 percent of free-world oil consumption.

Appropriate lag lengths for the variables were selected in a two-step statistical procedure. After the appropriate autoregressive structure for the dependent variable was found, it was used in determining the appropriate lag length for the independent variables. Under this procedure, lags for all variables were set at two quarters.

The autoregressive structure of the dependent variable was determined by regressing the dependent variable on various lags of itself. The appropriate structure yields the highest F value for the hypothesis that regression coefficients other than the intercept are zero. On this basis, the structure of the dependent variable was found to be two lags.

After the lag structure of the dependent variable was set, that for the independent variables was selected. Selection of the lags for the independent variables was based on overall goodness of fit, adjusted for degrees of freedom.

In a series of regressions, various lags of the three independent variables were included as regressors along with the coincident series for the value of the dollar, the coincident series for aggregate economic activity, and the two lags of the dependent variable. For any one regression, the same number of lags was used for each independent variable. The appropriate lag length for the independent variables was chosen by increasing the lag length until the adjusted R^2 peaked. A search was not conducted to determine whether the peak was local or global because the sample size limited the degrees of freedom for regressions with many lags. On this basis, two lags were selected for the independent variables.[6]

Estimation was conducted with quarterly data for the interval from fourth quarter 1973 through fourth quarter 1984. The beginning date was selected to avoid inclusion of any data prior to second quarter 1973 because it was the first quarter in which exchange rates were no longer fixed. The availability of data determined the end date.

Equation 3 was estimated as follows:[7]

$$\begin{aligned}
\ln(P_t) = {} & \underset{(6.56)}{1.11} + \underset{(7.12)}{0.91} \ln(P_{t-1}) - \underset{(-2.50)}{0.26} \ln(P_{t-2}) \\
& + \underset{(2.03)}{0.87}\, X_t - \underset{(-0.53)}{0.32} \ln(X_{t-1}) - \underset{(-1.86)}{0.81} \ln(X_{t-2}) \\
& - \underset{(-2.69)}{3.98} \ln(Y_t) + \underset{(2.05)}{5.49} \ln(Y_{t-1}) - \underset{(-0.45)}{0.82} \ln(Y_{t-2}) \\
& - \underset{(-2.14)}{0.95} \ln(Q_{t-1}) + \underset{(2.08)}{0.90} \ln(Q_{t-2})
\end{aligned}$$

$R^2 = .96, \bar{R}^2 = .95$, Durbin's $h = -1.01$
Overall $F_{11,34} = 80.24$

where

P_{t-i} = the real official price of Mideastern light crude oil in quarter $t-i$.

X_{t-i} = an index of the real oil-consumption-weighted value of the dollar in foreign currency during quarter $t-i$ and is calculated with real exchange rates from the big seven countries excluding the United States.

Y_{t-i} = an oil-consumption-weighted index of real aggregate economic activity in the big seven countries during quarter $t-i$.

Q_{t-i} = world oil production during quarter $t-i$.[8]

Overall test statistics indicate that the model provides an acceptable explanation of real official prices for Mideastern light crude oil. The overall F statistic indicates that the model explains the dollar price of oil at greater than the 99-percent confidence level. And the model satisfies requirements for dynamic stability of the endogenous variable, and the Durbin's h statistic indicates the absence of autocorrelation.[9]

The expected degree of multicollinearity between the independent variables and their lagged values makes it difficult to interpret the signs or significance of individual coefficients. Nevertheless, tests for the joint significance of groups of variables are possible. Furthermore, by combining coefficients, long-run elasticities of the dollar price of oil with respect to the exogenous variables can be derived. These elasticities are more indicative of the impact of movements in the exogenous variables on the dollar price of oil than are individual coefficients.

The F statistic shown in Table 1 indicates that jointly the coefficients on natural logs of current value of the dollar and its lags are significant at the 99-percent level. At -0.74, the estimated long-run elasticity of the dollar price of oil with respect to the value of the dollar is consistent with theory, which predicted that the elasticity would be negative but greater than -1.

The F statistic shown in Table 1 indicates that jointly the coefficients on natural logs of current aggregate economic activity and its lags are significant at greater than the 99-percent level. At 1.99, the long-run elasticity of the dollar price of oil with respect to aggregate economic activity is positive and consistent with theory.

The F statistic shown in Table 1 also indicates that jointly the coefficients on natural logs of the lags of the quantity variable are significant at the 93-percent level. Nevertheless, the estimated long-run elasticity of price with respect to quantity is not significantly different from zero. The lack of significance of this long-run elasticity suggests that whatever impact lagged quantity has in the short run, these effects cancel each other when they reach the equilibrium price in the long run.

