

1983

Three essays in international and intraregional economics

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THREE ESSAYS IN INTERNATIONAL AND INTRAREGIONAL ECONOMICS

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Three essays in international and
intraregional economics

by

Lee David Zinser

A Dissertation Submitted to the
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GENERAL INTRODUCTION

The goal of economic theory is to provide a systematic explanation of the actions of economic agents and institutions within an economy, and to explain the overall operation of an economy. How an economy functions may be examined from the standpoint of an isolated economy or an economy that exists in a global setting.

Economic theory often develops in response to questions of real-world importance. Early economic theory developed, in part, from attempts to answer two questions relating to the functioning of economies in an international context. The first question concerned why trade occurs and how the gains from trade are distributed between nations. The second question concerned how overall economic performance in one country is linked to the level of economic activity in other countries.

Early attempts to explain basic economic relationships often generated more questions regarding how economies function. As economic theory became more sophisticated, so too did the real-world questions that economists were called upon to answer.

Changes in the economic framework often generate new sets of questions that change the focus of economic theory. For instance, the switch to flexible exchange rates in 1974 by the major industrial nations sparked interest in the question of how the relative values of currencies are determined. Since then a major focus of international economists has been the construction of economic models that explain exchange rate movements.

Changes in social values may also affect the type of questions that are directed toward economists. In the late 1960s and early 1970s, environmental quality became an important concern in the industrialized nations. Economists responded to the new questions that were being raised about environmental quality. Less attention was placed on simply determining how the maximum output could be achieved from a given resource base. More time and effort was devoted to developing models that explained the relationships between levels of economic activity and environmental quality. Attention was focused on constructing models that allowed a systematic accounting of the costs and benefits associated with given levels of environmental quality.

Regardless of the type of questions that economists are called to answer, economic investigation follows a common procedure. An economist begins by specifying a set of assumptions that are relevant to the question or issue that has been raised. The assumptions reflect the economist's view of the world. From the set of assumptions, the economist derives testable hypotheses. The empirical validity of the hypotheses is then determined through the application of appropriate empirical methodology.

The nature of the subject matter usually prohibits economists from conducting controlled experiments. Therefore, economists are limited to considering only some of the relevant variables. Results are often subject to differing interpretations, and single empirical tests are rarely conclusive. A theory is widely accepted only when a large body of evidence exists which supports the theory. Likewise, established theory

is discarded only in the face of a substantial amount of empirical evidence that is inconsistent with the theory.

Even as economic understanding increases, real-world questions often remain only partially answered. Today, economists are still trying to explain why trade occurs and how economic activity in one country is linked to levels of economic activity in other countries. Given the inability to conduct controlled experiments, it may be that the best that economics can do is to determine which answers are clearly false.

Knowing which answers are false and which policies will not work, is important to citizens and policymakers. Therefore, economists continue to attempt to answer questions and to advance the limits of economic knowledge. Progress is made through the combined efforts of many economists.

Explanation of Thesis/Dissertation Format

This dissertation consists of three essays in international and intraregional economics. Each essay represents an attempt to answer a specific question that arose as the result of changes in the economic framework and in social values that occurred in the early 1970s. Each essay is an original paper written by the candidate and each is presented in a separate section.

The study presented in the first section represents an attempt to answer the question of whether monetary variability influences the relative value of a currency. The answer is important because revealed theory has led economists to focus attention on the relative levels of money supplies as a significant determinant of the exchange rate. If monetary

variability does influence the exchange rate, then economists should consider relative monetary variability as well as relative money supplies when making exchange rate predictions.

The study presented in the second section consists of an attempt to explain how the Eurodollar market functions. It is important to determine how the Eurodollar market operates in order to answer the question concerning whether the Eurodollar market is a source of global inflation. If the Eurodollar market is capable of creating credit through multiple deposit expansion, then it may be partially responsible for the surge in world inflation in the 1970s, and it may represent a potential source of world monetary instability.

The study presented in the third section consists of an attempt to assess the impact of nonpoint source pollution control policy in the presence of alternative energy price regimes. The answers provided by the study may prove useful to policymakers as they attempt to select appropriate pollution control policies.

The same general procedure is followed in each section. First, the problem is presented and the relevant literature is reviewed. Second, the model used to analyze the problem is developed. Third, the results of tests of the model are presented. Finally, inferences from the study are drawn, and suggestions for additional studies are given.

SECTION I. THE IMPACT OF MONETARY VARIABILITY ON
EXCHANGE RATES UNDER A REGIME OF GENERALIZED
FLOATING: AN EMPIRICAL ASSESSMENT

The switch to generalized floating of exchange rates in 1974 generated renewed interest in the theory of exchange rate determination. One theory advanced to explain exchange rate movements was the monetary theory. The monetary theory of exchange rate determination was an extension to flexible exchange rates of the monetary approach to the balance of payments which was developed in modern form by Jacob Frenkel and Harry Johnson and others (10).

The monetary approach to exchange rate determination views the exchange rate as the relative price of two national moneys. Thus, the equilibrium exchange rate between two currencies depends on the willingness of economic agents to hold the actual supplies of each currency.

Although relative supplies of and demands for money are the proximate determinants of an exchange rate, the monetary approach does not ignore the impact of real factors on the value of a currency. Rather, the monetary approach proposes that real factors exert their influence on an exchange rate through monetary channels.

A typical exchange rate determination equation developed from the monetary approach would show the relative value of a currency to be dependent on relative money supplies, relative real income, and relative nominal interest rates. Attempts to establish the empirical validity of the monetary approach have met with mixed success.

Recently, studies by Lapan and Enders (15) and King, Putnam, and Wilford (14) have suggested that the relative variability of money supplies will also affect the exchange rate. These studies reach opposite conclusions, however, regarding the impact of greater monetary variability on the relative value of a currency. Lapan and Enders maintain that an increase in the variance of a national money supply will appreciate that country's currency. King, Putnam, and Wilford contend that an increase in monetary variability in a country will depreciate that country's currency.

The purpose of this study is to empirically assess the impact of monetary variability on an exchange rate. The study will be conducted within the general framework of the monetary approach to exchange rate determination, and it will focus on the United States/Canada exchange rate during the period from 1974 to 1979.

LITERATURE REVIEW

The monetary approach to exchange rate determination emphasizes that an exchange rate is the relative price of two national moneys, and that the equilibrium exchange rate is achieved when the existing stocks of the two moneys are willingly held (9). Therefore, the monetary approach focuses attention on the determinants of the supply and demand for money in its explanation of exchange rate adjustment.

The monetary approach posits the existence of a demand for money that is a stable function of a few variables. Belief in the monetary approach does not necessitate the acceptance of one particular functional form for the demand for money, but a form commonly employed in empirical tests of the monetary approach is:

$$\frac{M}{P} = c_0 Y^{c_2} e^{-c_3 I}, \quad (1)$$

where

M = the nominal stock of money demanded;

P = the price level;

Y = the level of real income;

I = the nominal rate of interest; and

c_0 , c_2 , and c_3 = parameters.

If equation (1) gives the domestic demand for money, then the demand for money in a foreign country can be represented as:

$$\frac{M^*}{P^*} = b_0 Y^* e^{b_2 - b_3 I^*} \quad (2)$$

with the asterisks denoting foreign variables. Real income is assumed to be exogenous, and changes in nominal interest rates are assumed primarily to reflect exogenous movements in the expected rate of inflation (3). The monetary approach also assumes that purchasing power parity will hold between the two countries so that:

$$P = SP^* \quad (3)$$

with S representing the spot price of foreign currency in terms of domestic currency.

When exchange rates are flexible the money supply in each country is exogenous so equations (1) and (2) determine the price levels. That is, prices adjust in each country to equate the stock demand for money with the actual supply. Equation (3) indicates that the exchange rate adjusts to equalize the purchasing power of both currencies expressed in a common unit.

The exchange rate determination equation is derived by taking logarithms of all three equations and substituting equations (1) and (2) into equation (3). After rearranging, the resulting equation is:

$$\begin{aligned} \ln(S) = & -\ln(c_0) + \ln(b_0) + \ln(M) - \ln(M^*) - c_2 \ln(Y) \\ & + b_2 \ln(Y^*) + c_3 I - b_3 I^*. \end{aligned} \quad (4)$$

Assuming that $c_0 = b_0$, $c_2 = b_2$, and $c_3 = b_3$, equation (4) can be expressed as:

$$s = m - c_2 y + c_3 DI \quad (5)$$

with

$$s = \ln(S);$$

$$m = \ln(M/M^*);$$

$$y = \ln(Y/\bar{Y}^*); \text{ and}$$

$$DI = (I - I^*).$$

According to the monetary approach, an increase in the domestic money supply would tend to cause an excess supply of domestic money, resulting in an increase in domestic prices and an increase in the exchange rate (a depreciation). An increase in domestic real income would cause an increase in the domestic demand for money which would be met by a decrease in domestic prices and the exchange rate if it was not satisfied by domestic monetary expansion. Likewise, with all other variables constant an increase in domestic nominal interest rates would cause a decrease in the demand for money and an increase in prices and the exchange rate.

In stochastic form, equation (5) would be:

$$s_t = \alpha_{0t} + \alpha_{1t} m_t + \alpha_{2t} y_t + \alpha_{3t} DI_t + \mu_t. \quad (6)$$

The monetary approach implies that $\hat{\alpha}_1$ and $\hat{\alpha}_3$ are greater than zero and that $\hat{\alpha}_2$ is less than zero. Specifically, $\hat{\alpha}_1$ should not be significantly

different than one and $\hat{\alpha}_0$ should not be significantly different than zero. Also, $\hat{\alpha}_2$ represents the (negative) income elasticity of the demand for money and $\hat{\alpha}_3$ represents the (negative) interest semielasticity of the demand for money.

The monetary approach can be tested either through direct estimation of the exchange rate determination equation or through tests of the assumptions (such as purchasing power parity) of the monetary approach (1). The following discussion will focus on direct tests of the monetary approach. Unless otherwise stated, it should be understood that the tests utilized ordinary least squares estimation techniques.

Tests of the monetary approach were conducted by Humphrey and Lawler (13) for the United States/United Kingdom exchange rate and for the United States/Italy exchange rate. M1 for each country was used in the estimations for the money supply variables, and real gross national product for the United States and real gross domestic product for the United Kingdom and Italy were used for the income variables. Treasury bill rates for each country were employed in the United States/United Kingdom equation, and the rates on medium-term government bonds were employed in the United States/Italy equation. Results for each equation were obtained using 18 quarterly observations of the variables from the first quarter of 1973 to the second quarter of 1977. Empirical estimates for the dollar/pound exchange rate were:

$$s = 3.47 + .55m - 1.39y + .22i, \quad (7)$$

(3.84) (4.00) (3.47)

$$D.W. = 1.63, R^2 = .94$$

and estimates derived for the dollar/lira exchange rate were:

$$s = -4.05 + .89m - .58y + .13i, \quad (8)$$

$$(4.98) \quad (1.56) \quad (1.85)$$

$$D.W. = 1.03, \quad R^2 = .95$$

with $i = \ln(I/I^*)$ and all other variables defined as for equation (5). The terms in parentheses represent the t-values of the estimated coefficients.

The results for both equations are generally supportive of the monetary approach, although the coefficients on the United States/Italy income and interest rate variables are not statistically significant. Humphrey and Lawler also tested the United States/United Kingdom exchange rate equation using quarterly observations from the first quarter of 1920 to the fourth quarter of 1924. The results of the estimation for the early 1920s are consistent with the monetary approach except that the coefficient on the income variable is positive and not statistically significant. Humphrey and Lawler did not report the results of any other estimations, but they did admit that attempts to test the monetary approach for other countries using recent data did not yield results as supportive as those for the dollar/pound and dollar/lira exchange rates.

Bilson (2) found strong support for the general monetary approach in a test of the mark/pound exchange rate for the period from June 1970 to August 1977. Bilson used monthly values of West German M2 and United Kingdom M3 for the money supply variables, and values for each country of the seasonally adjusted index of industrial production for the real income

variables. The interest rate differential was proxied by the one-month forward premium (FP).¹ When two-stage least squares techniques were utilized to estimate a monetary model that was composed of an exchange rate determination equation, a price adjustment equation, and an interest rate differential equation, the following results for the first equation were obtained:

$$s = 1.264m - 1.385y + 11.376FP - .425d + 2.027DU, \quad (9)$$

(14.9) (7.1) (3.8) (3.0) (5.3)

$$D.W. = 1.651, R^2(\text{adj.}) = .995.$$

Bilson estimated equation (9) using a weighted Cochrane-Orcutt transformation of his original equation. An intercept term was included in the estimated equation but its value was not reported.

In an attempt to determine the extent of deviations from purchasing power parity, Bilson included the "d" variable in the estimated equation. Bilson set "d" equal to $(\ln(P/P^*) - \ln(S))$ with P and P* proxied by the consumer price index for each country. A value significantly different than zero suggests purchasing power parity did not hold completely for the two countries during the study period. The DU term represents a dummy variable that reflects the impact on the demand for sterling of oil revenue deposits in London. The dummy variable had an initial value of .15 in January 1974 and declined exponentially thereafter.

¹In a related study, Bilson (3) found treasury bill rate differentials to be empirically less satisfactory than the forward exchange premium.

Frankel (8) analyzed the mark/dollar exchange rate between July 1974 and February 1978 using a modified version of the monetary approach. In his estimation, Frankel utilized monthly values of seasonally adjusted M1 for the money supply variables, and monthly values of the seasonally adjusted index of industrial production for the income variables. He employed short-term interest differentials as well as long-term interest differentials in the exchange rate determination equation. Three-month money market rates were used for the short-term interest differential, and long-term government bond rates were used for the long-term differential. The long-term bond rate differential was seen as a proxy for the expected long-run inflation differential. Frankel included both interest rate differentials to capture the short-run liquidity effects and long-run inflationary effects of a change in monetary policy. When instrumental variables for the expected inflation differential were employed in the estimation, and a Fair-type (7) technique was used to correct for first-order serial correlation, the following estimates were derived:

$$e = 1.39 + .97m - .52y - 5.40DI_S + 29.40DI_L^1. \quad (10)$$

((.12))((.21)) ((.22))((2.04)) ((3.33))

Terms in double parentheses are the standard errors of the coefficients, and DI_S and DI_L represent the short-term and long-term interest rate differentials. The results support the monetary approach since all coefficients are significant, carry the anticipated signs, and have values

¹An R^2 and Durbin-Watson were not reported for this estimate.

that are plausible. The results also support the view that when the variation in the inflation differential between countries is moderate (like that for Germany and the United States), the exchange rate will be negatively related to the short-term nominal interest differential, but positively related to the anticipated long-run inflation differential.

Dornbusch (6) found little support for the monetary approach in a similar test of the dollar/mark exchange rate for the period from the second quarter of 1973 to the fourth quarter of 1979. To estimate the exchange rate determination equation, Dornbusch employed quarterly values of seasonally adjusted M1 for the money supply variables, and seasonally adjusted gross national product measured at 1975 prices for the income variables. Dornbusch included interest rate differentials for both short-term and long-term rates in the exchange rate equation. Rates on representative money-market instruments were used for the short-term interest rate variables, and rates on domestic government bonds were used for the long-term interest rate variables. The exchange rate equation was estimated in a number of forms, but the results for the basic equation were:

$$s = 5.76 - .03m - 1.05y + .01DI_S + .04DI_L, \quad (11)$$

$$(2.81) \quad (-.07) \quad (-.97) \quad (1.90) \quad (2.07)$$

$$D.W. = 1.83, R^2 = .33.$$

These results indicate that the monetary approach is an inadequate theory of exchange rate determination for the dollar/mark rate. Neither the coefficient on the money supply term, or the coefficient on the income

term are significant. In addition, the sign of the coefficient on the money supply term is negative, and R^2 is rather low.

Frenkel (9) tested the empirical validity of the monetary approach for the period in the 1920s when exchange rates were flexible. He estimated exchange rate determination equations for the franc/pound and franc/dollar exchange rates using monthly data from February 1921 to May 1925. He employed the Theil-Goldberger mixed-estimation procedure (19) with stochastic restrictions to derive estimates for the franc/pound equation:

$$\begin{aligned}
 s &= .001 + .999\ln(M) - .972\ln(M^*) + .188\ln(Y) \\
 &\quad ((.010)) \quad ((.099)) \quad ((.099)) \quad ((.281)) \\
 &\quad + .926\ln(Y^*) + 3.914FP, \\
 &\quad \quad ((.520)) \quad ((.970)), \\
 D.W. &= 1.86, R^2 = .92
 \end{aligned}
 \tag{12}$$

and for the franc/dollar equation:

$$\begin{aligned}
 s &= .006 + .995\ln(M) - .995\ln(M^*) + .225\ln(Y^*) \\
 &\quad ((.011)) \quad ((.099)) \quad ((.100)) \quad ((.327)) \\
 &\quad - .369\ln(Y^*) + 3.971FP, \\
 &\quad \quad ((.370)) \quad ((.974)) \\
 D.W. &= 1.81, R^2 = .86.
 \end{aligned}
 \tag{13}$$

As before, the terms in double parentheses are the standard errors of the coefficients, FP represents the forward premium on foreign exchange, and the other variables are defined as in equations (1) and (2). None of the

coefficients on the income terms is significant and, with the exception of foreign income in equation (12), none of the income coefficients have the anticipated signs. All of the other coefficients are significant and have the anticipated signs and values.

Clements and Frenkel (5) estimated an exchange rate determination equation for the dollar/pound exchange rate for the same time period in the 1920s. Employing an iterative Cochrane-Orcutt procedure, they derived the following estimates:

$$\begin{aligned}
 s = & -4.297 + .415 \ln \left(\frac{P_T/P_N}{P_T^*/P_N^*} \right) + 1.050 \ln(M) - .044 \ln(M^*) \\
 & ((1.396)) \quad ((.099)) \quad \quad \quad ((.182)) \quad \quad \quad ((.143)) \\
 & + 188y + .363DI, \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad (14) \\
 & ((.066)) \quad ((.350)) \\
 \text{D.W.} = & 1.55, R^2 = .96.
 \end{aligned}$$

The P_T and P_N terms represent the prices of traded and nontraded goods in the United States.

The results give only limited support to the monetary approach. The coefficients on the relative price structure term and the U.S. money supply variable are significant and have the expected signs. However, the coefficients on the United Kingdom money supply variable and the interest rate differential are not significant. The coefficient on the relative income term is statistically significant but it carries a positive sign rather than the anticipated negative sign.

Frenkel (9) also estimated a mark/pound exchange rate equation for the period of German hyperinflation in the 1920s. Frenkel assumed that

changes in the German money supply during the period of hyperinflation would dominate changes in real income and changes in the British money supply, so the latter terms were not included in the estimated equation. Likewise, he assumed that the interest rate differential would be dominated by expectations of German inflation so the forward premium on pounds was employed as a proxy for expectations of future inflation. Frenkel used two-stage least squares following Fair's method to estimate the mark/pound exchange rate for the period from February 1921 to August 1923. The resulting estimates were:

$$s = -6.030 + .970\ln(M) + 3.886FP, \quad (15)$$

$$((1.696)) \quad ((.092)) \quad ((1.131))$$

$$D.W. = 2.56, R^2 = .99.$$

The estimates are strongly supportive of the monetary approach. All of the coefficients are significant, the value of the coefficient on the German money supply variable is close to one, and the semielasticity of the FP term is similar in magnitude to previous estimates of the interest rate semielasticity of the demand for money.

Recent studies by King, Putnam, and Wilford (14) and Lapan and Enders (15) have expanded the basic monetary approach by showing that the variance of a country's money supply, as well as the level of that money supply, will be important determinants of the relative value of that currency. However, the studies reach differing conclusions as to the effect of increased monetary variability on a country's exchange rate. King, Putnam, and Wilford suggest that an increase in the variance of a

country's money supply will cause a depreciation of that country's currency, and Lapan and Enders show that an increase in monetary variability will cause an appreciation of a country's currency.

King, Putnam, and Wilford develop a portfolio adjustment model in which economic agents hold foreign currencies as well as domestic currency in order to satisfy their demand for monetary services. The elasticity of currency substitution in real money demand depends on the degree of integration of world goods and capital markets. Actual currency substitution within a portfolio of currencies occurs with changes in exchange rate expectations and with changes in the degree of uncertainty surrounding those expectations.

King, Putnam, and Wilford propose that an increase in the variance of the domestic money supply will cause an increase in the uncertainty associated with expectations of the future value of the domestic currency. Even though the exchange value of any particular foreign currency is simultaneously becoming more uncertain with respect to the home currency, it is assumed that the exchange value of the foreign currency is unchanged in its perceived variability with respect to other foreign currencies. Therefore, a risk-averse economic agent will reduce the total variance of his or her portfolio by decreasing domestic currency holdings. The portfolio shift away from domestic currency will lead to exchange rate depreciation. King, Putnam, and Wilford believe that increased monetary variability will also increase the need to monitor exchange rates and, thereby, raise the cost of holding the domestic currency in the portfolio.

Lapan and Enders develop a two-country, overlapping generations loan consumption model that explicitly shows how aggregate money and commodity demands arise from the optimizing behavior of economic agents who have rational expectations. Individuals are assumed to live for two periods. The first time period is a work period, the second is a retirement period. Commodities are assumed to be perishable so retired individuals live from accumulated currency holdings. First-generation individuals determine first-period consumption and currency holdings based on current and expected future prices. Since it is assumed that individuals are free to hold currency from either country and that explicit transactions demands do not exist for either currency, individuals must determine the composition as well as the level of their currency portfolio holdings. Lapan and Enders show that if economic agents assign a zero weight to the probability of capital controls, then the ratio of foreign currency to domestic currency in portfolios will be determined by the distributions of the money supplies (as long as output disturbances are not correlated with money supplies).

One of the important implications of the Lapan and Enders model is that in the presence of uncertainty about currency supplies, the equilibrium exchange rate will depend on relative money supplies and on the means and variances of the distributions of the money supplies. In particular, an increase in the variance of the domestic money supply will cause an appreciation of the domestic currency as long as economic agents are not very risk averse.

Within the context of the model, greater variability of the domestic money supply will cause greater variability of real income associated with holdings of the domestic currency. If individuals are not too risk averse, the increased variability of real income will lead to an increase in expected utility. Individuals will accentuate the risk, then, by increasing their holdings of the domestic currency which will cause the currency to appreciate. The result is another application of the principle that some individuals may benefit from price variability.

The Lapan and Enders model and the King, Putnam, and Wilford model both imply the existence of an exchange rate determination equation that has the same general form as one developed within the monetary approach, and in addition has the relative variance of national money supplies as an argument. In the next section, an exchange rate determination equation will be presented which is consistent with the monetary approach but which includes money supply variability as an argument.

MODEL

By modifying equation (5), an exchange rate determination equation can be developed which is suggestive of the ones implied by the Lapan and Enders study and by the King, Putnam, and Wilford study. Letting V represent domestic monetary variability and V^* represent foreign monetary variability, a modified version of the exchange rate equation would be:

$$s = m - c_2y + c_3DI - c_4V + b_4V^*. \quad (16)$$

Equation (16) reflects the Lapan and Enders hypothesis if the parameters c_4 and b_4 are greater than zero, and it reflects the King, Putnam, and Wilford hypothesis if c_4 and b_4 are less than zero. The modified exchange rate equation is generally consistent with the type of exchange rate determination equations implied by both studies. However, it is important to keep in mind that the exchange rate determination equation presented by King, Putnam, and Wilford is based on an aggregate money demand function that is specified a priori. The exchange rate equation developed by Lapan and Enders is derived from a utility-maximizing microeconomic foundation. In addition, in the context of the Lapan and Enders model, V and V^* should be interpreted as unanticipated monetary variability.

Neither Lapan and Enders or King, Putnam, and Wilford assign much importance to relative real income as a determinant of the exchange rate. In the Lapan and Enders model, output uncertainty will not affect the

currency composition of portfolio holdings as long as output disturbances are not correlated with the money supply.

The King, Putnam, and Wilford model implies that it may not be possible to specify a priori the effect of a change in real income on the exchange rate. If economic agents hold many different currencies, an increase in real income in one country may cause an increase in demand for all of the currencies held. The ultimate effect on the exchange rate will depend on the responsiveness of the currency composition of money portfolios to the change in real income.

Lapan and Enders also downplay the importance of nominal interest rate differentials as determinants of the relative value of a currency. This follows from the assumption in their model that money is the only store of value.

Estimation of a modified version of the exchange rate determination equation should provide a means of determining the effect of monetary variability on relative currency values. Since it is not possible to specify "the" variance of a money supply at each moment in time, it seems reasonable to view V and V^* as the expected domestic and foreign monetary variability. Before developing proxies for V and V^* , it is necessary to specify assumptions regarding how individuals form expectations of monetary variability.

One possible assumption is that in the period after the collapse of the Bretton Woods system, individuals were not sure that the money supply process would be stable. If the money supply process is not stable over

time, then the best estimate of current monetary variability might be the variance of the money supply during a recent period.

Another possible assumption is that individuals believed that the money supply process would be stable under a regime of flexible exchange rates. If the money supply process was perceived as stable, then individuals would use all available observations during the flexible rate period in forming their expectations. A proxy for expected monetary variability at a particular point in time might be the actual variance of the money supply from the beginning of the flexible rate period to that particular point.

A final assumption is that individuals have accurate knowledge of the money supply process, but not the variance of the process. Then, an appropriate proxy for V and V^* might be the variance of the forecast errors that arise from the use of the true model of the money supply process. Expectations of monetary variability at a point in time might be the actual variance of the forecast errors from the beginning of the flexible rate period to that point in time.

The first assumption, then, is that individuals do not have information about the stability of the money supply process. The second assumption is that individuals perceive that the money supply process is stable but do not know the process. The third assumption is that individuals know the underlying process that generates the money supply but not its variance.

The next section presents the results of estimates of exchange rate determination equations for the U.S. dollar/Canadian dollar exchange rate.

The results of regressions using each of the three classes of proxies are reported in separate subsections along with a description of how each proxy was constructed.

