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FIXING EXCHANGE RATES: A
VIRTUAL QUEST FOR FUNDAMENTALS

Robert P. Flood
Andrew K. Rose

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ABSTRACT

Fixed exchange rates are less volatile than floating rates. But the volatility of macroeconomic variables such as money and output does not change very much across exchange rate regimes. This suggests that exchange rate models based only on macroeconomic fundamentals are unlikely to be very successful. It also suggests that there is no clear tradeoff between reduced exchange rate volatility and macroeconomic stability.

Robert P. Flood
Research Department
International Monetary Fund
700 19th Street, NW
Washington, D.C. 20431
and NBER

Andrew K. Rose
School of Business Administration
350 Barrows Hall
University of California
Berkeley, CA 94720
and NBER

An Introduction and Some Motivation

It is clear that exchange rate volatility is costly; expensive and enduring institutions have been developed to combat exchange rate volatility. Currently, most countries in the world manage their exchange rates in some way, and indeed this has been the norm throughout the twentieth century. Why do most countries control their exchange rates? When exchange rates are ignored by central banks, they are typically extremely volatile; when exchange rates are managed, much of this volatility vanishes. Fixing the exchange rate "fixes" the "problem" of exchange rate volatility. This paper is motivated by the question: What happens to the volatility? Most models of exchange rate determination argue that this volatility is transferred to other economic loci. For instance, monetary models of the exchange rate imply that stabilization of the exchange rate is achieved at the cost of a more volatile money supply. In this paper, we argue empirically that the volatility is not in fact transferred to some other part of the economy; it simply seems to vanish. When exchange rates are stabilized, there do not appear to be systematic effects on the volatility of other macroeconomic variables. This result is intuitively plausible: the volatility of variables such as money and output does not appear to be significantly different during regimes of fixed and floating exchange rates, and is rarely considered to be different by empirical macroeconomic researchers.

If exchange rate stability can be bought without incurring the cost of other macroeconomic volatility, then it is possible that floating exchange rates may be excessively volatile. Countries that choose not to manage their exchange rates, implicitly allow exchange rate turbulence to persist when it could be reduced with few apparent effects on volatility of other macroeconomic variables. While it is not possible to make a definitive policy prescription in the absence of a model that *can* explain exchange rate volatility, it seems intuitively possible that much exchange rate volatility is not welfare-improving.

Our primary objective in this paper is to study the implications of exchange rate volatility in regimes of fixed and floating rates for typical OECD countries. However, we also seek to make a methodological contribution, by developing a technique that allows economists to identify potential fundamental determinants of exchange rates. Economists typically model exchange rates as linear functions of fundamentals. It is indisputable that conditional exchange rate volatility depends dramatically on the exchange rate regime. We argue that this fact can be used to distinguish potentially interesting exchange rate models from non-starters which are doomed to have little empirical content.

Suppose that the structural-form linking fundamentals to exchange rates does not change dramatically across regimes, as is true in many theoretical models. The conditional volatility of a typical exchange rate rises dramatically when a previously fixed exchange rate begins to float. *Any potentially valid exchange rate fundamental determinant must also experience a dramatic increase in conditional volatility when a previously fixed exchange rate is floated.* As we shall see, the empirical relevance of this point is particularly strong, since it depends only on structural equations, rather than reduced-forms with unknown and possible unstable coefficients. Empirically, we cannot find macroeconomic variables with volatility characteristics which mimic those of OECD exchange rates even approximately. Intuitively, if exchange rate stability varies across regimes without corresponding variation in macroeconomic volatility, then macroeconomic variables will be unable to explain much exchange rate volatility. Thus existing models, such as monetary models, do not pass our test; indeed, this is also true of any potential model which depends on standard macroeconomic variables. We are driven to the conclusion that the most critical determinants of exchange rate volatility are not macroeconomic.^{1/}

^{1/} Further, our evidence shows that any (e.g., microeconomic) factor which operates by affecting money market equilibrium is also at odds with the data.

The following section of the paper lays out the theory and methodology for the analysis which follows. The data is then presented in section II. The core of the paper is section III, which presents our basic empirical results. The paper ends with a brief conclusion.

I: The Theory and Methodology

Monetary models of the exchange rate are natural choices for our study, since they are simple and conventional. But we hope to show that the thrust of our analysis is much more general.

Ia: Virtual and Traditional Fundamentals for the Flexible-Price Monetary Model

The generic monetary exchange rate model begins with a money-market equilibrium condition, expressed in logarithms as:

$$m_t - p_t = \beta y_t - \alpha i_t + \epsilon_t \quad (1)$$

where: m_t denotes the (natural logarithm of the) stock of money at time t ; p denotes the price level; y denotes real income; i denotes the nominal interest rate; and ϵ denotes a well-behaved shock to money demand.

We assume that there is a comparable equation for the foreign country, and that domestic and foreign elasticities are equal. Subtracting the foreign analogue from (1) and solving for the price terms, we have:

$$(p-p^*)_t = (m-m^*)_t - \beta(y-y^*)_t + \alpha(i-i^*)_t - (\epsilon-\epsilon^*)_t. \quad (1')$$

If we assume that prices are perfectly flexible, then in the absence of transportation costs and other distortions, purchasing power parity holds, at least up to a disturbance:

$$(p-p^*)_t = e_t + \nu_t \quad (2^F)$$

where: e denotes the domestic price of a unit of foreign exchange; and ν is a stationary disturbance. Substituting this equation into (1'), it is trivial to solve for the exchange rate:

$$e_t = (m-m^*)_t - \beta(y-y^*)_t + \alpha(i-i^*)_t - (\epsilon-\epsilon^*)_t + \nu_t. \quad (3)$$

At this point, it is traditional to invoke uncovered interest parity (UIP):

$$(i-i^*)_t = E_t(de_t)/dt \quad (4)$$

where $E_t(de_t)/dt$ is the expected rate of change of the exchange rate. The canonical structural-form single factor exchange rate equation can be expressed as:

$$e_t = f_t + \alpha E_t(de_t)/dt \quad (3')$$

where f_t denotes the "fundamental determinant" of the exchange rate.

In the flexible-price model, a standard way to measure f is the "traditional fundamental" (TF), defined by:

$$TF_t^p \equiv (m-m^*)_t - \beta(y-y^*)_t. \quad (5)$$

We will also examine a variant of (5), augmented to include a term for money demand disturbances:

$$ATF_t^p \equiv (m-m^*)_t - \beta(y-y^*)_t - (\epsilon-\epsilon^*)_t. \quad (5^A)$$

Neither β nor $(\epsilon-\epsilon^*)$ is known in reality, although this will not turn out to be very important for our empirical work.

ATF and TF differ in a number of respects. In our empirical work, we parameterize TF explicitly, but measure ATF without an explicit money demand model. Thus one advantage of using ATF rather than TF is that mis-specification of TF will not affect our

measured ATF. Another reason to prefer ATF to TF is that it is closer to the latent "fundamental" variable.

By way of contrast, our "virtual fundamental" (VF) can be derived from (3) (or by assuming UIP and backing a measure of fundamentals out of (3')):

$$VF_t \equiv e_t - \alpha(i-i^*)_t. \quad (5')$$

The key α parameter is unknown, but our results will prove to be robust across a wide range of interesting and plausible values.

Virtual fundamentals, unlike traditional fundamentals, will always be tightly related to the exchange rate within the sample in a statistical sense for reasonable choices of α . Virtual and traditional fundamentals are merely alternative ways of measuring the same latent variable. Both are model-based, use raw economic data, and rely solely on the structural equation (3).

In the absence of substantive measurement error, virtual and traditional fundamentals should behave similarly if the monetary model with flexible prices describes reality "well" (i.e., ν_t is relatively unimportant in the sense of having small unconditional and conditional variance). Much of the analysis which follows hinges on comparing the time-series characteristics of VF, TF and ATF (the latter differ only by $(\epsilon-\epsilon^*)$). Our chosen metric is conditional volatility, which we choose because: a) it is intrinsically interesting; b) it has proven to be difficult to explain with current exchange rate models; c) it allows us to avoid non-stationarity issues; and d) it seems to vary in an interesting and systematic (regime-specific) way.

Ib: Tangential but Brief Notes on the Literature

Our paper differs from the literature in emphasizing regime-specific fundamental volatility. Many models of managed exchange rates assume that exchange rate management does not alter the conditional volatility of fundamentals substantially. For instance, the

early target zone literature (Krugman, 1991) typically assumed that the conditional volatility of fundamentals did not change with the exchange rate regime. Instead, the conditional volatility of the exchange rate was dampened because of a change in the (reduced-form) functional form of the relationship linking the exchange rate to fundamentals, often dubbed the "honeymoon effect". Related recent work which emphasizes "leaning against the wind" (Lewis (1992), Lindberg and Soderlind (1992) and Svensson (1992)) still assumes that the conditional volatility of fundamentals does not change much.

As should become obvious below, our use of "fundamental" is not synonymous with "exogenous"; we intend to compare virtual and traditional fundamentals through regimes of both fixed and floating exchange rates, *without claiming that either fundamentals or the regimes themselves are exogenous in any relevant sense*. This is completely reasonable in the context of our monetary model. A set of (ϵ - ϵ^*) shocks striking the money-market should affect the volatility of money if the exchange rate is fixed completely exogenously; but during a pure float, these shocks drive the exchange rate, since money is exogenous. Thus, the monetary model with flexible prices implies that the conditional volatility of both virtual and traditional fundamentals should be substantially higher during regimes of floating exchange rates than during fixed-rate regimes.

The typical exchange-rate model in the literature consists of: a set of structural equations; a set of equilibrium conditions involving the structural equations; a set of relations for the forcing processes; and an expectations assumption, all of which lead to a reduced-form relation between the exchange rate and a set of variables deemed to be fundamental to the exchange rate. The best known theoretical papers concerning exchange-rate volatility, Dornbusch (1976) and Krugman (1991), direct attention to the shape of the reduced-form relation. For instance, the Dornbusch "overshooting" result showed how the reduced-form relation can result in conditional exchange rate volatility that is a multiple of

the conditional volatility of monetary variables. Krugman's work, which was directed toward an exchange rate floating inside an explicit "target zone", showed how the reduced-form relation can result in conditional exchange rate volatility that is a fraction of the volatility of the relevant market fundamentals. Empirical work directed toward studying reduced-forms, e.g., Meese and Rogoff (1988) and Flood et. al. (1991) has been almost uniformly unresponsive of the theory. In contrast, our derivation of virtual and traditional fundamentals did not rely on reduced-form equations; nor will our empirical work rely on reduced-form estimates.

It is well known that models of exchange rates work poorly in floating exchange rate regimes (e.g., Meese and Rogoff (1988)). This leads most economists to conclude that there is an important variable (or set of variables) omitted from standard models. The contribution of this paper consists in pointing out a striking characteristic of the omitted (set of) variable(s), namely that it has regime-specific conditional volatility, and does not appear in traditional measurements of macroeconomic fundamentals (including deviations from money market equilibrium).

Ic: The Sticky-Price Model

In reality prices look sluggish, and deviations from purchasing power parity (i.e., v_t are large and persistent. Further, across exchange rate regimes, nominal and real exchange rate volatility are highly correlated (except possibly at very low frequencies). For all these reasons we examine models which do not rely on perfectly flexible prices.

A standard way to allow for price stickiness is to substitute a Phillips-curve equation in place of the assumption of continuous purchasing power implicit in equation (2^p) (e.g., Obstfeld and Rogoff (1984)):

$$p_{t+1} - p_t = \mu(y - y^{LR})_t + g_t + E_t(\hat{p}_{t+1} - \hat{p}_t)$$

$$y_t = \theta'(e + p^* - p)_t + \phi'r_t$$

$$\Rightarrow p_{t+1}-p_t = \theta(e+p^*-p)_t + \phi r_t + g_t + E_t(\hat{p}_{t+1}-\hat{p}_t) \quad (2^s)$$

where: y^{LR} is the long-run level of output (ignored for simplicity); g is a well-behaved shock to goods market equilibrium; $r_t \equiv i_t - E_t(p_{t+1}-p_t)$ is the ex ante expected real interest rate; and \hat{p} is defined by:

$$\theta(e+p^*-\hat{p})_t + \phi r_t + g_t = 0. \quad (6)$$

Obstfeld and Rogoff (1984) provide a detailed discussion of the latter term.