The impact of recent exchange rate movements on the price of oil

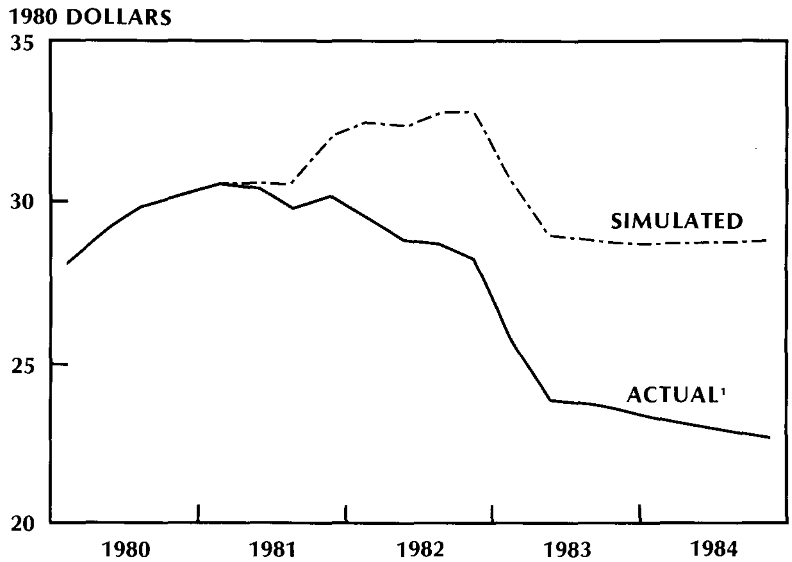
To estimate the impact of exchange rate movements from 1981 through 1984, a simulated price series was computed. This series represents the price of oil

Table 1
SUMMARY STATISTICS

	Independent variables		
	Value of the dollar (X)	Aggregate economic activity (Y)	Quantity (Q)
F statistic for joint significance of coefficients	4.23	4.64	2.86
Degrees of freedom for F test	($F_{3,34}$)	($F_{3,34}$)	($F_{2,34}$)
Estimated long-run elasticity of price with respect to indicated variable	-0.74	1.99	-0.15
Standard error of estimated long-run elasticity	0.60	0.54	1.19
Significance of estimated long-run elasticity (in percent)	89*	>99*	<12**

* Significance level for a one-tail test.
** Significance level for a two-tail test.

Chart 3
Actual and Simulated Real Dollar Oil Price



1. Entry is the official price of Mideastern light crude oil, deflated to 1980 dollars.
SOURCES OF PRIMARY DATA: International Monetary Fund.
Petroleum Intelligence Weekly.
Authors' estimates.

under the assumption that the value of the dollar remained at its 1980 level through the end of 1984. A comparison of this simulated price series with actual oil prices during the period 1981-84 indicates that the appreciation of the dollar had a substantial impact on the dollar price of oil.

To establish the price of oil that would have prevailed in the absence of the dollar's appreciation from its 1980 level, the actual price was multiplied by a simulation multiplier derived from the estimating equation and calculated as follows:

$$(5)\quad M_t = M_{t-1}^{\hat{\beta}_1} \cdot M_{t-2}^{\hat{\beta}_2} \cdot (X_{80}/X_t)^{\hat{c}_0} \cdot (X_{80}/X_{t-1})^{\hat{c}_1} \cdot (X_{80}/X_{t-2})^{\hat{c}_2}$$

where

M_{t-i} = the value of the multiplier for quarter $t-i$, for which values prior to first the quarter of 1981 are set at one.

$\hat{\beta}_i$ = the estimated coefficient for the ith lag of the dependent variable.

X_{t-i} = 1 for quarters prior to first quarter 1981 and the actual value of the dollar for quarters following fourth quarter 1980.

X_{80} = the 1980 value of the dollar.

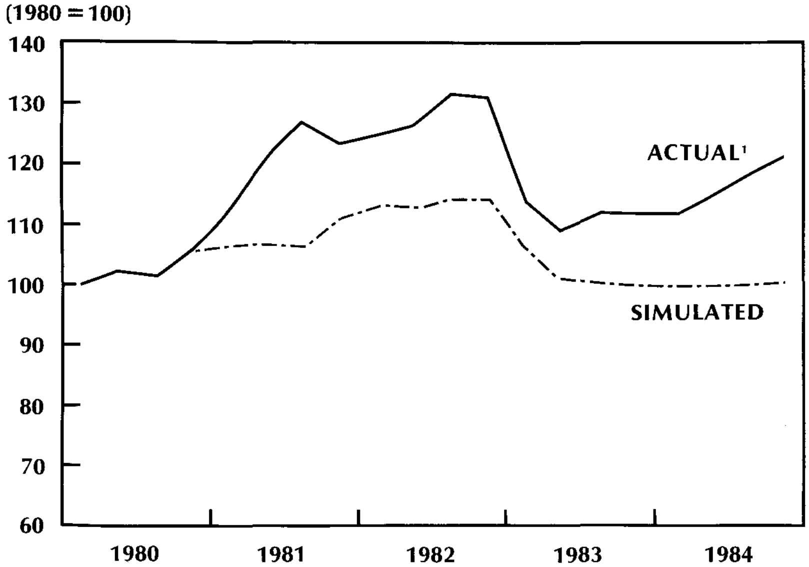
$\hat{c}_i$ = a transformation of the estimated coefficient for the log of the ith lag of the value of the dollar.

For the simulation, the estimated coefficients were transformed to smooth the impact of changes in the value of the dollar on the price of oil. This transformation preserved the long-run elasticity of the dollar price of oil with respect to the value of the dollar.[10]

The result of the simulation is shown in Chart 3. According to the simulation, the actual dollar price of oil was more than 20 percent lower in the fourth quarter of 1984 than it would have been had the dollar not appreciated during the 1980s.

