Australian Journal of Agricultural Economics, Vol. 36, No. 1 (April 1991), pp. 49-76

THE EFFECTS OF FLEXIBLE EXCHANGE RATES ON AUSTRALIAN WOOL PRICES*

SHAUNA PHILLIPS and RONALD BEWLEY
Business Econometrics and Forecasting Group
University of New South Wales
Kensington, NSW 2033

The implication of price stabilisation under a volatile exchange rate is an increasingly volatile price denominated in a foreign currency. Time series analysis is used to model the relationship between exports, prices and AWC stocks. This model is used to assess the distribution of the impact of exchange rate shocks on prices denominated in local and foreign currencies. It is found that the AWC has significantly reduced the impact of exchange rate shocks on domestic prices.

Introduction

Under a flexible exchange rate regime, the behaviour of the Australian dollar has been characterised by short periods of extreme volatility interspersed by periods of narrow trading ranges. Traditionally, the primary function of the exchange rate has been to regulate trade flows through the price mechanism. However, since the float, both the level and the volatility of the currency have been dominated by monetary policy and currency speculation.[1]

Models of exchange rate volatility have been well established both theoretically (Dornbusch, 1986) and empirically (Matthews and Valentine, 1986). Volatility can be harmful in the sense that it need not represent real forces and, therefore, is potentially damaging to trade in two ways. First, exchange rate volatility may distort price signals and, second, it increases risk and uncertainty and redistributes profits and losses between different groups. While it is the case that forward markets can be used to reduce exchange rate risk, the uncertainty

* This paper is an extension of Phillips' undergraduate thesis at the Department of Agricultural Economics, University of Sydney. We would both like to express our thanks to that department for its support and, in particular, Carolyn Tanner for her encouragement. We would also like to thank Anil Bera, Trevor Breusch, and John Connell for their comments. David Orden provided numerous comments and suggestions during the revision process and these have helped to improve the content and exposition of our paper. We are particularly grateful to David Orden for his input but the usual disclaimer applies. The project has been partially funded by an Australian Research Council Grant.

[1] See, for example, Adam and Bewley (1990).

associated with production levels reduces the effectiveness of such cover (McKinnon, 1988).

Given that macroeconomic policy in Australia is now subject to the influence of the balance of payments constraint, it is important to examine the effects of flexible exchange rates on trade. Wool is historically one of Australia's most valuable export industries and output is great enough to influence world prices. The effect of the 1983 float on wool prices is potentially complex as the level of output affects prices and, in turn, prices may feed back into the value of the dollar.

The broad aim in this analysis is to assess the effects of exchange rate volatility on the export market for Australian wool. Since 1974, the Australian Wool Corporation (AWC) has operated the Reserve Price Scheme (RPS) to stabilise producer prices denominated in the local currency.[2] Since producers and exporters face prices denominated in Australian dollars ($A) and importers of Australian wool the same price in a foreign currency, the operation of the RPS in stabilising prices is made more difficult and more important by a floating exchange rate regime. The AWC must distribute currency-induced price fluctuations between producers and importers. In particular, in this analysis the aim is to assess the degree of success of this policy with the use of econometric analysis. Since an exact relationship exists between prices denominated in local currency, foreign currency and the exchange rate, it is possible to draw logical conclusions from a model denominated in local currency and the exchange rate about prices in foreign units. In this way, estimated aggregate volatility can be distributed among the prices denominated in the two currencies.

Using a Vector Autoregressive (VAR) methodology, a two-stage analysis to examine the impact of the exchange rate on prices and quantity is carried out. In the first stage, a VAR is used to analyse the dynamic interactions of various shocks to prices, quantities and the exchange rate. Following Rogoff (1985), the effects of volatility can also be considered by describing the behaviour of the estimated variance of the shock, or unexplained variation, from the first stage. The second-stage analysis is effectively a VAR on squared residuals from the first-stage analysis.

This second-stage process carries the assumption of the predictability of the variance of the disturbance terms in the first-stage VAR, implying a form of heteroscedasticity, and is a variant of the Autoregressive Conditional Heteroscedasticity (ARCH) model introduced by Engle (1982), and adopted in Han, Jansen and Penson (1990). This multivariate ARCH process assumes that variances are constant in an unconditional sense but vary over time, conditional on recent behaviour.

The implication of the approach is that the first-stage innovation analysis describes the unconditional behaviour of the system. The

[2] The RPS was 'temporarily' abandoned at the beginning of 1991.

second-stage innovations describe the volatility interactions between the wool market variables and these changing conditional variances have implications for a first-stage *conditional* innovation analysis. If the second-stage analysis had also described the behaviour of conditional *covariances*, it would have been possible to conduct unconditional and conditional innovation analyses on the basic VAR model. However, given the magnitude of the problem and the extreme computational complexity of relating the two stages of analyses, a pragmatic two-stage procedure has been adopted. Thus, the first-stage innovation analysis relates to unconditional, or average, behaviour while the second stage describes how the volatility of the component variables evolves and provides some insight into how the conditional first-stage innovations might behave.

The results indeed indicate that the second-stage volatility-effects model enriches the interpretation from that of a standard VAR (first-stage) approach. From the first-stage analysis, the AWC appears to have been partially successful in removing the effect of shocks to the exchange rate on domestic (auction) prices denominated in $A. In the second stage, it was found that a shock to the level of volatility of the exchange rate causes $A-denominated prices also to be more volatile, but that the $US-denominated price remains unaffected. In that sense, during periods of extreme volatility, the AWC cannot insulate the domestic market from exchange rate shocks but, in an average, or unconditional sense, the AWC has been at least been partially successful in achieving its goal.