Equation (6) can be solved for \hat{p}_t and thus $E_t(\hat{p}_{t+1}-\hat{p}_t)$; when these expressions are substituted back into (2^s), one arrives at:

$$\begin{aligned} p_{t+1}-p_t &= \theta(e+p^*-p)_t + \phi r_t + g_t + E_t(p^*_{t+1}-p^*_t) \\ &\quad + E_t(e_{t+1}-e_t) + \theta^1 E_t(g_{t+1}-g_t) + \phi/\theta E_t(r_{t+1}-r_t). \end{aligned} \quad (2^{s'})$$

Solving this for the exchange rate by substituting into (1'), one can derive:

$$\begin{aligned} e_t &= (m-m^*)_t - \beta(y-y^*)_t + \alpha(i-i^*)_t - (\epsilon-\epsilon^*)_t \\ &\quad - \theta^1 E_t[(e_{t+1}-e_t) + (p^*_{t+1}-p^*_t)] + \theta^1 (p_{t+1}-p_t) \\ &\quad - \theta^1 g_t - \theta^2 E_t(g_{t+1}-g_t) - \phi r_t - \phi/\theta E_t(r_{t+1}-r_t) \end{aligned} \quad (7)$$

The analogues to (5) and (5[^]) for the sticky-price model are therefore:

$$\begin{aligned} TF_t^s &\equiv (m-m^*)_t - \beta(y-y^*)_t - \phi r_t - \phi/\theta E_t(r_{t+1}-r_t) \\ &= TF_t^p - \phi r_t - \phi/\theta E_t(r_{t+1}-r_t) \end{aligned} \quad (8)$$

and

$$\begin{aligned} ATF_t^s &\equiv (m-m^*)_t - \beta(y-y^*)_t + (\epsilon-\epsilon^*)_t - \phi r_t - \phi/\theta E_t(r_{t+1}-r_t) \\ &= ATF_t^p - \phi r_t - \phi/\theta E_t(r_{t+1}-r_t). \end{aligned} \quad (8^A)$$

If the sticky-price monetary model provides an accurate description of the data (so that the goods market shock g_t is relatively unimportant), then virtual and sticky-price traditional fundamentals should have similar properties.

II: The Data

IIa: Discussion of the Raw Data

Our empirical work focuses on bilateral American dollar exchange rates from 1960 through 1991 inclusive. We choose this sample because we are interested in comparing exchange rates and their fundamental determinants during regimes of both fixed and floating rates. The Bretton Woods regime of the 1960s is a good example of a fixed exchange rate regime. The exchange rate bands were narrow ($\pm 1\%$, compared with e.g., the $\pm 2.25\%$ of the narrow band of the Exchange Rate Mechanism in the European Monetary System). The Bretton Woods system was a regime of universally pegged exchange rates, with a clear commitment to intervention by the associated central banks (the EMS is a system of exchange rates which are pegged vis-a-vis each other but float jointly relative to other major currencies). One disadvantage of the Bretton Woods era is that Euro-market interest rate data (which are unaffected by political risk) are unavailable for much of the sample. As we discuss below, this will not turn out to be a very serious problem, since few of our results depend on UIP holding exactly.

Since much of our interest is on conditional volatility of both exchange rates and macroeconomic fundamentals, we choose to work at the monthly frequency. A coarser frequency (e.g., quarterly) would enable us to use national accounts data, but limit the number of observations severely; a finer frequency would preclude use of standard macroeconomic fundamentals such as money and prices. This issue is also discussed further below.

We use industrial production indices for our measure of output. We also use narrow (M1) money indices, the consumer price index for prices, and three-month treasury bill returns as interest rates. Our data are transformed by natural logarithms unless otherwise noted (interest rates are often annualized and always measured as nominal rates divided by 100 so that e.g., an interest rate of 8% is often used as .08). The data is taken from the IMF's *International Financial Statistics* and has been checked and corrected for e.g., transcription and rebasing errors. We consider eight large industrial countries (above and beyond the United States): the United Kingdom; Canada; France; Germany; Holland; Italy; Japan; and Sweden. The United States is always considered to be the domestic country so that our exchange rates are measured as the price (in American dollars) of one unit of foreign exchange (e.g., \$2.80/£).

Time-series graphs of our raw data are presented in figures 1-5. The exchange rate data are graphed with the $\pm 1\%$ bands during the Bretton Woods regimes that we consider. Tick marks on the abscissa denote the end of the Bretton Woods era (and the beginning of the relevant Bretton Woods regime for Canada, Germany, and Holland, countries which adjusted their pegs early in the 1960s). The actual exchange rate pegs and explicitly declared bands are tabulated in Table I. Interest rate differentials are the difference between annualized American and foreign rates; prices, money and output are portrayed as the ratio of the (natural logarithms of the) American to the foreign variable. Throughout our empirical work, the scales in our graphics are country-specific; comparisons should be done across exchange rate regimes for a given country, rather than between countries.

We note that the nominal exchange rates are obviously quite stable during the Bretton Woods era, but quite volatile during the period which followed. (This well-known characteristic is also true of real exchange rates (Stockman (1983))). However, this dramatic increase in volatility does not characterize such traditional fundamental determinants of exchange rates as money and output (a fact noted by Baxter and Stockman

(1989) in a slightly different context). Unless the link between fundamentals and exchange rates varies dramatically across regimes, this constitutes *prima facie* evidence that variables such as money and output are *not* in fact important determinants of exchange rate volatility, at least for our sample. In some sense, the rest of the empirical work in this project merely extends this result.

IIb: Some Naive Evidence on Volatility Tradeoffs

Frenkel and Mussa (1980, 379) state:

... while as a technical matter, government policy can reduce exchange-rate fluctuations, even to the extent of pegging an exchange rate, it may not be assumed that such policies will automatically eliminate the disturbances that are presently reflected in the turbulence of exchange rates. Such policies may only transfer the effect of disturbances from the foreign exchange market to somewhere else in the economic system. There is no presumption that transferring disturbances will reduce their overall impact and lower their social cost. Indeed, since the foreign exchange market is a market in which risk can easily be bought and sold, it may be sensible to concentrate disturbances in this market, rather than transfer them to other markets, such as labor markets, where they cannot be dealt with in as efficient a manner.

In this sub-section, we attempt to get a handle on this issue in a very naive way.

For each of the nine countries in our sample, we obtained the monthly IFS measure of the nominal effective exchange rate. These data (which are discussed in detail in *International Financial Statistics*) were obtained from 1975 through 1990. After dividing our sample into eight two-year samples, we computed the sample standard deviation of the first-difference of the natural logarithm of the effective exchange rate for each of the eight periods and nine countries. We then computed the analogues for domestic output, interest rates, and money. We are then left with a panel of 72 observations (nine countries by eight sample periods) of volatility. Scatter plots are provided in figures 6-8, which respectively graph exchange rate volatility against the volatility of output, interest rates, and money. In these graphs, observations are marked by country (America, Britain, Canada, France, Germany, Holland, Italy, Japan, Sweden).

The graphs indicate that there is no substantial tradeoff between exchange rate volatility and the volatility of (domestic) interest rates. Some evidence of a tradeoff between exchange rate volatility and both output and money volatility is apparent in the graphs, mostly because of a few outliers in the lower right part of the graphs. Significantly negative simple correlations between $\sigma(e)$ and both $\sigma(y)$ and $\sigma(m)$ can be confirmed statistically at traditional confidence levels. However, the finding of a negative correlation between $\sigma(e)$ and $\sigma(m)$ vanish when the outliers are excluded; the only robust result is the tradeoff between exchange rate and output volatility.^{1/}

It may be interesting to note parenthetically that there is also no clear sign of a tradeoff between exchange rate and stock return volatility. Figure 9 is a scatter plot of exchange rate volatility and stock market volatility computed in an analogous manner (that is, the standard deviation of the first difference of the log of the IFS aggregate stock market index, computed for samples of two years of monthly data). Our data also do not reveal any signs of a simple tradeoff between exchange rate volatility and either the level or volatility of inflation.

To summarize, with the exception of a negative, statistically significant correlation between nominal effective exchange rate volatility and output volatility, there do not appear to be simple tradeoffs between exchange rate volatility and the volatility of standard macroeconomic variables. The absence of a correlation between exchange rate and money volatility is especially striking in the context of monetary models.

IIc: More on Reserves

Monetary models of the exchange rate imply that stabilization of the exchange rate is achieved at the cost of a more volatile money supply. Thus, the tradeoff between exchange

^{1/} The R^2 of this relationship is approximately .2. None of these results depend on the absence (or presence) of either country- or time-specific "fixed effects" (or both). Also, there is no significant tradeoff between the volatility of the exchange rate and the *levels* of the macroeconomic variables considered.

rate volatility and money supply volatility *should* be more apparent for narrower concepts of money such as the monetary base, or indeed international reserves (e.g., Stockman (1983)). The correlation between exchange rate and money volatility was not well determined from the evidence above, given the important outliers. It is therefore interesting to see whether a clearer picture can be obtained from an examination of more narrow monetary aggregates.

Figure 10 is a scatter plot of nominal effective exchange rate volatility against the volatility of total reserves, computed in the same fashion as in the sub-section above. The hypothesis that there is no correlation between exchange rate and reserve volatility can only be rejected at the 40% confidence level. Figures 11 and 12 show similar results for two more narrow reserve concepts, total non-gold reserves and reserves of foreign exchange only.

It may seem striking that there is no apparent tradeoff between exchange rate volatility and the behavior of international reserves. Some further detail on this issue can be found in Figure 13, which shows time-series plots of the percentage change in total reserves for each of the nine countries. In figure 13, the plots are broken into two distinct segments: the period during the Bretton Woods regime when the country was obligated to intervene to maintain the currency within tight bands; and the period after June 1973. Of course, the period after 1973 does not correspond to a generalized float, since many countries managed their floats either implicitly (as is true in e.g., the Canadian case) or explicitly (as is true of the ERM countries). There are sometimes major differences in the time-series characteristics of reserves between the Bretton Woods era and the post-1973 era. However, there is little evidence of a general *decrease* in reserve volatility as countries moved from the Bretton Woods regime of adjustable pegs to the post-1973 era.

Indeed the volatility of reserves for Canada, France, Germany, Italy, and Sweden seems to be systematically higher after the demise of Bretton Woods.^{1/}^{2/}

III: Empirical Results

IIIa: Virtual Fundamentals

The construction of virtual fundamentals requires only one piece of non-observable information, i.e., α .

The literature indicates that α , the interest semi-elasticity of money demand, is likely to be a small number (e.g., the discussion in Flood et. al. (1991)). We believe that a value of $\alpha = .1$ is reasonable, and that $\alpha = 1$ is excessively high. While we believe that $\alpha = .5$ is implausibly high, we pick it as our default value so as to make our case under adverse conditions (lower, more realistic, values of α will typically strengthen our arguments). However, it turns out that our results do not really depend on α that much; even α values of substantially greater than unity deliver our main point.^{3/}

^{1/} This result is not true of narrower concepts of reserves. For both total non-gold and foreign exchange reserves, the U.K., France, Germany, Holland and the USA experienced decreases in reserve volatility.

^{2/} European monetary arrangements (beginning with the Snake and continuing with the EMS) may explain some of this increase in reserve volatility for France, Germany and Italy. However, this is by no means clear, given the exchange controls, loose bands, and poor credibility of European exchange arrangements, especially in the early 1980s.

^{3/} We have attempted to estimate α directly. We derive our estimating equation by using UIP in (3') and taking first-differences:

$$\Delta e_t = \alpha \Delta(i-i^*)_t + \eta_t$$

where the fundamental process is given by $f_t = f_{t-1} + \eta_t$ and η is a well behaved disturbance term (white noise if f_t is a random walk).

To estimate this equation, we use IV, using 3 lags of both Δe and $\Delta(i-i^*)$ as instrumental variables. The results are poor in the sense that $\hat{\alpha}$ is usually imprecisely estimated, always with a *negative* point estimate. (While we doubt that our instrumental variables are highly correlated with the regressor, we note that OLS delivers similar results, although positive but insignificant estimates are obtained for the U.K. and Canada).

We have also tried to estimate α directly through various money demand equations with similarly poor results; α typically turns out to be small and insignificant, often negative.

Figure 14 is a series of time series plots of the first-difference in virtual fundamentals for our eight different exchange rates, using a value of $\alpha=.5$. (An analogue for our preferred value $\alpha=.1$ is included in the appendix, and leads to similar conclusions.) If fundamentals follow a random walk, then the first-difference is also the innovation.^{1/} As usual, in our time series plots we graph the variables for both the Bretton Woods regime when the exchange rate was pegged, and the period of more floating rates which began after June 1973. The graphs show a striking phenomenon which is central to this paper, namely that *the volatility of virtual fundamentals is much higher in regimes of floating rates than during regimes of fixed rates*. This result does not depend on the exact choice of α .

IIIb: Traditional Fundamentals for the Flexible-Price Monetary Model

A β value is required to measure traditional fundamentals. This parameter corresponds to the income elasticity of money demand; we choose $\beta=1$ as a reasonable benchmark (Goldfeld and Sichel (1990) provide a relevant survey).