The simulation also has implications for the foreign price of oil. As shown in Chart 4, appreciation of the dollar resulted in a sizable net increase

Chart 4
Actual and Simulated Real Foreign Oil Price



1. Entry is an index of the official price of Mideastern light crude oil that has been deflated to 1980 U.S. dollars and multiplied by an oil-consumption-weighted index of the real foreign value of the U.S. dollar.

SOURCES OF PRIMARY DATA: International Monetary Fund.
U.S. Department of Energy.
Petroleum Intelligence Weekly.
Authors' estimates.

in the foreign price of oil. According to the simulation, the foreign price of oil was more than 20 percent higher in the fourth quarter of 1984 than it would have been had the dollar held its 1980 value. The direct impact of a more than 50-percent appreciation of the dollar was partially offset by the resulting decline in the dollar price of oil.

Outlook

Appreciation of the dollar contributed to downward pressure on the dollar price of oil from 1981 through 1984 because it increased the price of oil faced by producers and consumers in countries outside the United States. Appreciation of the dollar increased the supply but reduced the demand for oil in these countries. And these changes in supply and demand contributed to downward pressure on the dollar price of oil.

Furthermore, the high value of the dollar likely contributed to oil price declines throughout 1985. Although the real value of the dollar reached a high in the first quarter of 1985, the official price of Mideastern light crude oil adjusts to changes in market conditions with a lag. Thus, some of the decline in oil prices occurring after this peak can be attributed to earlier increases in the value of the dollar.

A number of factors other than exchange rate movements also were important in reducing the dollar price of oil in the first half of the 1980s. And they may still be contributing downward pressure. Nevertheless, the depreciation of the dollar occurring in 1985 should eventually alleviate some of this pressure. To the extent that the dollar depreciates further, it would moderate any future downward pressure on the price of oil.

1. Stephen Brown and Keith Phillips have shown that an increased value of the dollar contributed to the decline in world oil consumption between 1980 and 1983. See Stephen P. A. Brown and Keith R. Phillips, "The Effects of Oil Prices and Exchange Rates on World Oil Consumption," *Economic Review*, Federal Reserve Bank of Dallas, July 1984, 13–21.

2. The major non-Communist industrialized countries are taken to mean France plus the 21 signatory nations of the International Energy Agency (IEA), which include Australia, Austria, Belgium, Canada, Denmark, West Germany, Greece, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

3. See Brown and Phillips, "The Effects of Oil Prices and Exchange Rates on World Oil Consumption."

4. A secondary effect of appreciation of the dollar is to reduce U.S. demand for oil and to increase foreign demand for oil. Appreciation of the dollar makes foreign goods cheaper in the United States and U.S. goods more expensive in foreign countries, shifting industrial production out of the United States and into foreign countries. Because those U.S. industries adversely affected by increased foreign competition are generally more energy-intensive than their foreign counterparts, world industrial demand for oil will fall. If this reduction in the world industrial demand for oil were the *only* effect of a higher-valued dollar, it would be possible for appreciation of the dollar to result in a lower foreign-currency price of oil. To the extent that such an effect occurs, however, it would be overshadowed by the primary shifts in demand and supply described above.

5. See Philip K. Verleger, Jr., "The Determinants of Official OPEC Crude Prices," *The Review of Economics and Statistics* 64 (May 1982): 177–83.

6. In a model with lagged dependent variables, ordinary least squares has poor small-sample properties, resulting in biased estimates.

   Selecting lag length to maximize the adjusted R^2 will result in choices that are quite similar to that made with Akaike's criterion for selecting lag lengths. Under Akaike's criterion, lag-length selection is based on a statistic known as the final prediction error. Both Akaike's criterion and the method employed here select the lags that best predict the dependent variable while rewarding parsimony in the number of lags chosen. The adjusted R^2 for selecting lags is preferred because it is more closely related to the F test for overall significance of the regression than is the final prediction error used in the Akaike procedure. For a description of the final prediction error and its use for selecting appropriate lag lengths, see H. Akaike, "Fitting Autoregressive Models for Prediction," *Annals of the Institute of Statistical Mathematics* 21 (1969): 243–47, as cited and discussed by David A. Bessler and James K. Binkley in "Autoregressive Filtering of Some Economic Data Using PRESS and FPE," *Proceedings*, Business and Economics Statistics Section, American Statistical Association, 1980, 261–65.

7. Figures shown in parentheses are t statistics.

8. The index of the oil-consumption-weighted value of the dollar was calculated as follows: $X_t = \Sigma w_j X_{j,t}$, where w_j is the weight given country j's currency; $X_{j,t}$ is an index of the real value of the dollar as measured in country j's currency at time t; and summation is over j for the big seven countries except the United States. The weight given each country is calculated on the basis of its share of oil consumption for these six countries during the period from 1973 through 1984.

   The index of aggregate economic activity is calculated as follows: $Y_t = \Sigma y_j Y_{j,t}$, where y_j is the weight given country j's aggregate economic activity; $Y_{j,t}$ is an index of real aggregate economic activity in country j during period i—measured by that country's gross national product or gross domestic product; and summation is over j for the big seven countries. The weight given each country is calculated on the basis of its share of big seven oil consumption during the period 1973 through 1984.