Data

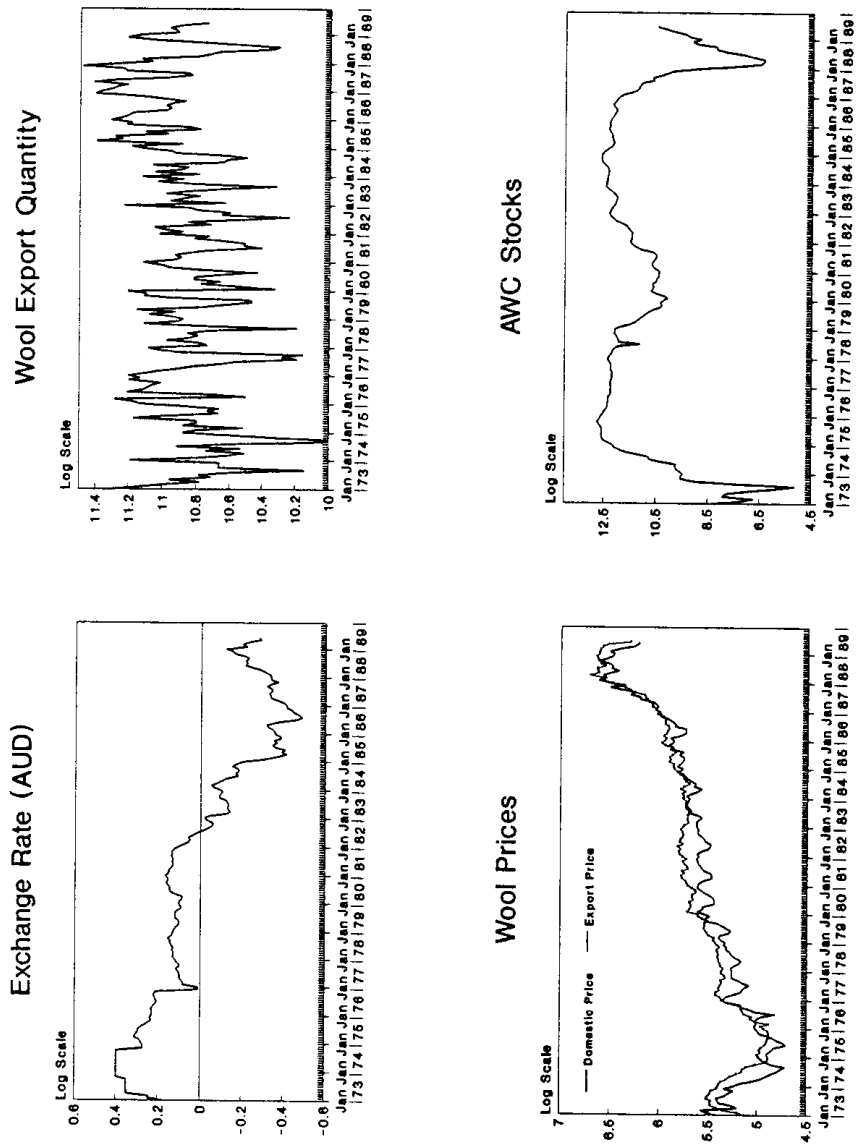
Monthly time-series data on export quantities, export values and domestic prices are collected by the Australian Bureau of Statistics, and an implicit export price index can be derived from the value and quantity series. The exchange rate denominated in $US was selected, as the majority of contracts for wool sales are written in $US. The series for AWC stocks was obtained from the Australian Wool Corporation. All variables are modelled in logarithms and have been collected for the period June 1974 to June 1989.

Our model incorporates the following variables:

Q ~ exports of greasy wool measured in tonnes
P ~ average wool price at auction in Australia in $A/100kg
V ~ value of greasy wool exports f.o.b. in $A millions
Π ~ average price of exports in $A: $P = V/Q$
E ~ currency valued in $US per Australian dollar at the end-of-month
S ~ AWC stocks (in bales) held in operation of the Reserve Price Scheme

Log plots of the data are given in Figure 1. With the exception of the turbulence in the exchange rate following the world-wide freeing up of foreign exchange markets in 1974, the volatility of the $A has increased markedly since its float in December 1983. In particular, two

FIGURE 1
Data



short, sharp depreciations took place in recent years. In the first three months of 1985, the $A fell by 19% against the $US and, in the three months following the May 1986 collapse in commodity prices, it fell again by 15%.

From the plot of AWC stocks, it can be noted that extreme values occur at either end of the sample period. This raises a potential problem for the stability of the estimated relationships. However, our analysis suggests that the model is robust to truncation of the sample to October 1974 through to December 1987.

Not surprisingly, the domestic and export prices for wool have been trending together but it can also be noted that substantial and prolonged differences have existed. The domestic price is set at auction and the export price is realised on shipment. However, most export contracts are struck on a firm-offer basis in foreign currency from 2 to 9 months in advance.[3] As a result, some lag is to be expected in export price formation and possibly an additional degree of volatility in the $A export price might arise due to unanticipated exchange rate fluctuations that occur between the auction and subsequent export.

Finally, export quantities appear to have been sensitive to major currency depreciations. This observation is based on the apparent shift in the mean of export quantities post-depreciation in 1985. This impression is confirmed when a univariate time series model is specified for the quantity series, and subjected to an intervention analysis.[4] This analysis generated an ARMA model with one regular and one seasonal autoregressive parameter. In addition, it detected seasonal pulse interventions, outliers, and, importantly, a step-change increase in quantity from June 1985. Given the major currency depreciation precipitated in January 1985, the implication that this depreciation led to a switch in demand, above the implicit price effect that would follow from a smaller price change, is tenable.

First-Stage Analysis

Econometric model specification involves a trade-off between the bias due to invalid over-identifying restrictions and inefficiency due to an insufficient number of *a priori* restrictions. Sims (1980) suggested an atheoretical approach to modelling economic relationships that simplifies this decision making process by estimating a dynamic unrestricted reduced form. This VAR (Vector Autoregressive) approach involves regressing every variable on itself and every other variable in the system lagged from one period up to some maximum lag length, p:

$$Y_t = A_0 + A_1 Y_{t-1} + A_2 Y_{t-2} + \ldots + A_p Y_{t-p} + u_t \tag{1}$$

[3] University of New England (1988), p. 21.

[4] The analysis was performed using the automatic intervention analysis procedure in AUTOBOX [Riley, 1988].

where, in our case, Y_t is a 5 x 1 vector $Y_t' = (E\ P\ S\ \Pi\ Q)$, u_t is a 5 x 1 vector white-noise disturbance term with an unconditional covariance matrix Ω, A_0 is a 5 x 1 vector of constants, and A_i (i = 1,..., p) are 5 x 5 matrices of fixed coefficients.

By backward substitution, equation (1) can be solved as an infinite moving average process providing that $A(L) = I - A_1L - A_2L^2 - A_pL^p$ has all of its roots outside the unit circle:

$$Y_t = B_0 + u_t + B_1u_{t-1} + B_2u_{t-2} + B_3u_{t-3} + \ldots \tag{2}$$

where $B_0 = A^{-1}(1)A_0$ and the 5 x 5 parameter matrices B_i (i = 1, 2,...) are functions of A_i (i = 1,..., p).

Within the VAR framework, interrelationships between the variables can be analysed by 'shocking' the system and observing the time path of Y_t, as in a dynamic multiplier analysis of a structural model. There is no formal economic structure to a VAR model, and this so-called innovation, or impulse response function analysis is usually achieved by decomposing the disturbances in a particular fashion. Disturbances are typically correlated across equations in (2) and the standard procedure is to identify a contemporaneous structure on the model by orthogonalising u_t using a Choleski decomposition. The structural identification of VAR models offers an alternative approach [Bernanke (1986), Blanchard (1989), Sims (1986), Orden and Fackler (1989), Myers, Piggott and Tomek (1990)] and is based on defining a new vector of shocks that are assumed to be associated with particular sources of behavioural innovation such as demand, supply and external shocks. Myers *et al.* use the structural approach to examine longer-term relationships in the wool market using quarterly data but this approach is less useful for studying short-term financial relationships and is not pursued here.

The unconditional disturbance covariance matrix is decomposed as $\Omega = HH'$, where H is lower triangular, and premultiplying (2) through by H (see Sims, 1980) gives

$$HY_t = D_0 + v_t + D_1v_{t-1} + D_2v_{t-2} + \ldots \tag{3}$$

where $D_0 = HB_0$; $D_i = HB_iH^{-1}$ (i = 1, 2, ...) and $v_t = Hu_t$.

Impulse response functions characterise the time profile of the responses of each variable to shocks of one standard deviation in each element of v_t. Because of the triangular structure of H, the first variable in Y is assumed to be contemporaneously exogenous and each subsequent variable in Y is assumed to only depend contemporaneously upon those variables listed above it. That is, the system is contemporaneously recursive and, by definition, the disturbances in this 'structural' form, v_t, are orthogonal. However, the dynamic structure, $D(L) = D_1L + D_2L^2 + \ldots$, allows each variable to affect each other after the first-round effect has been completed. It should be noted that the form of the recursive structure is dependent on the ordering of the variables in Y.