RESULTS

The United States/Canada exchange rate equations were estimated in the form:

$$s_t = \beta_{0t} + \beta_{1t}m_t + \beta_{2t}y_t + \beta_{3t}I_t + \beta_{4t}I_t^* + \beta_{5t}V_t + \beta_{6t}V_t^* + \mu_t \quad (17)$$

with all variables defined as in equations (1), (2), (5), and (16). All equations were estimated using quarterly data for the period from the first quarter of 1974 through the fourth quarter of 1979. All regressions were made using ordinary least squares techniques.

In other studies of the monetary approach, researchers have employed both seasonally adjusted money aggregates and seasonally unadjusted aggregates. Hodrick (12) believes that seasonally unadjusted money supplies should be used in estimating exchange rate determination equations. According to his argument, central banks may recognize that the demand for money has a seasonal component, and they may adjust their money supplies to compensate for the seasonal change in demand for money. If such an adjustment is made by central banks, then the seasonally unadjusted money stocks would correspond more closely to the true money demand functions, and hence to the exchange rate. On the other hand, rational agents may discount the seasonal component of the money supply in which case seasonally adjusted monetary aggregates should be used in estimating exchange rate equations.

Most of the equations in this study were estimated using both seasonally adjusted and unadjusted M1. The results usually did not indicate a clear-cut superiority of one or the other so the estimates are presented for both.

United States gross national product measured in 1972 dollars, and Canadian gross national product measured in 1971 Canadian dollars were used for the real income variables. Representative money market rates were used for the nominal interest rate variables. Proxies for V and V* were based on assumptions regarding how economic agents form expectations of monetary variability.

Money supply, income, and exchange rate data were drawn from Organization for Economic Cooperation and Development publications (11, 17). Interest rate data was obtained from Morgan Guaranty publications (20). All observations were at or near the end of the quarter.

Before reviewing specific results, a number of points should be made. The first is that the estimates were supportive of the monetary approach with the exception that the sign of the estimated coefficient on "I" was negative (in every equation in which the coefficient was significant). Also, the sign of the estimated coefficient on I* was positive. These results indicate that an increase in U.S. (Canadian) nominal interest rates will cause an appreciation (depreciation) of the exchange rate. This is contrary to the expectations of the general monetary approach but is consistent with Frankel's (8) version.

The explanation for the results lies in the fact that the U.S. and Canadian economies are highly integrated, and the variation in the

inflation differential between the two countries is relatively small (8). If inflationary expectations are similar, then the nominal interest rate differential will reflect differences in real interest rates. Higher real interest rates in the U.S. will induce short-term capital inflows which will tend to appreciate the exchange rate.

The second point that should be made is that the Durbin-Watson statistic for each regression lies in its indeterminate range. A convenient method for determining whether autocorrelation is serious in regressions with small samples has been suggested by Rao and Griliches (18). They propose that for sample sizes of 20 it is not necessary to correct for autocorrelation as long as the estimated first-order autocorrelation coefficient is less than .30 (16). Using that as a rough guide, only equation (24) is suspect. For each regression other than equation (24), the estimated first-order autocorrelation coefficient (not reported) is less than .30. The first-order autocorrelation coefficient estimated for equation (24) is .306. However, when the ordinary least squares residuals for equation (24) were regressed on their one-period lagged values, the t-value of the autocorrelation coefficient was not significant even at the .10 significance level.

Finally, it should be noted that an F-test of the joint hypothesis that the intercept is not significantly different than zero and the value of the coefficient on the money supply variable is not significantly different than one was conducted for each regression. An F-statistic larger than the .05 significance value would indicate that the joint hypothesis should be rejected. The F-statistic for the estimated

equations was larger than its critical value only for equations (20), (24), and (28).

Results for the First Class of Proxies

The first class of proxies for V and V^* to be employed in the regressions were developed on the assumption that economic agents form expectations regarding monetary variability based on recent variability. A proxy that was used for expected monetary variability at the end of each quarter was the normalized standard deviation of the past six monthly values of the money supply. The normalized standard deviations of the past nine, and the past twelve, monthly values of the money supply were also employed in alternate estimates of the exchange rate determination equation.

Table I-1 gives the results of the regressions.

The variables NS, NN, and NT represent the normalized standard deviation of the past six, nine, and twelve monthly values of the U.S. money supply. The "F" listed beside R^2 in each equation gives the value of the F-statistic for that equation. A superscript "A" indicates that seasonally adjusted money supply values were used in that equation.

Equation (18) gives results that are strongly supportive of the Lapan and Enders version of the monetary approach. The coefficients on the monetary variability proxies are significant and have the signs predicted by the Lapan and Enders model. The coefficient on relative money supplies is strongly significant and close to its expected value of one. The estimated coefficient on the U.S. interest rate variable is significant and is plausible as a value of the interest semielasticity of the demand

Table I-1. Results when monetary variability for each quarter is proxied by the normalized standard deviation of the money supply during the previous six, nine, or twelve months^a

$$s = -.30 + .92m - .91y - 1.50I + .52I^* - 7.15NS + 1.76NS^* \quad (18)$$

(-.19) (6.05) (-1.65)(-2.42) (.79) (-3.30) (2.55)

$$D.W. = 1.48, R^2 = .896, F = .62, SEE = .0129$$

$$s = -.03 + .80m - .89y - 1.45I + .74I^* - 5.39NN + 1.23NN^* \quad (19)$$

(-.02) (3.85) (-1.37)(-2.03) (.99) (-2.10) (1.27)

$$D.W. = 1.54, R^2 = .867, F = 1.12, SEE = .0165$$

$$s = -1.64 + .77m - .17y - 1.96I + 1.32I^* - 6.83NT + .40NT^* \quad (20)$$

(-.81) (5.02) (-.23) (-2.74) (1.71) (-2.85) (.54)

$$D.W. = 1.39, R^2 = .877, F = 3.99, SEE = .0152$$

$$s = -1.08 + 1.07m^A - .81y - 2.30I + 1.63I^* - .97NS^A + .54NS^A^* \quad (21)$$

(-.57) (5.25) (-1.31) (-3.17) (2.30) (-.33) (.67)

$$D.W. = 1.75, R^2 = .887, SEE = .0140$$

^aAn F-test was not performed for equation (21).

for money. Multiplying the coefficient on "I" by its mean value over the sample period (.08) gives an interest rate elasticity of .12. The estimated coefficients on relative income and the Canadian interest rate are not significant at the .05 level.

Equations (19) and (20) were estimated using nine-month and twelve-month proxies for monetary variability. The results for both equations are similar to those for equation (18) except that the coefficients on NN* and NT* are not significant. In addition, the coefficient on the U.S. interest rate variable in equation (19) is significant only at the .06 significance level. Equation (19) is especially interesting in terms of the Lapan and Enders model since the results for (19) imply that the exchange rate is determined only by relative money supplies and U.S. monetary variability.

In this set of estimates, the seasonally unadjusted money supply data yielded better results than the seasonally adjusted values. When seasonally adjusted data were employed in the regressions, none of the monetary variability proxies was significant at the .05 level. Equation (21) is listed for comparison purposes with equation (18). The other estimates are not reported.

Assuming that expectations regarding monetary variability are based on recent monetary variability, an alternative proxy might be the variance of the rate of growth of the money supply over a recent period of time. Table I-2 gives the results of regressions that were performed using the variance of the rate of growth of the money supply over the past six,

Table I-2. Results when monetary variability for each quarter is proxied by the variance of the rate of growth of the money supply during the previous six, nine, or twelve months

$$s = 1.82 + .72m - 1.61y - 1.26I + .92I^* - 40.94VS + 10.29VS^* \quad (22)$$

(.81) (3.42) (-2.16) (-1.24) (.91) (-.70) (.32)

$$D.W. = 1.56, R^2 = .822, F = .95, SEE = .0220$$

$$s = 2.90 + .60m - 1.92y - .54I + .32I^* - 97.82VN + 56.59VN^* \quad (23)$$

(1.40) (2.70) (-2.84) (-.52) (.32) (-.86) (1.44)

$$D.W. = 1.59, R^2 = .837, F = 1.64, SEE = .0202$$

$$s = 2.17 + .35m - 1.28y + .04I + .28I^* - 607.48VT + 47.79VT^* \quad (24)$$

(1.35) (1.77) (-2.24) (.05) (.38) (-3.04) (1.21)

$$D.W. = 1.36, R^2 = .887, F = 5.85, SEE = .0140$$

$$s = .33 + .92m^A - 1.23y - 1.82I + 1.26I^* - 989.64VS^A + 36.81VS^{A*} \quad (25)$$

(.20) (5.19) (-2.24) (-2.74) (1.84) (-1.68) (.90)

$$D.W. = 1.84, R^2 = .901, F = .13, SEE = .0122$$

$$s = -.21 + .94m^A - 1.02y - 1.92I + 1.33I^* - 866.99VN^A + 61.83VN^{A*} \quad (26)$$

(-.10) (4.37) (-1.49) (-2.78) (1.82) (-.94) (.92)

$$D.W. = 1.71, R^2 = .894, F = .22, SEE = .0132$$

$$s = -2.47 + 1.08m^A - .24y - 2.21I + 1.18I^* - 735.92VT^A$$

(-.93) (4.71) (-.26) (-3.45) (1.39) (-.57)

$$+ 164.38VT^{A*} \quad (27)$$

(1.49)

$$D.W. = 1.54, R^2 = .901, F = .81, SEE = .0123$$

nine, and twelve months as proxies for the end-of-quarter expected monetary variability.

The variables VS, VN, and VT represent the variance of the past six, nine, and twelve monthly growth rates for the U.S. money supply. In general, the results are not as strong when the variance of the growth rate is used as a proxy.

None of the interest rate variables or monetary variability proxies in equations (22) and (23) are statistically significant. The coefficient on VT in equation (24) is significant, but the coefficient on relative money supplies in (24) rather low, and is significant only at the .10 significance level. The coefficient on relative income is significant in each of the three equations.

The use of seasonally adjusted money supply data does not improve the results with respect to the monetary variability proxies. The t-value for VS^A in equation (25) indicates that the coefficient is significant at the .12 level. The t-values for the other money supply proxies in equations (25), (26), and (27) are even lower.

The major difference between equations (22)-(24) and equations (25)-(27) is that the coefficient on the U.S. interest rate variable is significant in each of the latter three equations. The estimated coefficient on the U.S. interest rate variable in equations (25), (26), and (27) implies an interest rate elasticity of .15 for equations (25) and (26), and an elasticity of .18 for equation (27). Also, the coefficient on relative income is not significant in equations (26) and (27).

Results for the Second Class of Proxies

Alternate assumptions regarding how individuals view the money supply process lead to different proxies for expected monetary variability. If individuals believe the money supply process is stable, but do not know the process that generates the money supply, then they may make use of all observations of the money supply in forming their views of monetary variability. Under this assumption, a proxy for monetary variability might be the normalized standard deviation of all past values of the money supply from the beginning of the flexible rate period to the current period.

Somewhat arbitrarily, March 1973 was chosen as the start of the study period. Therefore, the value of the proxy for expected monetary variability at the end of the first quarter of 1974 was the normalized standard deviation of the monthly values of the money supply from March 1973 to the end of the first quarter of 1974. The value of the proxy for expected monetary variability at the end of the second quarter of 1974 was the normalized standard deviation of the monthly values of the money supply from March 1973 to the end of the second quarter of 1974. Thus, all available observations from the start of the study period were used to calculate values for expected monetary variability. Table I-3 gives the results of regressions using the new proxies.

The variable NC represents the normalized standard deviation of the U.S. money supply from March 1973 to the end of each consecutive quarter. The final value of NC is the actual normalized standard deviation of the monthly values of the U.S. money supply during the study period. Thus,

Table I-3. Results when monetary variability for each quarter is proxied by the normalized standard deviation of the money supply for all observations from the beginning of the study period to the end of each consecutive quarter

$$s = 1.50 + .35m - 1.08y + .61I + .21I^* - 4.64NC + 2.48NC^* \quad (28)$$

(1.26) (1.87) (-2.06) (.72) (.30) (-3.47) (2.24)

$$D.W. = 1.49, R^2 = .942, F = 6.17, SEE = .0072$$

$$s = .38 + .56m^A - .86y - .005I + .54I^* - 4.12NC^A + 2.33NC^{A*} \quad (29)$$

(.32) (2.36) (-1.91) (-.007) (.90) (-3.54) (2.48)

$$D.W. = 1.66, R^2 = .948, F = 1.86, SEE = .0064$$

the quarterly estimates of monetary variability converge to the actual variability of the money supply during the study period.

The results indicate that these monetary variability proxies are important determinants of the exchange rate. As suggested by the Lapan and Enders model, an increase in U.S. monetary variability will cause an appreciation of the exchange rate, and an increase in Canadian monetary variability will cause a depreciation of the exchange rate.

The results are slightly better when the exchange rate equation is estimated using seasonally adjusted money supply data. The coefficients on the interest rate variables are not significant in either equation (28) or (29). The coefficient on relative money supplies is significant in equation (29). The coefficient on the money supply variable in equation (28), and the coefficient on the income variable in equation (29), are both significant only at the .08 significance level. The t-value of the coefficient on relative income in equation (28) is just below the .05 critical value.

Under the assumption that expectations regarding monetary variability at a point in time are based on actual monetary variability from the beginning of the relevant period to that point in time, an alternate proxy might be the variance of the rate of growth of the money supply during the relevant period. The "variance of the rate of growth" proxies were developed using the same starting point as above. Thus, the value of the proxy for expected monetary variability at the end of the first quarter of 1974 was the variance of the monthly growth rates of the money supply from March 1973 to the end of the first quarter of 1974. The value of the

proxy at the end of the second quarter of 1974 was the variance of the monthly growth rates of the money supply from March 1973 to the end of the second quarter of 1974. All available observations from the start of the relevant period were used to calculate the values of expected monetary variability. Table I-4 shows the estimates derived using the variance of the rate of growth of the money supply as an alternative proxy for monetary variability (assuming individuals use all available observations to form expectations of monetary variability).

The variable VC represents the variance of the monthly rates of growth of the U.S. money supply from March 1973 to the end of each consecutive quarter. The final value of VC is the actual variance of the rate of growth of the U.S. money supply during the study period. Thus, the quarterly estimates of monetary variability converge to the actual variability of the rate of growth of the money supply during the study period.

The results are not quite as good when the variance of the rate of growth of the money supply is used instead of the normalized standard deviation of the money supply. The coefficients on relative money supplies and relative incomes in equation (30) are both significant. However, none of the coefficients on the interest rate variables or monetary variability proxies is significant at the .05 level.

The results were improved when equation (30) was estimated in a slightly different form. Equation (30') indicates that the coefficient on U.S. monetary variability is significant at the .06 significance level.

Table I-4. Results when monetary variability for each quarter is proxied by the variance of the rate of growth of the money supply for all observations from the beginning of the study period to the end of each consecutive quarter

$$s = 2.71 + .58m - 1.75y - .66I + .65I^* - 948.91VC + 110.80VC^* \quad (30)$$

(1.25) (3.01) (-2.27) (-.71) (.74) (-1.86) (.62)

$$D.W. = 1.58, R^2 = .848, F = 2.45, SEE = .0188$$

$$s = 2.75 + .58m - 1.76y - .65DI - 953.94VC + 111.81VC^* \quad (30')$$

(1.46) (3.43) (-2.58) (-.77) (-2.04) (.65)

$$D.W. = 1.58, R^2 = .848, F = 3.14, SEE = .0188$$

$$s = -1.29 + 1.06m^A - .72y - 1.88I + 1.30I^* - 3407.12VC^A$$

(-.66) (3.62) (-1.27) (-2.74) (1.73) (-.64)

$$+ 403.52VC^{A*} \quad (31)$$

(1.52)

$$D.W. = 1.57, R^2 = .901, F = .38, SEE = .0122$$

$$s = -1.77 + 1.18m^A - .69y - 1.79I + 1.11I^* - 443.87DV^A \quad (31')$$

(-1.01) (6.70) (-1.24) (-2.74) (1.69) (-1.77)

$$D.W. = 1.67, R^2 = .900, F = .58, SEE = .0124$$

The coefficients on relative money supplies and the U.S. interest rate in equation (31) are statistically significant. None of the coefficients on the other variables is significant at the .05 level. An estimated value of -1.88 for the U.S. interest rate variable implies an interest rate elasticity of .15.

An F-test of the hypothesis that $VC^A = VC^{A*}$ was conducted for equation (31). The resulting F-statistic of .52 indicates that the hypothesis cannot be rejected at the .05 significance level. When equation (31') was estimated with $DV^A = VC^A - VC^{A*}$, the estimated coefficient on the DV^A term was found to be significant at the .10 level.

Results for the Third Class of Proxies

The third alternative assumption made regarding the formation of expectations of monetary variability is that individuals know what the money supply process is (but not what its variance is). Expectations of monetary variability will be based on the variance of the forecast errors that arise from the use of the true model of the money supply process.

The first step in developing the new proxy for expected monetary variability is to determine what the actual money supply process was during the study period. The method used to identify the money supply process was a Box-Jenkins (4) time series analysis of the U.S. and Canadian money supplies using seasonally adjusted monthly data for the period January 1973 to December 1979.

Second differences of the original money supply values for both series were taken to achieve stationarity. Autocorrelation functions and

partial autocorrelation functions were then estimated for both samples. An examination of the correlograms and partial correlograms indicated that the U.S. series was generated by a first-order moving-average process, and that the Canadian series was generated by a second-order autoregressive process. When the processes were estimated, the following least squares estimates were obtained:

$$z_t - \bar{z} = \epsilon_t - \frac{.99594}{(20.68)} \epsilon_{t-1}, \quad (32)$$

Q = 20.91 (23 degrees of freedom),

$$z_t^* = \frac{-.53493}{(-5.26)} z_{t-1}^* - \frac{.43737}{(-4.28)} z_{t-2}^* + \epsilon_t^*, \quad (33)$$

Q = 19.78 (22 degrees of freedom),

where $z_t = M_t - 2M_{t-1} + M_{t-2}$, and "Q" is the chi-square statistic. The terms in parentheses are t-statistics.

The U.S. money supply working series was centered about its sample mean before being estimated ($\bar{z} = .0268293$). Later, when forecasts were made, the sample mean of the working series was added back in.

The reported chi-square statistics are consistent with the hypothesis that the residuals for each model are white noise. In fact, the hypothesis of random residuals cannot be rejected even at the .50 significance level.

Once again, March 1973 was assumed to represent the beginning of the relevant period for study. Starting at that point, the models were used

to make one-month-ahead forecasts of the money supply. The values of the proxies for expected monetary variability were determined for each quarter by taking the standard deviation of the values of all the monthly forecast errors to the end of the quarter. This methodology is based on the strong assumption that at the beginning of the relevant period all individuals knew the true model of the money supply process. An alternate assumption might be that individuals developed a progressively better idea of what the money supply process was as more information became available during the study period. The second assumption was not explored in this study.

When the standard deviation of the monthly forecast errors was used as a proxy for monetary variability, the following results were derived:

$$s = -.15 + .71m^A - .75y - 1.83I + 1.55I^* - .17SR^A + .32SR^{A*}, \quad (34)$$

$$(-.08) \quad (2.17) \quad (-1.46) \quad (-2.93) \quad (2.26) \quad (-2.18) \quad (1.08)$$

$$D.W. = 1.43, R^2 = .913, F = 1.07, SEE = .0108.$$

The variable SR^A represents the standard deviation of the monthly forecast errors generated by using equation (32) to predict monthly levels of the U.S. money supply. The value of the proxy at the end of any quarter is the standard deviation of the monthly forecast errors from the beginning of the study period to the end of that quarter. The final value of SR^A is the standard deviation of all of the monthly forecast errors during the study period. Thus, the quarterly estimates of monetary variability converge to the actual (conditional) variability of the U.S. money supply during the study period.

The results again support the Lapan and Enders version of the monetary approach. The coefficient on the proxy for U.S. monetary variability is negative and significant at the .05 level. The coefficient on relative money supplies and the coefficients on the interest rate variables are also statistically significant at the .05 level. The coefficients on the interest rate variables both imply interest elasticities of .15 (when the coefficient on the Canadian interest rate variable is multiplied by its mean value of .0969 and when the coefficient on the U.S. interest rate variable is multiplied by its mean value of .08).

If individuals are assumed to understand the process that generates the money supply (but not the variance of the process), then an alternative proxy for expected monetary variability might be the variance of the forecast errors generated by using a true model of the rate of growth of the money supply. A time series analysis was conducted to determine the process that generates the rate of growth of each money supply. Then, a series of values for each new proxy was developed.

The time series analysis made use of seasonally adjusted monthly values of the U.S. and Canadian money supplies for the period January 1973 to December 1979. Before beginning the analysis, the monthly data was converted to monthly rates of growth. After converting to rates of growth, the Canadian series was stationary. However, first differences of the U.S. growth rate series were needed to achieve stationarity.

Sample autocorrelation and partial autocorrelation functions were estimated for both working series. An examination of the correlograms and partial correlograms indicated that the U.S. series was generated by a

first-order moving-average process, and that the Canadian series was generated by a second-order moving-average process. When the processes were estimated, the following least squares estimates were derived:

$$g_{M_t} - g_{M_{t-1}} = .00003 + \varepsilon_t - .9916 \varepsilon_{t-1}, \quad (35)$$

Q = 22.24 (22 degrees of freedom),

$$g_{M_t}^* = .00744 + .16278 \varepsilon_{t-1}^* - .20839 \varepsilon_{t-2}^*, \quad (36)$$

Q = 18.60 (21 degrees of freedom),

where $g_{M_t} = (M_t - M_{t-1})/M_{t-1}$.

The chi-square statistics are consistent with the hypothesis that the residuals for each model are white noise. The hypothesis of random residuals cannot be rejected for the U.S. model even at the .40 level, and the null hypothesis of random residuals cannot be rejected for the Canadian model even at the .60 level.

March 1973 was assumed to be the beginning of the relevant period for study. Starting at that point, the models were used to make one-month-ahead forecasts of the rate of growth of the money supplies. The values of the proxies for expected monetary variability were determined for each quarter by taking the variance of the forecast errors of the rate of growth of the money supplies from the beginning of the study period to the end of each consecutive quarter. When the variance of the forecast

errors in the growth rates was used as a proxy for monetary variability, the following results were obtained:

$$\begin{aligned}
 s = & -1.65 + 1.13m^A - .67y - 1.81I + 1.16I^* - 2995.48VR^A \\
 & (-.83) \quad (3.87) \quad (-1.16) \quad (-2.58) \quad (1.48) \quad (-.56) \\
 & + 549.66VR^{A*}, \\
 & \quad (1.66)
 \end{aligned} \tag{37}$$

D.W. = 1.58, $R^2 = .903$, $F = .43$, $SEE = .0120$.

The variable VR^A represents the variance of the monthly forecast errors generated by using equation (35) to predict monthly monetary growth rates for the United States. The value of the proxy at the end of any quarter is the variance of the monthly forecast errors from the beginning of the study period to the end of that quarter. The final value of VR^A is the variance of all of the monthly forecast errors during the study period. Thus, the quarterly estimates of monetary growth variability converge to the actual (conditional) variability of the rate of growth of the U.S. money supply during the study period.

The results are not as strong when the variance of the "rate of growth" forecast errors is used. Equation (37) indicates that the exchange rate depends only on relative money supplies and U.S. interest rates. None of the coefficients on the other variables is significant at the .05 level.

An F-test of the hypothesis that $VR^A = VR^{A*}$ was conducted for equation (37). The resulting F-statistic of .45 indicated that the hypothesis could not be rejected at the .05 significance level. When

equation (37) was estimated with $DVR^A = VR^A - VR^{A*}$, the following results were derived:

$$s = -2.03 + 1.23m^A - .64y - 1.72I + .99I^* - 589.32DVR^A, \quad (37')$$

(-1.15) (6.66) (-1.14) (-2.62) (1.47) (-1.89)

$$D.W. = 1.67, R^2 = .902, F = .79, SEE = .0122.$$

The coefficient on DVR^A in equation (37') is significant at the .08 significance level. The other results are very similar to those obtained in equation (37).

CONCLUSIONS

The empirical findings of this study are broadly supportive of the Lapan and Enders version of the monetary approach. In particular, the results indicate that an increase in U.S. monetary variability will cause an appreciation of the U.S. dollar/Canadian dollar exchange rate. This result is consistent for a number of specifications of expected monetary variability. The results are generally better when monetary variability proxies are based on money supply levels rather than rates of growth.

The findings were not as strong for Canadian monetary variability as they were for U.S. monetary variability. The coefficient on the proxies for expected Canadian monetary variability was statistically significant at the .05 level in only a few equations. The coefficient on the proxies for Canadian monetary variability did carry a positive sign in all of the regressions.

No support can be drawn from this study for the King, Putnam, and Wilford hypothesis about the effect of monetary variability on the exchange rate. On the basis of these results the King, Putnam, and Wilford hypothesis, as it applies to the U.S./Canadian exchange rate, must be rejected.

The results are supportive of the monetary approach to exchange rate determination. Various estimates of the U.S./Canada exchange rate equation indicate that relative money supplies and U.S. nominal interest rates are important determinants of the exchange rate. The estimated coefficient on the U.S. interest rate variable did carry a negative sign,

probably due to the similarity of inflationary expectations in both countries.

In general, the results of this study suggest that exchange rate predictions made from monetary models will be improved by taking account of monetary variability. The results also support the belief that monetary variability has important economic effects. To avoid unintended consequences of policy, decisionmakers must consider the degree of monetary variability attendant with a particular monetary policy.

The R^2 's for most of the estimated equations are comparable to ones derived by Humphrey and Lawler (13) and Frenkel (9) in estimates of exchange rate determination equations for other exchange rates. Humphrey and Lawler believe that these types of models would yield even higher R^2 's if exchange rates were completely flexible. Periodic government intervention in foreign exchange markets may reverse the direction of causality between money supplies and exchange rates, leading to a violation of the assumption of money supply exogeneity. The results of these types of studies may also suffer to the extent that short-run data is being used to test a long-run equilibrium model. Finally, it is possible that some other aggregate exists which would serve as a better proxy for expected monetary variability than the ones employed in this study.