   Nominal oil price data were obtained from the *Petroleum Intelligence Weekly* and deflated with the U.S. implicit price deflator, which was obtained from the International Monetary Fund (IMF). Indexes of the real value of the dollar measured in each currency and indexes of aggregate economic activity in each country were calculated with IMF data. World oil production data were obtained from various issues of the *Oil and Gas Journal*, July 1973 through April 1985.

9. Given that the coefficient estimates satisfy stationarity conditions, the estimated model will have a stable equilibrium for each setting of the exogenous variables. Had the coefficient estimates not satisfied these conditions, the model would be dynamically unstable, and a change in an exogenous variable would result in the endogenous variable never reaching a steady state again.

   Stationarity is indicated if the following conditions hold:

$$b_2 + b_1 < 1$$
$$b_2 - b_1 < 1$$
$$-1 < b_2 < 1$$

   where b_1 and b_2 are the coefficients of first and second lags of the dependent variable. Statistical tests based on these conditions indicated rejection of nonstationarity at greater than the 95-percent confidence level. For derivation of these stationarity conditions, see George E. P. Box and Gwilym M. Jenkins, *Time Series Analysis: Forecasting and Control* (San Francisco: Holden-Day, Inc., 1970), 58–59.

10. Simulated prices calculated with these transformed coefficients are different than those calculated with the estimated coefficients, but values calculated with the two methods approach each other asymptotically.

The Labor-Intensive Nature of Manufacturing High-Technology Capital Goods

Robert T. Clair

Economist
Federal Reserve Bank of Dallas

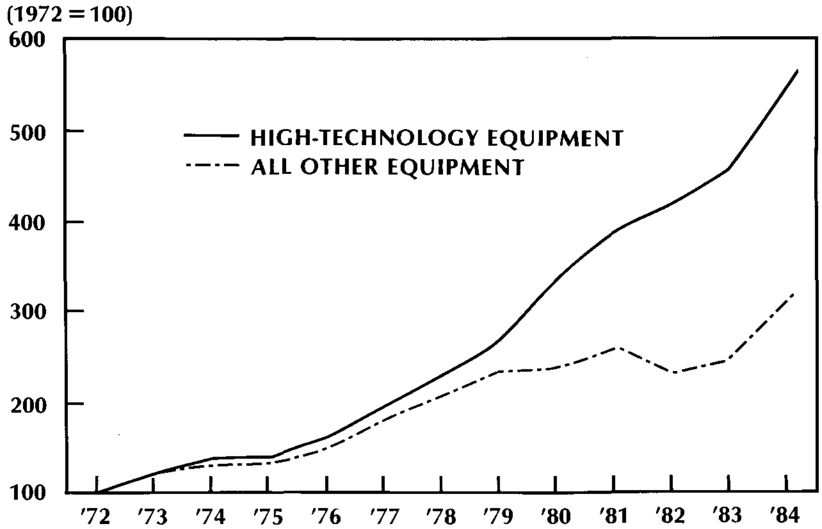
With unemployment in the economy a costly problem, state governments may be seeking a solution by encouraging the expansion of high-technology equipment manufacturing. One approach to reducing unemployment is to encourage the development of firms utilizing production processes that are labor-intensive. A substantial number of state programs have been designed to attract all types of high-technology firms to their locale or to encourage the expansion of high-technology firms already in the state.

This article analyzes the production process for manufacturing high-technology equipment in an effort to determine whether the production characteristics of that industry are consistent with state objectives to encourage the expansion of labor-intensive industries. The research here uses the U.S. Department of Commerce definition of high-technology equipment, which consists of office, computing, and accounting equipment; communications equipment; and instruments.[1] The results of the analysis show that an expansion in high-technology equipment manufacturing will create more jobs than expansion in manufacturing of other types of producers' durable goods. Hence, state government programs designed to attract or encourage the expansion of firms that manufacture high-technology equipment are consistent with the goal of reducing unemployment. Additional analysis shows that high-technology manufacturing utilizes low-skilled workers and that the average wage in this industry is relatively low. As a result, income gains may not appear as substantial as employment gains.

Growth of high-technology industries attracts interest of state and local governments

The growth of output and employment in the high-technology equipment industry has been extremely rapid in recent years. Private purchases of high-technology equipment rose at an annual rate of 15.8 percent from 1977 to 1984, double the rate of growth for all other producers' durable equipment. The private purchases of high-technology equipment and all other capital equipment for 1972 through 1984 are plotted in Chart 1. Because of the rapid growth of purchases of high-technology equipment, its share of the total producers' durable goods

Chart 1
Purchases of Producers' Durable Equipment



SOURCE OF PRIMARY DATA: U.S. Department of Commerce, Bureau of Economic Analysis.

market rose from 21.4 percent in 1972 to 32.6 percent in 1984.

The rapid growth of the output of high-technology equipment generated tremendous employment gains. Indexes of high-technology and total nonagricultural employment are plotted in Chart 2. From 1977 through 1983, high-technology employment in the United States increased more than 30 percent, compared with a 9-percent increase in total nonagricultural employment. Although high-technology employment is only a small share of the nation's work force, representing less than 3 percent of total employment, it accounted for 7 percent of the new jobs created over that six-year period.