Wool model

In order to translate the general VAR methodology to the case of analysing the formation of wool prices, exports and stocks, two data-based decisions need to be taken. The first relates to whether it is appropriate to model the levels or the differences of the variables and the second to the determination of the lag length.

If it were preferable to model all of the variables in differences rather than levels, the lag polynomial A(L) could be factorised as $(1-L)A^*(L)$, where $A^*(L)$ is of order $(p - 1)$ and has no unit roots. Between the two extremes of levels and differences are $(p - 1)$ models in which some of the variables (or linear combinations of the variables) are differenced. Since differencing some or all of the variables is equivalent to placing restrictions on A(L), biases will exist if 'over-differencing' takes place.[5] On the other hand, if too few variables (or linear combinations) are differenced, some inefficiency results but the OLS estimator of A(L) is still consistent when such restrictions are valid. Given the potential complexity of this model of wool-market variables, and our focus on the behaviour of the formation of the variances of the residuals, we have chosen not to attempt to restrict A(L), allowing its estimate to approximate the behaviour associated with differencing, should differencing be appropriate for some of the variables.

The lag length was chosen using a sequence of Sims' (1980) adjusted likelihood ratio (LR) tests. Each row of Table 1 presents the adjusted LR statistic for a null lag length of $(p - 1)$ against an alternative of p for a range of $p = 9$ to $p = 4$. Using a 1% significance level to accommodate the build-up of type-I error in a sequence of hypothesis tests, a VAR with 8 lags was selected.

Twelve seasonal dummies were originally included but only four were retained as all others were insignificant at the 5% level. A dummy

TABLE 1
VAR Lag Length Selection

Lag (p)	adj. LR
9	35.6
8	48.2
7	43.1
6	32.6
5	31.9
4	46.9

The adjusted LR statistic is asymptotically distributed as $\chi^2(25)$ with a 1% critical value of 44.3.

[5] Differencing amounts to placing rank restrictions on $C = A(1)$. If $\text{rank}(C) = p$, all variables are in levels and, if $\text{rank}(C) = 0$, all of the variables appear in differences.

variable taking the value zero prior to January 1985 is included to capture the shift in exports noted in the previous section. In some sense, this dummy variable allows for a large change in the value of the currency while E accounts for smaller changes. A linear time trend was also included, as is commonly the case in the Sims' methodology. This was augmented by a slope and intercept dummy centred at January 1980 to allow for more complicated nonstationary behaviour. Summary statistics from the estimated model are presented in Table 2. The Box-Pierce (1970) tests on the first 13 autocorrelations of the residuals fail to reject the hypotheses of serially uncorrelated errors at the 5% level for any of the equations.

TABLE 2
Summary Statistics

Equation	DW	Q(13)
E	2.02	2.36
P	2.18	2.09
S	1.89	2.59
Π	1.87	1.07
Q	2.12	4.93

The 5% critical value of the Box-Pierce (Q) statistic is 12.59.

Granger-causality tests

Tests for Granger causality are tests for the exclusion of a particular variable at all lags from a given equation, conditional on the presence of the other variables in the system, and provide an initial basis for analysing interactions in the model. These test results are reported in Table 3. Because the second-stage model implies a form of conditional heteroscedasticity in this first-stage model, White's (1980) general heteroscedastic correction was applied to the standard errors of the parameter estimates. However, this correction made little difference and only the uncorrected statistics are reported.

It can be seen from Table 3 that own-lag effects are significant for each variable. In addition, domestic price is causally prior to export price, and stocks are causally prior to the exchange rate, domestic price and export quantity. When the data set is truncated to avoid the extreme variation in stocks noted in the previous section, the null of no causality from stocks to quantity cannot be rejected (the observed F-value falls from 2.3 to 0.7). Furthermore, the truncated data set analysis (October 1974 to December 1987) reveals the emergence of causality from domestic price to the exchange rate which is only

significant at the 10% level for the full sample analysis (the F-statistic rises from 1.8 to 3.0).

TABLE 3
Tests for Granger Causality

Equation	Variable				
	E	P	S	Π	Q
E	27.0	1.8	2.6	1.5	1.7
P	1.8	27.5	2.8	0.9	1.9
S	0.4	1.1	167.6	1.7	1.2
Π	1.1	5.5	1.7	21.7	0.9
Q	0.9	1.5	2.3	2.0	3.3

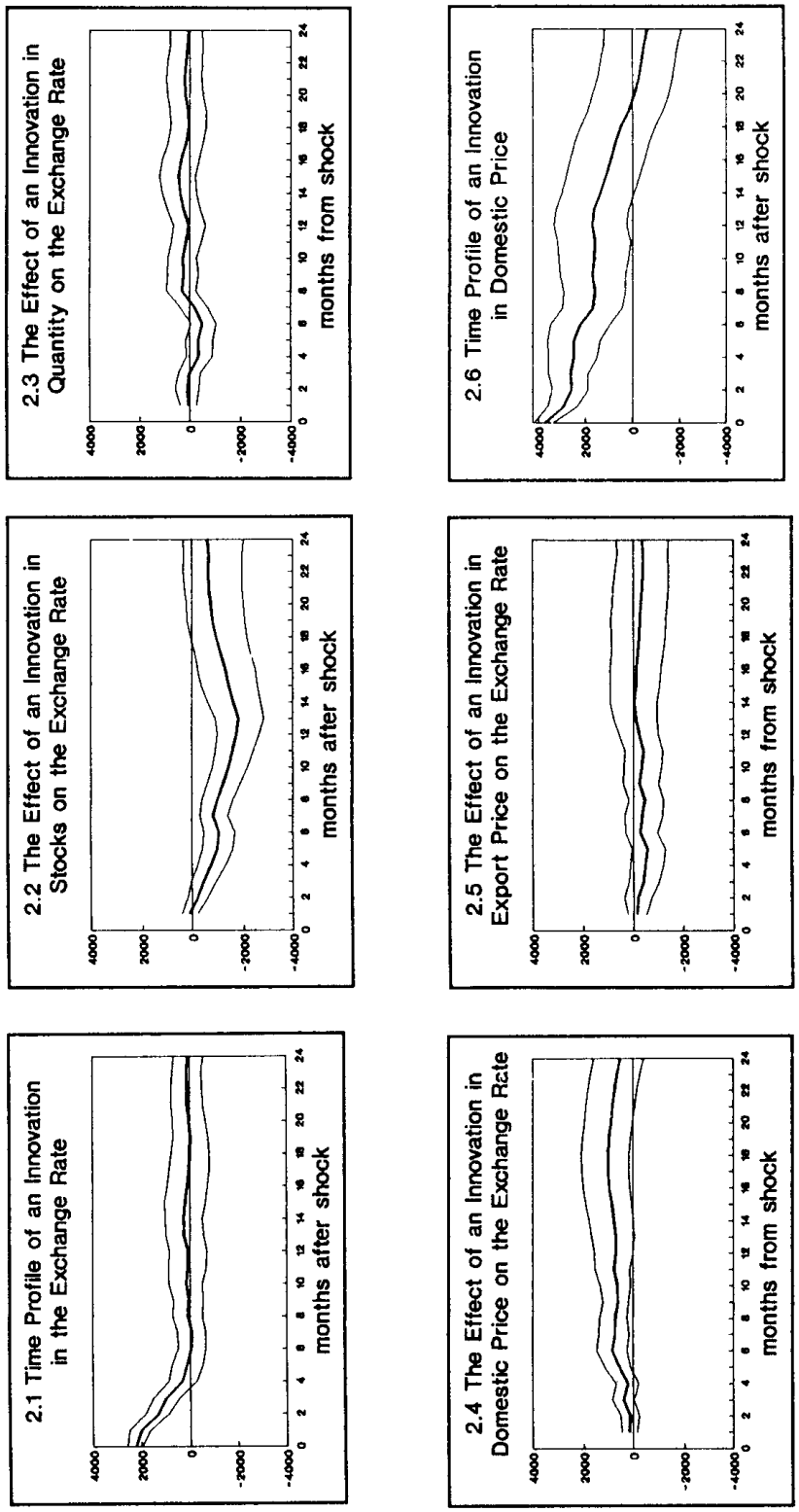
The 5% critical value of F is 2.0 at the 5% level.