This study focused on one pair of countries in order to conduct a comprehensive test of alternative proxies for expected monetary variability. The next step is to apply the methodology developed here to the analysis of other exchange rates.

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SECTION II. THE EURODOLLAR MARKET:
THEORY AND EVIDENCE

The Eurodollar market is a global market for the trading of dollar-denominated deposits that are booked with banks located outside of the United States, including foreign branches of U.S. banks. The market has grown very rapidly since its inception in the late 1950s, and it is now the primary avenue for international short-term capital movements (12).

Its rapid growth has been the source of much controversy within the economics profession. Writers such as Friedman (6) and Bell (2) have proposed that the large expansion of Eurodollar deposits is the result of a multiple deposit expansion process similar to that which occurs in a domestic banking system. Other economists view Eurodollar bankers more as auctioneers of short-term capital than as analogues of government-regulated domestic bankers. Freedman (5) and Hewson and Sakakibara (8, 9) believe that the highly competitive and virtually unregulated Eurodollar market more closely resembles a perfectly competitive financial market than a domestic credit market.

Empirical tests of the two opposing viewpoints were conducted for the Eurodollar market during the period when the major industrial countries maintained fixed exchange rates. Makin's (18) test of the fractional reserve banking model and Hewson's and Sakakibara's (8) test of the perfectly competitive banking model reached differing conclusions about the Eurodollar market.

The purpose of this study is to develop a model of the Eurodollar market that corresponds more closely to the current international finance

structure than the previous paradigms. The model is then tested for the period of flexible exchange rates that followed the collapse of the Bretton Woods system.

LITERATURE REVIEW

A Eurodollar is a dollar-denominated deposit liability of a commercial bank located outside of the United States, including foreign branches of U.S. banks. Eurodollars are created when an economic entity removes funds from an account with a U.S. bank and deposits them in a "dollar" account of a foreign bank, or when the economic entity trades foreign currency for dollars in the foreign exchange market and then deposits the dollars with a foreign bank. Dollar banking activity outside of the U.S. is concentrated in Western Europe, primarily the London money market. However, major dollar markets are also located in Canada, Singapore, Japan, Bahrain, and the Bahamas (31).

Eurodollar deposits consist mainly of short-term time deposits. As of November 1979 about 23 percent of all Eurocurrency deposits in United Kingdom-based Eurodollar banks were in the less than eight-day maturity range, 47 percent were in the eight-day to three-month range, and 26 percent were in the three-month to one-year range (26).

The primary sources of dollar balances that go into the Eurodollar market are large corporations, foreign commercial banks, central banks, and international organizations such as the Bank for International Settlements (13). Originally central banks were the most important source of funds to the Eurodollar market, holding in 1962 about two-thirds of all Eurodollar deposits (15). Since then, corporations have become the predominate sources of funds (13), although central bank holdings of Eurodollars are still substantial (31).

Borrowers of the dollar claims deposited with Eurodollar banks are primarily other Eurodollar banks and corporations. Some Eurodollar banks act only as intermediaries between Eurodollar banks (15).

The emergence of the Eurodollar market in the late 1950s can be traced to three events. The first was an attempt by the Soviet Union and other Eastern European countries to protect their dollar assets in the event of heightened tensions with the United States. To guard against a possible freeze or confiscation of their dollar accounts, these countries transferred their dollar balances from U.S. commercial banks to banks in London and Paris (13).

The second event which helped to create the Eurodollar market was the sterling crisis of 1957 which prompted the British authorities to prohibit the use of sterling in financing nonsterling trade. British bankers responded to the ban by offering dollar loans in place of sterling loans, and since London was one of the major financial centers for international trade, this created a considerable demand for dollar deposits. The final event which enabled the Eurodollar market to develop occurred in 1958 when the major European countries made their currencies freely convertible into the dollar (15).

The development of the Eurodollar market was enhanced in the 1960s by U.S. government policies aimed at correcting U.S. balance of payments deficits. Concern with capital account deficits prompted U.S. authorities to enact a number of restrictions on U.S. foreign investment. The 1963 Interest Equalization Tax restricted the access of borrowers in overseas industrialized countries to the U.S. capital market by placing a levy on

the sale of foreign bonds and equities in the U.S. The 1965 "voluntary" credit restraint program asked banks and nonbanks to limit their overseas lending, and the 1968 mandatory program forced multinational corporations to look for dollar financing outside of the U.S. All of these programs forced European corporations and U.S. subsidiaries to turn to the Euro-dollar market for dollar financing of investment (22).

Federal Reserve credit tightening and time deposit interest rate ceilings also spurred the growth of the Eurodollar market in the late 1960s. In 1966, and again in 1969, Federal Reserve credit restriction caused interest rates to rise sharply. As nominal rates rose above Regulation Q ceilings, banks could not compete for funds and the large New York banks experienced a runoff of certificates of deposit as multinational corporations switched their deposits to the Eurodollar market. The large New York banks then borrowed back these funds from the Euro-dollar market, usually operating through their foreign branch offices. At that time, the Eurodollar market was a very attractive source of funds for U.S. banks since there was no reserve requirement on Eurodollar borrowings and because the Eurodollar market offered funds with maturities similar to the CDs they replaced (13).

On a more theoretical level, Swoboda (27) attributed the early growth of the Eurodollar market to a more or less conscious effort by European banks to bid away some of the denomination rents that accrued to the U.S. banking system under the fixed exchange rate system because of the ability of U.S. banks to offer liabilities that were accepted as the key international currency. The Eurodollar market in this analysis would be seen

by Eurodollar banks as a means of breaking the monopoly of American banks on dollar financial transactions.

The Eurodollar market has been able to compete with the U.S. banking system for dollar-denominated financial assets and liabilities by offering potential investors rates of return on Eurodollar investments that are higher than those on other comparable investments, and by offering borrowers credit on more favorable terms than could be arranged elsewhere (13). In order to offer investors higher rates of return and borrowers lower loan rates, Eurodollar banks must operate on much narrower margins than other commercial banks. For Eurodollar transactions between prime Eurodollar banks, the margin is usually between 1/4 and 1/32 percent. Eurodollar banks are able to operate on such narrow margins because transactions are large-scale and borrowers are large, widely-recognized economic entities (hence affording low default risk), and because there are typically no (or very low) reserve requirements on Eurodollar deposits (15).

The self-imposed reserve ratio for Eurodollar deposits may be as low as one or two percent (24). There are four basic reasons why such small reserves are held against Eurodollar deposits. First, banks that offer Eurodollar accounts are large banks with considerable domestic assets. Second, Eurodollar banks all have lines of credit established with correspondent banks in the U.S. Third, the extensive Eurodollar market is itself a ready source of funds. Finally, there is a high degree of matching of Eurodollar assets and liabilities in terms of maturity and

since the bulk of deposits are time deposits Eurodollar banks do not face significant stochastic reserve losses (13).

It seems likely that the major role played by the U.S. balance of payments deficits in the development of the Eurodollar market was the provision of enough international liquidity so that the post-war exchange controls could be removed. There is little empirical relation between the rate of growth of the Eurodollar market and the U.S. balance of payments deficits. One can point to the rapid growth of the Eurodeutsche mark market during a time in which the West German balance of payments was in a strong surplus position to illustrate the fact that a balance of payments deficit is not necessary for the development of any particular Euro-currency market (4).

Mayer (21) believes that the U.S. balance of payments deficits actually slowed the growth of the Eurodollar market since they reduced confidence in the dollar. If the U.S. balance had been in surplus, then credit would have been tighter in foreign countries, leading to a dollar flow from the U.S. through the Eurodollar market to other countries.

The effective exercise of oil cartel power in 1974 and the concomitant oil price increases also enhanced the growth of the Eurodollar market since a large volume of dollars accrued to OPEC members who had a strong preference for short-term investments. The Eurodollar market with its high deposit rates and freedom from regulations became a key recipient of OPEC funds (22).

Even though the development of the Eurodollar market was clearly enhanced by inadvertent U.S. government policies and by the ability of

Eurodollar banks to attract funds by operating on narrow margins, Euro-dollar deposits grew so rapidly that it led economists to question whether the growth of the Eurodollar market could be attributed in part to multiple credit expansion within the Eurodollar banking system. In 1960, total Eurodollar deposit liabilities measured one billion dollars. During the next ten years, Eurodollar deposits grew at a rate of approximately 50 percent per annum (15), and during the 1970s at an average annual growth rate of about 30 percent. By the fourth quarter of 1981, gross Eurodollar deposits totaled approximately 1,350 billion dollars (31).

Two of the earliest writers to use the multiple credit expansion model were Bell (2) and Friedman (6). Both writers believed that the Eurodollar market could create credit by a process directly analogous to credit creation in the U.S. banking system, implying that the rapid growth of the Eurodollar market was the result of multiple deposit expansion in a fractional reserve banking system.

As Friedman explained it, Eurodollar deposit creation began when an economic entity, say a corporation, transferred funds from an account with a U.S. bank to a dollar account with a foreign bank. If the amount of the transfer was \$1 million, then that amount would be credited to the corporation's account with the foreign bank, and the foreign bank would hold a \$1 million claim in the form of a deposit liability of a U.S. bank. Since the foreign bank needed to hold only a fraction of the deposit as reserves the bank had excess dollars to loan out. If the foreign bank held reserves that amounted to ten percent of Eurodollar deposits then it would be able to make \$900,000 worth of loans.

Now assume that the foreign bank loaned out the \$900,000 to a second corporation. This it would do by transferring ownership of \$900,000 of the deposit liability of the U.S. bank to the second corporation. Assume further that the corporation used the claim to purchase \$900,000 worth of goods from a third corporation, and that the third corporation deposited the claim on the U.S. bank with a second Eurodollar bank.

At this stage in the credit creation process \$1,900,000 worth of Eurodollar deposit liabilities have been created--\$1,000,000 held by the first corporation and \$900,000 held by the third corporation. Notice also that if all participants in the chain of transactions have accounts at the same U.S. bank, then the U.S. bank's overall balance sheet has not been affected. Instead of \$1,000,000 of demand deposit liabilities owed to the first corporation, it has \$100,000 of deposit liabilities owed to the first Eurodollar bank and \$900,000 of deposit liabilities owed to the second Eurodollar bank. Unless the legal reserves that the U.S. bank must hold against demand deposits are affected by who owns the deposits, then the U.S. money supply will not be affected. However, the world supply of dollars net of interbank deposits has increased by \$900,000 and the second Eurodollar bank has excess dollar reserves with which it can extend more dollar-denominated loans.

In this simple example, the Eurodollar-creation process will continue until someone who receives a Eurodollar loan deposits the dollars with a U.S. bank, or transfers the dollars to someone else who deposits them with a U.S. bank. The Eurodollar deposit creation process as described by

Friedman is, thus, directly analogous to the textbook illustration of the working of a two-stage banking system.

Following Niehans and Hewson (24), it is possible to express the Friedman Eurodollar-creation model in an algebraic form that relates the stock of Eurodollar deposits to a base. Let E represent Eurodollar deposits held by the nonbank public, let R represent demand deposits at U.S. banks that are held by Eurodollar banks as reserves, and let r be the reserve ratio. Now make the simplifying assumption that the amount of Eurodollar deposits that the nonbank public desires to hold is a linear function of their total liquid dollar assets (A), where A is defined to be the U.S. money supply (M) plus Eurodollar deposits (E) minus U.S. bank deposits held by the Eurodollar banks (R). Then, a Friedman-type model of the Eurodollar market would consist of the following equations:

$$R = rE, \quad (1)$$

$$E = aA + b, \text{ and} \quad (2)$$

$$A = M + E - R. \quad (3)$$

Substituting equations (1) and (3) into equation (2) gives an expression for the supply of Eurodollars:

$$E = \left(\frac{1}{1-a(1-r)} \right) (aM + b) \quad (4)$$

where the U.S. money supply serves as the monetary base for the Eurodollar system. For a given U.S. money supply, the effect of a shift from U.S.

dollars into Eurodollars (measured by db) on the volume of Eurodollars is given as:

$$\frac{dE}{db} = \frac{1}{1-a(1-r)} \quad (5)$$

where the term on the right is the Eurodollar multiplier. Since "a" represents the fraction of total liquid dollar assets that the nonbank public wishes to hold in the form of Eurodollar deposits, it is the redeposit ratio and can be taken as a measure of "leakages" out of the Eurodollar system. The redeposit ratio equals $(1-c)$ where "c" is the leakage ratio, so that the smaller the leakages, the larger is the value of "a."

It is apparent that the Eurodollar multiplier derived above has exactly the same form as the simple money multiplier for a domestic banking system. Just as the size of the domestic money multiplier is determined by the reserve ratio and leakages from demand deposits into currency, so too is the size of the Eurodollar multiplier limited by the values of the Eurodollar reserve ratio and the leakages from Eurodollars into U.S. domestic dollar accounts.

The degree to which Eurodollars are actually created through multiple deposit expansion depends on the values of "a" and "r." Since Eurodollar banks hold small reserves against their dollar-denominated liabilities, "r" will tend to be small and the multiplier will tend to be large. This leads Friedman to state that Eurodollars "are mostly the product of the

bookkeeper's pen--that is, the result of fractional reserve banking" (6, p. 10), even though he admits that leakages could be large. One of the implications of the Friedman model is that the Eurodollar market is a source of world inflation because of its ability to increase the world supply of dollars through multiple deposit expansion. If the Eurodollar market is capable of multiple credit expansion, then it is also capable of multiple credit contraction and must be a potential source of monetary instability.

It is possible to get a general idea of the size of multiplier implied in the Friedman model by assigning values to the multiplier coefficients. If a relatively high value of "a" is assigned (say .25), and a low value of "r" is assigned (say .01), then the simple Eurodollar multiplier equals 1.33.

Bell (2) increases the possibility that the Eurodollar multiplier will be large by introducing central banks into the model. According to his analysis, if Eurodollar borrowers convert their loans into local currency, and if the central banks place the dollars they acquire in accounts at Eurodollar banks, then the Eurodollar system can extend more credit than suggested by the simple multiplier. Even allowing for central bank redepositing of Eurodollar loan proceeds that go into the foreign exchange market, Bell admits that leakages are probably larger in the Eurodollar market than in a domestic banking system.

A number of writers have criticized Friedman for confusing financial institutions that maintain fractional reserves with financial institutions that engage in multiple credit expansion. Klopstock (11, 12), and more

recently Willms (30), maintain that credit expansion in the Eurodollar market much more closely resembles that which occurs in a three-stage banking system than in a two-stage banking system. In particular, only a small proportion of Eurodollar deposits serve as a medium of exchange; most call and overnight deposits are held by other Eurodollar banks (12). Also, the reserves of Eurodollar banks are held as deposits with U.S. commercial banks rather than with central banks. Eurodollar banks are viewed as financial intermediaries in an international money market that attract funds from surplus areas and disburse them to deficit areas. The correct domestic analogue, then, is the saving and loan association rather than the commercial bank.

The main difference between U.S. commercial banks and Eurodollar banks, according to Klopstock (12), is that, as a group, the Eurodollar banks can count on recapturing as deposits only a small fraction of their loans. Two major characteristics of the Eurodollar system for which there is no clear analogy in the U.S. banking system account for large deposit leakages. The first characteristic is that a large proportion of the dollar deposits coming into the foreign branches of U.S. banks are funneled back to their home offices. Most of these funds are, in turn, employed in the U.S. The second characteristic is the tendency for a large amount of the balances placed in the Eurodollar market to go into the foreign exchange market. In Klopstock's view, any redepositing of Eurodollar loan proceeds acquired by central banks in the foreign exchange market is the exception to the general rule that when Eurodollars are

loaned out, only a small part of the loan proceeds ever show up as deposits in other Eurodollar banks.

Since leakages are larger for a three-stage banking system than for a two-stage system, the multiplier for a "Klopstock" Eurodollar market is smaller than the multiplier for a "Friedman" Eurodollar market. In fact, Klopstock believes that leakages are so large that the Eurodollar credit multiplier lies between 0.5 and 0.9 (11). Given the low value of the multiplier, one need not be very concerned with the inflationary consequences of the Eurodollar market. Instead of the bookkeeper's pen, Klopstock believes that the rapid growth of Eurodollar deposits must be accounted for by the "breadth, convenience, safety, low costs of doing business, and relatively high interest rates" (11, p. 19) provided by the Eurodollar market.

Empirical studies have not helped to resolve the differences between the Friedman and Klopstock schools of thought since attempts to estimate the Eurodollar multiplier have yielded widely different results. Lee (13) calculated a Eurodollar multiplier that averaged about 1.5 from the first quarter of 1963 to the fourth quarter of 1969, and Makin (18) estimated a long-run deposit multiplier of 18.45 for a time period almost identical to that considered by Lee.

Lee derived a simple form for a Eurodollar multiplier by working from a money supply identity and a Eurodollar "base" identity and then replacing the components of the multiplier with their actual values. The money supply equation Lee used was directly analogous to a domestic money supply equation, having the form:

$$D_f = \left(\frac{D_o/E_n + D_c/E_n + D_p/E_n + D_i/E_n + 1}{D_o/E_n + D_c/E_n + D_p/E_n + D_i/E_n + R/E_n} \right) B. \quad (6)$$

The term in parentheses is the Eurodollar multiplier with E_n representing Eurodollars net of interbank deposits, with R representing Eurodollar banks' reserves held with New York banks, and with D_o , D_p , and D_i representing short-term dollar holdings in the U.S. of foreign official institutions, foreign private nonbanks, and international organizations. D_c represents the dollar holdings in the U.S. of foreign commercial banks other than those holdings used as reserves by Eurodollar banks. In Lee's framework, the sum $D_o + D_c + D_p + D_i$ represents an aggregate that performs a function in the Eurodollar market that is analogous to currency in a domestic banking system. In Lee's model, D_f is identically equal to $D_o + D_c + D_p + D_i + E_n$ and the equation is analogous to a domestic money supply identity. B is equal to $D_o + D_c + D_p + D_i + R$ and is the Eurodollar market's counterpart to a domestic monetary base.

Foreign holders of dollars in the above model indirectly affect the volume of Eurodollar deposits through their determination of the ratio of dollars held in the U.S. to dollars held in the Eurodollar market. The ratio of Eurodollar reserves held with New York banks to net Eurodollar deposits also affects the overall level of Eurodollar deposits.

Lee used actual quarterly observations of D_o/E_n , D_c/E_n , D_p/E_n , D_i/E_n , and R/E_n to calculate twenty-eight quarterly values for the multiplier. He found that the multiplier grew steadily from a value of 1.2663 for the first quarter of 1963 to 1.9213 by the fourth quarter of 1969. The values of the multiplier were consistent with the view that leakages

from the Eurodollar system are large. Lee also calculated that central banks may be responsible for as much as 67.9 percent of the return flow of funds into the Eurodollar market (lending support to Bell's contention that central bank redepositing may be an important source of funds to the Eurodollar market). Foreign private nonbanks ranked second in importance by contributing 18 percent of the return flow.

Makin (18) derives a Eurodollar reserve multiplier using empirical estimates of stock supply and demand functions for Eurodollars. Makin's model of the Eurodollar market consists of equations for the stock demand for Eurodollars, the stock supply of Eurodollars, the ratio of precautionary reserves to Eurodollars supplied, and a market-clearing equation. Formally:

$$EDD = f(I, r_e, r_{cd}, g, DM), \quad (7)$$

$$EDS = h(EBR), \quad (8)$$

$$EBR/EDS = j(r_e, r_{cd}, S_A^2, EDS), \text{ and} \quad (9)$$

$$EDD = EDS \quad (10)$$

where EDD and EDS represent the real stock of Eurodollars demanded and supplied, and where EBR represents the real stock of Eurodollar banks' precautionary reserves (measured by demand deposits of foreign commercial banks held at U.S. banks, exclusive of claims on head offices by foreign branches). The scale variable in the demand equation is real imports of industrial countries; and the substitution variables, r_e , r_{cd} , g , and DM ,

are, respectively, the rate of return on 90-day Eurodollar time deposits, the rate of return on 90-day negotiable certificates of deposit, the expected return on gold, and the forward premium of dollars against deutsche marks in annual percentage terms. The EDS term in the reserve ratio equation represents the effects of economies of scale in reserve management, the r_{cd} term is a proxy for the cost of running out of reserves, and the S_A^2 is a proxy for the variance of net receipts and disbursements. The endogenous variables in Makin's system are the level of precautionary reserves, the rate of return on Eurodollar deposits, and the stock supply of Eurodollars.

The model was fitted for 26 quarterly observations from the third quarter of 1964 through the fourth quarter of 1970. Assuming that the adjustment of the supply of Eurodollars to changes in Eurodollar bank reserves takes place over time, the stock supply equation was estimated as a distributed lag of the Koyck type. The formulation employed was:

$$EDS_t = \lambda a_0 + \lambda a_1 EBR_t + (1-\lambda)EDS_{t-1} + \lambda e_t \quad (11)$$

where the desired stock of Eurodollars supplied was:

$$EDS_t^d = a_0 + a_1 EBR_t + e_t \quad (12)$$

and the rate of adjustment of supply to desired supply is " λ " as given by:

$$\Delta EDS_t = \lambda(EDS_t^d - EDS_{t-1}). \quad (13)$$

The estimated values of the equation were:

$$EDS_t = -193.2 + 16.36EBR_t + .733EDS_{t-1} \quad (14)$$

with all coefficients significant and $R^2 = .989$.

The coefficient on the EDS_{t-1} term implies that $\lambda = .267$, or that about one-fourth of the adjustment of supply to changes in reserves is completed in one quarter. With $\lambda = .267$ it is apparent that $a_1 = 61.25$.

If "f" represents the feedback ratio of funds reentering the Euro-dollar system, then the Eurodollar multiplier is $1/(1-f)$. To calculate this multiplier, it is necessary to take account of the fact that between 1964 and 1970 the level of reserves held against Eurodollar deposits declined at a rate of about 3.45 percent per quarter. This means that:

$$\frac{\Delta EDS_t}{\Delta EBR_t} = \frac{1}{1-Kf} \text{ where } K = \frac{\Delta EBR_t}{\Delta EBR_{t-1}}. \quad (15)$$

Since K is approximately equal to 1.04, it follows from equation (14) that in the short run (one quarter):

$$\frac{\Delta EDS_t}{\Delta EBR_t} = 16.36 = \frac{1}{1-1.04f_{SR}}. \quad (16)$$

If the short-run multiplier is $1/(1-f_{SR})$, then solving equation (16) gives $f_{SR} = .903$ and the short-run Eurodollar multiplier is about 10.31.

In the long run, the actual stock supply of Eurodollars will equal the desired supply. It follows, then, from equation (12) that in the long run:

$$\frac{\Delta EDS_t}{\Delta EBR_t} = 61.25 = \frac{1}{1-1.04f_{LR}} \quad (17)$$

which indicates that $f_{LR} = .9458$ and that the long-run Eurodollar multiplier equals 18.45.

To get an idea of the proportion of Eurodollar deposit growth that was attributable to the multiple deposit expansion process, Makin multiplied the long-run Eurodollar multiplier of 18.45 by the change in reserves of Eurodollar banks that occurred during the study period, and compared that figure with the total change in Eurodollar deposits that occurred during the same time. That comparison led Makin to believe that 40 percent of the growth of Eurodollar deposits during the study period was due to multiple deposit expansion, with 60 percent of the growth due to new deposits. The conclusion that emerges from Makin's study is that Friedman-type multiple deposit expansion has accounted for a large portion of the growth of the Eurodollar market.

Until the early 1970s, most of the theoretical discussions of the Eurodollar market focused on whether the two-stage or three-stage banking model was the appropriate one for analyzing Eurodollar credit creation.

Despite differences of opinion as to the size of the Eurodollar multiplier, adherents of both schools of thought were in agreement that the general Eurodollar deposit creation process could be expressed as:

$$D = mR \quad (18)$$

where D represents the stock of Eurodollar deposits and R represents the stock of precautionary reserves held in the U.S. banking system (3, 30). The value of the multiplier (m) is, of course, determined by the value of the "leakage" coefficients--the proportion of liquid dollar assets that are held in the Eurodollar system and the proportion of Eurodollar deposits held as reserves with U.S. commercial banks. For $D = mR$ to be a meaningful expression, the coefficients must be "fixed" in the sense that new dollar inflows from the U.S. do not affect interest rates on dollar or Eurodollar short-term assets. Otherwise, new dollar inflows would change interest rates and changes in interest rates would cause portfolio adjustments by Eurodollar banks and by the nonbank public which would alter the values of the leakage coefficients.

That this "fixed coefficient" approach should be used so widely in explaining the operation of the Eurodollar market is somewhat surprising. As early as 1963, Tobin (28) pointed out that the fixed coefficient money multiplier paradigm is most appropriate for credit markets in which legal reserve requirements are effective and in which deposit rates are rigid and, therefore, fail to clear the market. The 1934 Banking Act prohibition of interest payments on demand deposits and the Regulation Q interest rate ceilings on time deposits, and the cartel-like structure of banking

in Europe, made deposit rates in both the United States and Europe relatively rigid throughout the 1960s and most of the 1970s (9). Therefore, it is not unreasonable as a first approximation to assume that during the 1960s and 1970s the leakages ratios in domestic banking systems in Europe and the United States were relatively constant. In particular, if a domestic banking system is prohibited from paying interest on demand deposits, then the ratio of currency to demand deposits that the nonbank public maintains should be constant in the short-run.

The highly competitive and largely unregulated Eurodollar market more closely resembles a perfectly competitive financial market than a domestic credit market. Eurodollar interest rates are determined competitively each day and are sensitive to new dollar inflows. This means that the leakage coefficients for the Eurodollar multiplier will not be fixed and that the interest rates on Eurodollar deposits will play a large role in determining the extent to which new dollar inflows can be translated into additional deposits. In particular, the "interest rate leakages" in the Eurodollar system must be considered.