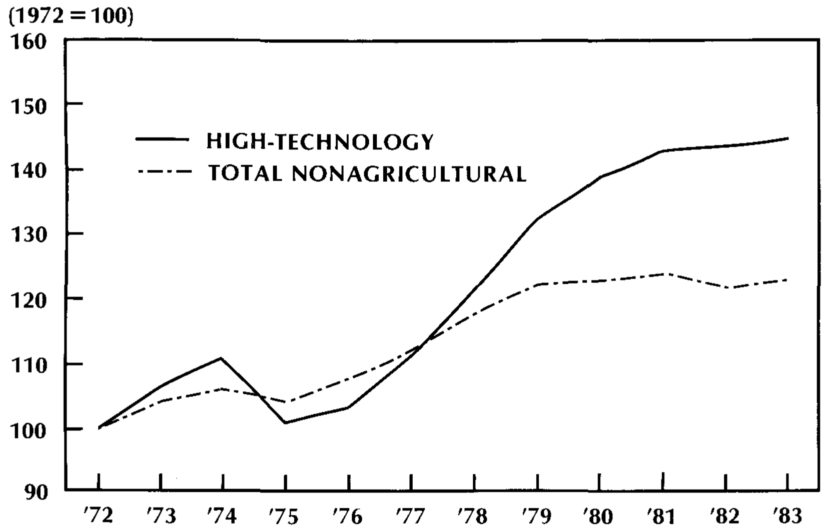
The rapid growth of high-technology output and employment has sparked the interest of state and local governments. Numerous programs have been undertaken by state governments to encourage all types of high-technology firms to expand their operations within the states and to encourage other high-technology firms to locate within the states' borders.[2]

These state programs use various methods of attracting or cultivating high-technology industries. Direct financial aid programs provide equity capital, research grants, lines of credit, and discounts on utility charges. Research assistance programs increase basic research at public institutions or reduce the cost of research and development to private firms.[3] A common type of research assistance program aids in the development of commercial applications based on basic research breakthroughs at universities and government research laboratories. In addition, some states are investing in infrastructure that will encourage and attract industries, and some of this investment is specifically designed to encourage the expansion of high-technology firms.[4] Finally, state educational programs assist in the development of a high-technology work force at all levels, from graduate degrees for professional engineers to vocational training for production workers.

State governments seek to reduce unemployment by encouraging high-technology firms

One reason state governments implement these programs is to increase the economic well-being of their citizens by providing employment opportunities. More specifically, reducing unemployment within the state is probably one of the goals of state governments. Unemployment carries a high cost in terms of output lost through the wasting of re-

Chart 2
High-Technology and Nonagricultural Employment



SOURCE OF PRIMARY DATA: U.S. Bureau of Labor Statistics.

sources. For a state government budget, unemployment results in the loss of tax receipts and an increase in state government expenditures, such as unemployment compensation and income transfer payments.

Three main issues need to be addressed in determining the feasibility and effectiveness of these types of state programs. First, will the state programs have an effect on the location and expansion decisions of a high-technology manufacturing firm?[5] Second, will the expected social benefits of such a program exceed the program's expected cost?[6] Third, will the expansion of operations of high-technology equipment manufacturers create jobs and, if so, what are the characteristics of these jobs? The third issue is the focus of this article.

The remainder of the article addresses the third issue by presenting empirical evidence that an expansion in the production of high-technology equipment will provide jobs and that the industry is relatively superior to other major types of capital equipment industries in this regard. The evidence was obtained by estimating and comparing the production processes for high-technology, heavy industrial, transportation, and "other" equipment industries.[7] By examining these production processes, it is possible to describe the type of employment that will most likely result from a program designed to encourage high-technology equipment producers. A production process that substantially reduces unemployment will be labor-intensive. Beyond this characteristic, the production functions are also examined for evidence of likely future wage increases and job stability.

The production function

The primary purpose of the empirical work is to obtain estimates of the production functions of four major types of producers' durable equipment. Foremost, these estimations of production functions will provide measures of labor share in the production process. Labor share data are necessary in determining the amount of job creation that can be expected from an expansion of various industries. In addition, the estimated production functions will provide measures of productivity and trends in long-run average costs that are needed to forecast likely future wage increases. The estimations will also produce a measure of the substitutability of capital and labor. This last characteristic is important in determining job stability.

A production function is simply a mathematical representation of the maximum quantity of output that can be produced from a given amount of inputs. To obtain these estimates, constant elasticity of substitution (CES) production functions were estimated. The CES production function assumes that the ability to substitute capital for labor remains constant whatever the mix of capital and labor. To simplify the analysis, separability of material inputs was assumed.

The CES production function was specified as

$$(1) \qquad X = \theta e^{\phi t} [(1 - \delta) K^{-\rho} + \delta L^{-\rho}]^{-\mu/\rho}.$$

Greek letters denote parameters that are to be estimated. Italic letters represent variables except for e, which is the base for natural logarithms. Output is denoted by X, capital by K, and labor by L. The variable t is a time trend. An interpretation of the relevant parameters is presented below.

In the previous section, it was hypothesized that state governments want to encourage labor-intensive production processes in order to create jobs and to reduce unemployment. Labor share, the measure of labor intensity, is the parameter δ. The higher the value of labor share, the more labor-intensive is the production process. If labor share were to equal 1, then labor would be the only input in the production process—that is, production would be completely labor-intensive. In contrast, if labor share were equal to zero, then labor would not be an input in the production process.