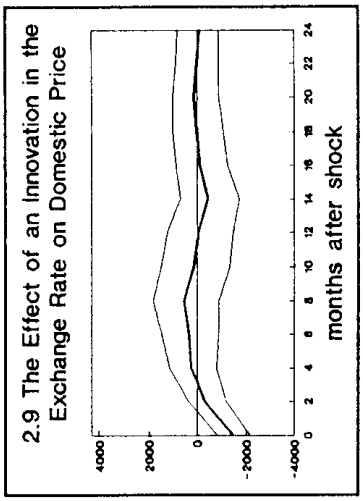
The results in Table 3 indicate that lagged exchange rate shocks have not directly affected auction or export price denominated in $A, conditional on the behaviour of the other variables, implying that the RPS has been successful in smoothing the $A price with respect to such shocks. However, F-tests for causality take no account of contemporaneous interactions. The correlations between the residuals of the exchange rate and the $A-denominated domestic and export price equations are –0.37 and 0.05, respectively. Naturally, these contemporaneous effects are reflected in the impulse response functions through H and are discussed in the following sub-section.

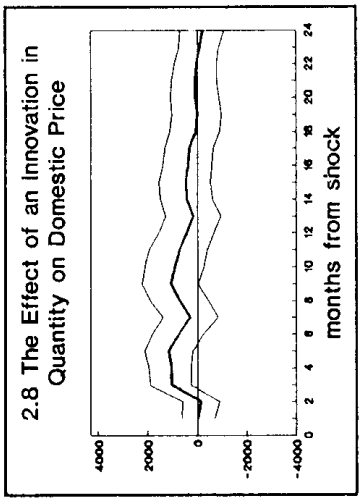
The above results are corroborated by an analysis of the model which replaces $A-denominated by $US-denominated prices. The F-statistic for the exchange rate effect on the export price rises from 1.1 to 3.0. The correlation between the residuals of the exchange rate and the $US-denominated export price equations is 0.63, and the correlation between the exchange rate and $US-denominated domestic price equations is 0.20. Thus, there are significant contemporaneous interactions between the exchange rate and auction price denominated in both currencies but, in a Granger-causal sense, the exchange rate affects $US-denominated and not $A-denominated export prices.

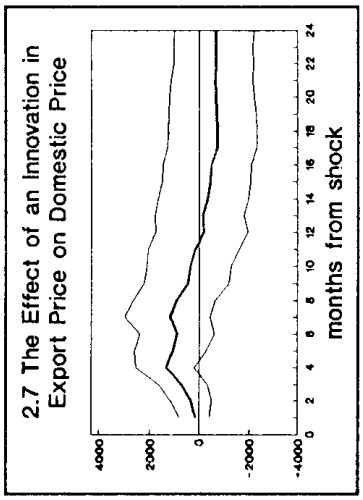
It is possible for two variables to be related in an *indirect* Granger causal sense, even if the direct effects are not significant. This can occur for one of two reasons. Either one variable directly affects another, which in turn affects a third variable or, as is the case with the exchange rate shocks described above, contemporaneous correlations transmit the response. An example of the former arises in Table 1 where S causes P and P causes Π, but S does not cause Π directly. Such an effect can also be accounted for in one of two ways. First, the pair-wise causality tests in Table 1 are partial so that, in the previous

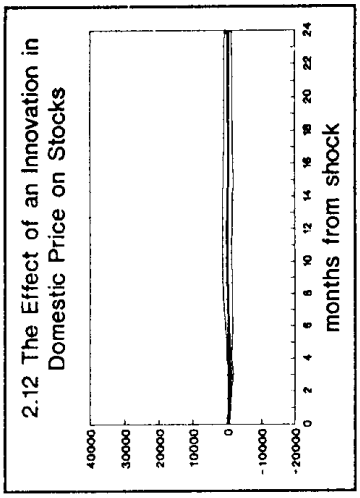
FIGURE 2
Unconditional Impulse Response Functions (x 10^5)

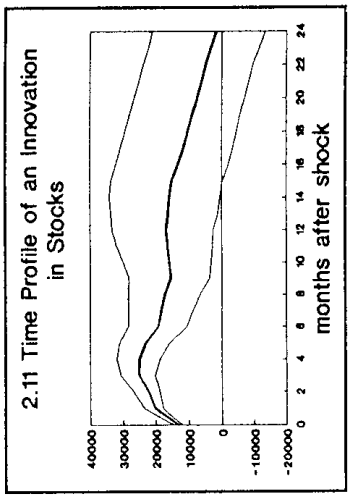


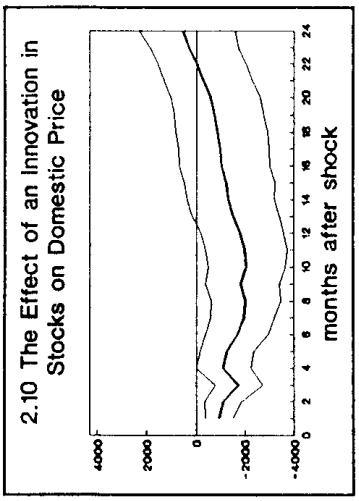

2.9 The Effect of an Innovation in the Exchange Rate on Domestic Price
4000
2000
0
-2000
-4000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock

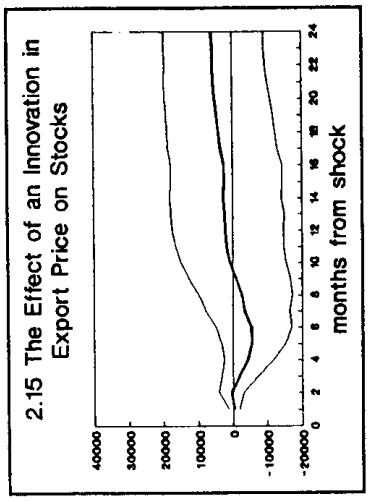

2.8 The Effect of an Innovation in Quantity on Domestic Price
4000
2000
0
-2000
-4000
0 2 4 6 8 10 12 14 16 18 20 22 24
months from shock