For simple money demand functions, all that is required for ATF construction is α . This can be seen by considering OLS on the differenced money demand function:

$$\begin{aligned} (m-m^*)_t - (p-p^*)_t &= \beta(y-y^*)_t - \alpha(i-i^*)_t + (\epsilon-\epsilon^*)_t & (9) \\ \Rightarrow (\hat{\epsilon}-\hat{\epsilon}^*)_t &\equiv (m-m^*)_t - (p-p^*)_t - \beta(y-y^*)_t + \hat{\alpha}(i-i^*)_t \\ \Rightarrow ATF_t^P &= (p-p^*)_t - \hat{\alpha}(i-i^*)_t. & (5^{**}) \end{aligned}$$

It might be objected that a simple static (differential) money demand function such as (9) is likely to fit the data extremely poorly. While this point is surely true, our interest in (9) is peripheral, since we are only interested in the *conditional innovations of the*

^{1/} The hypothesis that virtual fundamentals (and, parenthetically, traditional fundamentals) contain a unit-root cannot typically be rejected at conventional significance levels. However a first-order autoregressive coefficient (typically with a coefficient of around .4) is often significant, so that the hypothesis of a pure random walk can frequently be rejected.

traditional fundamentals. That is, including extra dynamics in (9) will result in the presence of extra lagged terms in (5'), but unchanged ATF innovation volatility.

Time series plots of the first-differences of TF generated with $\beta=1$ are presented in figure 15; comparable plots for ATF generated with $\alpha=.5$ are presented in figure 16. There are some country-specific differences in TF volatility between regimes of fixed and floating rates. However, these are relatively small and subtle. Again, the appendix contains analogues for different parameter values. All are consistent with the conclusion that *in contrast with virtual fundamentals, the volatility of traditional fundamentals does not vary dramatically across exchange rate regimes*.

IIIc: Comparing Alternative Fundamentals for the Flexible-Price Monetary Model

We now compare virtual and traditional fundamentals for the flexible-price model. This can be done directly by comparing figure 14 (i.e., ΔVF) with figures 15 and 16 (ΔTF and ΔATF respectively). Clearly, the conditional volatility of VF rises when one compares the Bretton Woods regime with the post-Bretton Woods data, sometimes by an order of magnitude. This is true for all reasonable values of alpha, and all currencies. Equally clearly, there is no comparably large difference in TF or ATF volatility across exchange rate regime, at least for the tabulated currencies and parameter values.

Although we find the plots in figures 14-16, (or their analogues in figures A1-A3) convincing, the evidence is ocular rather than econometric. Nevertheless, it is remarkably easy to produce the statistical analogues. Suppose that ΔTF_t ($\equiv TF_t - TF_{t-1}$), ΔATF_t , and ΔVF_t are normally distributed. Then the ratio of the regime-specific sample variances, e.g., $\hat{\Sigma}(\Delta TF_{\text{Float}})/\hat{\Sigma}(\Delta TF_{\text{Fix}})$, suitably scaled by a factor to correct for degrees of freedom, is

distributed as F under the null hypothesis of equal variances across exchange rate regimes.^{1/}

Table II contains estimates of the ratio of the *standard deviation* of the first-difference of fundamentals during the post-Bretton Woods era to the standard deviation of the first-differences of fundamentals during the Bretton Woods regime. (We tabulate ratios of standard deviations (rather than the corresponding F-statistics) in order to highlight situations where fundamental volatility was actually lower in the post-1973 regime than in the Bretton Woods regime.) Different lines correspond to different concepts of fundamentals and different parameter values. The relevant F statistics can be obtained by simply squaring the tabulated statistic (or $|x-1|+1$ if $x < 1$ where x is the statistic). Under the null hypothesis of equal volatility, the appropriate number of degrees of freedom in the numerator is approximately 220, and the number of degrees of freedom in the denominator is approximately T, tabulated in Table I. As the .05 and .01 critical values for F(200,100) are 1.32 and 1.48 respectively, the statistics tabulated in Table II are inconsistent with the null hypothesis at the .05 (.01) confidence level if they surpass approximately 1.15 (1.22). Starred statistics denote combinations where the null hypothesis of no substantial increase in volatility *cannot* be rejected at different confidence levels. This hypothesis is wholly at odds with all the VF series; it fares much better (but is still frequently rejected) for traditional fundamentals.^{2/}

^{1/} We checked for normality by looking for excess skewness and kurtosis. For some currencies and some alpha values, there are clear signs of non-normality which lead one to reject the hypothesis of normality at conventional confidence levels. We conclude that the hypothesis of normality is not literally true, but does not seem to be grossly at odds with the data. Thus we try not to take the exact confidence levels of our tests too literally; it turns out that there is no reason for us to do so.

^{2/} The end of an exchange rate peg is often associated with a large change in e and VF. It is therefore interesting to note in passing that the dramatic increase in VF volatility when a fixed rate begins to float also characterizes VF time series when the fixed-rate regime is extended through the month(s) at the end (and beginning) of the Bretton Woods peg.

It is striking that the traditional fundamentals often do not show a marked secular increase in volatility across exchange rate regimes; indeed, there are a number of instances of lower traditional fundamental volatility in the post-Bretton Woods regime. Nevertheless, we are not really interested in the null hypothesis that fundamental volatility is equal across regimes. Rather, we are interested in the question: do virtual and traditional fundamentals have similar time-series characteristics? In particular, do the TF and ATF series mimic the increase in volatility experienced by all the VF series? The answer is clearly negative; the hypothesis that the ratio of post-Bretton Woods to Bretton Woods volatility is equal for the virtual and traditional series can be rejected at better than the .99 level for all currencies and parameter values considered.

Scatter plots of ATF against VF for $\alpha = .5$ are contained in Figure 17 (the TF:VF analogue is contained in figure A5). In the graph, non-parametric data smoothers are drawn to "connect the dots"; Bretton Woods observations are highlighted by diamond marks. It is clear that virtual and traditional fundamentals are only loosely associated. This finding can be corroborated with standard regression techniques, which show that virtual and traditional fundamentals are positively but very imperfectly correlated (the R^2 in a regression of virtual on traditional fundamentals is typically around .05).^{1/}

To summarize, there is overwhelming evidence that the volatility of virtual fundamentals rises significantly when a fixed rate begins to float. However, this is by no means clear for traditional fundamentals; for reasonable α values, there is no substantial

^{1/} Since $(i-i^*)$ enters both ATF and VF, deviations from UIP cannot explain the different volatility characteristics between the two. Indeed, deviations from UIP which are not regime-specific cannot explain regime-specific volatility patterns. Insofar as there are regime-specific UIP deviations, they are likely to be smaller during the floating rate regime, since capital controls have gradually diminished in importance; however, this makes the jump in VF volatility in even more striking.

increase in volatility. Traditional and virtual are positively correlated for reasonably high values of α (e.g., .5), but the relationship is very noisy.^{1/}

IIIId: Traditional Fundamentals for the Sticky-Price Monetary Model

Construction of virtual and traditional fundamentals for the monetary model with flexible prices required only α and β above and beyond raw data. In order to construct traditional fundamentals for the monetary model with sticky prices, we need estimates of θ , ϕ , $E_t(e_{t+1}-e_t)$, $E_t(p^*_{t+1}-p^*_t)$, and r_t .

We use the literature to guide us in choosing appropriate θ and ϕ values. The largest estimate we have found for θ is in Frankel (1979), who uses a variant of (7) with quarterly data and estimates θ to be .19. Papell (1985) also uses quarterly data and estimates θ to be between .02 and .12 for four different countries. Meese and Rogoff (1988) estimate θ to be between .01 and .03, insignificantly different from zero; Mark (1990) finds comparable results. We consider $\theta=.01$ to be quite reasonable, and $\theta=.1$ to be an extreme upper bound at the monthly frequency.^{2/} As higher values of theta make our case harder to prove, we choose $\theta=.1$ as the default. We also choose $\phi=.1$ as our default, although there is a much smaller empirical literature on ϕ values (Papell estimates ϕ to be between .01 and .76, though with large standard errors).

We use uncovered interest parity to substitute $(i-i^*)_\lambda$ for $E_t(e_{t+1}-e_t)$. We construct a proxy for $E_t\Delta p^*_{t+1}$ by regressing Δp^*_{t+1} against a "reasonable" information set, typically consisting of $\{\Delta p^*_t, \Delta p^*_{t-1}, \Delta q_t, \Delta q_{t-1}, \Delta y^*_t, \Delta y^*_{t-1}\}$. In order to construct a proxy for the real interest rate, we construct a proxy for $E_t(p_{t+1}-p_t)$ by regressing Δp_{t+1} on a comparable

^{1/} Parenthetically, for $\alpha=.1$, the slope of the e:VF relationship is often insignificantly different during regimes of fixed and floating exchange rates,

^{2/} Direct estimation of θ leads to estimates of around .01, insignificantly different from zero.

domestic information set, and subtracting the fitted value from the nominal interest rate, since $r_t \equiv i_t - E_t(p_{t+1} - p_t)$.^{1/}

Figures 18 and 19 are the time series plots of our benchmark TF and ATF series for the sticky-price model; figures A4 and A5 are analogues for different parameter values while figures A7 and A8 are scatter plots of VF against the sticky-price TF and ATF. It is clear that none of our conclusions are changed substantially by modelling prices as sticky rather than perfectly flexible. The reason for this is that, even apart from the size of θ and ϕ , the volatility of r_t does not vary much across exchange rate regimes. Adding a term with relatively constant volatility to the traditional fundamental reinforces the fact that the volatility of TF (or ATF), unlike that of VF, does not vary much across exchange rate regimes. Indeed, for this reason, we expect that virtually all known macroeconomic exchange rate models will deliver broadly comparable results, since they depend on variables whose volatility does not systematically vary much across exchange rate regimes (Baxter and Stockman (1989) provide some relevant evidence).^{2/}

On a different note, we note in passing that the volatility of traditional fundamentals is not always roughly constant, since TF volatility rises dramatically during hyperinflationary periods. For instance, the volatility of the growth of German prices and money rises by an order of magnitude from 1921 to 1923. Thus, the poor correspondence between VF and TF volatility which characterizes "normal" periods, disappears during hyperinflations.

^{1/} With the exception of Holland, the relationships between inflation and the information sets are often tight, with R^2 values ranging up to .5.

^{2/} The results which have been presented in the paper have been computed with monthly data. As it is well-known that the time-series with which we are concerned can all be empirically modelled as processes with unit-roots, it is plausible to believe that our results will also hold at coarser frequencies. Nevertheless, we temporally aggregated all of our data up to the quarterly frequency and recomputed our test statistics; none of our conclusions were substantially altered.

V: A Summary and a Tentative Conclusion

Economists know remarkably little about exchange rates. In this paper, we have tried to exploit a fact that we do know: conditional exchange rate volatility is substantially higher in floating rate regimes than it is during regimes of fixed rates. We propose a simple benchmark as a specification test: any plausible empirical model of exchange rates should be able to account for this stylized fact. This indisputable fact has considerable power: for instance, flexible- and sticky-price monetary models cannot account for it. Indeed, as few macroeconomic variables for OECD countries experience dramatic changes in volatility which coincide with exchange rate regimes, we doubt that any exchange rate models based only on macroeconomic fundamentals can pass our simple empirical hurdle, at least during periods of tranquility.

Given that exchange rate volatility frequently seems to change dramatically when the volatility of macroeconomic variables does not, it should not be surprising that we cannot find any strong tradeoff between exchange rate volatility and the volatility of a variety of different macroeconomic variables (e.g., interest rates, relative prices, money, reserves, and stock returns). That is, we can see little empirical evidence that reducing exchange rate volatility compromises the stability of other macroeconomic variables. We are unwilling to make policy recommendations in the absence of a fully articulated model which *can* explain exchange rate volatility (let alone sustainable exchange rate *levels*). Nevertheless, we can see few economic advantages of pure exchange rate volatility *per se*.

We believe that future research should shy away from macroeconomic fundamentals, and concentrate on more microeconomic detail. Krugman and Miller (1992) introduce stop-loss traders into a simple model of the foreign exchange market. A microeconomic focus like this may well provide a future rationalization for the phenomenon of regime-varying VF volatility.