The production functions were also analyzed for evidence of likely future wage increases. Future wage increases are important to state governments because they will correspond to increases in future tax receipts. Wage increases must typically be supported by additional productivity. One source of additional productivity is an increase in the quality of inputs. For example, as labor becomes more experienced, it becomes more productive. This type of productivity is measured by the rate of technical change, ϕ. The rate of technical change is the percentage increase in output that can be expected each year without increasing any of the inputs. A high value of ϕ suggests a high rate of future wage increases.

Productivity gains can also result from expanding operations to take advantage of possible economies of scale. In some industries, increasing the scale of operations permits average unit cost to fall. This implies that labor becomes more productive as the average output per worker increases. The potential to exploit economies of scale is measured by the returns-to-scale parameter, μ. If the production function exhibits increasing returns to scale, a value of μ greater than 1, then productivity gains can be achieved by increasing the scale of operations. Such gains can support higher future wages.

Finally, the production function was examined for evidence of job stability. Although job stability is not needed to reduce unemployment, it is assumed that job stability is probably a secondary goal of state government. Of course, one of the primary factors determining job stability will be the stability of demand for the output, but an analysis of the demand for each type of producers' durable equipment is outside the realm of this article.

The parameter ρ from the estimated production functions does provide a measure of how stable employment is, given changes in the relative costs of inputs: more specifically, how sensitive is the mix of capital and labor to changes in wages relative to the cost of capital. The elasticity of substitution between capital and labor measures this sensitivity. The elasticity of substitution, σ, in the CES production function is

$$(2) \qquad \sigma = 1/(1 + \rho).$$

A lower value for σ implies a less sensitive reaction in the input mix. For example, if wages should rise relative to the cost of capital, then firms will substitute capital for labor. The lower the value of σ, the less substitution of inputs will occur. Consequently, a lower value of σ indicates greater job stability.

Estimation technique and empirical results

The CES production function was estimated using a two-step procedure. In the first step, the equilibrium condition in the factors markets is used to estimate the labor share and elasticity of substitution. These estimates are then used in the second step, in which the remaining parameters in the production function are estimated. The details of this procedure are provided in the Appendix. The estimations used data for 1968 to 1976.

The empirical results support the proposition that, other things equal, an expansion in high-technology equipment manufacturing will create more jobs than expansion in the manufacture of other categories of capital equipment. The results of the

Table 1
PRODUCTION FUNCTION PARAMETERS FOR FOUR MAJOR TYPES OF CAPITAL GOODS, 1968-76 PERIOD

	Estimated from equilibrium condition		Estimated from production function		
Type of capital goods	Labor share δ	Elasticity of substitution σ	Returns to scale μ	Rate of technical change ϕ	Efficiency θ
High-technology ...	.325*	1.166*	1.098*	.028*	.107*
Heavy industrial ...	.281*	1.251*	.978*	.019*	.250*
Transportation	.069*	2.420*	1.082*	.033*	.173*
Other	.112*	1.642*	.998*	-.030*	.829

* Significant at the .05 level.

estimations are presented in Table 1.[8] The differences between high-technology parameters and the parameters of the other industries are presented in Table 2. The statistical significance of these differences is also presented in Table 2.[9] Estimates of δ, the measure of labor intensity, indicate that the production of high-technology equipment is significantly more labor-intensive than transportation or "other" equipment production. High-technology equipment production has a labor share of 0.325, which is higher than for any other category of equipment production. Being more labor-intensive suggests that expansion of high-technology equipment manufacturing will create more jobs than similar expansions in the manufacture of other types of capital equipment.

Wages of high-technology workers are likely to increase at a more rapid rate than are wages of heavy-industrial workers or workers in the "other" category.[10] In the long run, wage increases are based on gains in productivity, and the rate of gain in the productivity of workers is measured by the rate of technical change. For high-technology equipment production the rate of technical change was 2.8 percent annually, significantly higher than the rates for heavy industrial and "other" equipment production. The high-technology rate of technical change, however, was significantly below the transportation rate of technical change.

High-technology equipment manufacturing has a

Table 2
DIFFERENCES IN PRODUCTION FUNCTION PARAMETERS FOR HIGH-TECHNOLOGY AND OTHER TYPES OF CAPITAL GOODS

Type of capital goods	Labor share δ	Elasticity of substitution σ	Returns to scale μ	Rate of technical change ϕ	Efficiency θ
	High-technology parameters less the respective parameters				
Heavy industrial ...	.044	-.085	-.121*	.009*	-.143*
Transportation	.256*	-1.254*	-.017*	-.005*	-.066*
Other	.213*	-.476*	-.101*	.057*	-.772*

* Significant at the .05 level.

greater potential for productivity gains resulting from expanding operations to take advantage of economies of scale. The ability to exploit increasing returns to scale requires the returns-to-scale parameter, μ, to be greater than 1. In the case of high-technology equipment manufacturing, the returns-to-scale parameter, at 1.098, is significantly greater than 1 and significantly higher than for the other three categories of equipment.