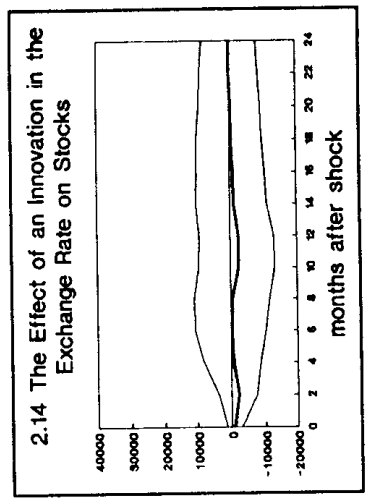

2.7 The Effect of an Innovation in Export Price on Domestic Price
4000
2000
0
-2000
-4000
0 2 4 6 8 10 12 14 16 18 20 22 24
months from shock

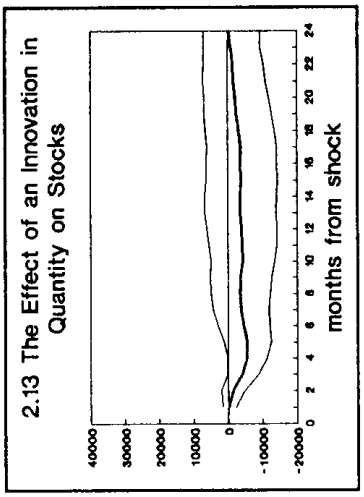

2.12 The Effect of an Innovation in Domestic Price on Stocks
40000
30000
20000
10000
0
-10000
-20000
0 2 4 6 8 10 12 14 16 18 20 22 24
months from shock

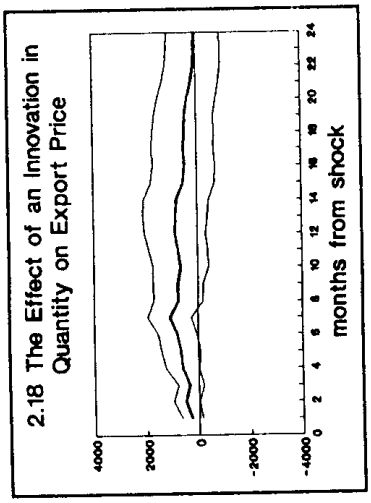

2.11 Time Profile of an Innovation in Stocks
40000
30000
20000
10000
0
-10000
-20000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock

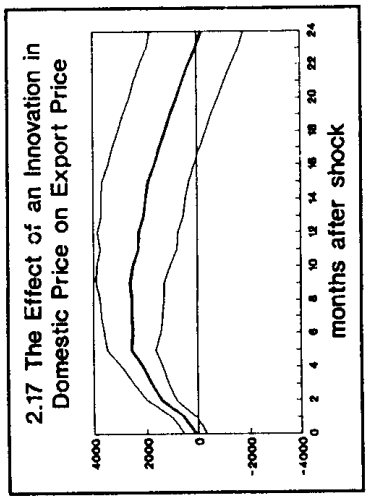

2.10 The Effect of an Innovation in Stocks on Domestic Price
4000
2000
0
-2000
-4000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock

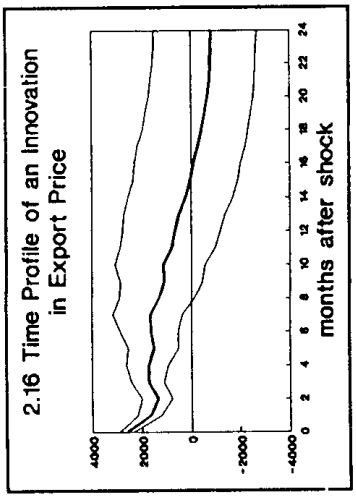

2.15 The Effect of an Innovation in Export Price on Stocks
40000
30000
20000
10000
0
-10000
-20000
0 2 4 6 8 10 12 14 16 18 20 22 24
months from shock

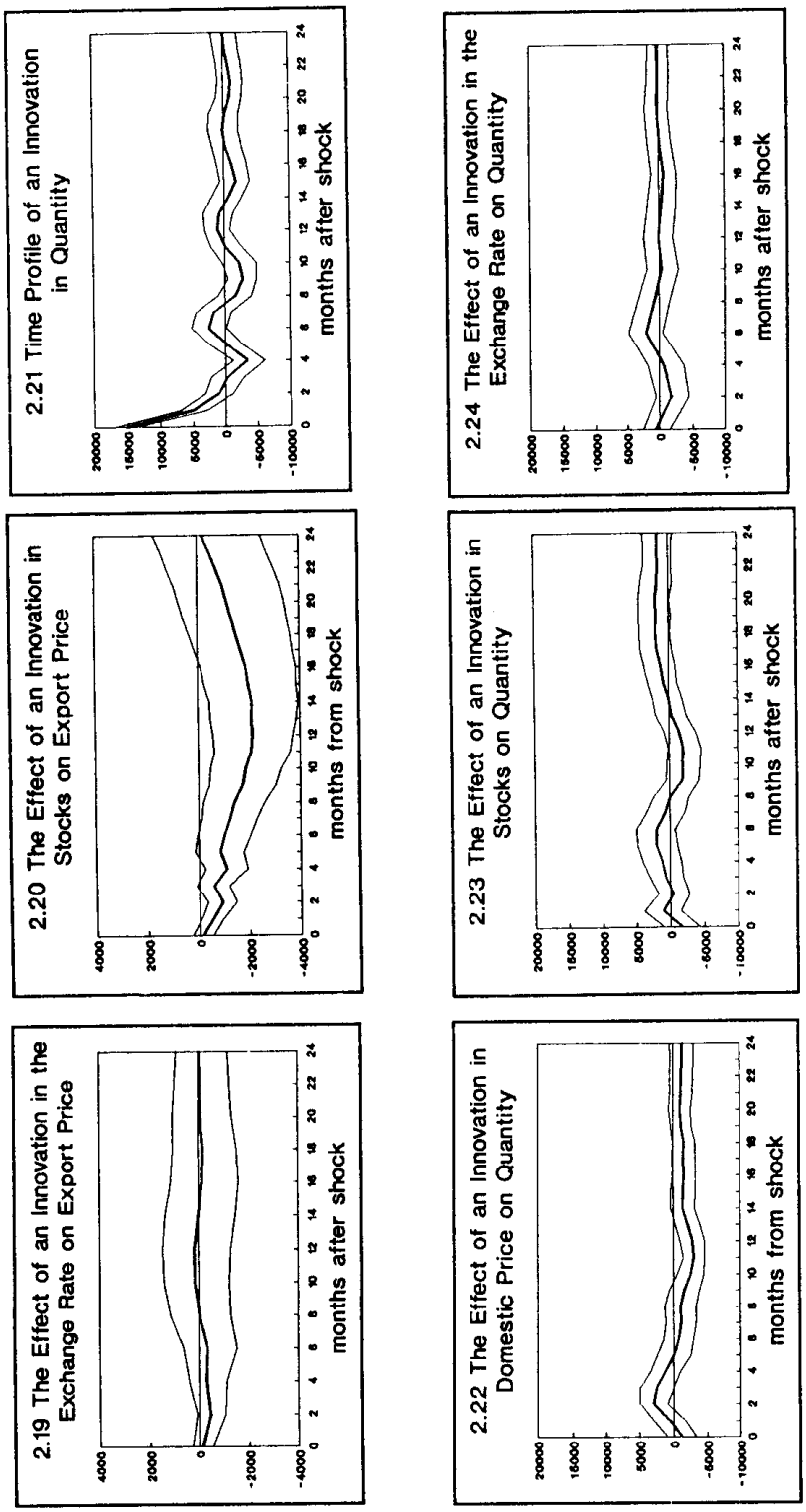

2.14 The Effect of an Innovation in the Exchange Rate on Stocks
40000
30000
20000
10000
0
-10000
-20000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock

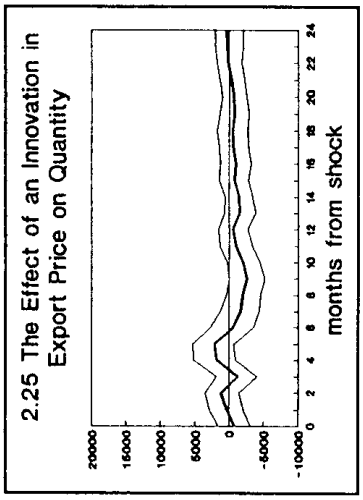

2.13 The Effect of an Innovation in Quantity on Stocks
40000
30000
20000
10000
0
-10000
-20000
0 2 4 6 8 10 12 14 16 18 20 22 24
months from shock

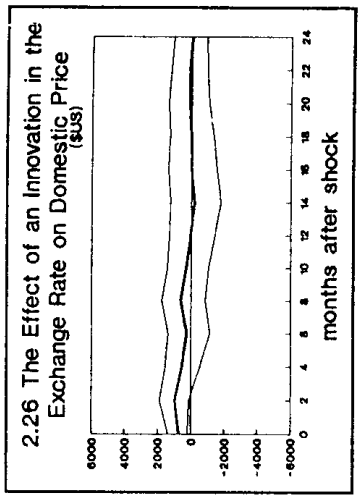

2.18 The Effect of an Innovation in Quantity on Export Price
4000
2000
0
-2000
-4000
0 2 4 6 8 10 12 14 16 18 20 22 24
months from shock

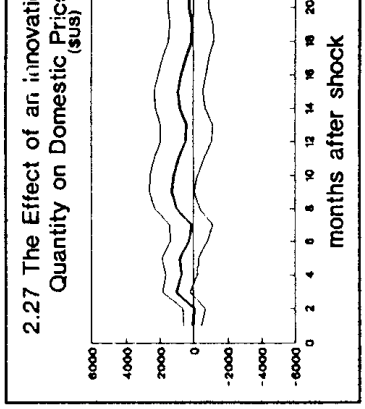

2.17 The Effect of an Innovation in Domestic Price on Export Price
4000
2000
0
-2000
-4000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock

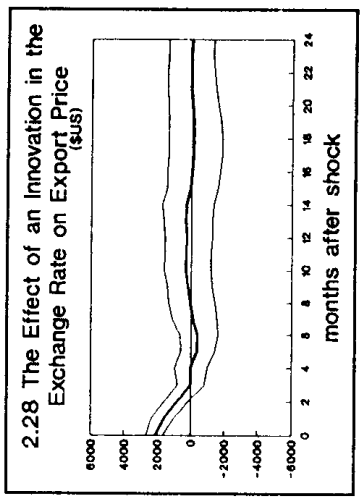

2.16 Time Profile of an Innovation in Export Price
4000
2000
0
-2000
-4000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock

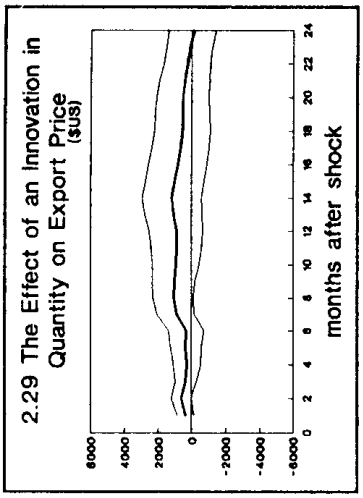

2.19 The Effect of an Innovation in the Exchange Rate on Export Price
months after shock
2.20 The Effect of an Innovation in Stocks on Export Price
months from shock
2.21 Time Profile of an Innovation in Quantity
months after shock
2.22 The Effect of an Innovation in Domestic Price on Quantity
months from shock
2.23 The Effect of an Innovation in Stocks on Quantity
months after shock
2.24 The Effect of an Innovation in the Exchange Rate on Quantity
months after shock


2.25 The Effect of an Innovation in Export Price on Quantity
20000
15000
10000
5000
0
-5000
-10000
0 2 4 6 8 10 12 14 16 18 20 22 24
months from shock


2.26 The Effect of an Innovation in the Exchange Rate on Domestic Price ($US)
6000
4000
2000
0
-2000
-4000
-6000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock


2.27 The Effect of an Innovation in Quantity on Domestic Price ($US)
6000
4000
2000
0
-2000
-4000
-6000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock


2.28 The Effect of an Innovation in the Exchange Rate on Export Price ($US)
6000
4000
2000
0
-2000
-4000
-6000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock


2.29 The Effect of an Innovation in Quantity on Export Price ($US)
6000
4000
2000
0
-2000
-4000
-6000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock

example, all of the effect of S on Π may occur directly through P. Second, the lags involved in the two causations may imply that the composite lag for S on Π is relatively long and that there might be insufficient power in these tests to detect the longer and weaker relationship. Indirect causal relationships through contemporaneous correlations can only be achieved by some identifying restrictions, such as those implied by the recursive nature of H in equation (3).

Unconditional impulse response functions

The orthogonalisation procedure imposes a recursive structure which depends on the ordering of the variables in Y_t. It is assumed that a variable can only be contemporaneously affected by other variables in the VAR if they are placed before that variable in the ordering. The exchange rate has been listed first in Y_t because it is assumed that its movement would be dominated by effects emanating from outside of the wool market. Export price is listed after the domestic price because of its contractual delays, and quantity appears last, being assumed to be the combined result of the interaction of price, the exchange rate and the actions of the AWC. The proper ordering of stocks and domestic price is not clear but experimentation showed that the ensuing results were not sensitive to this ordering.

The 25 impulse response functions of the $A-denominated system, together with Monte Carlo generated 95% confidence intervals, are presented in Figure 2. The same scales have been maintained on the vertical axes for each response variable to facilitate a comparison of relative effects. It was found in this analysis that, in some cases, there was conflict between the confidence interval approach and the Granger causality tests. Since the latter is not dependent on the ordering of the included variables, these differences are influenced by the nature of the imposed contemporaneous structure. Only those impulse responses from the $US-denominated price model that offer additional insight from those denominated in $A are presented.

The exchange rate responds negatively to a shock in stocks (Fig. 2.2) with a peak response at twelve months. The downward pressure of an innovation in stocks on domestic price (Fig. 2.10) also reaches a maximum at this time. The combination of these two effects is evidence of the importance of commodity markets in determining the value of the Australian dollar. This is further illustrated by the positive response of the exchange rate to a domestic price innovation (Fig. 2.4) which showed a significant Granger causality test in the truncated but not the full sample. The impact of both quantity and export price on the exchange rate are insignificant.

Although the exchange rate is not causally prior to domestic price in the Granger sense, the contemporaneous interaction is reflected in the exchange rate impulse response function (Fig. 2.9). It can be noted that an increase in the exchange rate of standard deviation (0.022) implies that domestic price will fall by 0.015 and, from Fig. 2.26, the

domestic price in $US increases by 0.007. That is, the AWC has been successful in insulating domestic prices in $A from about one third of an unexpected exchange rate shock instantaneously and, from the profiles of these two response functions, it can be noted that the operations of the AWC rapidly increases that dampening effect on $A-denominated domestic prices.