References

- Baxter, Marianne and Alan C. Stockman (1989) "Business Cycles and the Exchange-Rate System" *Journal of Monetary Economics* 23, 377-400.
- Dornbusch, Rudiger (1976) "Expectations and Exchange Rate Dynamics" *Journal of Political Economy* 84, 1161-1176.
- Flood, Robert P., Andrew K. Rose and Donald J. Mathieson (1991) "An Empirical Exploration of Exchange-Rate Target Zones" *Carnegie-Rochester Series on Public Policy* 35, 7-66.
- Frankel, Jeffrey A. (1979) "On the Mark: A Theory of Floating Exchange Rates Based on Real Interest Differentials" *American Economic Review* 69-4, 610-622.
- Frenkel, Jacob A. and Michael L. Mussa (1980) "The Efficiency of Foreign Exchange Markets and Measures of Turbulence" *American Economic Association Papers and Proceedings* 70-2, 374-381.
- Goldfeld, Stephen M. and Daniel E. Sichel (1990) "The Demand for Money" in *Handbook of Monetary Economics* (B.M. Friedman and F.H. Hahn, eds; North-Holland, Amsterdam).
- Krugman, Paul "Target Zones and Exchange Rate Dynamics" *Quarterly Journal of Economics* 106, 669-682.
- and Marcus Miller (1992) "Why Have a Target Zone" mimeo.
- Lewis, Karen K. (1992) "Occasional Interventions to Target Rates" mimeo.
- Lindberg, Hans and Paul Soderlind (1992) "Target Zone Models and the Intervention Policy: The Swedish Case" mimeo.
- Mark, Nelson C. (1990) "Real and Nominal Exchange Rates in the Long Run" *Journal of International Economics* 28-1/2, 115-136.
- Meese, Richard A. and Kenneth Rogoff (1988) "Was It Real?" *Journal of Finance* XLIII-4, 933-948.
- Obstfeld, Maurice and Kenneth Rogoff (1984) "Exchange Rate Dynamics with Sluggish Prices under Alternative Price-Adjustment Rules" *International Economic Review* 25-1, 159-174.
- Papell, David K. (1985) "Expectations and Exchange Rate Dynamics after a Decade of Floating" *Journal of International Economics* 25, 303-317.
- Stockman, Alan C. (1983) "Real Exchange Rates under Alternative Nominal Exchange-Rate Systems" *Journal of International Money and Finance* 2-2, 147-166.
- Svensson, Lars E.O. (1992) "Recent Research on Exchange Rate Target Zones: An Interpretation" *Journal of Economic Perspectives*, forthcoming.

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Table I: Bretton Woods Regimes of Fixed Exchange Rates after 1960

Country	Par Value	Declared Range	T	Dates
UK	\$2.8=£	(2.78,2.82)	94	through 11-18 1967
Canada	C\$1=\$.9275	(+/- 1%)	95	5-2 1962 through 5-31 1970
France	Ffr4.93706=\$	(4.9,4.974)	115	through 8-10 1969
Germany	DM4=\$	(3.97,4.03)	101	3-6 1961 through 9-30 1969
Holland	f13.62=\$	(3.5295,3.6475)	121	3-7 1961 through 5-9 1971
Italy	Lit625=\$	(620.5,629.5)	139	through 8-15 1971
Japan	¥360=\$	(357.3,362.7)	139	through 8-27 1971
Sweden	Skr5.17321=\$	(5.135,5.2125)	139	through 8-23 1971

Table II: Volatility Ratios of First-Differenced Fundamentals

Country	U.K.	Canada	France	Germ'y	Holland	Italy	Japan	Sweden
Benchmark Parameters ($\alpha=.5, \beta=1, \theta=\phi=.1$)								
VF	9.07	3.38	9.31	7.44	8.63	9.74	3.95	5.82
Flexible-Price Model								
TF	1.02**	1.15*	.50**	1.19*	1.70	1.10**	1.06**	1.00**
ATF	1.66	1.60	1.39	1.07**	.88**	1.79	1.28	1.40
Sticky-Price Model								
TF	1.14**	1.33	.80**	1.25	1.48	1.06**	1.08**	1.13**
ATF	1.27	1.26	1.26	1.10**	1.32	1.47	1.04**	1.40
Perturbations								
VF ($\alpha=.1$)	18.37	4.27	18.68	10.68	13.42	15.74	9.45	12.78
VF ($\alpha=1.$)	5.26	2.59	5.44	4.90	6.05	6.33	2.28	3.54
Flexible-Price Model								
TF ($\beta=1.5$)	1.06**	1.16*	2.34	1.11**	1.72	1.08*	1.00**	1.02**
ATF ($\alpha=.1$)	1.47	1.52	1.06**	1.16*	1.99	1.19*	1.14**	1.22
ATF ($\alpha=1.$)	1.89	1.67	1.63	1.30	1.41	2.39	1.36	1.54
Sticky-Price Model								
TF ($\theta=\phi=.01$)	1.28	1.30	1.30	1.15*	1.17*	1.35	1.09**	1.28
ATF (")	1.30	1.28	1.27	1.13**	1.17*	1.40	1.09**	1.32