Interest rate leakages occur because an autonomous shift of dollar deposits into the Eurodollar system will cause a reduction in Eurodollar interest rate and an induced shift of Eurodollar deposits out of the system. Studies by Freedman (5) and Hewson and Sakakibara (8, 9) have applied Tobin-type (29) general equilibrium portfolio models to the Eurodollar market to examine interest rate leakages and likely values of the Eurodollar multiplier. These general equilibrium Eurodollar models view Eurodollar banks as pure financial intermediaries that do not possess

independent demand and supply functions for loans and deposits. Since the Eurodollar market is highly competitive, it is assumed that Eurodollar banks earn a constant margin between Eurodollar loan and deposit rates. For simplicity, it is usually assumed that Eurodollar banks hold no reserves and that the margin between loan and deposit rates is, in fact, zero: the justifications being that Eurodollar banks do not face stochastic reserve losses so they do not need to hold precautionary reserves, and that the margin is constant and very narrow. The Eurodollar market, then, is a perfectly competitive market in which adjustments in the Eurodollar interest rate occur to equate the supply of Eurodollar deposits with the demand for Eurodollar loans.

Hewson and Sakakibara (8) developed a general equilibrium portfolio adjustment model of the Eurodollar market along the lines of the above assumptions, and they introduced central banks into the analysis by proposing that they place in the Eurodollar market a constant fraction of their total foreign reserve holdings. Their equilibrium equation for the Eurodollar market is:

$$cd \cdot \text{FOR} + \sum_{i=1}^n D_i = \sum_{i=1}^n L_i \quad (19)$$

where D_i is the demand by country i for Eurodollar deposits, L_i is the demand by country i for Eurodollar loans, FOR is the total foreign reserves of central banks (assuming that the dollar is the only international reserve currency), and cd is the ratio of central bank foreign

reserves held on deposit in Eurodollar banks to total foreign reserves. The demand functions for deposits and loans are assumed to be functions of net wealth, income, and rates of return on alternative short-term assets.

The world is assumed to be on a fixed exchange rate system. Given that the level of foreign reserves of the central banks equals the sum of their deposits with Eurodollar banks ($D_{EC,ED}$) plus the accumulated overall U.S. balance of payments deficit on the official settlements account (B_{US}), then an equation for foreign reserves can be represented as:

$$FOR = D_{EC,ED} + B_{US} \quad (20)$$

or

$$FOR = cd \cdot FOR + B_{US} \quad (21)$$

or

$$FOR = (1/(1-cd)) (B_{US}). \quad (22)$$

Substituting yields:

$$\left(\frac{cd}{1-cd}\right)B_{US} + \Sigma D_i = \Sigma L_i. \quad (23)$$

For convenience, assume that all the scale and substitution variables are constant except for the rate of return on Eurodollar deposits (r). Now let "s" represent an autonomous inflow of dollars. By assumption, this will be completely loaned out and the individuals receiving the loans will convert them to domestic currency. The first round impact of an autonomous portfolio shift is to increase B_{US} and ΣD_i by the same amount.

The shift parameter impacts on both terms. If "V" is the total volume of Eurodollar deposit liabilities, then the Eurodollar "interest rate" multiplier is:

$$m = \frac{dV}{ds} = \frac{d\left(\frac{cd}{1-cd} (B_{US} + s) + (\Sigma D_i + s)\right)}{ds} \quad (24)$$

or

$$m = \frac{\frac{cd}{1-cd} \cdot \frac{\partial B_{US}}{\partial r} dr + \frac{cd}{1-cd} ds + \frac{\partial \Sigma D_i}{\partial r} dr + ds}{ds} \quad (25)$$

Simplifying yields:

$$m = \frac{dV}{ds} = \frac{1}{1-cd} + \left(\frac{\partial \Sigma D_i}{\partial r} + \frac{cd}{1-cd} \cdot \frac{\partial B_{US}}{\partial r}\right) \frac{dr}{ds} \quad (26)$$

Totally differentiating equation (23) with respect to s gives:

$$\frac{dr}{ds} = \frac{1}{(1-cd)\Sigma_i \left(\frac{\partial L_i}{\partial r} - \frac{\partial D_i}{\partial r}\right) - cd \frac{\partial B_{US}}{\partial r}} \quad (27)$$

Since $\partial L_i / \partial r < 0$, $\partial D_i / \partial r > 0$, and $\partial B_{US} / \partial r > 0$ it is apparent that $dr/ds < 0$. Substituting into equation (26) yields:

$$m = \frac{1}{1-cd} + \frac{\frac{\partial \Sigma D_i}{\partial r} + \frac{cd}{1-cd} \cdot \frac{\partial B_{US}}{\partial r}}{(1-cd)\Sigma \left(\frac{\partial L_i}{\partial r} - \frac{\partial D_i}{\partial r}\right) - cd \frac{\partial B_{US}}{\partial r}} \quad (28)$$

An important implication of the Hewson-Sakakibara model is that in the absence of central bank depositing of foreign reserves in the Euro-dollar market ($cd=0$), the Eurodollar multiplier would lie between zero and unity. An autonomous shift of dollars from the U.S. to the Eurodollar market would tend to lower the Eurodollar rate relative to U.S. (and European) interest rates, thereby diminishing the attractiveness of Euro-dollar deposits and causing a secondary shift out of Eurodollars. However, the lower rate on Eurodollar loans would increase the quantity demanded so the overall effect of the shift of funds into the Eurodollar market would be positive. With central bank participation in the Euro-dollar market, the maximum value of the multiplier would be $1/(1-cd)$.

To derive a value for the Eurodollar multiplier, Hewson and Sakakibara arbitrarily dropped the $\partial B_{US}/\partial r$ terms and divided the world into two regions: the United States and Canada, and Western Europe (except Switzerland). They then determined the values of the partials in the multiplier by simultaneously estimating loan and deposit demand functions for both regions using monthly data for the period 1968-72. The actual Eurodollar variables employed were dollar assets and liabilities of United Kingdom banks with respect to residents and banks of the two regions. Hewson and Sakakibara assumed that demand for Eurodollar deposits and loans was a function of wealth variables, income variables, interest rate variables, and speculative variables. They also included dummy variables in each equation relating to controls over short-term capital flows that were imposed during the period and to speculative activity coinciding with the suspension of convertibility of official

dollar holdings into gold. As a proxy for cd they used the ratio of "the change in the sum of 'Identified official holdings of Euro-dollars' plus 'Unidentified Euro-currencies and residual' to the change in total foreign reserves of all member countries of the International Monetary Fund" (8, p. 324).

The value of the multiplier was found to be 1.41 when estimated values of the partials and the cd term were substituted into the multiplier equation. This was considered a maximum value since the proxy for cd tends to overstate its true value, and because the assumption that cd is fixed ignores the interest rate impacts on central bank holdings of Eurodollars and, thus, overstates the multiplier. Hewson and Sakakibara believed it realistic to assume in the context of this model that the true multiplier is close to unity.

The estimated value of the multiplier was substantially lower when a different proxy was used for cd . When an average ratio of central banks' holdings of Eurodollars to total foreign reserves was used as the cd term, the value of the multiplier was .54.

Although the values of the multipliers obtained by Lee (13) and Hewson and Sakakibara (8) are numerically similar, they are not comparable because they conceal sharply differing views of how the Eurodollar market functions. In particular, adherents of the "general equilibrium" viewpoint would insist that it was meaningless for Lee to calculate a ratio of total Eurodollar deposits to some measure of Eurodollar reserves and deduce an ex post multiplier (19).

Makin (18) has been alternately criticized for using too narrow a definition of Eurodollar bank reserves (30) or too broad a definition (8). The main problem with Makin's study, however, lies with his attempt to relate a stock of Eurodollar deposits to a level of Eurodollar bank reserves when those reserves are actually transactions balances rather than precautionary reserves.

A final school of thought to emerge from the debate concerning the working of the Eurodollar market contends that regardless of the size of the multiplier, the Eurodollar market creates very little liquidity. Niehans (23) asserts that the asset transformation performed by financial intermediaries can increase the liquidity of the nonbank public only if the claims of the nonbank public against the financial intermediaries are in the aggregate more liquid than its debts to the financial intermediaries. This implies that the impact of the Eurodollar market on world liquidity can be assessed by analyzing the maturity matching of Eurodollar assets and liabilities. One way to do this is to imagine that the maturity of different liabilities and assets has a liquidity "weight" that varies between zero and one. If cash has a liquidity weight of one and the least liquid asset in an economy has a zero weight, then the Eurodollar system creates liquidity only if the weighted sum of Eurodollar deposits exceeds the weighted sum of Eurodollar loans owed to Eurodollar banks.

Niehans and Hewson (24) examined the maturity structure of Eurocurrency claims and liabilities for all United Kingdom-based Eurocurrency banks as of September 30, 1973 and found an extremely close maturity

matching of assets and liabilities. By dividing bank claims and liabilities into seven maturity classes and arbitrarily assigning weights to each maturity class, they discovered that for every dollar of deposits, liquidity creation amounted to just 4.45 cents. When they examined the claims and liabilities of those Eurocurrency banks relative to nonbanks they found that liquidity creation amounted to 16.49 cents for every dollar of deposits. The low degree of maturity transformation implies that a large value for the Eurodollar multiplier would be meaningless because deposit expansion does not add liquidity to the world economy. If the Eurodollar system does not create liquidity then it cannot generate inflation. Since Eurodollar banks closely match the maturities of assets and liabilities, they are less subject to liquidity risk than domestic banks so the Eurodollar system may be more stable than domestic banking systems.

The results of the study are consistent with the view that the Eurodollar system is a network for the efficient distribution of short-term funds. In particular, the Eurodollar market is an interbank market in which funds from ultimate lenders pass through many Eurodollar banks before reaching ultimate borrowers. According to Niehans and Hewson, the ability of the Eurodollar system to lower the cost of information to ultimate transactors is what accounts for the rapid growth of the Eurodollar market.

A later study by Heinevetter (7) indicates that the results obtained by Niehans and Hewson may be dependent on the base year selected. Heinevetter shows that liquidity creation in the Eurodollar market has

increased considerably since 1973 and now may be at a level that is significant when compared to some domestic banking systems.

Additionally, one must question whether the "maturity" of assets and liabilities is the only characteristic which is important in determining liquidity. For instance, the ability of the Eurodollar system to perform "risk transformation" on assets and liabilities may have a significant impact on the behavior of ultimate transactors in the market.

Since the "fixed coefficient" approach suffers from attempting to describe an unregulated and highly competitive financial market with a model that is more appropriate to a heavy regulated domestic financial market it seems apparent that the "general equilibrium" approach offers the most satisfactory model of the Eurodollar market. This suggests that the proper focus of an attempt to examine the impact of new dollar inflows on the volume of Eurodollar deposits must be the interest rate multiplier rather than the reserve multiplier.

There is one area, however, in which the general equilibrium models can be improved, and that is in their treatment of central banks. Hewson and Sakakibara (8) assume that central banks deposit a constant fraction of their foreign reserve holdings in the Eurodollar market. This seems to be an overly simplified and unnecessarily restrictive assumption. A more appropriate assumption might be that central banks have the same motivation as private investors in determining the combination of financial instruments to hold in their portfolios. Therefore, a central bank demand function for Eurodollar deposits should have a scale variable that relates to its official reserve holdings, it should have interest rate variables

that relate to alternative opportunities for investment, and it should have speculative variables that relate to expectations about future movements of exchange rates.

While there may be some justification under a fixed exchange rate system for assuming, as Hewson and Sakakibara (8) did, that every Euro-dollar loaned out finds its way through the foreign exchange market into the hands of central banks, that assumption is no longer tenable. The breakdown of the Bretton Woods system and the switch to flexible exchange rates has relieved central banks of the need to maintain fixed parities. Although central banks do interfere with competitive forces in foreign exchange markets from time to time, a more appropriate assumption under current circumstances is that central banks do not intervene in foreign exchange markets.

In the next section, a general equilibrium portfolio adjustment model of the Eurodollar market will be presented. Explicit in its development will be the assumption that central banks' decisions to place dollars in the Eurodollar market are affected by the same types of variables that influence private investors' decisions about placement of funds in the Eurodollar market.

MODEL

The central assumption underlying the Eurodollar model developed in this study is that Eurodollar bankers are auctioneers of short-term dollar funds. That is, Eurodollar banks do not possess independent demand and supply functions for Eurodollar deposits and loans and, thus, do not exert an independent influence on the equilibrium Eurodollar interest rate. Instead, the Eurodollar rate adjusts quickly to equate Eurodollar deposits and loans.

A second assumption is that because of maturity matching of assets and liabilities, Eurodollar banks do not hold any precautionary reserves. What need there may be for precautionary balances is met by maintaining standby lines of credit with other banks. Balances held by Eurodollar banks with New York banks are viewed as transactions balances and are ignored because they are very small relative to Eurodollar deposits.

It is also assumed that intense competition between Eurodollar banks causes the margin between loan and deposit rates to be constant and narrow. For convenience, the margin is assumed to be zero.

The Eurodollar market, then, can be represented in structural form as:

$$S^1 + S^2 + S^3 = D^1 + D^2; \quad (29)$$

$$S^1 = F^1(W^1, RE, RCD, RUK, DM); \quad (30)$$

$$S^2 = F^2(W^2, RE, RCD, RUK, DM); \quad (31)$$

$$S^3 = F^3(W^3, RE, RCD, RUK, DM): \quad (32)$$

$$D^1 = G^1(W^1, RE, RCP, RLP, DM, UN^1); \quad (33)$$

$$D^2 = G^2(W^2, RE, RCP, RLP, DM, UN^2); \quad (34)$$

where

S^1 = stock supply of Eurodollar funds (Eurodollar deposits) held by residents of the United States, Canada, and Japan;

S^2 = stock supply of Eurodollar funds (Eurodollar deposits) held by residents of Europe and "other" countries;

S^3 = stock supply of Eurodollar funds (Eurodollar deposits) held by central banks;

D^1 = stock demand for Eurodollar funds (Eurodollar loans) by residents of the United States, Canada, and Japan;

D^2 = stock demand for Eurodollar funds (Eurodollar loans) by residents of Europe and "other" countries;

W^1 = total wealth of residents of the United States, Canada, and Japan;

W^2 = total wealth of residents of Europe and "other" countries;

W^3 = total wealth of central banks;

RE = rate on three-month Eurodollar deposits (prime banks' bid rate in London);

RCD = rate on three-month negotiable certificates of deposit;

RUK = covered rate on three-month time deposits with London banks;

RCP = rate on three-month prime industrial paper in the U.S.;

RLP = covered rate on unsecured overdrafts for prime borrowers in
London;

DM = forward premium on deutsche marks in annual percentage terms;

UN¹ = seasonally adjusted unemployment rate for the United States,
Canada, and Japan; and

UN² = seasonally adjusted unemployment rate for Europe and "other"
countries.

The "other" countries referred to above are those countries outside of Europe, and excluding the United States, Canada, and Japan, that participate in the Eurodollar market. In the case of the S^2 variable, the stock of Eurodollar funds held by residents of Europe and "other" countries is exclusive of holdings of Eurodollar deposits by central banks.

The stock supplies of and demands for Eurodollar funds are assumed to be determined by wealth variables, interest rate variables, and the speculative variable. In addition, the demand for Eurodollar loans is assumed to be influenced by the business outlook for which the unemployment rate is taken as a proxy.

The endogenous variables in the model are the stock supplies of and demands for Eurodollar funds and the rate of return on Eurodollars. All other variables are assumed to be predetermined. This formulation treats the Eurodollar market as a subsector of the international financial system with interest rates in the United States and Europe determined outside of the Eurodollar market.

A unique feature of this model is the introduction of an explicit central bank demand function for Eurodollar deposits (supply function of funds to the Eurodollar market by central banks). Central banks are seen as responding to the same set of variables as private investors. The asymmetric treatment afforded central banks in the model reflects their traditional role as suppliers, but not users, of funds in the Eurodollar market (1).

In order to derive the Eurodollar multiplier from the above structural model, assume that all predetermined variables are constant, and express the equilibrium condition as:

$$S^1(RE) + S^2(RE) + S^3(RE) = D^1(RE) + D^2(RE). \quad (35)$$

Now, let "s" represent an autonomous inflow of dollars to the Eurodollar market, let ED represent the total volume of Eurodollar deposits, and let "m" represent the Eurodollar multiplier. Total differentiating $ED + s$ yields:

$$m = \frac{dED}{ds} = \frac{d(S^1(RE) + S^2(RE) + S^3(RE) + s)}{ds}. \quad (36)$$

Simplifying gives:

$$m = 1 + \left(\frac{\partial S^1}{\partial RE} + \frac{\partial S^2}{\partial RE} + \frac{\partial S^3}{\partial RE} \right) \frac{dRE}{ds}. \quad (37)$$

To find dRE/ds it is necessary to totally differentiate equation (35) with respect to the shift parameter which yields:

$$\frac{dRE}{ds} = \frac{1}{\left(\frac{\partial D^1}{\partial RE} + \frac{\partial D^2}{\partial RE}\right) - \left(\frac{\partial S^1}{\partial RE} + \frac{\partial S^2}{\partial RE} + \frac{\partial S^3}{\partial RE}\right)} \cdot \quad (38)$$

Substituting equation (38) into equation (37) gives the Eurodollar multiplier:

$$m = 1 + \frac{\left(\frac{\partial S^1}{\partial RE} + \frac{\partial S^2}{\partial RE} + \frac{\partial S^3}{\partial RE}\right)}{\left(\frac{\partial D^1}{\partial RE} + \frac{\partial D^2}{\partial RE}\right) - \left(\frac{\partial S^1}{\partial RE} + \frac{\partial S^2}{\partial RE} + \frac{\partial S^3}{\partial RE}\right)} \cdot \quad (39)$$

It is apparent that the multiplier is between one and zero, given typical assumptions about the signs of the partials. The initial effect of a shift of funds from a U.S. commercial bank to a Eurodollar bank will be partially offset by secondary effects that result from a decrease in the Eurodollar deposit rate. Interest rate leakages cause the "multiplier" to be a divisor.

To determine the value of the multiplier, it is necessary to measure the responsiveness of Eurodollar deposits and loans to changes in Eurodollar interest rates. The next section reports the results of estimations of the Eurodollar model and calculates the multiplier using the derived values of the parameters.

RESULTS

The structural equations of the Eurodollar model were estimated using quarterly observations from the fourth quarter of 1974 through the fourth quarter of 1980. The time period was chosen because it coincides with the post-Bretton Woods period of flexible exchange rates and because it is the period for which data is available.

Data on Eurodollar deposits and liabilities were obtained from the Bank for International Settlements (1). The Bank for International Settlements lists Eurodollar data provided by banks in Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Luxemburg, the Netherlands, Sweden, Switzerland, and the United Kingdom. The Bank for International Settlements' reporting area does not encompass the total Eurodollar market, but it does represent a major part of the market. During the study period, banks in the Bank for International Settlements' reporting area held approximately 70 percent of total Eurodollar liabilities (31). Use of the Bank for International Settlements' data is also justified since the European segment of the Eurodollar market dominates in determining Eurodollar interest rates (22).

The quarterly data used in the estimation were obtained from tables entitled "Estimated sources and uses of Euro-currency funds" (1). The data is net of interbank deposits except that "the reporting banks themselves are considered as original suppliers of Eurocurrency funds to the extent that they use funds obtained in domestic currency for switching into foreign currency; and similarly they are counted on the uses side of

the market to the extent that they use foreign currency funds for switching into domestic currency" (20, p. 60). The Bank for International Settlements' Eurocurrency data is disaggregated by countries or groups of countries.

As a preliminary step toward estimation, the Eurocurrency deposit totals (sources of funds) for the United States, Canada, and Japan were combined, as were the deposit totals for Europe and "other" countries. Similar aggregations were performed for Eurocurrency loans (uses of funds). To convert Eurocurrency totals to Eurodollar totals, a Morgan Guaranty quarterly series was used which gives Eurodollars as a percent of Eurocurrency liabilities (31). The Morgan Guaranty series has a mean value of .758 for the study period with a standard deviation of .027.

Using the above method to convert Eurocurrency totals to Eurodollar totals implies that at any point in time residents of the United States, Canada, and Japan in the aggregate maintain the same proportion of Eurodollars to Eurocurrency as is maintained by residents of Europe and "other" countries in the aggregate. While that assumption would be too strong on a microeconomic level, it seems reasonable given the high degree of aggregation.

The Bank for International Settlements in its 1982 report published a quarterly series listing Eurodollar holdings of official monetary authorities with banks in the European reporting area. That series was subtracted from the series of total Eurodollar deposits held by Europe and "other" countries described above. The two resulting series were Eurodollar deposits held by official monetary authorities and Eurodollar

deposits held by residents of Europe and "other" countries, exclusive of holdings of official monetary authorities.

Unfortunately, the series on Eurodollar holdings of official monetary authorities only has observations for the fourth quarter of 1977, the fourth quarter of 1978, the four quarters of 1979, and the four quarters of 1980. That means observations on S^2 , as calculated above, as well as S^3 , are not available. The problem of the missing observations on S^2 and S^3 is handled by creating an instrumental variable for RE and using ordinary least squares techniques to estimate the five structural equations using all available observations for each equation.

As Makin notes, "no direct wealth measure is available since the exact identity of all Eurodollar depositors is not known" (18, p. 384). As a proxy for the wealth of those holding Eurodollar deposits and loans in the United States, Canada, and Japan, the combined gross national product of the three countries in 1975 dollars and at 1975 exchange rates was used. The seasonally adjusted index of industrial production for the European members of the Organization for Economic Cooperation and Development was used as a wealth proxy for holders of Eurodollar deposits and loans in Europe and "other" countries. The official reserve assets (measured in Special Drawing Rights) of the European members of the Organization for Economic Cooperation and Development was used as a wealth proxy for central banks.

The unemployment rate for the United States, Canada, and Japan was calculated as a weighted average of seasonally adjusted quarterly values for each country. The quarterly weights used were the relative shares of

combined gross national product measured in 1975 dollars at 1975 exchange rates.

The combined unemployment rate of Italy and the United Kingdom was used as a proxy for the unemployment rate for Europe and "other" countries. The combined unemployment rate was calculated as a weighted average of seasonally adjusted quarterly values for both countries. The quarterly weights used were the relative shares of combined gross domestic product for Italy and the United Kingdom measured in 1975 dollars at 1975 exchange rates.

Exchange rate data as well as data relating to the unemployment rates and wealth proxies were obtained from Organization for Economic Cooperation and Development publications (10, 17). Interest rate data were obtained from Morgan Guaranty publications (31). Covered interest rates and the forward premium on deutsche marks were calculated using data from both of the above sources. All data were measured at or near end of quarter.

The equations representing the stock demand for Eurodollar deposits (supply of funds to the Eurodollar market) were estimated in the form:

$$S^i = a_{i1} + a_{i2}W^i + a_{i3}(RE-RCD) + a_{i4}RUK + a_{i5}DM \quad (40)$$

for $i = 1$ to 3. A priori expectations about the signs of the a_{ij} 's are that a_{i2} and a_{i3} are positive and that a_{i4} and a_{i5} are negative. This formulation views United States negotiable certificates of deposit as close substitutes for Eurodollar deposits. A change in the difference

between those rates will cause portfolio adjustments by investors. The demand for Eurodollar deposits will also be affected by the level of interest rates on other financial instruments and by investor wealth and expectations about future exchange rates.

The equations representing the stock demand for Eurodollar loans (demand for Eurodollar funds) were estimated in the form:

$$D^i = b_{i1} + b_{i2}W^i + b_{i3}(RE-RLP) + b_{i4}RCP + b_{i5}DM + b_{i6}UN^i \quad (41)$$

for $i = 1$ to 2 . A priori expectations about the signs of the coefficients are that b_{i3} and b_{i6} are less than zero and that b_{i2} , b_{i4} , and b_{i5} are greater than zero. This formulation views loans by London banks to prime customers as close substitutes for Eurodollar loans. A change in the difference between the Eurodollar rate and the London prime rate (covered) will cause portfolio adjustments by holders of Eurodollar loans. The demand for Eurodollar loans will also be affected by the level of interest rates on other financial instruments, by wealth, by expectations about future exchange rates, and by the unemployment rate.

The complete Eurodollar model consists of the Eurodollar equilibrium condition (equation 29) and the five structural equations represented by equations (40) and (41). Since the Eurodollar model is a simultaneous-equation model, it is necessary to determine whether the parameters of all of the equations are identified.

Maddala (16) presents a test for determining whether the rank condition for identification is met. The test requires the creation of a

matrix consisting of all endogenous and predetermined variables in the structural equations. Each row of the matrix represents a structural equation. For each variable in a row, an "X" is marked if the variable appears in the corresponding equation and a "0" is marked if it does not. To determine whether a particular equation is identified, delete the row corresponding to that equation and pick up the columns associated with the elements that have zeros in that row. If G is the number of structural equations, then the row (equation) is identified if the rank of the resulting matrix is $G-1$. The rank test provides a necessary and sufficient condition for identification.

By performing the type of rank test described above, it is possible to establish that each of the structural equations in the Eurodollar model is identified. The Eurodollar equilibrium equation is identified since it is an identity (25).

The number of predetermined variables excluded from each structural equation is greater than the number of included endogenous variables minus one. Therefore, by the order condition the system is overidentified (25).