Domestic price responds negatively to an increase in stocks (Fig. 2.10). *A priori*, price should not fall in response to an increase in stocks since AWC operations in constricting supply are aimed at preventing such outcomes. However, it is plausible that a shock to stocks should be interpreted as a supply shock. On the other hand, an innovation in quantity has a significant positive influence on domestic price (Fig. 2.8) suggesting a demand response; that is, as more wool is exported, there is pressure on price to rise.

A shock to domestic price has a positive effect on export price (Fig. 2.17) which peaks over the 4 to 9 month period. As firm-offer contracts are dominant and forward sales increasingly frequent, the effect on export price of contracts struck at a time when the domestic price rises will register when the shipment is made several months later. This response function reflects a profile of contractual lags as some contracts are for prompt delivery but most are for between two to nine months delivery. Stocks affect export price (Fig. 2.20) indirectly through domestic price. Export price follows a similar path to domestic price with a slightly longer delay, echoing the lagged response of export to domestic price revealed by the domestic price innovation.

The impulse responses of stocks to export price (Fig. 2.15), quantity (Fig. 2.13) and the exchange rate (Fig. 2.14) are insignificant. The response of stocks to domestic price (Fig. 2.12) is small relative to the own effect, and, as it is negative, it is consistent with the operation of the Reserve Price Scheme.

Causality is established in the $US-denominated model from quantity to domestic price, with the F-statistic rising from 1.9 to 2.9 and the response being positive (Fig. 2.27), so that a shock to the export quantity increases both $A- and $US-denominated auction prices.

Second-Stage Analysis

The disturbances u_t in equation (1) were assumed to have constant unconditional variances so that the analysis outlined in the previous section represents the impact of various shocks on the variables in the model in an unconditional or average sense. However, if it is not taken as given that the shocks are homoscedastic, conditional on recent behaviour, the variances of the residuals from the VAR can themselves be analysed to evaluate volatility interactions within the system.

Rogoff (1985) used a VAR analysis to measure the success of the European Monetary System (EMS) in reducing exchange rate volatility within its member countries. Rogoff split his VAR model into two sub-periods, pre- and post introduction of the EMS, compared the

residual sum of squares for each equation, and found that the EMS had coincided with more predictable exchange rates. Such an analysis was also conducted here around the floating of the dollar and it was found that there was no significant difference between regimes. However, such a test has little power if variance, or volatility, alters in some more systematic fashion.

Engle (1982) suggested a model that has an unconditional constant variance but, at a given point of time, the variance of a disturbance term can be predicted from its recent volatility. This ARCH process for the variance of a single equation might be expressed as

$$\sigma_t^2 = s + \alpha_1 u_{t-1}^2 + \alpha_2 u_{t-2}^2 + \ldots + \alpha_k u_{t-k}^2 \tag{4}$$

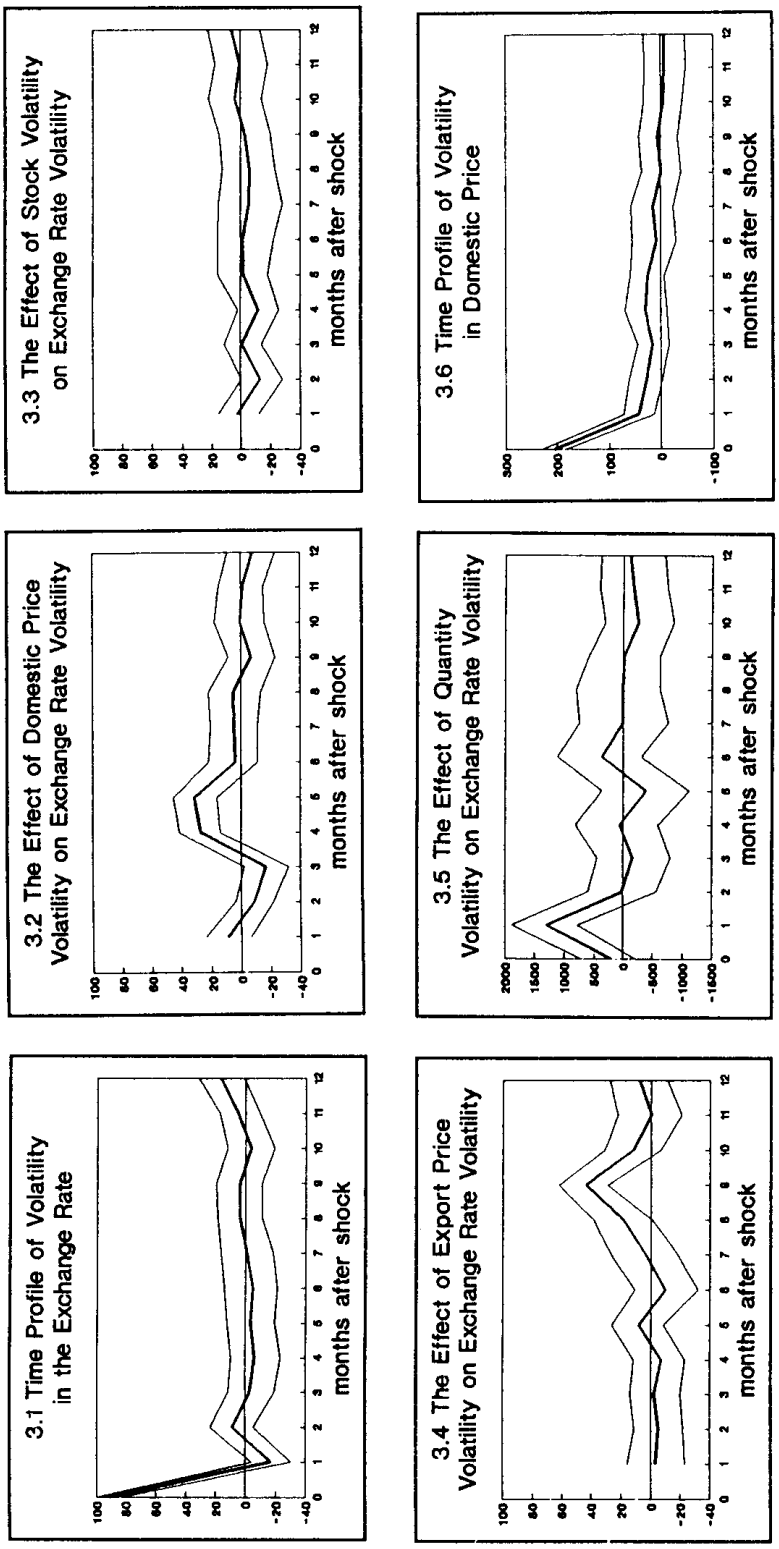
where σ_t^2 is the conditional variance at time t. Under the null of homoscedasticity, $\alpha_1 = \alpha_2 = \ldots = \alpha_k = 0$ but, under the alternative, such a model allows for periods of extreme volatility interspersed by periods with relatively constant variances. Such a model is, therefore, far more flexible than that suggested by a two-regime approach employed by Rogoff.