It is clear that high-technology workers appear likely to have larger wage increases than either heavy-industrial workers or "other" workers, but it is ambiguous whether wages of high-technology workers will increase more than wages of transportation workers. Compared with heavy-industrial and "other" workers, high-technology workers are in production processes in which labor has both a higher rate of technical change and a greater potential for the advantages of economies of scale. Compared with transportation workers, high-technology workers also have a greater possibility of productivity gains attributable to economies of scale. The transportation workers, however, have a higher rate of technical change. The ambiguity occurs in whether the rate of technical change or the potential for economies of scale will be the dominant factor in determination of productivity gains and wage increases in the future.

When the goal of long-run job stability is taken into account, high-technology workers are less likely to be replaced by capital. As stated before, this is only one factor promoting job stability, but a lower value for the elasticity of substitution does indicate the relative difficulty in substituting capital for labor in the long run. High-technology equipment production has an elasticity of substitution between capital and labor of 1.166—the lowest among the four categories of capital goods and significantly lower than the elasticity of substitution for transportation or "other" equipment. Consequently, in the long run, changes in the relative costs of capital and labor will have less effect on employment for high-technology equipment production than for production of transportation or "other" equipment.[11]

High-technology manufacturing reduces structural unemployment of low-skilled workers

The employment gains that would result from an expansion in high-technology equipment manufacturing are likely to be concentrated among low-skilled workers. It is clear from the estimation of the production function that high-technology equipment production is labor-intensive. While there is a correlation between labor-intensive production processes and processes utilizing low-skilled workers, further evidence is needed to show that the high-technology work force is low-skilled.

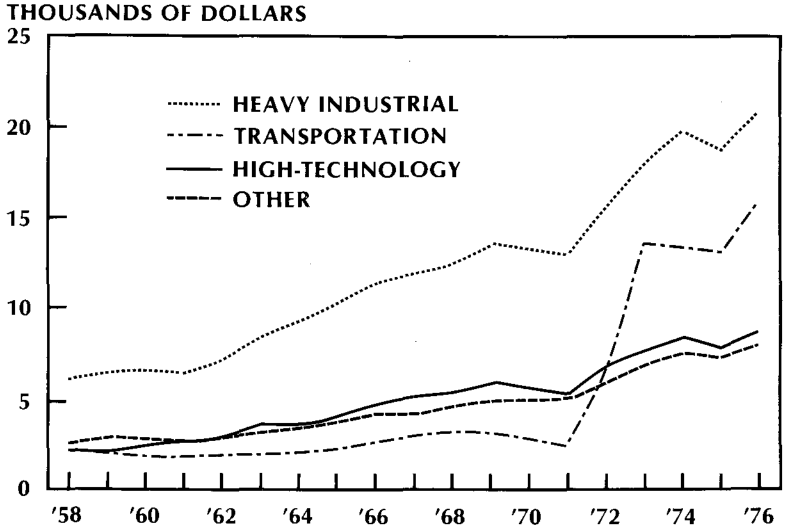
The best evidence that the work force of high-technology equipment producers is low-skilled is its low relative wage. Low-skilled workers are less productive and, consequently, receive a lower wage. The average wage in high technology is substantially below that in heavy industrial or in transportation. Chart 3 shows the average annual wage in each of the four categories of producers' durable equipment production. In 1976 the average wage of workers in high-technology equipment production was roughly two-fifths that of heavy-industrial workers and one-half that of transportation workers. It was marginally above the average wage of "other" workers. Given this wage structure, it is apparent that high-technology equipment production is a low-skilled, labor-intensive process.

Creating jobs for low-skilled workers is very important because unemployment of these workers is much higher than average. A direct measure of the unemployment rate for low-skilled workers is not available, but a close proxy may be the unemployment rate for teenagers. Workers 16 to 19 years of age typically have little job experience and, consequently, have not obtained on-the-job training that might provide job skills. Furthermore, at their young age, it is unlikely that these workers have received advanced formal education, such as in college. The unemployment rate for individuals 16 to 19 years old is, on average, more than three times the unemployment rate for individuals 20 and older.

High-technology manufacturing faces substantial foreign competition

One reason for the high unemployment of low-skilled workers in the United States is the competition these workers face from foreign low-skilled workers. In nonindustrialized economies, there is usually a large work force of low-skilled labor. This plentiful supply of workers depresses the wages of foreign low-skilled labor. As a result, businesses deciding to locate low-skilled, labor-intensive production processes must evaluate whether savings from the lower labor cost of operating in many

Chart 3
Average Wages in Equipment Manufacturing



SOURCE OF PRIMARY DATA: U.S. Bureau of the Census.

foreign countries will offset the higher shipping costs and any tariffs. In general, low-skilled, labor-intensive industries in the United States are at a disadvantage when competing with Third World producers. Consequently, fewer low-skilled jobs are created in the United States, and unemployment of low-skilled U.S. workers is higher.