As a preliminary step, ordinary least squares techniques were employed to estimate the parameters of the structural equations. Though inconsistent (and biased), the resulting estimates provide a useful comparison with consistent estimators. Letting $DC = RE - RCD$ and $DL = RE - RLP$, the results (with t -values in parentheses) are given below:

$$S^1 = -98.18 + .05W^1 + 1195.85DC + 123.96RUK - 234.98DM, \quad (42)$$

(-6.68)
(7.52)
(4.37)
(3.57)
(-4.70)

$$D.W. = 1.63, R^2 = .948;$$

$$S^2 = 206.84 + -.93W^2 + 5952.34DC + 1260.3RUK - 1726.4DM, \quad (43)$$

(.69)
(-.34)
(2.59)
(2.71)
(-3.43)

$$D.W. = 2.69, R^2 = .893;$$

$$S^3 = 29.67 + .0001W^3 + 859.23DC + 180.85RUK - 292.94DM, \quad (44)$$

(1.38)
(.51)
(1.68)
(1.21)
(-1.61)

$$D.W. = 1.73, R^2 = .881;$$

$$D^1 = -122.18 + .04W^1 + 4.97DL + 247.98RCP - 142.12DM$$

(-7.30)
(7.60)
(.23)
(10.34)
(-4.76)

$$+ 707.03UN^1, \quad (45)$$

(6.89)

$$D.W. = 1.73, R^2 = .972;$$

$$D^2 = -346.50 + 2.42W^2 - 323.17DL + 1314.98RCP - 637.06DM$$

(-3.75)
(2.22)
(-2.00)
(7.40)
(-2.85)

$$+ 3295.29UN^2, \quad (46)$$

(5.13)

$$D.W. = 1.67, R^2 = .963.$$

To obtain consistent estimators for the parameters of the structural equations, an instrumental variable technique was employed. The structural equations represented by equations (40) and (41) were substituted into equation (29) and the RE variable was solved for in terms of all of

the predetermined variables. The resulting equation was estimated using ordinary least squares. All 25 observations of each of the predetermined variables were used in the instrumental variable estimation process. The following equation gives the results of the reduced form estimation for RE:

$$\begin{aligned}
 RE = & -0.0190 + .00001W^1 - .0002W^2 - .0000001W^3 - .0275DM \\
 & (-.55) \quad (.37) \quad (-.50) \quad (-.14) \quad (-.37) \\
 & 1.1857RCD - .0081RCP - .0921RUK + .0545RLP + .2137UN^1 \\
 & (10.59) \quad (-.10) \quad (-1.01) \quad (.68) \quad (1.41) \\
 & + .0171UN^2, \quad (47) \\
 & \quad (.13) \\
 & D.W. = 2.13, R^2 = .999.
 \end{aligned}$$

The predicted values of RE from equation (47) were substituted for the actual values of RE and the structural equations of the model were reestimated using ordinary least squares. If \hat{RE} is the predicted value of RE and if $DC^Z = (\hat{RE} - RCD)$ and $DL^Z = (\hat{RE} - RLP)$, then the results of the estimation using the instrumental variable are:

$$\begin{aligned}
 S^1 = & -102.81 + .05W^1 + 1757.37DC^Z + 93.17RUK - 240.9DM, \quad (48) \\
 & (-9.19) \quad (10.22) \quad (6.95) \quad (3.40) \quad (-6.37) \\
 & D.W. = 2.03, R^2 = .970;
 \end{aligned}$$

$$\begin{aligned}
 S^2 = & 577.69 - 3.81W^2 + 13620.06DC^Z + 233.77RUK - 1187.98DM, \quad (49) \\
 & (1.91) \quad (-1.46) \quad (3.35) \quad (.35) \quad (-2.45) \\
 & D.W. = 2.65, R^2 = .923;
 \end{aligned}$$

$$S^3 = 39.97 + .00007W^3 + 1793.66DC^Z + 55.79RUK - 229.71DM, \quad (50)$$

(1.78) (.34) (2.02) (.38) (-1.42)

$$D.W. = 2.04, R^2 = .897;$$

$$D^1 = -121.88 + .04W^1 + 4.24DL^Z + 248.38RCP - 142.6DM$$

(-7.28) (7.57) (.19) (10.34) (-4.77)

$$+ 705.96UN^1, \quad (51)$$

(6.88)

$$D.W. = 1.74, R^2 = .972;$$

$$D^2 = -345.25 + 2.42W^2 - 333.88DL^Z + 1318.8RCP - 644.17DM$$

(-3.76) (2.23) (-2.08) (7.47) (-2.90)

$$+ 3282.22UN^2, \quad (52)$$

(5.14)

$$D.W. = 1.66, R^2 = .963.$$

Since the Durbin-Watson test statistic lies in its indeterminate range for equations (49)-(52) the ordinary least squares residuals were computed for each of the four equations and regressed against their one-period lagged values. None of the resulting t-values for the first-order autoregressive parameters was significant even at the .10 level, indicating that the hypothesis of first-order autocorrelation should be rejected.

In equations (48)-(50) which represent the demand for Eurodollar deposits, all of the coefficients except the ones on the RUK variable and the one on W^2 have the anticipated signs. The positive sign on the RUK variable indicates that an increase in the covered rate on three-month

London time deposits increases the stock demand for Eurodollar deposits. A possible explanation for the sign might be that since London is the major center for Eurodollar banking activity, higher covered rates on London time deposits attract funds from throughout the world (particularly the United States, Canada, and Japan), some of which go into the London Eurodollar market. Sterling funds may be converted to dollars by London banks and placed in Eurodollar accounts.

All of the coefficients in equation (48) are highly significant. However, the coefficients on the wealth proxies and the RUK variables in equations (49) and (50) are not significant. The coefficients on the other independent variables in equation (49) are statistically significant at the .05 level. The coefficients on DC^2 and DM are significant in equation (50) at the .10 and .22 levels, respectively.

The fact that the coefficient on W^2 in equation (49) is negative and not statistically significant may indicate that the index of industrial production is not a good proxy for the wealth of those residents of Europe and "other" countries that hold Eurodollar deposits. Since the coefficient on W^2 in equation (52) is significant and does carry the anticipated sign it may be that the results for W^2 in equation (49) are due to the limited number of observations available.

The results for equation (50) give mild support for the proposition that central banks react to the same interest rate and speculative variables as private investors. The strongest result is that central banks increase their holdings of Eurodollar deposits when Eurodollar rates increase relative to rates on United States certificates of deposit.

Equation (50) also gives strong indications that central bank holdings of Eurodollar deposits are not related to their holdings of official reserves.

It might be that the official reserve holdings of European countries is too broad a measure to use as a proxy for the wealth of the central banks that participate in the Eurodollar market. The foreign reserve holdings of a particular central bank may correspond much more closely to that central bank's holdings of Eurodollars. Since data is not available for individual central banks, only the broad proposition can be tested.

The results of equation (50) might also be improved by incorporating variables into the equation which reflect restrictions on central bank activities imposed by particular countries. As with equation (49), the results for equation (50) must be viewed with caution, given the number of observations.

The assumptions underlying this model of the Eurodollar market do not suggest that the RUK variable should be dropped from equation (50), but if it is then interesting results occur. Estimating equation (50) without the RUK variables yields:

$$S^3 = 37.74 + .0001W^3 + 1912.05DC^Z - 176.43DM, \quad (50')$$

(1.88) (.67) (2.48) (-2.43)

$$D.W. = 1.99, R^2 = .894$$

with both DC and DM significant at the .05 level.

Results from equation (48) indicate that a one percent increase in DC^Z will cause a .37 percent increase in S^1 . Equations (49) and (50)

indicate that a one percent increase in DC^2 will cause a .56 percent increase in S^2 and a .27 percent increase in S^3 .

All of the variables in equation (51) are highly significant except DL^2 . Apparently, the stock demand for Eurodollar loans by residents of the United States, Canada, and Japan is not influenced by the differential between the Eurodollar rate and the London prime rate. All of the estimated coefficients in equation (52) are significant at the .05 level. Participants in the Eurodollar market in both regional aggregates react significantly to higher costs of funds in the United States (proxied by RCP) by increasing their borrowing from the Eurodollar market.

The signs of the coefficients on the DM variable in equations (51) and (52) are different than anticipated. One might expect that anticipations of a lower value of the dollar would lead to increased borrowing of Eurodollars. Negative coefficients on DM may indicate that anticipations of a fall in the value of the dollar lead to increased taking of loans from United States' banks at the expense of Eurodollar banks.

If high levels of unemployment are associated with tight credit conditions in local credit markets, then an increase in the unemployment rate may lead to increased borrowing from the Eurodollar market and less borrowing from domestic credit markets. Such an explanation is consistent with a positive coefficient on UN^1 and UN^2 in equations (51) and (52), in which case the unemployment rate is a proxy for credit conditions rather than for business confidence.

Results from equation (52) indicate that a one percent increase in the absolute value of DL^Z (a lowering of the \hat{RE} relative to RLP) would cause a .003 percent increase in D^2 . Equation (51) indicates that a one percent increase in the absolute value of DL^Z would cause a .0002 percent decrease in D^1 .

Taking partial derivatives of equations (48)-(52) with respect to RE yields values that can be substituted into equation (39) to determine the Eurodollar interest rate multiplier. Substituting estimated values of the partials into equation (39) gives a Eurodollar multiplier equal to .019. This value is much lower than other estimates but is generally consistent with Niehans' and Hewson's (24) contention that very little liquidity can be created by the Eurodollar market. Dropping the partial derived from equation (51) does not change the value of the multiplier since that partial is so low relative to the others.

Part of the explanation for the low value of the multiplier is the interest rate sensitivity of central bank holdings of Eurodollar deposits. If the partial derived from equation (50) is also dropped from the determination of the multiplier, then the multiplier would have a value of .021.

The low value of the multiplier can also be attributed to the high responsiveness of Eurodollar deposits in Europe and "other" countries to changes in the Eurodollar rate. However, even if $\partial S^2 / \partial \hat{RE}$ was excluded from equation (43) (with $\partial S^3 / \partial \hat{RE}$ included) the multiplier would be less than .10 in value.

The main reason that the multiplier has a low value is because the responsiveness of the demand for Eurodollar loans to changes in the Eurodollar rate is low relative to the responsiveness of the demand for Eurodollar deposits to changes in the Eurodollar rate. An autonomous shift of dollars into the Eurodollar market will cause a decrease in the Eurodollar rate which will induce a large decrease in the demand for Eurodollar deposits. However, the lower Eurodollar rate will cause only a relatively small increase in the demand for Eurodollar loans so the overall impact on the value of Eurodollar deposits will be very low.

If equations (42)-(46) are used to supply estimates of the partials employed in equation (39), then the resulting multiplier has a value of .038. The value of the multiplier derived using the original ordinary least squares estimates is twice as large as the multiplier implied by the instrumental variable estimates, though it is still very low.

CONCLUSIONS

The estimated coefficients of the structural parameters in equations (48)-(52) suggest that the Eurodollar interest rate multiplier is very low. That implies that the ability of the Eurodollar market to grow through multiple deposit expansion is very limited if exchange rates are flexible and central banks do not intervene in the foreign exchange markets. Therefore, the growth of the Eurodollar market must be explained in terms of the interest rates and credit facilities offered investors and by the ability of the Eurodollar banks to act as brokers of short-term funds, attracting funds from surplus areas and distributing them to deficit areas. Much of the growth of the Eurodollar market may be due to the role that Eurodollar banks play in lowering the risk involved in transactions between ultimate borrowers and ultimate lenders of funds, and in lowering the risk inherent in international trade under a flexible exchange rate system.

If the Eurodollar multiplier is as low as suggested by this study, then the Eurodollar market cannot be a source of global inflation, and will in fact exert a stabilizing influence on the world financial structure. For instance, a sudden withdrawal of funds from the Eurodollar market would cause Eurodollar rates to rise which would induce a significant increase in the placement of new dollar funds in the market, and would cause a lesser decrease in demand for Eurodollar loans. Very little liquidity would be destroyed by the initial withdrawal of funds from the Eurodollar market.

The results also lend mild support to the contention that central banks react to the same set of interest rate and speculative variables as private investors. On the other hand, the results offer no support to the belief that central banks maintain a constant fraction of their foreign reserves in the form of Eurodollar deposits. The results concerning central banks' demand for Eurodollar deposits must be accepted with a considerable amount of caution, given the paucity of available data on central banks' holdings of Eurodollars.

The overall empirical results are good, given the degree of aggregation and the lack of precision in measuring holdings of Eurodollar deposits and loans. The results give strong support to the proposition that participants in the Eurodollar market are sensitive to changes in interest rates. Given the flexibility of Eurodollar rates, it seems very unlikely that investors will hold a fixed proportion of Eurodollar deposits to total dollar assets. A model developed according to fixed coefficient assumptions will give an inaccurate picture of the Eurodollar market. Explicit portfolio choice by participants in the Eurodollar market must be acknowledged.

The present model could be improved by developing a microeconomic foundation that allows for the specification of aggregate demand functions for Eurodollar deposits and loans based on utility-maximizing criteria. Making the Eurodollar model dynamic would also be an improvement on the current models.

More sophisticated research techniques are also dependent upon improvements in the accuracy and comprehensiveness of Eurodollar data

collection. Particularly lacking is data concerning Eurodollar transactions at the microeconomic level. Hopefully, the availability of data will increase over time and additional studies will help to resolve the issues relating to the functioning of the Eurodollar market.

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SECTION III. SOIL EROSION UNDER ALTERNATIVE
POLICY AND ENERGY CONSTRAINTS

Of concern to farmers, consumers, and policymakers alike is soil erosion and the related problem of nonpoint source pollution. Nonpoint source (NPS) pollution is that pollution that cannot be characterized as entering the environment at a particular point from a specific source.

Point source pollution is the kind of pollution typically referred to in classroom discussions of externalities. A factory smokestack belching pollution into the air, or waste from a chemical plant flowing through a sewer pipe into a river, are images of point source pollution. In both cases, the source and point of entry of the pollution are readily apparent. NPS pollution enters the environment in a diffuse manner. For instance, two farms may lie on a hill--one above the other. Both farms may contribute to the pollution of a stream at the base of the hill, but it may not be obvious exactly where each farm's pollution enters the waterway or to what extent each farm contributes to the pollution of the stream.

The NPS pollution this study is concerned with is that which arises as a derivative of agricultural production. The primary type of NPS pollution is soil erosion. Soil erodes when rain washes soil from fields into waterways. Modern tillage systems that break up the soil, or turn the soil over prior to planting, leave the fields particularly vulnerable to soil erosion. Once the soil enters the waterways, it degrades the aquatic habitat and directly reduces the recreational value of the streams.

Two other types of NPS pollution that are related to farm production are fertilizers and pesticides. Once in waterways, fertilizers encourage and enhance algae growth. When pesticides are washed into waterways, they may pose direct health hazards if the water is consumed by humans, or indirect health hazards if humans eat fish that contain amounts of the pesticides. Water treatment plants that draw water from rivers that are polluted with pesticides must purchase charcoal filters to prevent the pesticides from entering the community drinking water.

In order to improve stream water quality, it is necessary to reduce soil erosion and the amount of fertilizers and pesticides entering the waterways. Since sediment acts to some extent as a transport mechanism for fertilizers and pesticides (10, p. 3), the primary type of NPS pollution considered in this study will be soil erosion. It will be assumed throughout this analysis that a decrease in soil erosion that results from changes in agricultural production techniques will bring about an improvement in stream water quality. It is hoped that this study will provide policymakers with better information on which to base NPS pollution control policies.

LITERATURE REVIEW

Interest among economists about nonpoint source pollution and its control is relatively recent, but some useful studies of the problem have been conducted. Before reviewing specific studies, it is advantageous to discuss two common procedures that are employed in studies of nonpoint source pollution.

The first point that should be noted is that each of the studies reported here made use of the universal soil loss equation to estimate the amount of gross soil erosion arising under alternative cropping practices. The universal soil loss equation is a model that predicts long-run average annual erosion according to the equation:

$$E = \rho\kappa\lambda\sigma\gamma\pi, \quad (1)$$

where E = soil loss in tons per acre per year;

ρ = rainfall/runoff factor;

κ = soil erodibility factor;

λ = slope-length factor;

σ = slope-steepness factor;

γ = cover and management factor; and

π = practice factor.

The parameter ρ measures the frequency and erosivity of rainfall in a given location. κ measures how readily a soil erodes. Its value will depend on the physical properties of the soil. The product of λ and σ is

the topographical factor and in part determines the amount of sediment that will be carried away.

The product $\rho\kappa\lambda\sigma$ is an estimate of the tons per acre of soil that would erode from a specific field during the course of a year if the field was continuously fallow. The cover and management factor γ gives the ratio of soil loss from land cropped under particular conditions to the soil loss that would occur if the field was clean-tilled and continuously fallow. The value of γ will vary depending upon crop sequence, residue, and tillage practices, and upon the stage of development of crop cover at which rainfall occurs. The parameter π gives the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row tillage. A common support practice is contour tillage.¹

The second point regarding common procedures used in NPS studies involves the type of erosion control policies considered. The most frequently analyzed erosion control policies are gross soil loss restrictions and soil loss taxes.

Soil loss restrictions establish per acre limits on the amount of soil erosion from farmland permitted during a given period of time. In effect, they limit a farmer's choice of production methods to those which generate an amount of soil erosion that is less than or equal to the specified level.

Soil loss taxes take the form of charges imposed on farmers for each ton of soil that erodes from farmland during a particular period of time.

¹A more detailed discussion of the universal soil loss equation is provided in a U.S. Department of Agriculture publication (17).

If "c" is the per ton charge, and if E^e is the number of tons that erode from an acre of farmland, then cE^e is the per acre tax that the farmer is assessed.

One of the unique features of the present study is that soil erosion abatement subsidies are considered rather than soil erosion taxes. A subsidy program allows for the payment of a specific amount of money to farmers for each ton of soil erosion abated from the current or "baseline" level. If "s" is the per ton subsidy, if E^b is the baseline erosion (in tons) on an acre of farmland, and if E^e is the actual erosion (in tons) on the acre of farmland, then $s(E^b - E^e)$ is the per acre subsidy paid to the farmer.

The per acre subsidy can be divided into a fixed payment (sE^b) and a per acre tax (sE^e). If $s = c$, then the subsidy and tax will differ only by the fixed amount. In general, the subsidy policy will have the same efficiency implications as the tax policy if the fixed payment can be made independent of the farmer's behavior (16). That condition is met by the linear programming model developed in the next section.¹

The equity implications of a soil loss abatement policy will differ from those associated with a soil loss tax policy. Erosion abatement subsidies will benefit farmers at the expense of consumers, while soil loss taxes will benefit consumers at the expense of farmers.

¹The number of farms in the study area is fixed and the size of each farm is fixed. Also, the baseline level of erosion is directly observable.

Important practical reasons exist for considering soil loss abatement subsidies rather than soil loss taxes. An unwritten rule of political economy is that those most directly affected by a policy will react most intensively to it. Farmers would be directly affected by any type of erosion control policy, and would strongly oppose attempts to establish a program involving soil erosion charges. While the effect on farmers would be direct, the benefits to consumers of soil loss taxes would be diffuse. Given the political importance of farmers, it seems highly unlikely that a charges policy will ever be seriously considered. It appears that the implementation of a soil erosion abatement subsidy policy would be much more likely than the implementation of a soil loss tax policy.

The effects of alternative NPS pollution control policies can be analyzed at many levels of aggregation. Three studies give insight into the economic impacts of soil erosion control policy on agricultural production. The first study focuses on crop production in the Corn Belt, the second on crop production in a regional watershed, and the third on agricultural production on individual farms.

Taylor and Frohberg (20) used a linear programming model of crop production in the Corn Belt to examine the partial equilibrium welfare effects of alternative NPS pollution control policies. Cropland in the study area was divided into 11 soil aggregates within each of 17 geographical areas in the Corn Belt. The model did not allow for live-stock production but did allow for production and sale of corn, soybeans, wheat, oats, hay, and pasture. Allowable cropping activities in each soil aggregate consisted of fall or spring moldboard plowing or chisel plowing;

straight row, contouring, or terracing practices; and an average of 11 different crop rotations. The objective function of the linear programming model was the maximization of consumers' and producers' surplus in the corn and soybean markets minus the total variable cost of producing a given amount of wheat, oats, hay, and pasture. To represent the demand side of the model, Taylor and Frohberg used stepped demand functions for corn and soybeans which they subjectively specified.

Taylor and Frohberg first solved the model without any pollution policy imposed in order to find a baseline for comparison purposes. They then estimated the partial welfare effects of a number of alternative NPS pollution control policies.¹ The policies they considered that are of primary interest in terms of the present study are gross soil loss restrictions and soil loss taxes.

Taylor and Frohberg found that either a soil loss restriction of 5 tons/acre or a soil loss tax of \$1/ton would reduce soil erosion in the Corn Belt by about 2.44 tons/acre (a 45 percent decrease). The soil loss restriction reduces the amount of corn and soybeans produced in the study

¹The welfare effects are partial since they take account of the change in the sum of producers' and consumers' surplus resulting from the production and consumption of corn, soybeans, wheat, oats, hay, and pasture, but not the environmental benefits derived from NPS pollution abatement or the administrative cost of the abatement policies. Taylor and Frohberg calculate the change in consumers' surplus for corn and soybeans as $(P_{Bi} - P_{Ri})(Q_{Bi} + Q_{Ri})/2$, where P_B and Q_B are the baseline price and quantity demanded, P_R and Q_R are the price and quantity demanded in those model solutions associated with the policy under consideration, and "i" is corn and soybeans. The change in consumers' surplus for wheat, oats, hay, or pasture is calculated as $(P_{Bi} - P_{Ri})Q_{Bi}$, where "i" represents one of the four crops. The change in consumers' surplus associated with a particular erosion control policy is the sum of the changes in consumers' surplus for each of the crops.

area. The soil loss tax increases corn production and decreases soybean production. Assuming that the net social cost of a policy can be measured by the change in producers' plus consumers' surplus, the welfare cost of the 5 tons/acre policy would be \$201 million, while the \$1/ton tax would have a welfare cost of \$108 million. While a soil loss tax policy appeared to be the socially least costly way of achieving a particular level of soil loss, Taylor and Frohberg found that for reductions of soil loss from the baseline of up to 33 percent, the soil loss restriction policy was only slightly less efficient than the tax policy.

The two policies do have significant equity differences. A soil loss restriction of 5 tons/acre would increase producers' surplus by \$232 million (and decrease consumers' surplus by \$433 million), while a \$1/ton soil loss tax would decrease producers' surplus by \$722 million (and increase consumers' surplus by \$286 million and raise \$328 million in tax revenue).

Alt and Heady (1) used a linear programming model to analyze the impacts of alternative soil erosion restrictions on the costs of field crop production in a 900,000 acre watershed of the Iowa River. They proceeded by dividing farmland into nine distinct soil aggregates, and building a model of crop production for each aggregate. No livestock production was allowed to occur in any aggregate, but each aggregate was allowed to produce continuous corn, corn-beans rotations, or rotations that combined corn, beans, oats, and meadow. Tillage practices were assumed to consist of spring or fall moldboard plowing, rotary-till planting, or no-till planting. Additionally, farmers in each aggregate were

allowed the option of contour planting or terracing. The objective function of the model was the minimization of the total cost of producing specified levels of output in the watershed. These specified levels represented projected output levels in the study area. Although separate models of crop production were built for each soil aggregate, the Alt and Heady programming model treated the whole watershed as if it was one farm.

To determine the characteristics of farm production in the study area in the absence of soil loss policy, a baseline solution was computed. The results of the baseline solution indicated that production of row crops would occur in only four of the nine soil aggregates, and that the only cropping practice used in the watershed would be fall moldboard plowing with straight row planting.

Programming solutions of the model were obtained for three different levels of soil loss restrictions: 10 tons/acre, 5 tons/acre, and 3 tons/acre. The results indicated that the 10 tons/acre limit would be met primarily by contouring and switching from fall to spring moldboard plowing. The 5 tons/acre and 3 tons/acre limits induced a switch to rotary-till and no-till planting, and brought about a dramatic increase in the number of acres terraced. While the 10 tons/acre erosion limit caused costs of production in the watershed to rise by only 2.5 percent, the cost of meeting tighter standards was considerably higher. Imposition of a 3 tons/acre soil loss standard caused the cost of production in the watershed to increase by over \$10.5 million (16.8 percent).

McGrann and Meyer (13) evaluated the farm level economic impacts of soil erosion control policy by constructing models of farms that are

representative of the farms located in three major soil association areas in Iowa. The representative farms for two of the soil associations were assumed to have 320 acres of cropland each, and the representative farm for the third soil association was assumed to consist of 240 acres of cropland. Each farm was allowed to conduct farrow-to-finish hog operations, cow-calf operations, and cattle feeding enterprises. Additionally, each farm could plant continuous corn, corn-bean rotations, corn-oats-meadow combinations, or continuous meadow. The cropping practice alternatives available to each representative farm consisted of moldboard or chisel plowing, and straight row planting, contouring, or terracing. Linear programming techniques were used to select the rotation and cropping practices that maximized net income for each farm.

McGrann and Meyer developed a baseline solution for each farm by requiring that each farm use moldboard plowing and straight row planting. They then imposed soil loss restrictions of 15, 10, 5 and 2 tons/acre on the farms. The results indicated that a 5 tons/acre limit would cause farm income to fall by \$10,068 (30 percent) on one farm, and by \$2,365 (4 percent) on another farm. A 5 tons/acre soil loss restriction would not cause any change in income on the third farm since its gross erosion in the baseline solution was less than 5 tons/acre. This suggests that the inequities associated with a uniform soil loss restriction policy would be substantial.

To determine whether the inclusion of livestock operations on the representative farms mitigated the income-reducing impact of soil loss policy, they imposed the soil loss restrictions on the farms and ran the

program with the livestock operations excluded. Their finding was that the existence of livestock operations on farms tends to mitigate part of the detrimental impact on income of soil loss restrictions.

These studies indicate some of the ways in which the economic impacts of alternative NPS pollution control policies can be analyzed. While interesting and useful, these approaches ignore the need to coordinate NPS pollution control policy with shifting relative costs of agricultural inputs.

One important input whose relative price is likely to change over the next ten to fifteen years is energy. The impact of changes in the relative price of energy will be manifested directly in changing fuel bills for farmers and indirectly in changing costs for farm inputs--fertilizers, herbicides, pesticides, and machinery. The change in energy costs will have an impact on the choice of farm production techniques and, therefore, on soil erosion and stream water quality.

One study of the effects of higher energy prices on farm production was conducted by Forster and Rask (6). They attempted to determine the impact of rising energy prices on the choice of tillage systems on Ohio farms. To do so, they constructed one representative farm for each of three different soil types common to Ohio cropland. Each farm was assumed to consist of 600 acres of cropland--half of which was planted in corn and the other half in soybeans. No livestock production was allowed to occur on any of the farms. Linear programming techniques were used to find for each farm the returns above variable costs associated with three

alternative tillage systems. The tillage systems that Forster and Rask considered were moldboard plowing, chisel plowing, and no-till planting.