G1

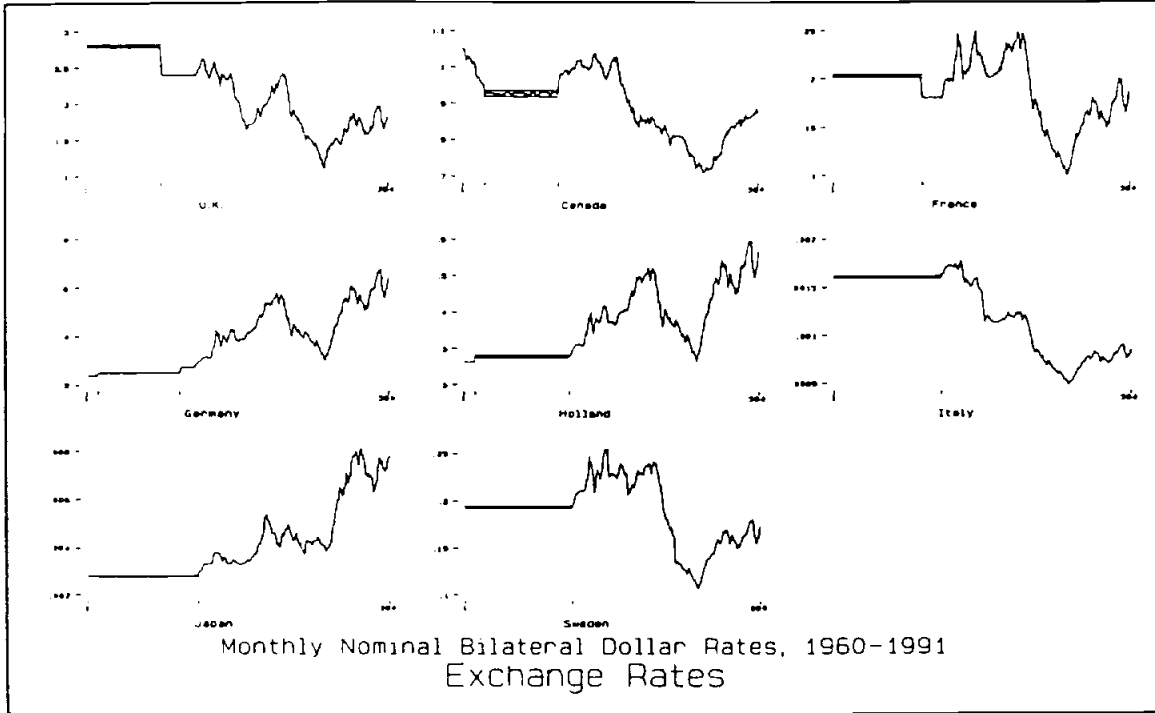


Figure 1: Time series of raw e data

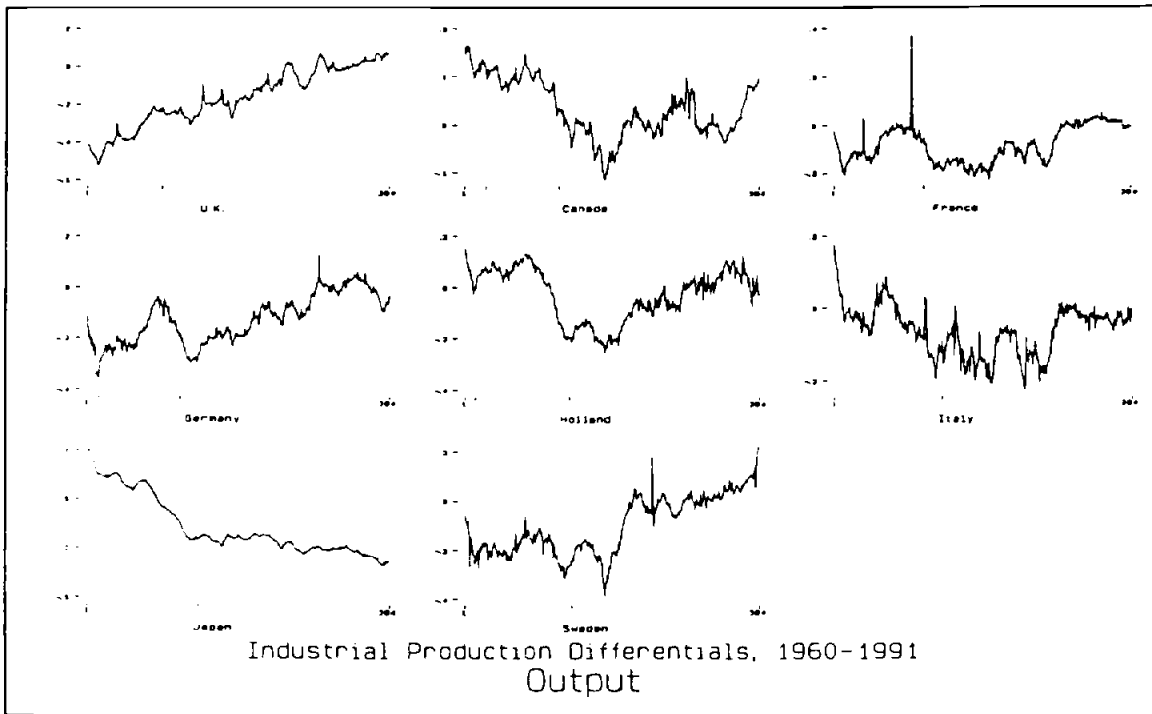


Figure 2: Time series of raw (y-y*) data

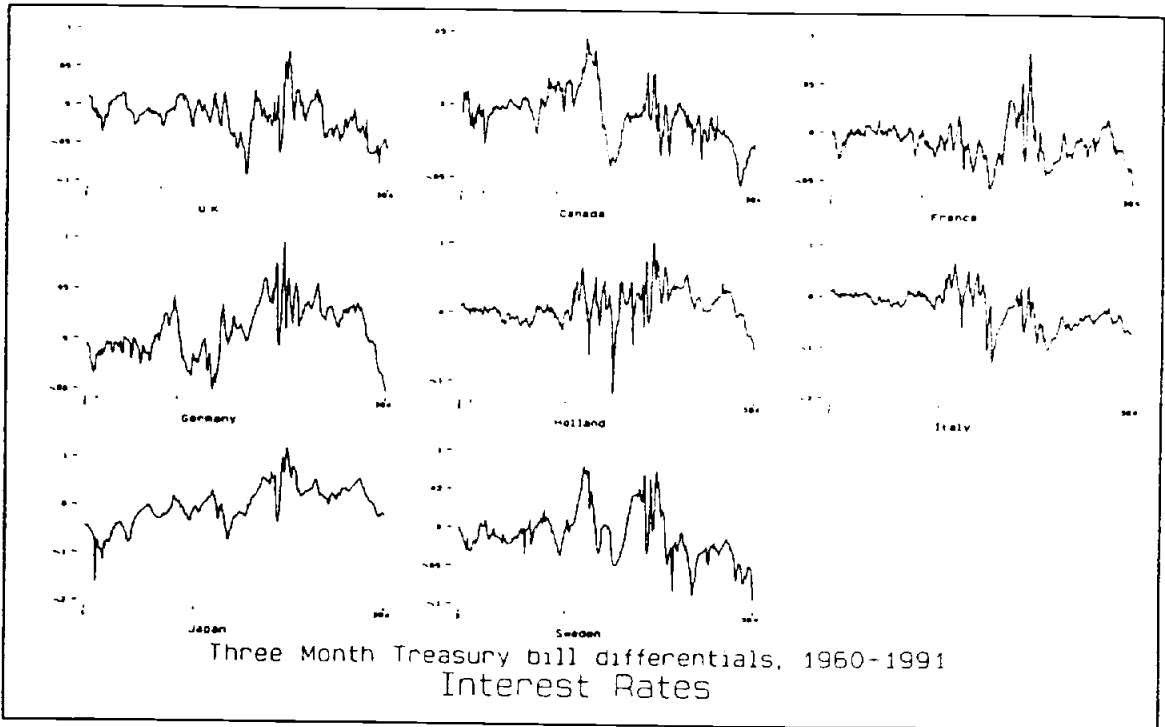


Figure 3: Time series of raw (i-i*) data

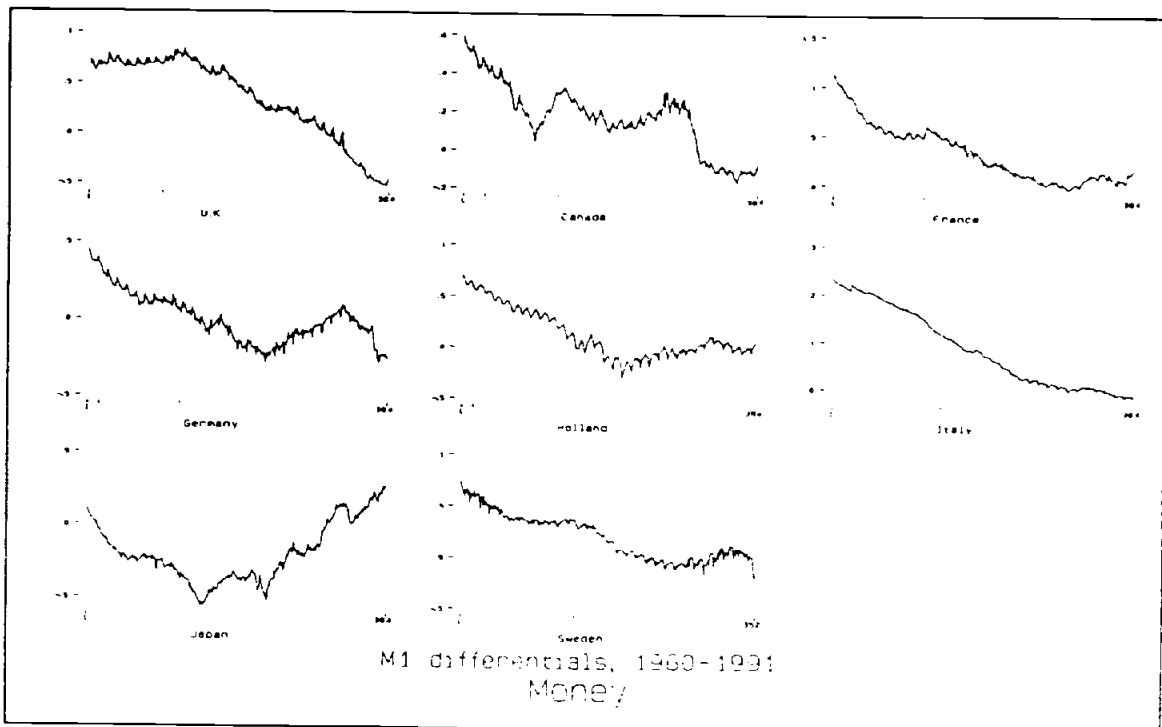


Figure 4: Time series of raw (m-m*) data

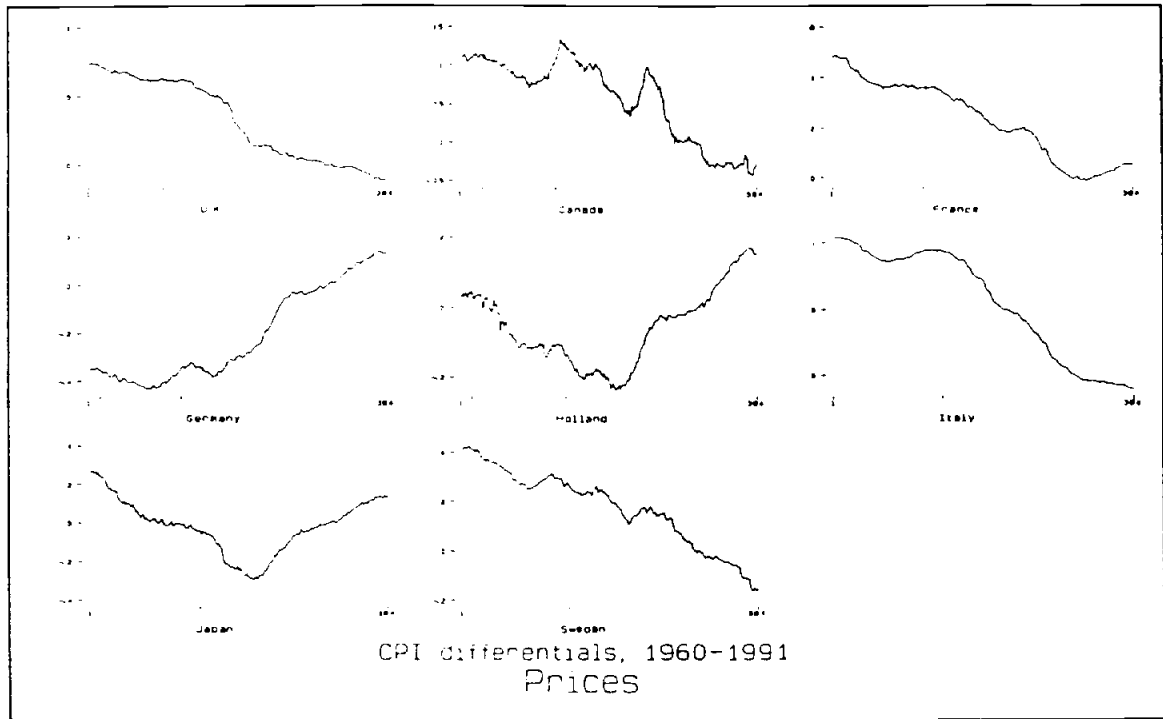


Figure 5: Time series of raw (p-p*) data

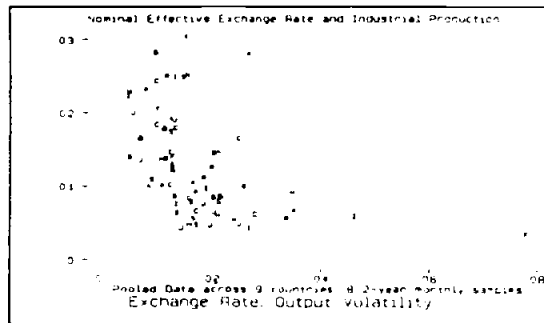


Figure 6: $\sigma(e)$ against $\sigma(y)$

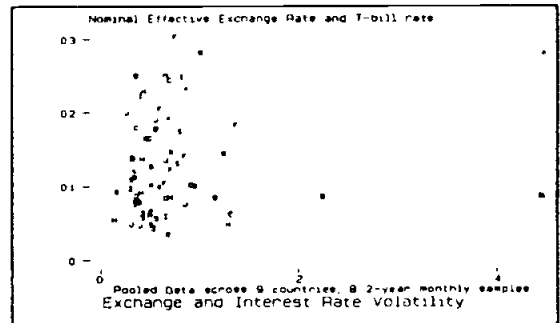


Figure 7: $\sigma(e)$ against $\sigma(i)$

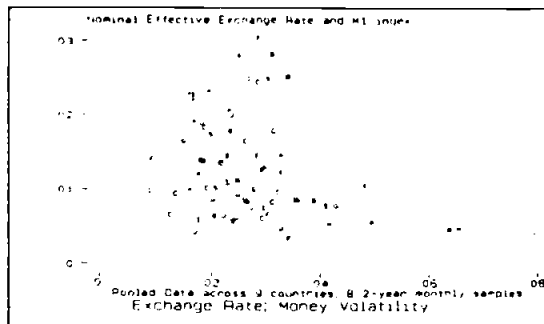


Figure 8: $\sigma(e)$ against $\sigma(m)$

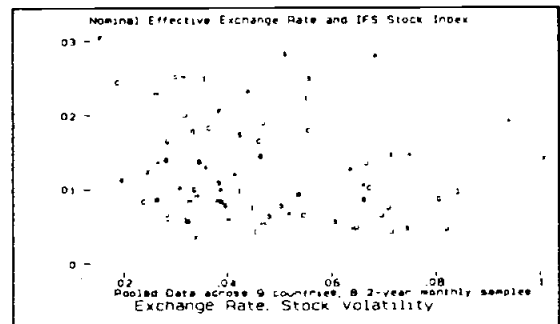


Figure 9: $\sigma(e)$ against $\sigma(\text{Stocks})$

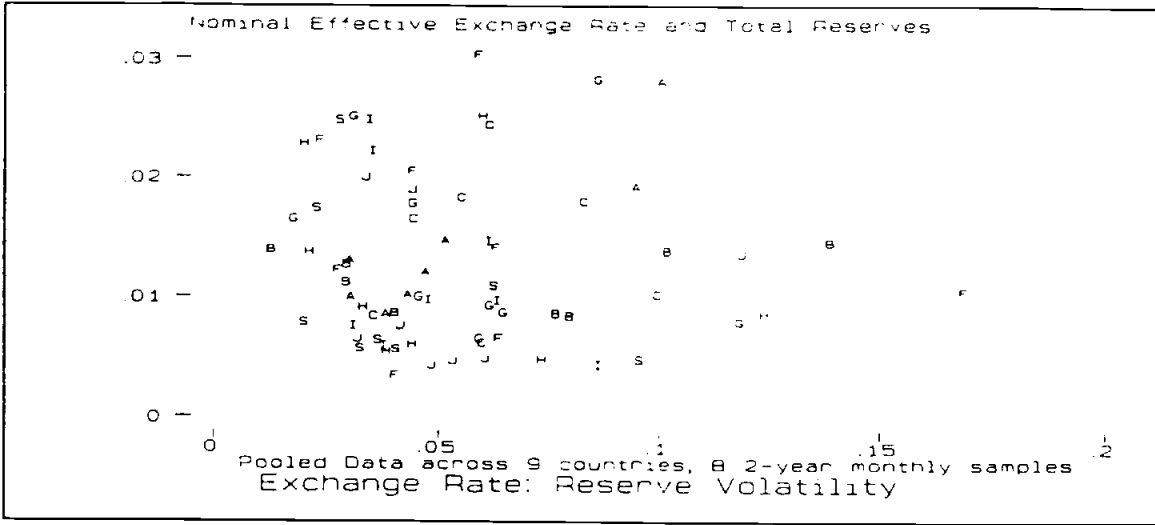


Figure 10: $\sigma(e)$ against $\sigma(\text{Reserves})$

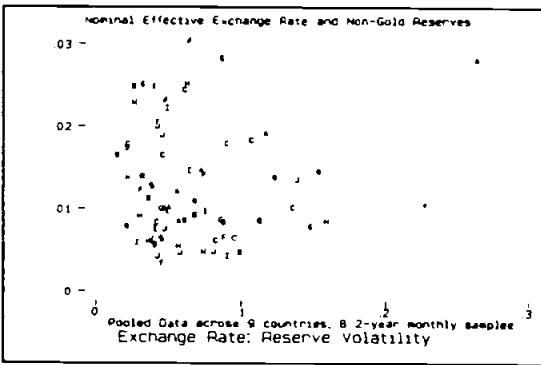


Figure 11: $\sigma(e)$ against $\sigma(\text{Non-Gold Resrv})$

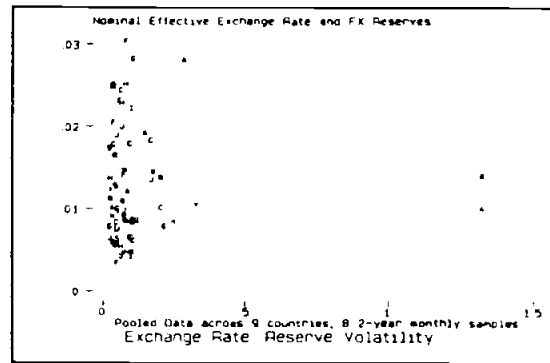


Figure 12: $\sigma(e)$ against $\sigma(\text{FX Reserves})$

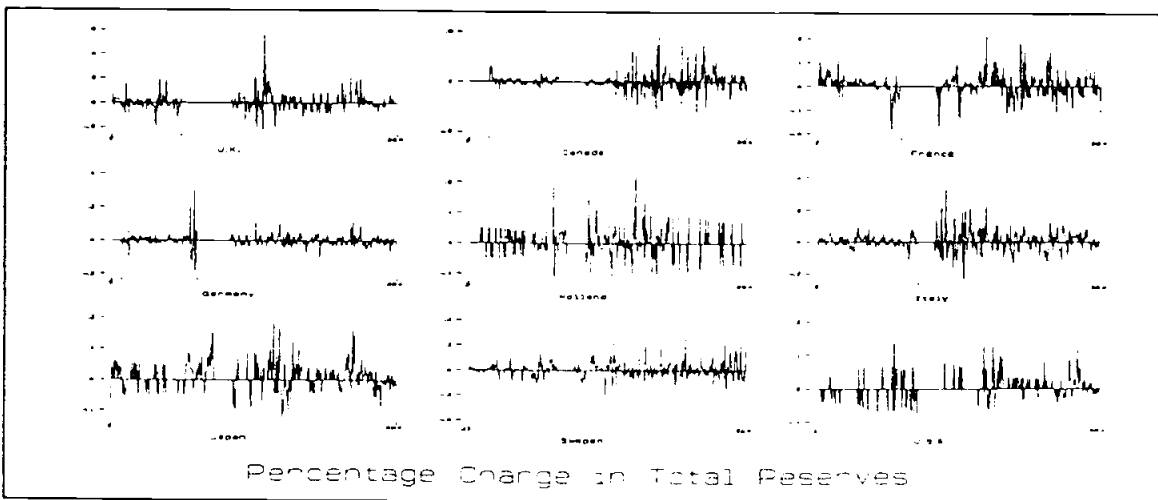


Figure 13: Time series of Reserves during Fixed and Floating Exchange Rate Regimes