Because high-technology equipment production is labor-intensive and utilizes low-skilled labor, it will be subjected to substantial foreign competition. There is already evidence of a shift of high-technology equipment manufacturing to foreign producers. The semiconductor industry began assembling chips in the Far East in the early 1970s. As quality controls of foreign producers improved, more complex components were "outsourced"—that is, produced overseas. Early in 1984, Atari completed transferring all its manufacturing operations to Taiwan. In late 1984, Motorola located three plants in Mexico, and Digital Equipment and IBM applied for permission to locate computer production facilities there.[12]

State governments face a real dilemma. Programs designed to attract or encourage the expansion of high-technology firms, with the goal of employing a sizable number of structurally unemployed workers, may produce fewer jobs in the long run as a result of foreign competition. On the other hand, encouraging the high-technology areas in which the United States could maintain a comparative advantage—such as research, software programming, and sophisticated manufacturing—will affect few of the structurally unemployed workers. The primary point of this dilemma is that there are no easy solutions to the problem of structural unemployment. For a governmental program to be successful in the long run, it will probably need to promote the retraining of the structurally unemployed workers and, at the same time, attract firms that can utilize their newly acquired skills.[13]

Conclusion

This article examines the implications for employment arising from state government programs designed to attract and encourage the expansion of high-technology firms. One method of reducing unemployment is to encourage the expansion of labor-intensive industries. The results of the research here show that state programs designed to attract or encourage the expansion of firms that manufacture high-technology equipment are consistent with the goal of reducing unemployment.

The production process of manufacturing high-technology equipment was estimated. From the results of this estimation, it is clear that high-technology manufacturing is relatively labor-intensive. In addition, an analysis of wages suggests that the high-technology workers are, on average, low-skilled workers. Consequently, the expansion of high technology will have a large impact on reducing structural unemployment of low-skilled workers. The results of the estimation also indicate that high-technology workers will have rising real wages over time as a result of productivity gains. Moreover, there is some evidence that long-run job stability is greater in high-technology manufacturing than in the manufacture of other types of producers' durable equipment.

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1. The term "high technology" has been applied to a multitude of industries, so much so that it may now be somewhat ambiguous. For the sake of clarity, the Commerce Department will soon call this category information-related durable equipment.

2. It is not possible to determine to what extent these programs are designed to attract or encourage the expansion of high-technology firms other than producers of high-technology equipment.

3. "Basic research" is defined as investigation to gain knowledge for its own sake.

4. Alton K. Marsh, "High Technology/Southwest U.S.: New Mexico to Build On-line Data Link," *Aviation Week & Space Technology*, 27 August 1984, 55-57.

5. There is evidence that state governments can affect decisions by high-technology firms to expand operations. A survey of 240 high-technology manufacturing firms in the Tenth Federal Reserve District showed that state government programs can have significant impact on the decision of high-technology manufacturing firms to expand operations within a state but state government programs are unlikely to exert a major influence in attracting new high-technology firms. The survey reveals that financial incentives provided by the state government, such as low-interest loans and reduced taxes, would be considered significant factors in expansion plans by 68 percent of the survey firms. The definition of high-technology manufacturing used in that survey is somewhat broader than the Commerce Department definition used in this article. See Tim R. Smith and Marla Borowski, "High-Technology Development in the Tenth District," *Economic Review*, Federal Reserve Bank of Kansas City, November 1985, 9-24.

6. Whether the social benefits exceed the costs is an unresolved question. The existence of state government programs to encourage the development of high-technology firms is evident. In 1985, 33 states had programs to promote high-technology industries. See Miriam Rozen, "State Programs Lure High Tech Companies," *Dun's Business Month*, March 1985, 93. The existence of such programs makes important the issue of whether the job characteristics of high-technology manufacturing are consistent with reducing unemployment.

7. The producers' durable equipment industries have been categorized by the Commerce Department, by type of output, as high-technology, heavy industrial, transportation, or other. The category "other" refers to all capital equipment that does not fit in the first three categories. High-technology equipment includes office, computing, and accounting equipment; communications equipment; instruments; and electronic components. The high-technology category also includes part of the software industry—that software produced and sold by computer manufacturers but not that written and sold by independent software houses.

   The category of heavy industrial equipment consists of a variety of goods, including engines, turbines, metalworking machines, and electrical transmission equipment, such as transformers and switchgears. Also included in this category are such general industrial machinery as pumps, fans, bearings, nonautomotive transmissions, and furnaces. Finally, heavy industrial equipment includes special machinery for such industries as food processing, textiles, woodworking, paper, and printing.

   The remaining two categories of producers' durable equipment are transportation and "other." All modes of transportation are included in the transportation equipment category except defense and space equipment and recreational motor vehicles, such as motorcycles and motor homes. The producers' durable equipment industries that are not classified above are grouped together as other equipment. This group includes construction equipment, mining and oil field machinery, and agricultural machinery.

   An alternative categorization of high-technology equipment and "all other" capital equipment was considered and rejected following empirical tests that showed the aggregation of heavy industrial, transportation, and other capital equipment was not justifiable.

8. The data used for the estimations were published in the Annual Survey of Manufactures and the Census of Manufactures. Output (X) was total value added, and labor (L) was total employment. The capital stock data were constructed using the Census data on book values of fixed assets as benchmarks and using the perpetual inventory method to generate capital stock figures for the years between censuses. Wages were calculated as total salaries and wages divided by total employment. The rate of return on capital was calculated as the difference of total value added less total salaries and wages divided by the capital stock. For a description of this method of generating the capital stock and the return on capital, see Robert F. Engle, "A Disequilibrium Model of Regional Investment," *Journal of Regional Science* 14 (December 1974): 367-76.

9. Two statistical tests of the differences in the parameters were conducted. First, the hypothesis that one of the other three production functions was identical to the high-technology production function was tested using a Chow test. The results

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