In the baseline solution of the model, Forster and Rask found the net return associated with each tillage system on each farm with energy prices at their 1976 levels. Their baseline results showed that no-till planting gave the highest net return for the first two farms, while moldboard plowing yielded the highest net return on the third farm.

They then considered four alternative energy price scenarios and the impact they would have on net returns under each tillage system on each farm. The alternative price scenarios allowed for a 50 percent or a 100 percent increase in energy prices in the short-run, and a 50 percent or 100 percent increase in energy prices in the long-run. According to their assumptions, in the short-run only fuel and nitrogen fertilizer prices are responsive to increases in energy prices; while in the long-run the prices of all inputs would be affected by higher energy prices. Solving the model for each price scenario, Forster and Rask found that higher energy prices have an almost identical impact on the profitability of the various tillage systems. For all energy price scenarios, no-till planting still yielded the highest net returns on the first two farms, while moldboard plowing still gave the highest net return on the third farm. These results indicated that higher energy prices would have little impact on the choice of tillage systems.

Effective public policy, aimed at reducing NPS pollution, requires a more complete understanding of the relationship between the costs of farm fuel and energy-related inputs and the level of NPS pollution that is

generated in the production process, than that provided by the Forster and Rask study. The purpose of this analysis is to assess the impacts of higher energy prices on soil erosion and on the effectiveness of NPS pollution control policies. This is accomplished by evaluating the impact of higher energy prices on soil erosion in the absence of NPS pollution control policies and in the presence of different NPS control policies.

The use of rising energy prices in the study is justified for two reasons. First, political instability in the Persian Gulf and world-wide recovery from recession will likely combine to bring about an increase in energy prices. Second, the results indicate that the major impact of rising energy prices on NPS pollution and pollution control policy will occur with only moderate increases in energy prices.

The next section presents a theoretical framework within which all production models are constructed. Attention is then given to the development of the specific model used in this analysis.

MODEL

In general, the role of a producer in an economic system is to choose a plan of action that optimizes some objective function, given the information available to the producer at that time. The most common objective that producers are assumed to maximize is the firm's net revenue, or profit. The information that guides the producer's choices consists of knowledge of technological relationships between inputs and outputs, knowledge of prices of inputs and outputs, and knowledge of any physical or political constraints that limit the extent that an input can be used or a particular technology employed.

In the context of modern economic theory, the sum of a producer's knowledge of feasible production processes can be represented by a production set. Let "W" consist of all production vectors that are feasible for the firm. One such production vector, w , specifies a particular transformation of inputs into outputs with the outputs appearing as positive numbers and the inputs appearing as negative numbers. For sake of economic analysis, it is usually assumed that the producer's choice set is closed and convex, and that the production processes are additive (3, pp. 39-41).

The production set will be closed if it contains all of its boundary points (11, p. 15). Assuming that w^1 and w^2 are both elements of W and that $0 \leq v \leq 1$, then W is convex if $vw^1 + (1-v)w^2$ is also an element of W. The production processes are additive if, when two processes are

independently possible, they are also jointly possible. If the null vector is an element of W , then additivity and convexity imply constant returns to scale (3, p. 42).

If certain crucial inputs are available to the producer in fixed amounts, then the production set may be bounded. That is, it will be possible to specify a hypercube sufficiently large to contain all of the points in the producer's choice set (11, p. 14). If the production set is closed and bounded, then it is said to be compact (11, p. 15).

Let " q " represent a vector of input and output prices. In order to maximize profits, a producer will choose a w^* such that $q \cdot w^*$ is a maximum. If the production set is compact, then w^* will lie in the boundary of W ; and a supporting hyperplane, normal to the price vector, will pass through w^* (3, p. 43).

Although the theory of the firm in its generalized version is very elegant, it is necessary to use a more specific formalization in order to construct models that allow for computations. To this end, economists can choose between models that make use of neoclassical production functions (which usually allow for large substitutability among inputs), and fixed coefficient models of which linear programming is one example (12, p. 45).

A Neoclassical Production Model¹

A general neoclassical production function for farm output might be expressed as:

$$X = h(Z_1, Z_2, Z_3), \quad (2)$$

where X = the quantity of aggregate farm output;

Z_1 = the quantity of the aggregate capital input;

Z_2 = the quantity of the aggregate labor input; and

Z_3 = the quantity of the aggregate energy input.

It is assumed that the production function is continuous and has continuous first and second-order partial derivatives.

According to the neoclassical theory of the firm, a farm entrepreneur will seek to maximize his or her net farm income, or profits. If "P" is the unit price of output, if C_1 , C_2 , and C_3 are the unit prices of the farm inputs, and if "I" is the farm net income (profit), then the entrepreneur's profit function can be represented as:

$$I = PX - C_1Z_1 - C_2Z_2 - C_3Z_3, \quad (3)$$

or

$$I = P \cdot h(Z_1, Z_2, Z_3) - C_1Z_1 - C_2Z_2 - C_3Z_3. \quad (4)$$

¹This subsection is based on the neoclassical production model presented by Henderson and Quandt (8).

The entrepreneur will select Z_1 , Z_2 , and Z_3 to maximize the profit function. The first-order conditions for profit maximization are:

$$P' h_{Z_1} - C_1 = 0, \quad (5)$$

$$P' h_{Z_2} - C_2 = 0, \text{ and} \quad (6)$$

$$P' h_{Z_3} - C_3 = 0. \quad (7)$$

Second-order conditions for profit maximization require that:

$$P'' h_{Z_1 Z_1}, P'' h_{Z_2 Z_2}, P'' h_{Z_3 Z_3} < 0, \quad (8)$$

$$P^2 \begin{vmatrix} h_{Z_1 Z_1} & h_{Z_1 Z_2} \\ h_{Z_2 Z_1} & h_{Z_2 Z_2} \end{vmatrix}, P^2 \begin{vmatrix} h_{Z_1 Z_1} & h_{Z_1 Z_3} \\ h_{Z_3 Z_1} & h_{Z_3 Z_3} \end{vmatrix}, P^2 \begin{vmatrix} h_{Z_2 Z_2} & h_{Z_2 Z_3} \\ h_{Z_3 Z_2} & h_{Z_3 Z_3} \end{vmatrix} > 0, \quad (9)$$

and

$$P^3 \begin{vmatrix} h_{Z_1 Z_1} & h_{Z_1 Z_2} & h_{Z_1 Z_3} \\ h_{Z_2 Z_1} & h_{Z_2 Z_2} & h_{Z_2 Z_3} \\ h_{Z_3 Z_1} & h_{Z_3 Z_2} & h_{Z_3 Z_3} \end{vmatrix} < 0. \quad (10)$$

A change in relative input prices will induce the entrepreneur to adjust the quantity of each input used. To examine the effects of a change in input prices, it is necessary to totally differentiate equations (5) - (7). Differentiating totally and expressing in matrix form yields:

$$\begin{bmatrix} P \cdot h_{Z_1 Z_1} & P \cdot h_{Z_1 Z_2} & P \cdot h_{Z_1 Z_3} \\ P \cdot h_{Z_2 Z_1} & P \cdot h_{Z_2 Z_2} & P \cdot h_{Z_2 Z_3} \\ P \cdot h_{Z_3 Z_1} & P \cdot h_{Z_3 Z_2} & P \cdot h_{Z_3 Z_3} \end{bmatrix} \begin{bmatrix} dZ_1 \\ dZ_2 \\ dZ_3 \end{bmatrix} = \begin{bmatrix} dC_1 - h_{Z_1} dP \\ dC_2 - h_{Z_2} dP \\ dC_3 - h_{Z_3} dP \end{bmatrix}. \quad (11)$$

Now let

$$\Delta = P^3 \begin{vmatrix} h_{Z_1 Z_1} & h_{Z_1 Z_2} & h_{Z_1 Z_3} \\ h_{Z_2 Z_1} & h_{Z_2 Z_2} & h_{Z_2 Z_3} \\ h_{Z_3 Z_1} & h_{Z_3 Z_2} & h_{Z_3 Z_3} \end{vmatrix}. \quad (12)$$

Using Cramer's rule, it is easy to show that an increase in the price of an input will always reduce the usage of that input. For instance, the impact of higher energy prices on energy use is given by:

$$\frac{\partial Z_3}{\partial C_3} = \frac{P^2 \begin{vmatrix} h_{Z_1 Z_1} & h_{Z_1 Z_2} \\ h_{Z_2 Z_1} & h_{Z_2 Z_2} \end{vmatrix}}{\Delta}. \quad (13)$$

Equation (13) implies that the own-price effect will be unambiguously negative if the second-order conditions are met.

The impact of higher energy prices on the amount of labor employed is given by:

$$\frac{\partial Z_2}{\partial C_3} = -P^2 \frac{\begin{vmatrix} h_{Z_1 Z_1} & h_{Z_1 Z_3} \\ h_{Z_2 Z_1} & h_{Z_2 Z_3} \end{vmatrix}}{\Delta}. \quad (14)$$

Equation (14) indicates that the sign of $\partial Z_2 / \partial C_3$ depends on the signs of the cross partials of the production function. A common assumption in microeconomics is that the cross partials have positive values. If so, higher energy prices will cause a decrease in labor usage, given that the second-order conditions are met.

Assuming that $h_{Z_2 Z_1}$ is greater than zero, the sign of $\partial Z_2 / \partial C_3$ will be unambiguously positive only if $h_{Z_2 Z_3}$ and $h_{Z_1 Z_3}$ are both less than zero. However, it is unlikely that $h_{Z_2 Z_3}$ and $h_{Z_1 Z_3}$ would both be less than zero.

It seems reasonable to assume that for most cases the cross partials of the production function will be positive. If the cross partials are positive, an increase in the price of an input will cause a decrease in the use of other inputs. Since the own-price effect is also negative, it follows that an increase in the price of an input will decrease the quantity of farm output.

Examination of the neoclassical production model provides insight into the behavior of entrepreneurs. However, a neoclassical production function for farm output is not directly known, and it is usually much easier to conduct empirical studies of agricultural production by employing linear programming techniques. A linear programming model is a workable alternative to the neoclassical model, but its use carries with it a number of limitations. A major drawback of linear programming production models is that they allow limited possibilities for substitution among inputs. This limitation is particularly serious when input price changes are large and occur over a long period of time, or when the production process allows rapid adjustment in relative input levels.

The use of linear programming models of farm production is partially justified because substitution among farm inputs is somewhat restricted in the short-run. Typically, a farmer owns an equipment set which consists of a tractor and a particular set of implements that are compatible with the tractor. The farmer's production decision is the extent to which he or she will use the type of equipment set he or she owns in the production of a limited choice of outputs. Since one worker is required to operate the tractor and accessories, the farmer is limited in making capital-labor substitutions--at least in the short run.

Although a farm production function is not directly observable, various farm production processes are. Linear programming is a convenient way of making use of knowledge of farm production processes to answer empirical questions about production decisions. It is ideally suited to show the impacts of physical constraints (amounts of land), and policy

constraints (soil loss restrictions), on farm decisions. The number of production processes available to farmers is limited. The addition of an assumption of linearity to the previous assumptions about production sets is sufficient to allow the linear programming approach to be used (4, p. 81).

A Linear Programming Model¹

To examine how pollution control policy is affected by prevailing energy prices, a linear programming model of farm production was developed for that part of the Iowa River Basin that lies above the Coralville Reservoir. The study area consists of approximately 1,899,600 acres of cropland and 61,400 acres of permanent pasture lying in all or part of Benton, Cerro Cordo, Franklin, Grundy, Hamilton, Hancock, Hardin, Iowa, Johnson, Linn, Marshall, Poweshiek, Tama and Wright counties in Iowa. This part of the Iowa River Basin encompasses farmland that ranges from gently sloping prairie in North Central Iowa to steeply sloped hills in Eastern Iowa.

For purposes of this study, the farmland was aggregated into nine basic soil areas according to agronomic and physical characteristics of the soils. Table III-1 shows the relationship between the study aggregates used in this analysis and the Soil Association Area designations made by the U.S. Soil Conservation Service. Table III-1 also lists the

¹Tom Fenton, Mark Wall, Jerry Gogan, and Ted Hall were helpful in providing some of the technical data used in constructing the coefficients of the programming model. Klaus Alt, Jim Shortle, and Mike Monson made useful suggestions relating to construction of the model.

Table III-1. Soil type composition of study aggregates^a

Study aggregate	Soil association area	Soil type and slope	Normalized percent
1	11	108A Wadena L	(14)
		559A Talcot CL	(26)
		138B1 Clarion L	(30)
		87A Colo-Zook CP	(30)
2	12,14,17,18	507A Canisteo SICL	(22)
		55A Nicollet L	(22)
		107A Webster SICL	(19)
		138B1 Clarion L	(22)
		138C2 Clarion L	(12)
3	13,117	107A Webster SICL	(46)
		138B1 Clarion L	(27)
		138C2 Clarion L	(14)
		138D2 Clarion L	(6)
		62E2 Sturden L	(7)
4	15	107A Webster SICL	(29)
		55A Nicollet L	(32)
		138B1 Clarion L	(29)
		138C2 Clarion L	(10)
5	7	87A Colo-Zook CP	(38)
		178A Waukee L	(17)
		220A Nodaway SIL	(10)
		315A Alluvial Land	(10)
		177B1 Saude L	(25)
6	57	129A Chaseburg SICL	(17)
		163B Fayette SICL	(26)
		163C2 Fayette SICL	(22)
		163D2 Fayette SICL	(21)
		163E2 Fayette SICL	(14)
7	46	280A Mahaska SICL	(12)
		281B1 Otley SICL	(35)
		281C2 Otley SICL	(21)
		281D2 Otley SICL	(32)
8	56,77	119A Muscatine SICL	(16)
		120B1 Tama SICL	(26)
		120C2 Tama SICL	(32)
		120D2 Tama SICL	(17)
		162E2 Downs SIL	(9)
9	55,59,65,78	119A Muscatine SICL	(24)
		120B1 Tama SICL	(41)
		120C2 Tama SICL	(35)

^aDerived from Soil Conservation Service Soil Survey Maps.

predominant soil types occurring in the study aggregates and their normalized percentages.

Each of the nine study aggregates was assumed to be composed of similar farms of 300 acres each, and a "typical" or "representative" farm was constructed for each study aggregate. Consistent with the cropping practices in the study area, each representative farm was given the option of growing continuous corn, corn-beans, or corn-corn-oats-meadow-meadow rotations. The representative farms could choose from a list of tillage systems that included fall moldboard plowing, fall chisel plowing, spring chisel plowing, spring disking, and no-till planting. For any tillage system, the representative farmer could use straight row or contour cultivation and could terrace the cropland. Table III-2 lists the cropping options for farmers in the river basin.

The livestock activities assumed available to each representative farm included farrow-to-finish swine operations, beef cow-calf operations, feeder steer finishing, and dairy enterprises. Livestock operations were limited to on-farm produced feed grain and forage. While livestock production activities have little direct effect on soil loss, their inclusion in the model is necessary because the forage crop requirements of livestock will reduce the number of acres available for row crops and will absorb some increases in forage production.

To determine a baseline solution for crop and livestock production in the study area, a linear programming model which maximized net farm income was constructed. The objective function of the model was:

Table III-2. Rotation, tillage system, and practice options for farmers

Rotations

- 1) Continuous corn
- 2) Corn-beans
- 3) Corn-corn-oats-meadow-meadow (CCOMM)

Tillage systems^a

- 1) Moldboard plow in fall
- 2) Chisel plow in fall
- 3) Chisel plow in spring
- 4) Spring disk
- 5) No-till planter

Practices

- 1) Straight row (up and down)
 - 2) Contour
 - 3) Terrace
-

^aListed in order of decreasing erosivity.

$$\text{BNI} = \sum_{a=1}^9 I_a, \quad (15)$$

where BNI is the total net farm income for the river basin, and I_a is the total net farm income in the a-th soil aggregate. As the model is constructed, the solution for each soil aggregate is independent of the others and the baseline solution is the sum of the solutions obtained from the nine models, one for each farm. This means that farmers in one study aggregate may adjust production techniques and output levels, but the model does not allow resources to be reallocated from one study aggregate to another; nor can farmers enter or leave the study area. The model allows a determination of the most efficient allocation of resources for a farmer; not a determination of the most efficient allocation of resources within the Iowa River Basin.

Net farm income for each study aggregate equals the total net income of the farms in that aggregate. To obtain an estimate of net income for each representative farm in study aggregate a, I_a is divided by the actual number of farms in the a-th study aggregate.

Net income is equal to the total receipts from crop and livestock sales less all costs except those constituting returns to farmland and management. All labor inputs are assumed to be purchased, so net income is exclusive of the returns to labor provided by the farm operator. It is also assumed that farmers do not hold inventories of inputs or outputs from one production year to the next. The net income estimates are for a

representative crop year under current technological conditions, given expected crop and livestock prices and input costs.

The objective function that is maximized in the solution of the a-th study aggregate is given by:

$$\begin{aligned}
 I_a = & \sum_{i=1}^5 P_i X_{ia} + \sum_{i=6}^9 X_{ia} (P_i - C_{ia}) \\
 & - \sum_r \sum_t \sum_p A_{artp} (Q_{artp} + \sum_{i=1}^5 K_i Z_{iartp} \\
 & + \sum_{i=6}^8 K_i Z_{iartpf}); \tag{16}
 \end{aligned}$$

with $a = 1, \dots, 9$ study aggregates;

$r = 1, 2, 3$ rotations;

$t = 1, \dots, 5$ tillage systems;

$p = 1, 2, 3$ practices;

$f = 1, 2, 3$ fertilizer requirement levels;

X_{1a} = corn sales in bushels of the a-th study aggregate;

X_{2a} = soybean sales in bushels of the a-th study aggregate;

X_{3a} = hay sales in tons of the a-th study aggregate;

X_{4a} = oats sales in bushels of the a-th study aggregate;

X_{5a} = straw sales in tons of the a-th study aggregate;

X_{6a} = number of steers in the a-th study aggregate;

- X_{7a} = number of calves in the a-th study aggregate;
 X_{8a} = number of dairy cows in the a-th study aggregate;
 X_{9a} = number of hog-litters in the a-th study aggregate;
 P_1 = per bushel price of corn;
 P_2 = per bushel price of soybeans;
 P_3 = per ton price of hay;
 P_4 = per bushel price of oats;
 P_5 = per ton price of straw;
 P_6 = sales price per steer;
 P_7 = sales price per calf;
 P_8 = milk price per cow;
 P_9 = sales price per litter;
 C_{6a} = cost per steer of steer feeding operations exclusive of feed;
 C_{7a} = cost per calf of cow-calf operations exclusive of feed;
 C_{8a} = cost per cow of dairy operations exclusive of feed;
 C_{9a} = cost per litter of hog operations exclusive of feed;
 A_{artp} = acres of rotation r in the a-th study aggregate utilizing the t-th tillage system and the p-th practice;
 Q_{artp} = per acre cost of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and the p-th practice, exclusive of chemical and fuel costs and exclusive of returns to farmland and management;
 Z_{1artp} = diesel fuel requirements per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice;

- Z_{2artp} = propane gas requirements per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice;
- Z_{3artp} = insecticide requirements per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice;
- Z_{4artp} = corn herbicide requirements per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and the p-th practice;
- Z_{5artp} = bean herbicide requirements per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and the p-th practice;
- Z_{6artpf} = nitrogen purchases per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice at the f-th level of nitrogen requirements;
- Z_{7artpf} = phosphorus purchases per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and the p-th practice at the f-th level of phosphorus requirements;
- Z_{8artpf} = potassium purchases per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice at the f-th level of potassium requirements;
- K_1 = price per gallon of diesel fuel;
- K_2 = price per gallon of propane;
- K_3 = price per acre of insecticide;
- K_4 = price per acre of corn herbicide;

K_5 = price per acre of bean herbicide;

K_6 = price per pound of nitrogen;

K_7 = price per pound of phosphorus; and

K_8 = price per pound of potassium.

The model requires the farmer to choose--given price vectors for crops, livestock, and inputs--the combination of rotations, tillage systems, practices, and levels of livestock activities that maximize the value of net income. The choice of crop production and livestock activities is made subject to the following constraints on land and crop output levels:

$$\sum_r \sum_t \sum_p A_{artp} + PP_a \leq L_a; \quad (17)$$

$$\sum_r \sum_t \sum_p Y_{1artpf} A_{artp} - X_{1a} - \sum_{i=6}^9 R_i X_{ia} \geq 0; \quad (18)$$

$$\sum_t \sum_p Y_{2ar_btp} A_{ar_btp} - X_{2a} \geq 0 \quad (19)$$

where $r = r_b$ is the index of the CB rotation;

$$\sum_t \sum_p Y_{3ar_mtp} A_{ar_mtp} - X_{4a} - O_a X_{9a} \geq 0 \quad (20)$$

where $r = r_m$ is the index of the CCOMM rotation;

$$\sum_t \sum_p Y_{5ar_mtp} A_{ar_mtp} - X_{5a} - S_a X_{8a} \geq 0; \quad (21)$$

$$\sum_t \sum_p Y_{4ar_m tp} (A_{ar_m tp} + PPTM_a) - X_{3a} - H_a X_{8a} \geq 0; \quad (22)$$

$$PP_a + MTPP_a - G_a X_{7a} \geq 0; \quad (23)$$

$$PP_a - PPTM_a \geq 0; \quad (24)$$

$$\frac{2}{5} \sum_t \sum_p A_{ar_m tp} - MTPP_a \geq 0; \quad (25)$$

$$\sum_r \sum_t \sum_p A_{artp} (N_{artpf} - M_{artpf} - Z_{6a}) = 0; \quad (26)$$

with PP_a = acres of permanent pasture in the a-th study aggregate;

L_a = total available acres in the a-th study aggregate;

Y_{1artpf} = corn yield per acre of the r-th rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice at the f-th level of nitrogen requirements;

$Y_{2ar_b tp}$ = bean yield per acre of the corn-bean rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice;

$Y_{3ar_m tp}$ = oats yield per acre of the CCOMM rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice;

$Y_{4ar_m tp}$ = hay yield per acre of the CCOMM rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice;

$Y_{5ar_m tp}$ = straw yield per acre of the CCOMM rotation in the a-th study aggregate utilizing the t-th tillage system and p-th practice;

- R_6 = corn requirement per steer;
 R_7 = corn requirement per calf;
 R_8 = corn requirement per dairy cow;
 R_9 = corn requirement per litter;
 O_a = oats requirement per litter;
 S_a = straw requirement per dairy cow;
 H_a = hay requirement per dairy cow;
 G_a = pasture requirement per calf;
 $MTPP_a$ = "change one acre of meadow to one acre of permanent pasture";
 $PPTM_a$ = "change one acre of permanent pasture to one acre of meadow";
 N_{artpf} = f-th level nitrogen requirements per acre of the r-th rotation
in the a-th study aggregate utilizing the t-th tillage system
and p-th practice; and
 M_{artpf} = nitrogen carryover per acre of the r-th rotation in the a-th
study aggregate utilizing the t-th tillage system and p-th
practice.

In addition to the above constraints, bounds of the following form were placed on feasible activity levels:

$$X_{ia} - \bar{X}_{ia}^U \leq 0, \quad i = 6, 7, 9; \quad (27)$$

$$X_{ia} - \bar{X}_{ia}^L \geq 0, \quad i = 6, \dots, 9; \quad (28)$$

$$\sum_r \sum_p A_{art_{Fp}} - \bar{F}_a^L \geq 0; \quad (29)$$

where $t = t_F$ is the fall moldboard tillage system option;

\bar{X}_{6a}^U = upper bound on the number of steers in study aggregate a
(\bar{X}_{6a}^L is a lower bound);

\bar{X}_{7a}^U = upper bound on the number of calves in study aggregate a (\bar{X}_{7a}^L
is a lower bound);

\bar{X}_{8a}^L = lower bound on the number of dairy cows in study aggregate a;

\bar{X}_{9a}^U = upper bound on the number of hog litters in study aggregate a
(\bar{X}_{9a}^L is a lower bound); and

\bar{F}_a^L = lower bound on fall moldboard tillage in study aggregate a in
number of acres.

These restrictions are imposed in the baseline solution and, except for the last one, in subsequent policy solutions. These constraints serve two purposes. In the baseline solution, they force the model's results to be representative of existing crop and livestock production activities in the study area. In some cases, this requires a lower bound and in others, an upper bound. Such bounding is necessitated when the baseline solution does not yield representative activity levels because of data imperfections or objectives not incorporated into the model but affecting the behavior of farmers. For example, the unbounded model predicts that

farmers in the study area will maintain smaller dairy herds than they actually do, and it also indicates that less moldboard plowing will occur than in practice. However, some farmers maintain low-return dairy operations as a hedge against unexpected downward movements in row crop prices. Similarly, some farmers may view moldboard plowing as a less risky tillage practice than the alternatives, or they may receive utility from having fields that are turned over in the fall. Bounds may partially compensate for not incorporating risk-avoidance and aesthetic goals in the model's objective function.

Capacity estimates were also used to limit unrealistically large swings in livestock numbers. The high costs associated with rapid adjustment of livestock production tend to keep producers in the market during unprofitable periods and inhibit others from entering the market during profitable periods. Bounds provide a method of taking account of the costs that are incurred when farmers rapidly adjust their livestock operations. Bounds also help take account of the price adjustment effects that would normally occur with large swings in livestock supply. When capacity bounds are used, the model generates livestock production levels that are comparable to current production and historical trends.

Crop yield estimates used for each study aggregate were the weighted averages of the crop yield estimates of each soil type appearing in the soil aggregate. Specific crop yield estimates for each soil type were taken from estimates published by Iowa State University (5).

The basic recommended fertilizer levels for each study aggregate were constructed by first finding the recommended fertilizer levels for each

soil type within a particular study aggregate, and then taking the weighted average of the fertilizer levels for the soil types. Fertilizer recommendations for the soil types were derived from two extension publications (18 and 19).