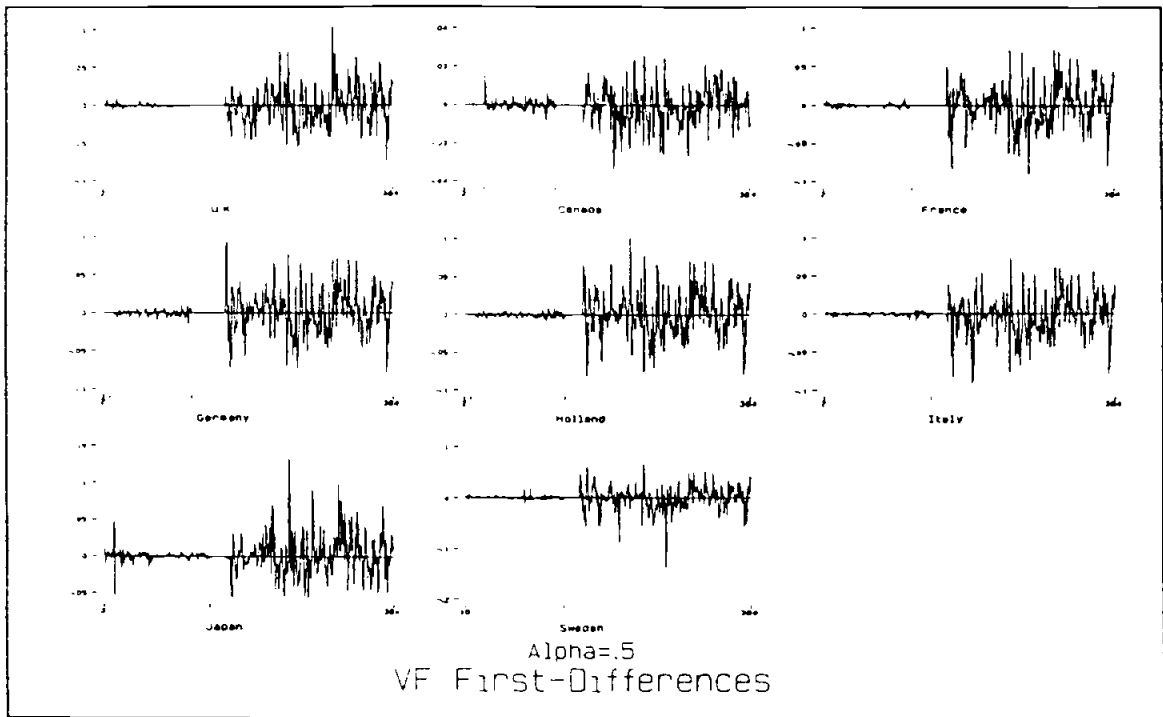


Figure 14: Time series of Benchmark Virtual Fundamentals

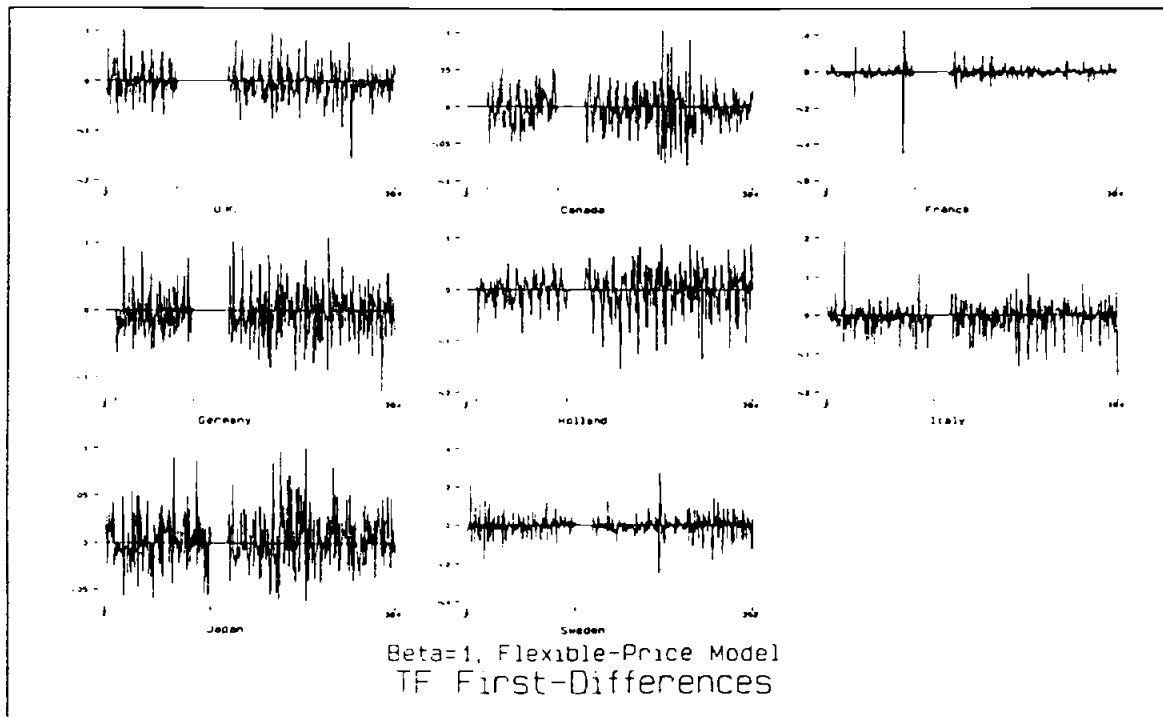


Figure 15: Time series of Traditional Fundamentals, Benchmark Flexible-Price Model

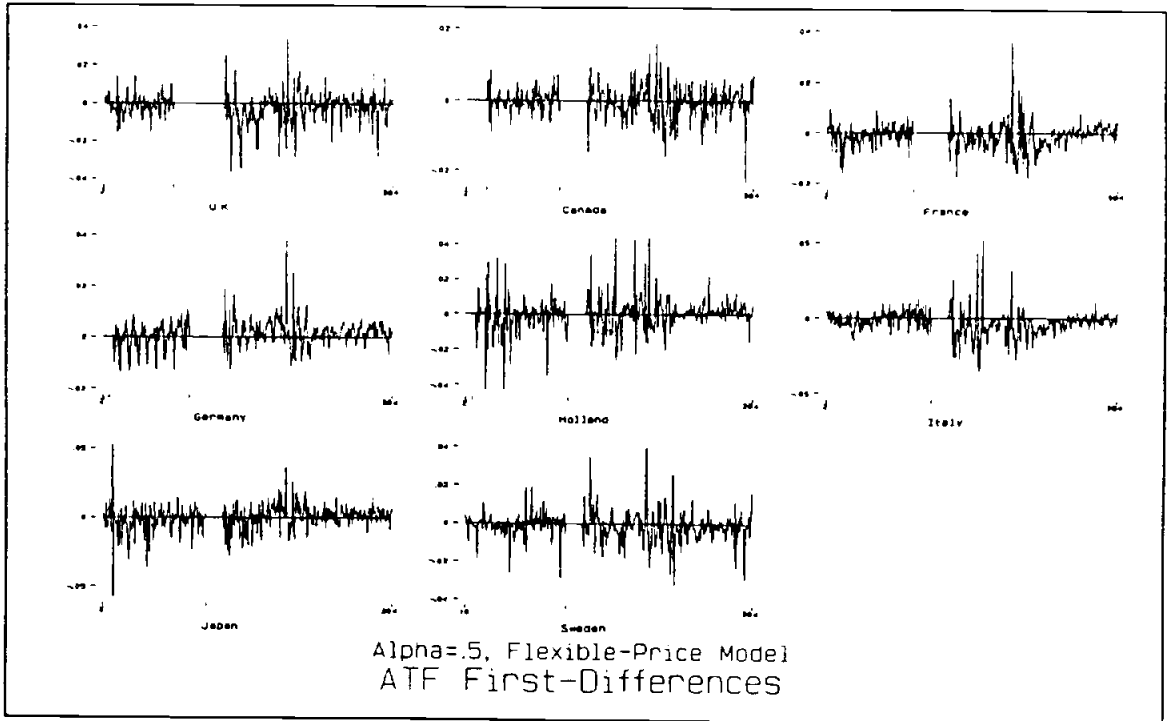


Figure 16: Time series of Augmented Traditional Fundamental, Flexible-Price Model