To determine the cost of operating and maintaining a particular machinery complement, an enterprise budget generator from the Cooperative Extension Service (I.S.U.) was used. This computer routine provides a means of delineating machinery complements data, performing the needed computations, and producing the fixed and variable costs associated with the machinery complements. To allow for a more direct analysis of fuel use, the fuel use component of the machinery complements was separated from the other costs of the machinery complement.

Farms in the model purchase diesel fuel to perform field operations, and purchase propane gas to dry corn. The diesel fuel requirements were developed from data prepared by the Iowa State University Cooperative Extension Service (2) which give the gallons per acre of diesel fuel required to perform various field operations on a Central Iowa loam soil (see Table III-3). A coefficient for each crop production activity in the model was constructed by summing the requirements for each field operation composing that activity. The coefficients are inflated by five percent for crop production activities involving contour tillage in order to allow for the extra fuel expenditure involved in handling point rows.

The propane gas requirements for corn drying were assumed to be 0.1856 gallons/bushel. This figure was derived from information contained in the enterprise budget generator.

Table III-3. Fuel requirements for various rotations and tillage systems

Rotation	Gallons per acre		
	Light	Medium ^a	Heavy
Continuous corn, fall moldboard	6.28	7.15	8.40
Corn-beans, fall moldboard	4.57	5.54	5.95
Continuous corn, fall chisel	5.96	6.95	7.10
Corn-beans, fall chisel	5.89	5.69	5.98
Continuous corn, spring chisel	5.96	6.95	7.10
Corn-beans, spring disk	4.46	5.04	4.88
Corn-beans, double chisel, fall	4.61	5.44	6.06
Corn-meadow, fall moldboard	2.70	3.11	3.65
Corn-meadow, fall chisel	2.99	3.38	3.79
Corn-meadow, spring chisel	2.99	3.38	3.79
Continuous corn, no-till	3.00	3.35	3.61
Corn-beans, no-till	2.44	2.79	3.05

^aThese figures are for a Central Iowa loam soil. The "light" and "heavy" column entries represent adjustments to these basic figures to reflect changes in fuel consumption.

A baseline solution of the model will have associated with it a level of gross soil erosion of

$$T = \sum_a \sum_r \sum_t \sum_p E_{artp} A_{artp} \quad (30)$$

where T is total erosion from farmland in the study area and E_{artp} is the gross soil loss per acre of the r -th rotation in the a -th study aggregate utilizing the t -th tillage system and p -th practice. Estimates of soil erosion are constructed using the universal soil loss equation that was presented earlier.¹

The values of $\rho\kappa\lambda\sigma$ for terraced and unterraced soil types, and the value of π for contouring were obtained for all soil types in the study area from data developed by Harmon, Knutson, and Rosenberry (7). The cover and management factors for the alternative crop production activities on each soil type were also obtained from data specific to Iowa (9). On the basis of these data, the gross erosion on each soil type was computed for any given crop production activity.

¹Equation (1) defines gross soil loss as follows:

$$E = \rho\kappa\lambda\sigma\pi.$$

RESULTS

To determine a baseline solution for the programming model, net farm income was maximized for each of the study aggregates (and, thus, for each representative farm in the study aggregates) using 1978 average prices for inputs and outputs.¹ Total net farm income for the river basin (BNI) was \$324,853,007, with 131,507,758 bushels of corn and 22,161,064 bushels of soybeans produced. In the baseline solution, no land was terraced and no contour or no-till planting occurred. Associated with the baseline production solution was gross erosion in the study area of 16,968,093 tons of soil or 8.65 tons/acre.

Results for Alternative Energy Prices in the
Absence of Soil Loss Policy

In order to analyze the effects of higher relative energy prices, the costs of machinery, nitrogen, phosphorus, potassium, corn herbicide, bean herbicide, and insecticide were adjusted in accord with 1985 and 1990 price projections (while output prices were held constant). Price projections for energy inputs were obtained from the U.S. Department of Energy (14). Energy input quantities used in the production of agricultural inputs were taken from data compiled by Pidgeon (15). The coal, natural gas, oil, and electricity requirements for the manufacture of fertilizers, herbicides, insecticides, and machinery were entered in the model, and the

¹The following crop and livestock prices were employed in the model: corn = \$2.50/bu., soybeans = \$6.50/bu., hay = \$62.76/ton, oats = \$1.40/bu., straw = \$30/ton, steers = \$62/hwt., calves = \$70/hwt., milk = \$10.50/hwt., and hogs = \$40/hwt.

costs of the farm inputs were increased as projected energy prices increased. Diesel fuel and propane costs were entered directly for each time period.

The overall results obtained by solving the programming model for projected 1985 and 1990 energy prices are that higher relative prices for energy inputs tend to decrease both soil erosion and the amount of fertilizer used by farmers. This reduction occurs in part because conservation tillage practices (no-till plantings) are less energy intensive. Also, continuous corn production is more energy-intensive and more fertilizer-using than soybean production. Table III-4 indicates that as energy prices rise, farmers are induced to switch away from continuous corn to corn-bean rotations, and to reduce fall chiseling and to increase no-till planting.

It is not surprising that these results are different from those of Forster and Rask (6). In constructing their model, Forster and Rask consider only three different soil types and allow farmers very few production alternatives. Farmers are not allowed to raise livestock and are constrained to use only the corn-beans rotation. Although farmers may choose from among three tillage systems, their baseline results indicate that no-till planting is the most profitable method for two of the representative farms even at 1976 energy price levels. Therefore, no energy-saving substitutions are possible on those farms. In addition, the third farm is constructed for a soil type that is particularly ill-suited for the use of no-till planting (6, p. 3).

The effect of energy price-induced alterations in rotations and tillage practices in the Iowa River Basin is shown in more detail in

Table III-4. Acreage in various rotations and tillage systems with alternative energy prices (no soil loss policy)

Cropping activity	1978	1985	1990
Continuous corn			
Fall chisel	519,797	24,057	0
Corn-beans			
Fall chisel	1,039,595	1,375,313	1,399,368
No-till	0	147,794	147,794
Total	<u>1,039,595</u>	<u>1,523,107</u>	<u>1,547,162</u>
CCOMM			
Fall moldboard	35,779	58,015	58,015
Fall chisel	304,471	304,471	304,471
Total	<u>340,250</u>	<u>362,486</u>	<u>362,486</u>
Permanent pasture	61,435	51,429	51,429

Table III-5. In the absence of soil loss restriction policy, soybean production would increase by 9.9 million bushels from 1978 to 1985, and by an additional 300,000 bushels between 1985 and 1990. Concomitantly, corn production would fall by 40 million bushels from 1978 to 1985, and would decrease an additional 3 million bushels between 1985 and 1990. The decrease in corn production would cause steer finishing to fall by 27,000 head.

The introduction of no-till planting in farm operations would cause total erosion for the river basin to fall by 3.6 million tons from 1978 to 1985, and by an additional 100,000 tons by 1990. According to the model, higher energy prices alone would by 1990 cause a 22 percent decrease in soil erosion in the river basin.

If energy prices follow their projected trend, then from 1978 to 1990, nitrogen use would fall by 56 million pounds (a 35 percent drop) with decreases in potassium and phosphorus use also occurring in the river basin.

The model predicts, then, that higher energy prices would tend to reduce the amount of NPS pollution originating from farm production activities. Table III-5 indicates that higher energy prices mean lower net income for farmers in the river basin and a decrease in the amount of fuel used.

The sensitivity of the model was tested by running programming solutions for "low" 1985 energy price projections and for 1995 projections. The results of the sensitivity tests were as expected. The farm-level adjustments for the "low" 1985 projections were intermediate of the results for the 1978 energy prices and the regular 1985 projections.

The solution values for the 1995 price levels were very similar to those obtained under 1990 price levels. Since technology is fixed in the

Table III-5. River basin results for higher energy prices with and without soil loss restrictions

	No restrictions			10T ^a restrictions			5T restrictions			3T restrictions		
	1978	1985	1990	1978	1985	1990	1978	1985	1990	1978	1985	1990
Basin net farm income (\$ million)	325	287	262	324	286	261	307	271	247	281	246	224
Decrease from baseline level (\$ million)	-	38	63	0.6	39	64	18	54	78	44	79	101
Total erosion (million tons)	17.0	13.4	13.3	13.1	12.7	12.6	7.75	7.73	7.67	5.44	5.43	5.39
Average erosion (tons/ acre)	8.65	6.83	6.79	6.70	6.47	6.40	3.95	3.94	3.91	2.77	2.77	2.75
Corn (million bu.)	132	92	89	131	92	89	119	92	82	110	79	74
Soybeans (million bu.)	22.2	32.1	32.4	21.7	31.4	31.8	21.2	27.5	29.5	19.8	26.6	27.5
Cows (1000 hd.)	122	122	122	122	122	122	154	155	154	157	157	157
Steers (1000 hd.)	88	61	61	88	61	61	88	61	61	88	61	61
Nitrogen (million lbs.)	160	106	104	157	105	102	149	106	94	143	95	89
Phosphorus (million lbs.)	106.7	104.6	104.5	106.5	104.4	104.3	105.3	103.1	103.0	103.9	101.6	101.5
Potassium (million lbs.)	60.8	56.5	56.4	60.7	56.4	56.3	58.9	56.2	55.4	57.9	54.5	54.1
Diesel (million gal.)	12.8	11.0	10.6	12.6	11.1	10.7	11.7	10.8	9.9	11.2	10.5	8.9
Propane (million gal.)	24.1	12.0	11.9	24.0	12.0	11.9	22.6	11.7	11.1	20.7	10.5	10.2
Contour (1000 acres)	0	0	0	322	105	106	164	114	140	177	259	270
No-till (1000 acres)	0	148	148	21	112	111	208	235	327	461	466	540
Terraced (1000 acres)	0	0	0	0	0	0	0	0	0	102	32	20

^a10T indicates that the policy option considered restricted soil loss to an average of 10 tons per acre per farm.

model, there are limited possibilities for energy-saving substitutions in farm production activities. As relative prices for energy rise, energy-saving substitutions are quickly exhausted. The sensitivity test shows that total erosion for the river basin falls less than one percent when 1995 energy prices replace 1990 prices.

In solutions where alternative control strategies are implemented, the model is modified by imposing additional restrictions on the selection of activities. Two alternative control strategies were considered--soil loss restrictions and soil loss reduction subsidies.

The soil loss restriction strategy imposed ten, five and three ton restrictions on the average per acre erosion on each farm. That is, each farm is allowed only those activities that result in an average per acre soil loss that is less than or equal to a specified level. After imposing each soil loss restriction, energy prices were increased to show how a particular control level interacted with higher energy prices.

The erosion-reduction subsidy strategy allows, in turn, for payments to farms of \$1, \$6, \$10, and \$14 for each ton of soil abated from the baseline level.¹ Each farm is allowed to alter rotations, tillage systems, cropping practices, and livestock activities in a manner that maximizes net farm income--given that the farm will receive \$X/ton for reduction in soil erosion from the baseline level. After generating each subsidy level, energy prices were increased to show how a particular subsidy level interacted with higher energy prices.

¹Subsidy levels of \$1, \$2, ..., \$20 were analyzed. The \$1, \$6, \$10, and \$14 levels are presented as representative.

Results for Soil Loss Restrictions with Baseline Energy Prices

The results of imposing various soil loss restrictions on farmers with energy prices at their baseline levels are shown in Table III-6. The primary ways that farmers meet the restrictions are by switching to contouring, no-till planting, and terracing; by transferring some fall plowing to the spring; and by removing land from continuous corn and corn-bean rotations to permanent pasture and CCOMM. The ratio of land in continuous corn to land in corn-beans rotations remains relatively constant at each level of restriction.

Table III-5 indicates that the imposition of a 10 tons/acre erosion limit on each farm would reduce erosion in the river basin by 1.95 tons/acre, or 23 percent. The 5 tons/acre restriction would reduce erosion in the study area by 54 percent. This compares with the 45 percent decrease in erosion that Taylor and Frohberg found would occur if a 5 tons/acre restriction was imposed throughout the Corn Belt (20, p. 31).

The 10 tons/acre soil loss restriction would cause net income in the river basin to fall by \$600,000. More restrictive soil loss limits cause much larger decreases in net farm income.

Since soil loss restrictions induce an increase in the total number of acres planted in permanent pasture and CCOMM rotations (Table III-6), more hay will be produced. With more hay available, farmers will increase the number of cows in their herds (Table III-5). On the other hand, the removal of land from continuous corn planting will cause a slight decrease in total fertilizer used.

Table III-6. Acres in various rotations and tillage systems with baseline (1978) energy prices and alternative levels of soil loss restrictions

Cropping activity	No restrictions	10 ton limit	5 ton limit	3 ton limit
Continuous corn				
Fall chisel	519,797	493,031	375,462	291,097
Fall chisel (C ^a)	0	8,449	15,743	0
Fall chisel (T ^b)	0	0	0	10,760
Spring chisel (C)	0	0	23,276	5,539
Spring chisel (T)	0	0	0	23,121
No-till	0	6,888	69,455	153,820
Total	519,797	508,368	483,936	484,337
Corn-beans				
Fall chisel	1,039,595	986,065	750,926	582,195
Fall chisel (C)	0	16,899	47,059	0
Spring disk (C)	0	0	78,039	11,078
Spring disk (T)	0	0	0	67,762
No-till	0	13,777	138,912	307,644
Total	1,039,595	1,016,741	1,014,936	968,679
CCOMM				
Fall moldboard	35,779	35,779	35,779	35,779
Fall chisel	304,471	62,308	7,718	0
Fall chisel (C)	0	296,434	0	7,582
Fall chisel (T)	0	0	0	136
Spring chisel	0	0	232,169	0
Spring chisel (C)	0	0	0	152,930
Total	340,250	394,521	275,666	196,427
Permanent pasture	61,435	41,430	186,524	311,618

^aC indicates contouring.

^bT indicates terracing.

Table III-5 shows that contouring is used extensively to meet the ten ton limit, and that no-till planting increases dramatically when more restrictive limits are imposed. These results are generally consistent with the results of the Alt and Heady study (1, p. 35). Table III-5 also indicates that only when a 3 tons/acre limit is in effect do farmers resort to terracing.

Results for Soil Loss Restrictions with Alternative Energy Prices

At any given level of soil loss restriction, higher relative prices for energy make the soil loss limit policy more restrictive relative to soil erosion and fertilizer use. Tables III-7 to III-9 give a detailed account of how higher energy prices interact with each soil loss limit to induce changes in rotations, tillage systems, and practices. It is apparent that for any level of restriction, higher energy prices cause a decrease in the number of acres planted in continuous corn and an increase in the number of acres planted by the no-till method.

The switch to no-till planting and the increase in the number of acres in permanent pasture and CCOMM rotations that is induced by higher relative prices for energy bring about a reduction in soil erosion. Table III-5 shows that for any given soil loss restriction, higher energy prices cause a reduction in soil erosion beyond that level which is obtained when energy prices are constant. With a ten ton soil loss limit in place, total erosion in the river basin would be 13.1 million tons per year. If energy prices follow their projected course, then total erosion would fall to 12.6 million tons by 1990 (a 3.8 percent decrease). The

Table III-7. Acres in various rotations and tillage systems with a ten ton limit and alternative energy prices

Cropping activity	1978 10 ton limit	1985 10 ton limit	1990 10 ton limit
Continuous corn			
Fall chisel	493,031	24,057	0
Fall chisel (C ^a)	8,449	0	0
No-till	6,888	2,781	0
Total	<u>508,368</u>	<u>26,838</u>	<u>0</u>
Corn-beans			
Fall chisel	986,065	1,568,408	1,399,366
Fall chisel (C)	16,899	0	0
No-till	13,777	109,417	111,098
Total	<u>1,016,741</u>	<u>1,677,825</u>	<u>1,510,464</u>
CCOMM			
Fall moldboard	35,779	58,015	58,015
Fall chisel	62,308	62,308	255,407
Fall chisel (C)	296,434	104,658	105,759
Total	<u>394,521</u>	<u>224,981</u>	<u>419,181</u>
Permanent pasture	41,430	31,424	31,424

^aC indicates contouring.

Table III-8. Acres in various rotations and tillage systems with a five ton limit and alternative energy prices

Cropping activity	1978 5 ton limit	1985 5 ton limit	1990 5 ton limit
Continuous corn			
Fall chisel	375,462	83,673	0
Fall chisel (C ^a)	15,743	0	0
Spring chisel (C)	23,276	23,276	0
No-till	69,455	0	0
Total	<u>483,936</u>	<u>106,949</u>	<u>0</u>
Corn-beans			
Fall chisel	750,926	1,004,004	995,040
Fall chisel (C)	47,059	0	0
Spring disk (C)	78,039	91,222	109,384
No-till	138,912	234,854	327,492
Total	<u>1,014,936</u>	<u>1,330,080</u>	<u>1,431,916</u>
CCOMM			
Fall moldboard	35,779	58,015	58,015
Fall chisel	7,718	7,718	13,788
Fall chisel (C)	0	0	30,170
Spring chisel	232,169	316,693	293,780
Total	<u>275,666</u>	<u>382,426</u>	<u>395,753</u>
Permanent pasture	186,524	141,613	133,399

^aC indicates contouring.

Table III-9. Acres in various rotations and tillage systems with a three ton limit and alternative energy prices

Cropping activity	1978 3 ton limit	1985 3 ton limit	1990 3 ton limit
Continuous corn			
Fall chisel	291,097	48,809	0
Fall chisel (T ^a)	10,760	0	0
Spring chisel (C ^b)	5,539	4,275	4,275
Spring chisel (T)	23,121	0	0
No-till	153,820	6,213	0
Total	<u>484,337</u>	<u>59,297</u>	<u>4,275</u>
Corn-beans			
Fall chisel	582,195	807,508	782,061
Spring disk (C)	11,078	8,551	21,031
Spring disk (T)	67,762	32,281	19,800
No-till	307,644	460,000	540,472
Total	<u>968,679</u>	<u>1,308,340</u>	<u>1,363,364</u>
CCOMM			
Fall moldboard	35,779	58,015	58,015
Fall chisel	0	0	1,149
Fall chisel (C)	7,582	7,582	6,569
Fall chisel (T)	136	136	0
Spring chisel (C)	152,930	238,214	238,214
Total	<u>196,427</u>	<u>303,947</u>	<u>303,947</u>
Permanent pasture	311,618	289,482	289,482

^aT indicates terracing.

^bC indicates contouring.

same energy price trend would induce a one percent decrease in soil erosion if a five ton soil loss restriction was in place during the period, or a .9 percent decrease in erosion if a three ton soil loss restriction was in effect during the period.

Table III-10 shows the impact of rising energy prices on soil erosion in each of the study aggregates with and without soil loss restriction policy in effect. It is clear that in the absence of soil loss restrictions, rising energy prices bring about the greatest decreases in soil erosion in those study aggregates that have the most erosive soil. For instance, soil erosion in study aggregate 6 is cut by 37 percent when energy prices increase from 1978 levels to projected 1985 levels. A similar increase in energy prices would cause a 27 percent decrease in erosion in study aggregate 7, and a 24 percent decrease in erosion in study aggregate 8 in the absence of any soil loss policy. The price-induced switch to no-till planting in the most erosive study aggregates brings about a dramatic decrease in soil erosion.

With soil loss restrictions in place, higher energy prices bring about decreases in soil erosion primarily in the less erosive study aggregates. This is evident from an examination of Table III-10. A 5 tons/acre soil loss limit, for instance, constrains agricultural production only in study aggregates 6-9. As energy prices rise to projected 1985 levels, soil erosion in these four study aggregates remains at the five ton limit. Erosion in study aggregates 2 and 4 is unaffected when energy prices rise to the 1985 projected levels. Erosion in study

Table III-10. Study aggregate erosion (in 1000s of tons and tons/acre) with and without soil loss restrictions

Study aggregate	No restrictions			10 tons/farm ave.			5 tons/farm ave.			3 tons/farm ave.		
	1978	1985	1990	1978	1985	1990	1978	1985	1990	1978	1985	1990
1	90 (1.4) ^b	87 (1.4)	87 (1.4)	* ^a	*	*	*	*	*	*	*	*
2	1,458 (2.9)	1,458 (2.9)	1,424 (2.8)	*	*	*	*	*	*	*	*	*
3	195 (4.1)	176 (3.7)	161 (3.4)	*	*	*	*	*	*	142 (3.0)	R ^c	R
4	230 (2.9)	230 (2.9)	224 (2.8)	*	*	*	*	*	*	*	*	*
5	208 (1.3)	204 (1.2)	204 (1.2)	*	*	*	*	*	*	*	*	*
6	3,723 (21.7)	2,355 (13.7)	2,355 (13.7)	1,716 (10.0)	R	R	858 (5.0)	R	R	515 (3.0)	R	R
7	2,296 (11.6)	1,681 (8.5)	1,681 (8.5)	1,977 (10.0)	*	*	988 (5.0)	R	R	593 (3.0)	R	R
8	5,989 (13.3)	4,557 (10.1)	4,557 (10.1)	4,491 (10.0)	R	R	2,296 (5.0)	R	R	1,347 (3.0)	R	R
9	2,780 (9.7)	2,650 (9.3)	2,626 (9.2)	*	*	*	1,429 (5.0)	R	R	857 (3.0)	R	R

^a* indicates that the study aggregate erosion equals the "no restrictions" value.

^bTerms in parentheses are tons/acre.

^cR indicates that the study aggregate erosion equals the given restricted value.

aggregates 1, 3, and 5 falls by 3,000 tons, 19,000 tons, and 4,000 tons, respectively, when energy prices rise from 1978 to projected 1985 levels.

An explanation of the above results can be found in the use of no-till planting methods. Soil loss restrictions necessitate the use of no-till planting in study aggregates that are constrained by the erosion limits. Since no-till planting is also energy-efficient, rising energy prices will induce a switch to no-till methods in some of those study aggregates that are not using no-till. However, the study aggregates that are constrained by the soil loss limits are already using no-till--the most energy-efficient method. Therefore, in those study aggregates constrained by the erosion limits, rising energy prices do not induce alterations in cropping practices that result in decreases in erosion below the policy limit. Of course, no price-induced set of alterations can occur that would raise soil erosion above the restricted level.

Terracing of farmland is very energy-intensive. If energy prices are at their 1978 levels, then a three ton soil loss restriction would be met, in part, by terracing 102,000 acres. Rising energy prices would reduce the number of acres terraced 69 percent by 1985 and 80 percent by 1990 (Table III-5).

Since rising energy prices work to decrease continuous corn planting, and since corn production requires more fertilizer than soybean production, higher energy prices induce a decrease in fertilizer use at any given level of soil loss restriction. Table III-5 shows that with a 10 tons/acre soil loss limit in effect, an increase in energy prices from 1978 levels to projected 1990 levels would cause a 35 percent decrease in

nitrogen use. If the same energy price increase occurred with a five ton (or three ton) erosion limit in effect, then nitrogen use would fall by 37 percent (or 38 percent).

Table III-5 indicates that an increase in energy prices would exacerbate the decrease in net income associated with any given level of soil loss restriction. A three ton soil loss limit would cause a \$44 million decrease in net farm income in the river basin if energy prices were at their 1978 levels. A three ton soil loss limit combined with projected 1990 energy prices would cause a \$101 million decrease in net income from the baseline level.

In order to understand better the ramifications of soil loss restriction policies, it is necessary to examine their effects on the net income of representative farms in the river basin. Table III-11 gives per farm net income in each study aggregate, as well as the decrease in net income for the representative farms caused by rising energy prices and the imposition of erosion limits.

In the absence of soil loss restrictions, higher energy prices by 1985 will cause a decrease in per farm net income that ranges from 9.4 percent (in study aggregate 8) to 14.1 percent (in study aggregate 2) with a mean decrease of 12.4 percent. If energy prices follow their projected course, then by 1990 per farm net income will have decreased between 15.6 percent (in study aggregate 8) and 23.5 percent (in study aggregate 2) with a mean decrease from the baseline level of 20.5 percent.

Table III-11 indicates that with energy prices at their baseline levels, a 10 tons/acre soil loss limit causes a small decrease in net

Table III-11. Baseline per farm net income and decreases from baseline in per farm net income

Study aggre- gate	Per farm income	No restrictions		10 tons/farm ave.			5 tons/farm ave.			3 tons/farm ave.		
		1985	1990	1978	1985	1990	1978	1985	1990	1978	1985	1990
1	\$43,838	\$5,996 ^a	\$10,135	* ^b	*	*	*	*	*	*	*	*
2	46,780	6,618	11,006	*	*	*	*	*	*	*	*	*
3	44,521	6,190	10,203	*	*	*	*	*	*	55	6,228	10,214
4	50,936	7,068	11,557	*	*	*	*	*	*	*	*	*
5	40,826	5,564	9,154	*	*	*	*	*	*	*	*	*
6	43,142	5,096	8,531	838	5,815	9,163	8,668	12,714	15,380	13,636	17,630	20,187
7	48,537	5,178	8,707	25	*	*	4,706	10,209	13,645	9,716	14,881	18,099
8	52,393	4,905	8,153	57	4,907	8,155	5,434	9,558	12,261	13,605	17,649	20,156
9	62,290	6,369	10,471	*	*	*	1,736	8,154	12,218	9,987	15,065	18,247

^aDollar amounts are the per farm decreases in net income from the baseline solution.

^b* indicates that the per farm decrease in net income from the baseline solution equals the "no restrictions" value.

income on farms in three of the study aggregates. The net income of farmers in the other study aggregates is not altered by the imposition of the 10 ton soil loss limit since erosion on these farms is less in the baseline solution than 10 tons/acre (see Table III-10).

The per farm cost of meeting tighter restrictions is considerably higher for farmers in study aggregates 6-9. The decrease in net income involved in meeting the five ton limit at 1978 prices ranges from \$1,736 per farm in aggregate 9 to \$8,668 per farm in aggregate 6. At the three ton limit with 1978 energy prices, a representative farm in study aggregate 6 may suffer a decrease in net income as high as \$13,636 (a 32 percent decrease), and at this level of restriction farmers in five of the nine study aggregates will experience some decrease in net income. These results support the conclusion drawn from the McGrann and Meyer study that there would be significant inequities in applying a uniform soil loss restriction (13, p. 8). Some farms are not affected by even the 3 tons/acre restriction while others would suffer substantial decreases in net income.