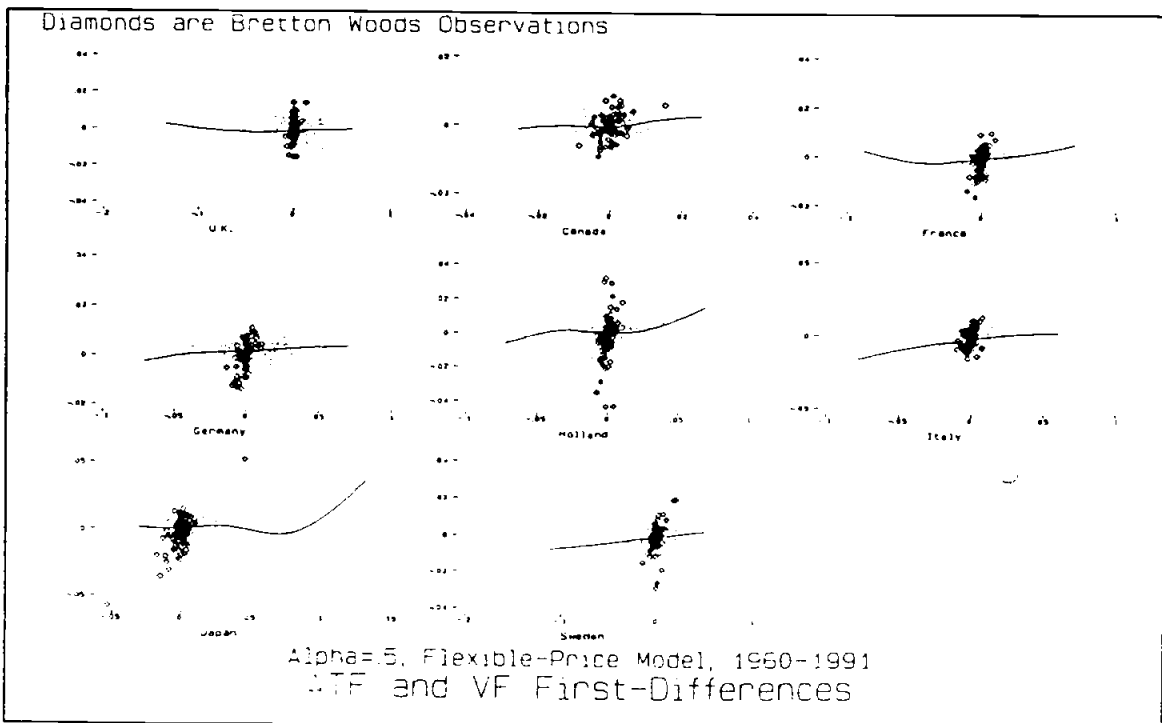


Figure 17: Direct Comparison of ATF and VF, Flexible-Price Benchmark

G7

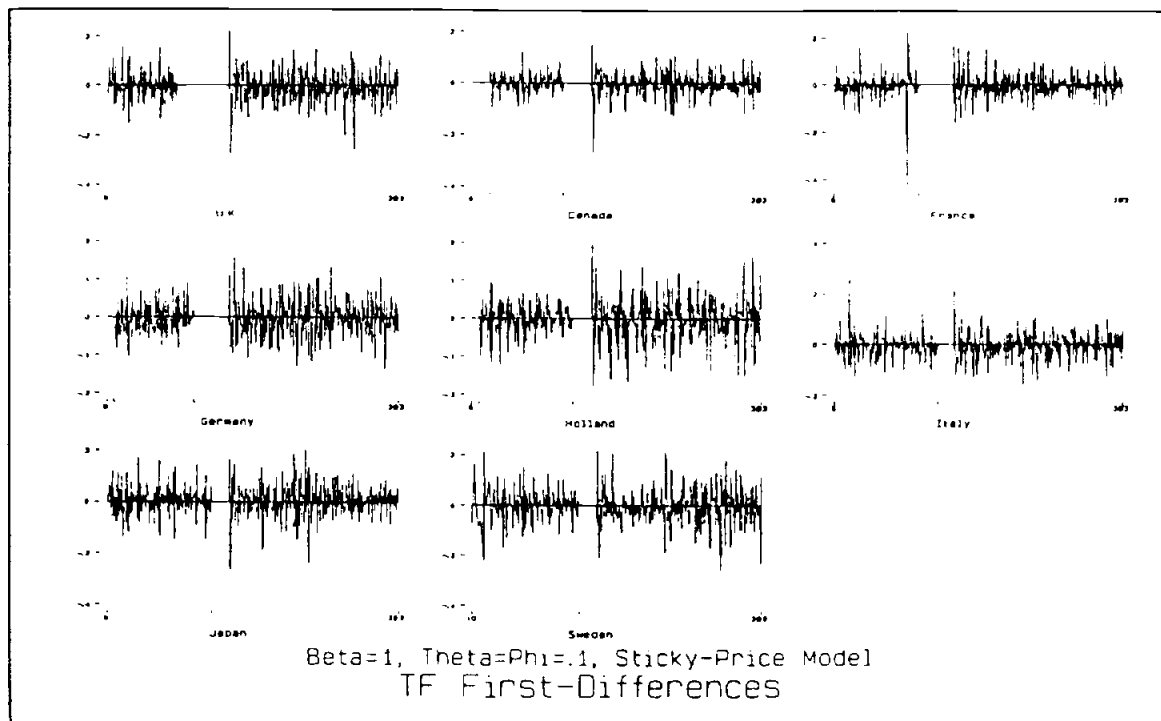


Figure 18: Time series of Traditional Fundamental, Benchmark Sticky-Price Model

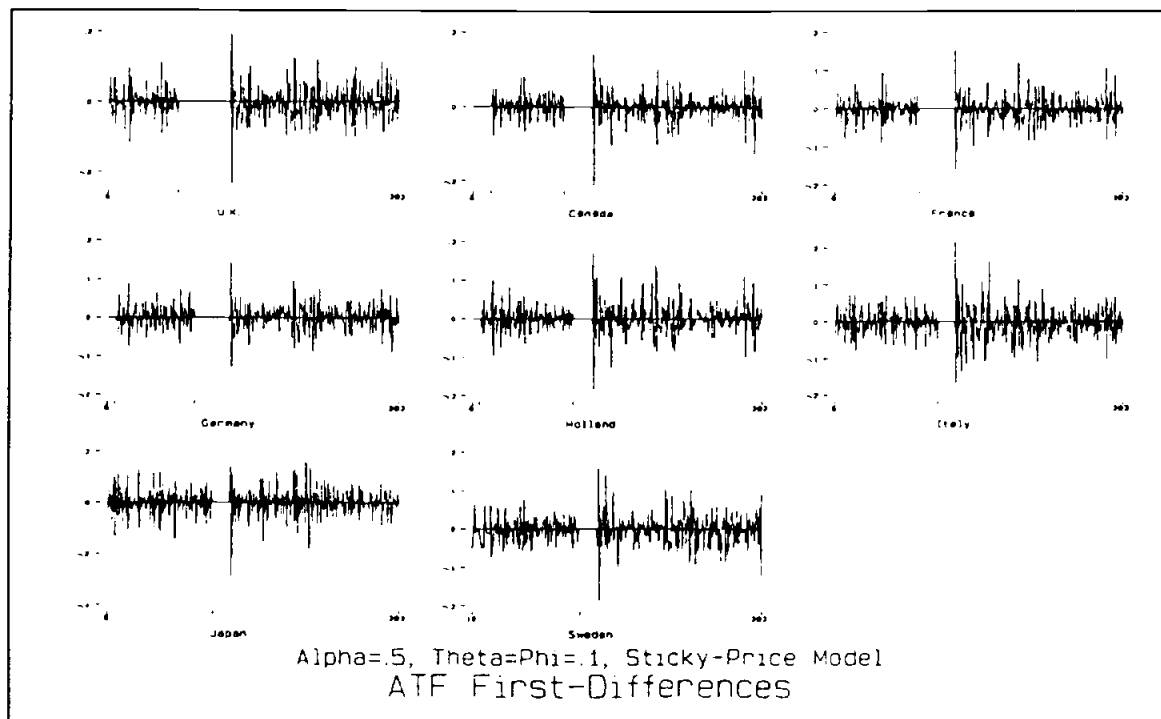


Figure 19: Time series of Augmented Traditional Fundamental, Sticky-Price Model

A1

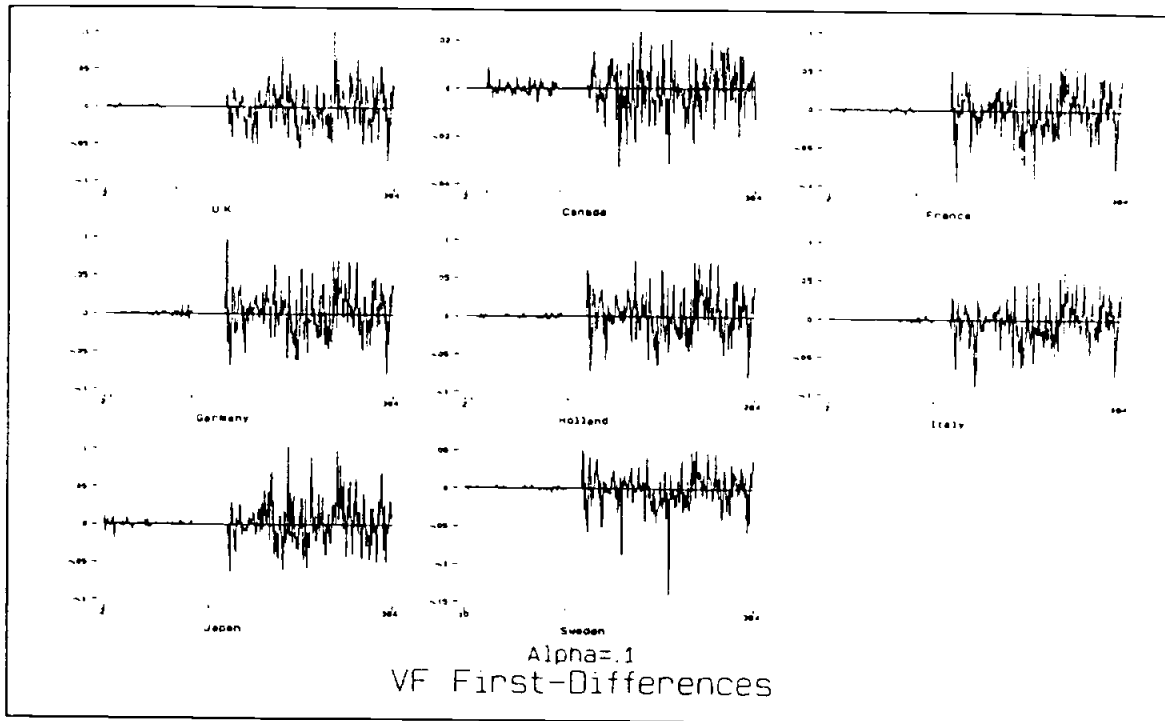


Figure A1: Time series of "Realistic" Virtual Fundamental

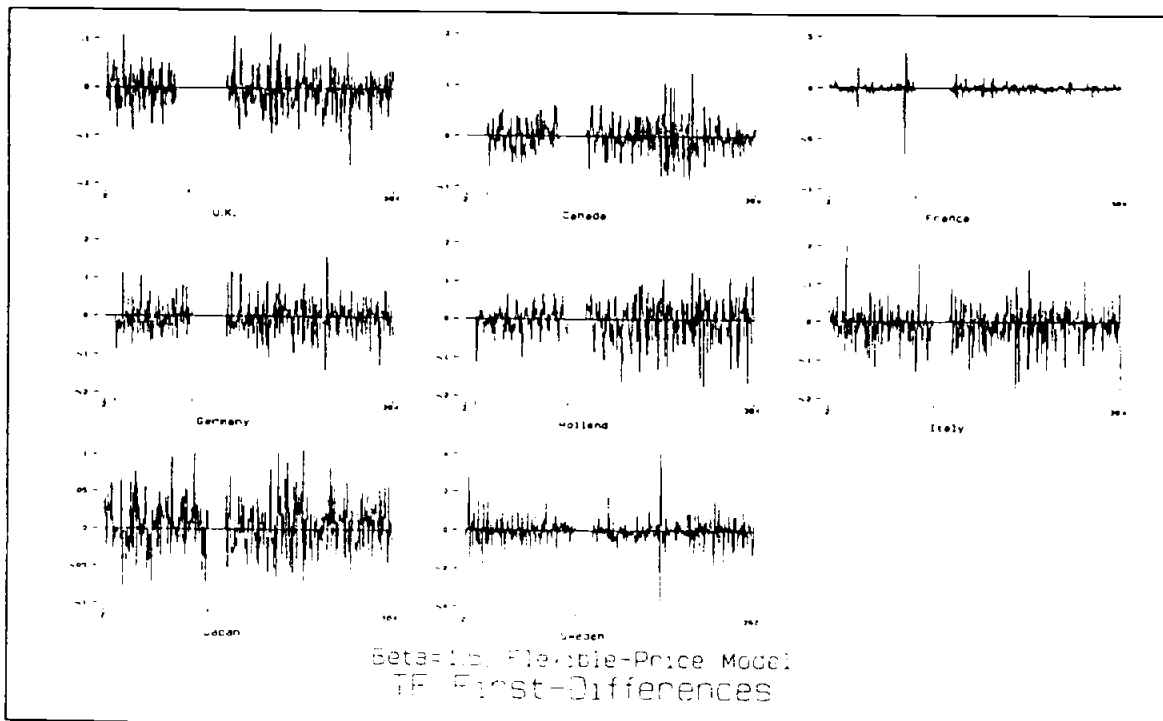


Figure A2: Time series of Trad'l Fundamental, Flexible-Price Model with "Large" Beta

A2

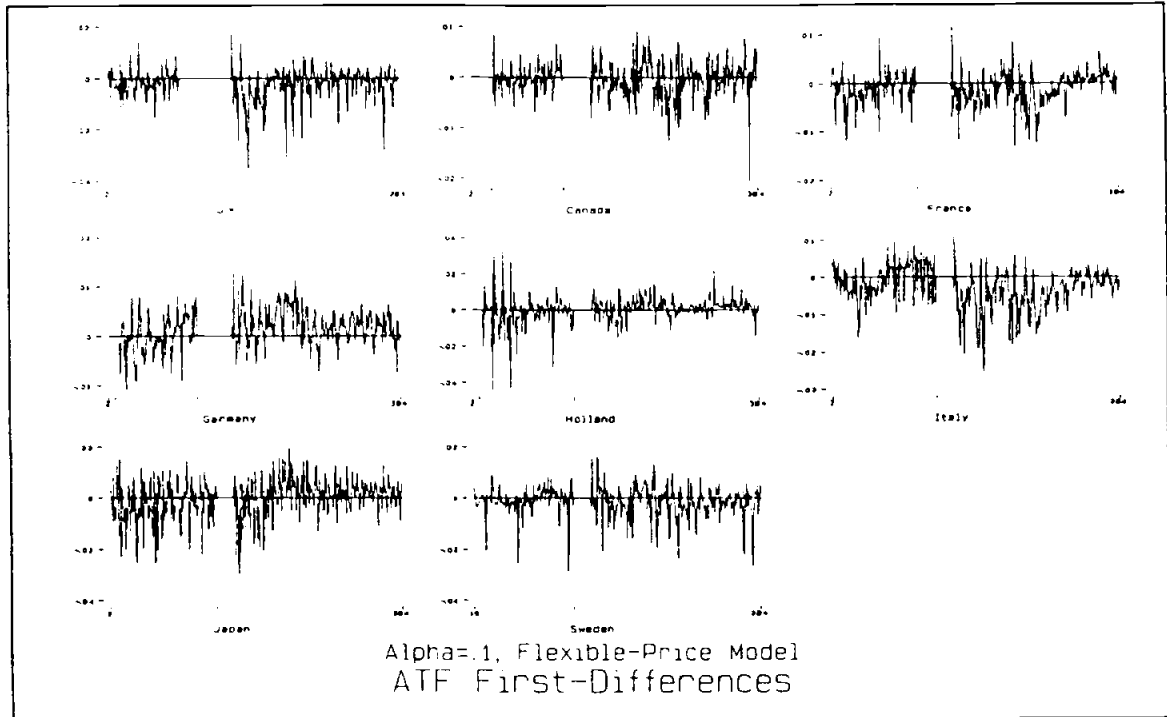


Figure A3: Time series of Augmented Trad'l Fundamental, "Realistic" Flex-Price Model

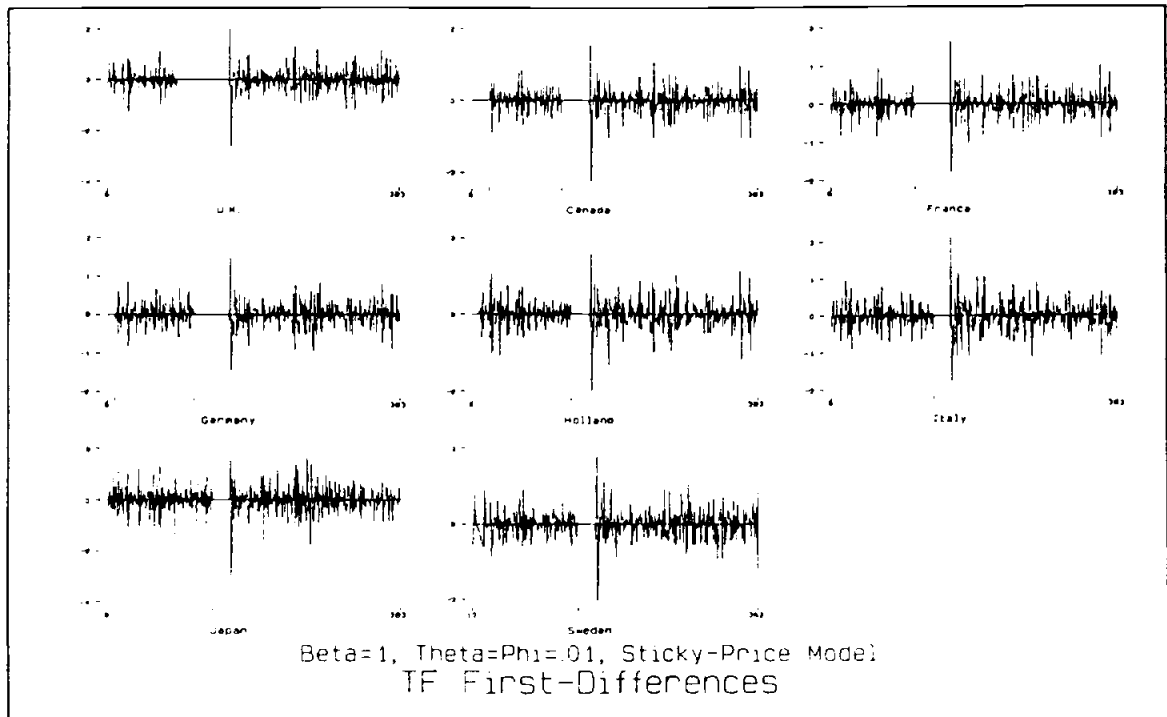


Figure A4: Time series of Traditional Fundamental, "Realistic" Sticky-Price Model

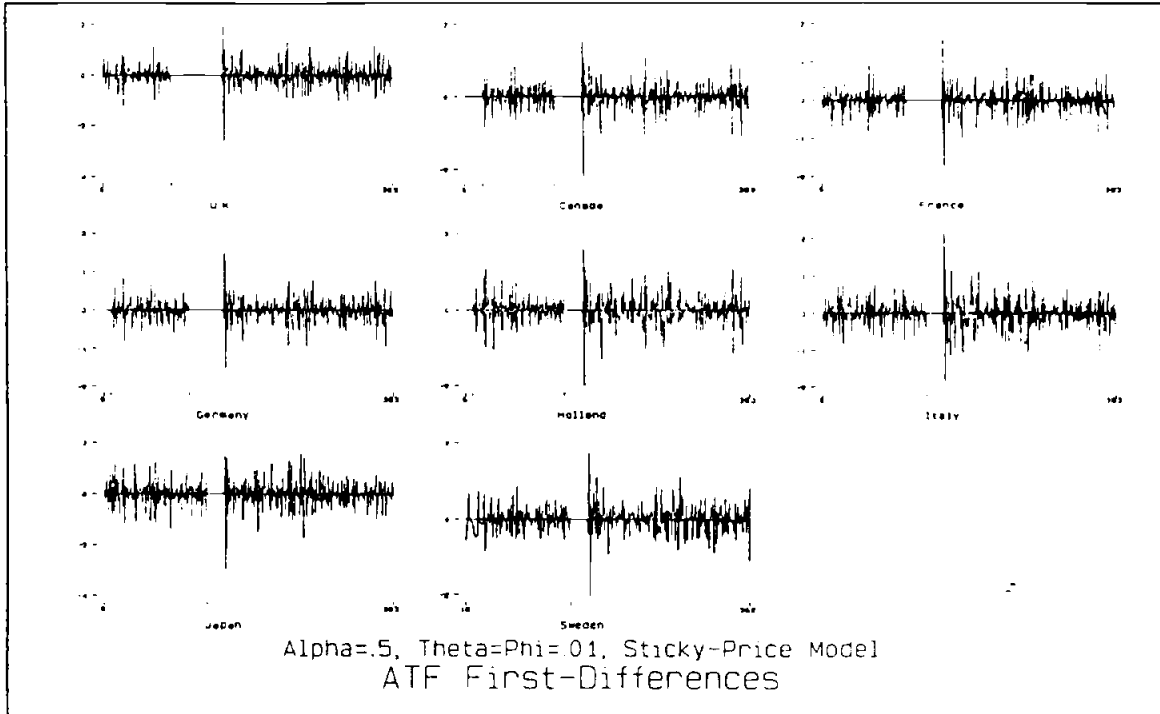


Figure A5: Time series of Augmented Trad'l Fundamental, "Realistic" Sticky-Price Model

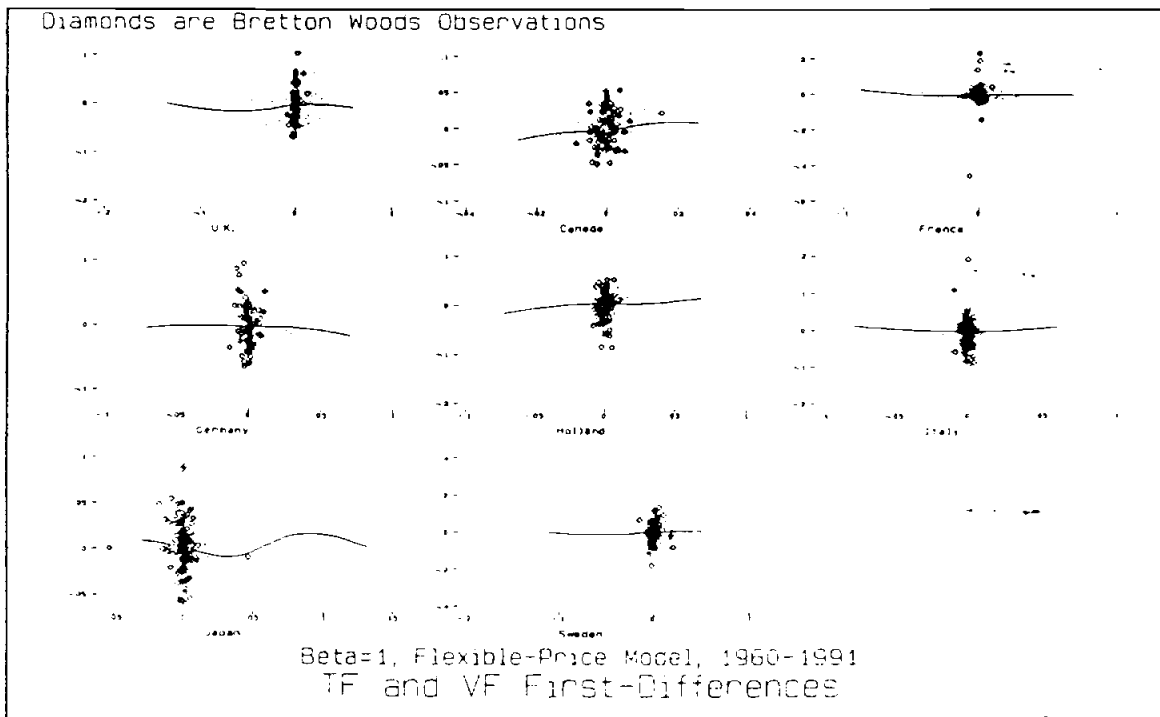


Figure A6: Direct Comparison of TF and VF, Flexible-Price Benchmark

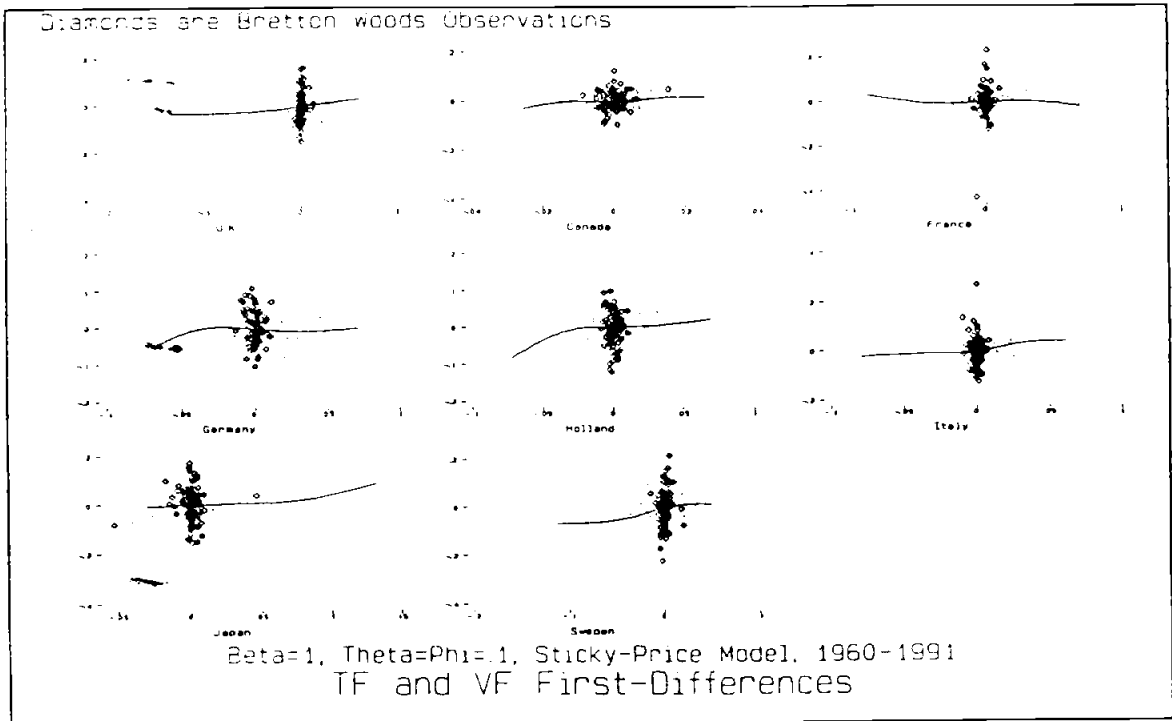


Figure A7: Direct Comparison of TF and VF, Sticky-Price Benchmark

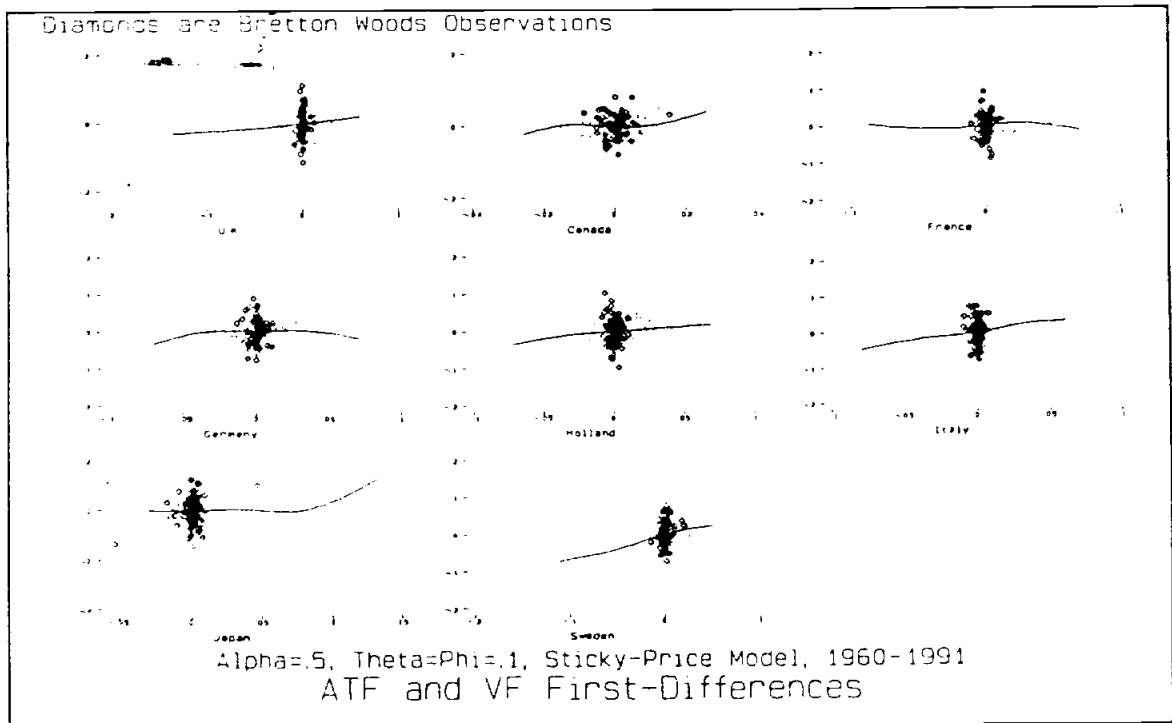


Figure A8: Direct Comparison of ATF and VF, Sticky-Price Benchmark