The decrease in per farm net income is much greater, of course, in the presence of soil loss restriction policies and higher energy prices. If projected 1990 energy prices prevail, then a three ton soil loss restriction may cause a decrease in study aggregate 6 of up to \$20,187 in per farm net income (a 47 percent decrease).

Results for Soil Loss Abatement Subsidies
with Baseline Energy Prices

Table III-12 shows the number of acres in various rotations and tillage systems for alternative soil erosion reduction subsidies when energy prices are at their baseline levels. As with soil loss restrictions, soil erosion abatement subsidies bring about a reduction in soil erosion primarily by inducing a switch to no-till planting and an increase in permanent pasture. At low subsidy levels, an increase in the use of contour planting and a switch of some fall planting to the spring play important roles in reducing soil erosion. Terracing does not become an economically viable method of erosion control for farmers in the river basin until a \$10/ton abatement subsidy is offered.

Table III-13 indicates that as more land is taken out of crop production and put into permanent pasture, corn production and soybean production (except for the \$6 subsidy level) decrease. Fertilizer and fuel use levels fall as a result of the decrease in crop production. The increase in hay production that occurs because of the increase in permanent pasture eventually causes an increase in the number of cows in the river basin.

A \$1/ton soil loss abatement subsidy would reduce soil erosion by 3.09 tons/acre to a 5.56 tons/acre average for the river basin. Table III-13 shows that the total cost of the \$1/ton subsidy would be \$6.1 million. To get soil erosion in the river basin down to a three tons/acre average, a \$10/ton abatement subsidy would be necessary. The cost of the \$10/ton subsidy would exceed \$100 million.

Table III-12. Acres in various rotations and tillage systems with baseline energy prices and alternative levels of soil loss abatement subsidies

Cropping activity	\$1/ton subsidy	\$6/ton subsidy	\$10/ton subsidy	\$14/ton subsidy
Continuous corn				
Fall chisel	440,332	440,332	239,245	83,496
Fall chisel (C ^a)	42,103	41,056	0	0
Fall chisel (T ^b)	0	0	10,760	10,760
Spring chisel (C)	0	0	23,277	23,277
No-till	33,284	0	201,086	356,835
Total	<u>515,718</u>	<u>481,388</u>	<u>474,368</u>	<u>474,368</u>
Corn-beans				
Fall chisel	880,666	880,666	478,493	166,994
Fall chisel (C)	84,208	141,569	47,059	0
Spring disk (C)	0	31,961	46,553	46,553
Spring disk (T)	0	0	21,521	21,521
No-till	66,568	0	402,172	713,671
Total	<u>1,031,439</u>	<u>1,054,196</u>	<u>995,798</u>	<u>948,739</u>
CCOMM				
Fall moldboard	58,015	58,015	58,015	58,015
Fall chisel	33,098	33,098	0	0
Fall chisel (C)	271,372	33,892	0	0
Fall chisel (T)	0	0	136	136
Spring chisel (C)	0	200,959	171,431	30,500
Total	<u>362,484</u>	<u>325,964</u>	<u>229,582</u>	<u>88,651</u>
Permanent pasture	51,429	99,528	261,327	449,316

^aC indicates contouring.

^bT indicates terracing.

Table III-13. River basin results under abatement subsidy programs and rising energy prices

	\$1/ton ^a			\$6/ton			\$10/ton			\$14/ton		
	1978	1985	1990	1978	1985	1990	1978	1985	1990	1978	1985	1990
Net farm income w/ subsidy (\$ million)	330.5	292.5	281.8	366.1	329.4	319.5	404.0	372.0	362.7	451.8	420.4	411.1
Net farm income less subsidy	324.4	286.4	275.7	319.3	277.4	267.4	293.0	254.7	245.9	259.7	229.5	220.6
Cost of subsidy (\$ million)	6.1	6.1	6.1	46.8	52.0	52.1	111.0	117.3	116.8	192.1	190.9	190.5
Total erosion (million tons)	10.9	10.8	10.8	9.2	8.3	8.2	5.9	5.2	5.3	3.2	3.3	3.4
Average erosion (tons/acre)	5.56	5.55	5.55	4.67	4.24	4.22	2.99	2.67	2.69	1.65	1.70	1.72
Corn (million bu.)	131	92	90	125	92	84	111	83	76	98	75	69
Soybeans (million bu.)	21.9	31.4	31.9	22.2	27.2	29.1	20.2	25.2	27.1	18.5	25.0	26.5
Cows (1000 hd.)	122	122	122	129	138	138	158	158	158	158	158	158
Steers (1000 hd.)	88	61	61	88	61	61	88	61	61	88	61	61
Nitrogen (million lbs.)	159	105	102	154	102	93	141	100	89	134	100	92
Phosphorus (million lbs.)	106.7	104.5	104.4	106.3	103.9	103.9	104.3	102.6	102.1	103.4	101.7	101.2
Potassium (million lbs.)	60.9	56.5	56.4	59.8	57.1	56.3	58.0	54.9	54.5	56.6	53.2	53.0
Diesel (million gal.)	12.3	10.8	10.7	12.0	9.2	9.0	10.1	8.1	8.0	9.1	8.8	8.7
Propane (million gal.)	24.1	12.1	12.0	24.1	11.9	11.4	21.4	10.8	10.4	18.7	9.8	9.5
Contour (1000 acres)	398	400	400	449	503	503	288	327	327	100	100	100
No-till (1000 acres)	100	118	118	0	638	638	603	1105	1105	1071	1105	1105
Terraced (1000 acres)	0	0	0	0	0	0	32	32	32	32	32	32
Permanent pasture (1000 acres)	51	31	31	100	46	46	261	222	222	449	448	448

^a\$1/ton indicates that a subsidy of \$1 is paid for each ton of erosion abated from the baseline level.

Results for Soil Loss Abatement Subsidies
with Alternative Energy Prices

Higher energy prices have the same qualitative effects on farm production when a soil erosion abatement subsidy policy is in place as they do when a soil loss restriction policy is in effect. Table III-13 shows that for any subsidy level, higher energy prices tend to reduce fertilizer and fuel use, decrease corn and steer production, and increase soybean production.

With a particular soil loss restriction imposed, higher energy prices unambiguously reduce the level of erosion in the river basin. The impact of higher energy prices on erosion with a subsidy program in effect depends on the level of abatement subsidy offered. At low subsidy levels, higher energy prices tend to bring about a decrease in erosion. For instance, if a \$6/ton abatement subsidy is offered, then as energy prices rise from their baseline levels to projected 1990 levels, erosion in the river basin will fall from 4.67 tons/acre to 4.22 tons/acre. The decrease in erosion occurs primarily because higher energy prices induce a switch to no-till planting from conventional tillage systems. If a \$14/ton abatement subsidy is offered, then as energy prices rise to their 1990 projected levels, erosion in the river basin will increase from 1.65 tons/acre to 1.72 tons/acre.

Table III-14 provides insight into why at high subsidy levels rising energy prices may induce an increase in soil erosion in the river basin. It is clear from the table that a \$14/ton erosion abatement subsidy would bring about extensive use of no-till planting methods at the baseline level of energy prices. When a \$14/ton abatement policy is in effect, the

Table III-14. Acreage in various rotations and tillage systems with a \$14/ton abatement subsidy and alternative energy price levels

Cropping activity	1978	1985	1990
Continuous corn			
Fall chisel	83,496	51,430	0
Fall chisel (T ^a)	10,760	10,760	0
Spring chisel (C ^b)	23,277	23,277	23,277
No-till	356,835	55,023	30,966
Total	474,368	140,490	54,243
Corn-beans			
Fall chisel	166,994	163,374	214,804
Spring disk (C)	46,553	46,553	46,553
Spring disk (T)	21,521	21,521	32,281
No-till	713,671	1,050,142	1,074,199
Total	948,739	1,281,590	1,367,837
CCOMM			
Fall moldboard	58,015	59,730	59,730
Fall chisel (T)	136	136	136
Spring chisel (C)	30,500	30,500	30,500
Total	88,651	90,366	90,366
Permanent pasture	449,316	448,631	448,630

^aT indicates terracing.

^bC indicates contouring.

main impact of rising energy prices is to induce a switch from no-till continuous corn to no-till corn-beans rotations. Since no-till corn-beans rotations are slightly more erosive than no-till continuous corn, the price-induced switch to no-till corn-beans rotations will cause erosion in the river basin to rise. If a soil loss restriction policy was in place, then the switch from no-till continuous corn to no-till corn-beans would have to be offset by an increase in permanent pasture or CCOMM rotations of a magnitude sufficient to keep erosion at the restricted level. However, farmers are not constrained by the subsidy policy to keep erosion below a particular value. At high subsidy levels, farmers react to higher energy prices by switching from no-till continuous corn to no-till corn-beans without making significant adjustments in the number of acres in permanent pasture or CCOMM rotations. To maximize net income, farmers tend to produce in a more erosive manner when energy prices rise and subsidies are high.

The cost of any subsidy program depends on the level of the soil erosion abatement subsidy and on the level of prevailing energy prices. Table III-13 shows that a \$14/ton subsidy will cost \$192.1 million if 1978 energy prices prevail, and \$190.9 million if 1985 projected energy prices prevail. The subsidy program will cost less, of course, if rising energy prices induce farmers to use more erosive cropping practices.

Table III-15 shows the subsidy receipts of representative farms in the various study aggregates at alternative subsidy and energy price levels. The table indicates a large difference in amounts of subsidy income that would be received by farmers in the river basin. At the

Table III-15. Per farm subsidy at alternative subsidy and energy price levels

Study aggre- gate	\$1/ton subsidy			\$6/ton subsidy			\$10/ton subsidy			\$14/ton subsidy		
	1978	1985	1990	1978	1985	1990	1978	1985	1990	1978	1985	1990
1	0	\$12	\$12	\$245	\$72	\$72	\$408	\$102	\$120	\$571	\$207	\$207
2	8	20	23	524	2,452	2,452	4,454	4,087	4,087	6,236	5,722	5,722
3	356	315	352	2,859	4,024	4,251	4,251	9,939	9,939	12,153	14,507	14,507
4	0	51	25	478	2,454	2,454	4,455	4,455	4,090	6,238	6,238	5,725
5	0	6	6	137	42	42	350	350	72	490	490	100
6	2,967	3,290	3,290	25,771	27,050	27,050	62,522	62,313	62,313	87,530	87,238	87,238
7	1,149	933	933	8,120	7,778	7,778	25,600	27,116	26,834	38,076	38,076	37,961
8	1,652	1,645	1,645	12,122	12,512	12,512	23,223	25,080	25,080	52,994	52,818	52,818
9	1,112	1,078	1,078	7,334	7,546	7,732	14,079	17,266	17,266	24,445	24,172	24,172

\$1/ton subsidy level with 1978 prices, farmers in three study aggregates will receive no subsidy payments; while subsidy income ranges from \$490 to \$87,530 per farm at the \$14/ton level with 1978 energy prices. The highest subsidy payments are associated with erosion abatement on the most erosive soils. In particular, subsidy payments of \$2,967, \$25,771, \$62,522, and \$87,530 per farm in study aggregate 6 are associated with subsidy levels of \$1/ton, \$6/ton, \$10/ton, and \$14/ton, respectively, at constant 1978 energy prices. With a baseline per farm net income of \$43,142 in study aggregate 6, the subsidy payments correspond to 7%, 60%, 145%, and 203% of baseline per farm net income. The impact of higher energy prices on per farm subsidy receipts varies according to whether higher energy prices induce a switch to more erosive, or less erosive, cropping practices.

CONCLUSIONS

The incremental cost of abatement of soil erosion under the soil loss restriction policy at 1978 and projected 1985 energy prices is shown by Figure III-1. Figure III-2 gives the marginal cost of abatement curves for the subsidy program at 1978 and projected 1985 energy prices. In the absence of any soil loss policy, rising energy prices bring about a reduction in soil erosion in the river basin by inducing the adoption of cropping practices that are less energy-intensive, and that also happen to be less erosive. Therefore, the incremental and marginal cost of abatement curves for projected 1985 energy prices will lie above their respective abatement curves for 1978 energy prices. The incremental (and marginal) cost of reducing soil erosion by a specified amount will be higher if projected 1985 energy prices prevail. If a marginal benefits of abatement curve was known and depicted in either figure, it would be clear that higher energy prices cause the socially desirable level of NPS pollution abatement to decrease (as long as the marginal benefits of abatement curve is not completely inelastic).

The overall policy implications of the study are that higher energy prices will enhance the effectiveness of soil loss restriction policies--bringing about a larger reduction in soil erosion and fertilizer use; but as the relative price of energy rises, the cost of abating an additional unit of soil erosion will rise. Unfortunately, higher energy prices will cause an even greater decrease in net farm income to be associated with a specific erosion limit than if energy prices were constant. The

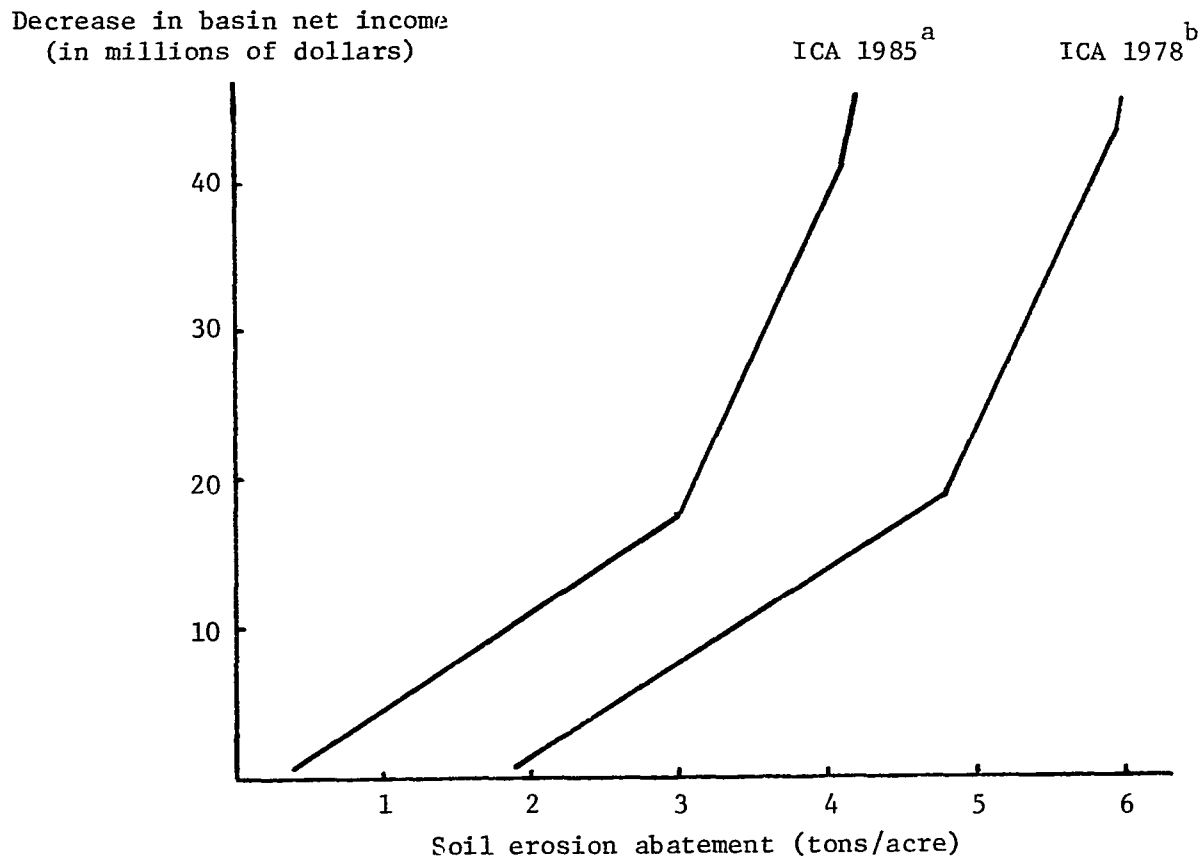


Figure III-1. Incremental cost of abatement for soil loss restriction policy for Iowa River Basin

^aThe ICA 1985 curve gives the incremental cost of abatement curve at projected 1985 energy prices (an ICA 1990 curve would be virtually identical to the ICA 1985 curve).

^bThe ICA 1978 curve gives the incremental cost of abatement curve at 1978 energy prices.

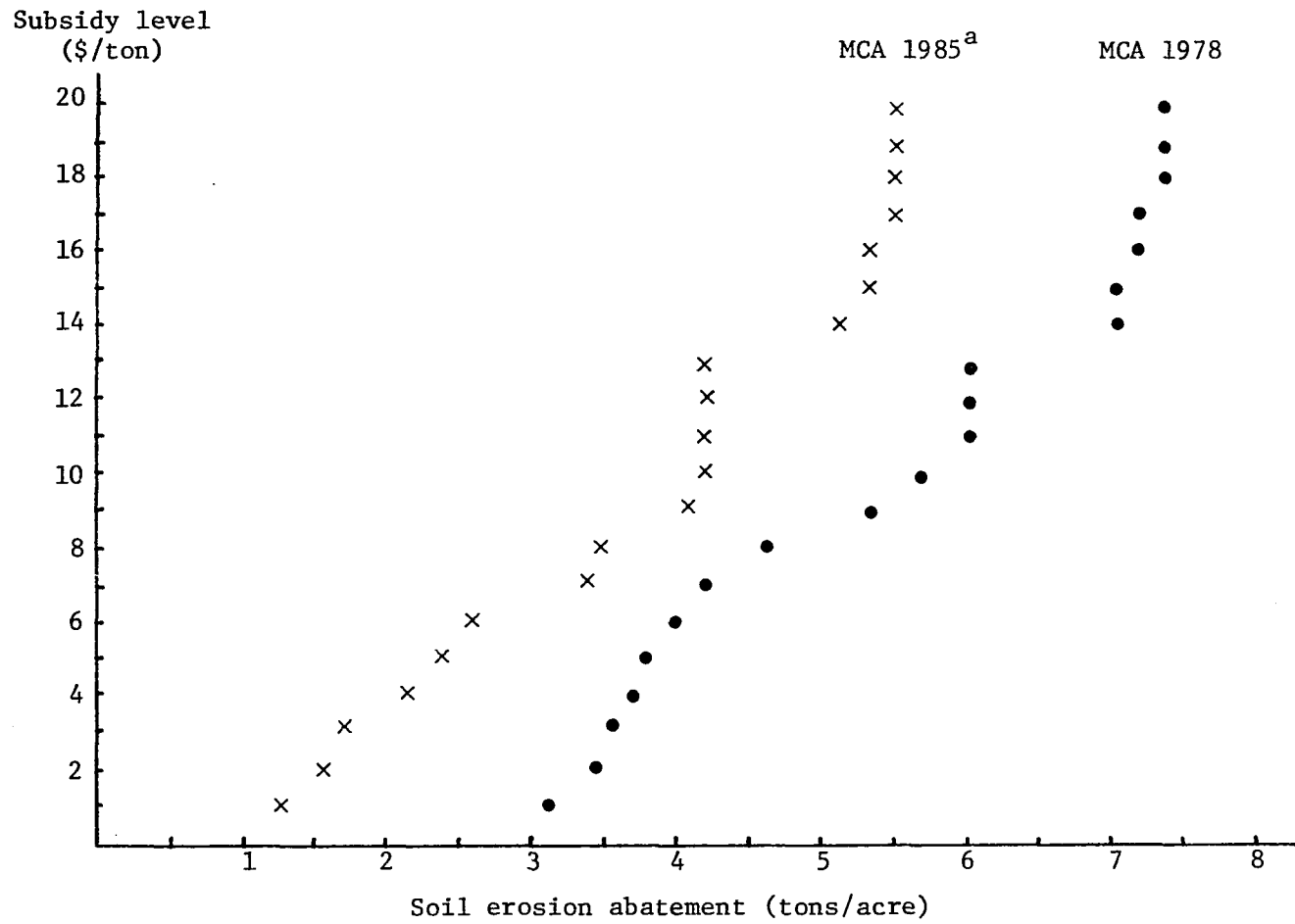


Figure III-2. Marginal cost of abatement for subsidy policy for Iowa River Basin

^aAn MCA 1990 curve would be almost identical to the MCA 1985 curve.

combination of higher energy prices and very restrictive soil loss limits may put a severe strain on the net incomes of those farmers with very erosive soil.

Subsidies for erosion abatement will also reduce soil loss and fertilizer use, but the impact of higher energy prices on the effectiveness of the policy is not unambiguous. At low subsidy levels, it seems clear that higher energy prices will enhance the effectiveness of the subsidy policy in the river basin. However, if subsidy levels are high, then rising energy prices may weaken the impact of abatement subsidy policy on soil erosion.

It is important to note that terracing does not play a very large role in erosion control under either policy when energy prices are allowed to follow their projected course. With an abatement subsidy policy in effect, terracing is not economically viable until the subsidies reach the \$10/ton level, and the number of acres terraced does not increase when a \$14/ton subsidy is offered. A three ton soil loss restriction will force the adoption of terraces, but higher energy prices greatly reduce the number of acres terraced.

In the absence of any soil loss constraints, higher relative prices for energy will cause a reduction in soil erosion. The model predicts that erosion in the study area will decrease by almost two tons per acre over the next seven years if relative prices for energy follow their projected course. The effect of higher energy prices on soil erosion by 1990 will be essentially the same as the imposition of a ten tons per acre

average soil loss limit on each farm in the river basin with energy prices constant.

There are clear limitations on the extent to which rising energy prices can induce a reduction in soil erosion, given current farm technology. To reduce soil loss beyond the level associated with higher energy prices, an erosion control policy is necessary. However, as soil loss limits are made more restrictive (or higher abatement subsidies are offered) an increasing amount of cropland will be put into permanent pasture, and farm net income will fall (or subsidy payments will increase).

This study attempted to identify important farm inputs whose relative prices are likely to change over the course of the next seven years. By focusing on energy inputs, insight was provided as to the impact of rising energy prices on farm production, and on the need to coordinate soil erosion policies with changes in energy prices. If energy prices do not increase as fast as projected, then the changes suggested above in cropping practices and soil erosion will not occur as soon as indicated.

Only two soil erosion control policies were considered in this analysis. A logical extension of this study would be to consider alternative policies such as user charges (per ton tax on soil erosion), practice-specific subsidies (subsidies provided for terracing or contour farming), practice-specific restrictions (no fall moldboard plowing), sale of pollution rights, or some combination of policies. It also would prove useful to consider the administrative and enforcement costs associated with alternative policies for this river basin.

Another useful extension would be to add a demand side to the model in order to examine the partial equilibrium characteristics of alternative policies and energy prices. The model developed above is a legitimate tool to use in analyzing the impacts of an erosion control policy if it is applied in only one region. Since the primary responsibility for controlling NPS pollution rests with state governments (20, p. 25), this model may provide helpful information to state-level policymakers. A national policy that significantly altered cropping practices would bring about changes in the prices of most farm inputs and outputs.

The suggestion that erosion control policy must be formulated with a recognition of possible changes that may occur in input and output prices, leads one to conclude that another useful extension of this model would be to make it fully dynamic. In a first-best world, a researcher would have accurate information about future price trends of all inputs and outputs, and would have sufficient resources to develop a model that allowed farmers a realistic set of production alternatives. Lacking the necessary information and resources, the model used in this analysis provides a reasonable second-best alternative.

Finally, to say that soil loss restrictions or abatement subsidies reduce soil erosion by a particular amount is not the same as saying these policies will improve water quality by that amount. Two further lines of research must be pursued. A transport model must be developed to show how particular quantities of soil enter the waterways and what their impact is on water quality. The transport model must then be integrated with the farm production model in this study.

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SUMMARY AND DISCUSSION

The purpose of the study presented in the first section of this dissertation was to determine the effect of monetary variability on an exchange rate. To that end, ordinary least squares techniques were used to estimate an exchange rate determination equation for the U.S. dollar/Canadian dollar exchange rate. The estimated equation was of a form typical of exchange rate equations derived from monetary theory models, but it was augmented by the inclusion of proxies for expected monetary variability for the United States and Canada. When the exchange rate equation was estimated for alternative specifications of expected monetary variability, the results gave strong support to the view that an increase in U.S. monetary variability would cause an appreciation of the exchange rate.

A model of the Eurodollar market was developed in the second section of this dissertation. The model followed the portfolio approach and was based on the assumptions that the Eurodollar market is a perfectly competitive market for international funds, and that Eurodollar banks serve as auctioneers of those funds. The model consisted of aggregate supply and demand functions for Eurodollar funds, one of which represented funds placed in the Eurodollar market by central banks. An instrumental variable technique was used to estimate the parameters of the system of structural equations that represented the Eurodollar market. The results were generally supportive of the portfolio approach.

When the estimated parameters were substituted into a Eurodollar interest rate multiplier equation, the resulting value of the multiplier was very low. This implies that the growth of the Eurodollar market during the study period was not the result of multiple deposit expansion. In addition, it suggests that the Eurodollar market is a source of stability within the international monetary system.

The regression results also indicate that central bank Eurodollar holdings respond to interest rates and expectations of future exchange rates, but not to the level of official reserves. Some caution must be exercised in accepting the results relating to central banks since the number of observations on central bank holdings of Eurodollar deposits is very limited.

The study presented in the third section involved an investigation of the impact of alternative energy price levels and pollution control policies on agricultural production and soil erosion. The study area consisted of a two million acre river basin in North Central Iowa. A linear programming model was developed to represent crop and livestock production in the study area. The programming model was solved for various energy price levels and alternative erosion control policies. The solution results indicated that higher energy prices alone would induce a switch to agricultural production techniques that are less erosive and that require lower levels of fertilizer use. However, the ability of higher energy prices to bring about lower levels of nonpoint source pollution is limited, given present technology. Substantial reductions in soil erosion will occur only as the result of pollution control policies.

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