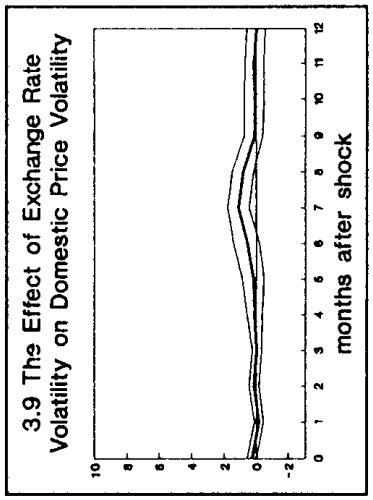
In the single-equation ARCH model, squared residuals are regressed on lagged squared residuals. The implied variances are used to weight the original regression and the process repeated until convergence. Following Bollerslev *et al.* (1988), Engle *et al.* (1984), Granger (1984) and Han *et al.* (1990), the single-equation ARCH process can be generalised for a system. The multivariate ARCH model adopted here allows for unanticipated volatility from one equation to influence the volatility of another. In this sense, the transmission of volatility in this study can be expressed as a vector-autoregression on the squared residuals. The existence of a multivariate-ARCH process implies that the first-stage estimates are inefficient. However, to properly allow for evolving variances and covariances, while maintaining the positive definiteness of Ω_t, requires an excessively complex estimation procedure and has not been attempted here.

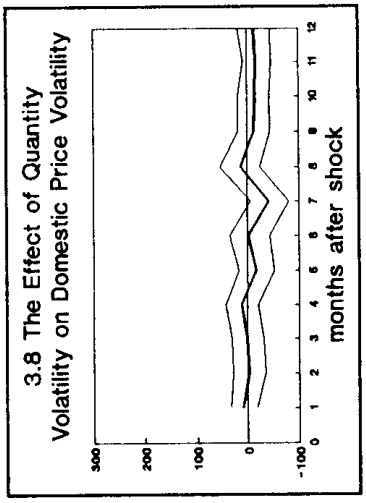
In order to test for the existence of an ARCH process, a Lagrange multiplier test of the type suggested by Breusch and Pagan (1979) can be employed. An asymptotically equivalent version of the Breusch-Pagan test, that is less sensitive to departures from normality, is used here. It is defined by TR^2, where R^2 is the coefficient of determination in the autoregression of squared residuals, and T is the number of observations [Judge *et al.*, 1985].

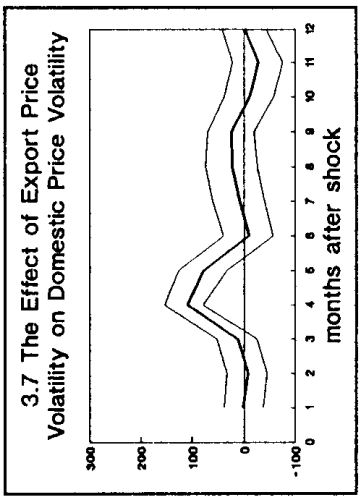
A VAR of the squared residuals from the first-stage analysis was estimated to test for the existence of a multivariate-ARCH process. For consistency with the first-stage analysis, the VAR included eight lags of each variable and a constant term in each equation. Table 4 presents the R^2 statistics for the 5-equation VAR model of the squared residuals with 8 lags. The 5% critical value of R^2 is 0.322 for a test with a null of conditional homoscedasticity in any one equation. Hence the null

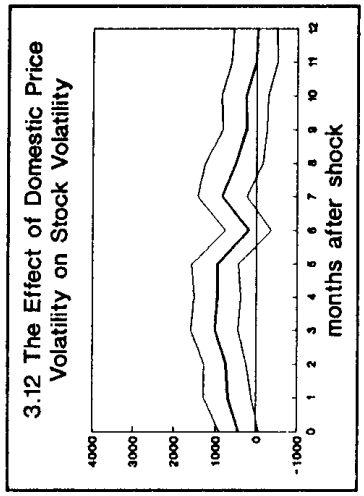
FIGURE 3
Second-stage Impulse Response Functions (x 10^5)
[N.B. Fig. 3.5 and Fig. 3.9 have different scales.]

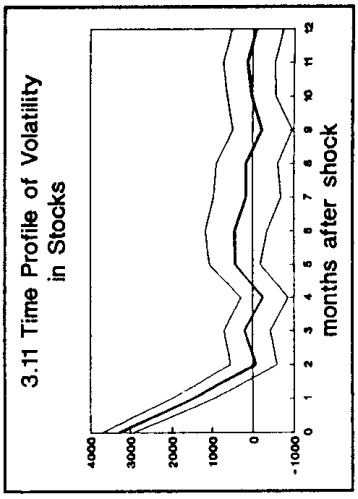


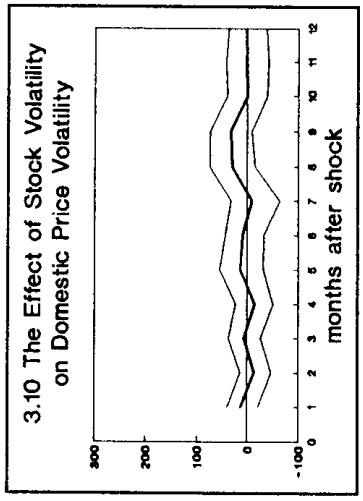

3.9 The Effect of Exchange Rate
Volatility on Domestic Price Volatility
months after shock

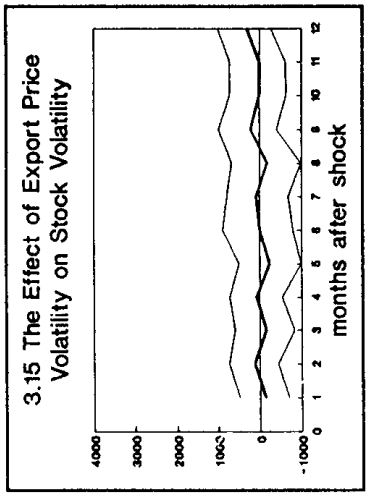

3.8 The Effect of Quantity
Volatility on Domestic Price Volatility
months after shock


3.7 The Effect of Export Price
Volatility on Domestic Price Volatility
months after shock

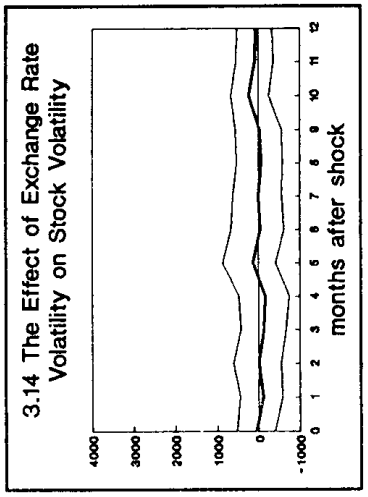

3.12 The Effect of Domestic Price
Volatility on Stock Volatility
months after shock


3.11 Time Profile of Volatility
in Stocks
months after shock

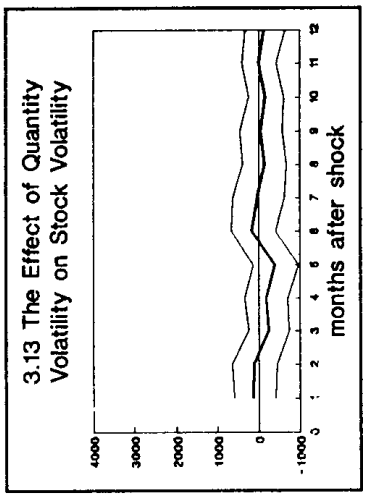

3.10 The Effect of Stock Volatility
on Domestic Price Volatility
months after shock



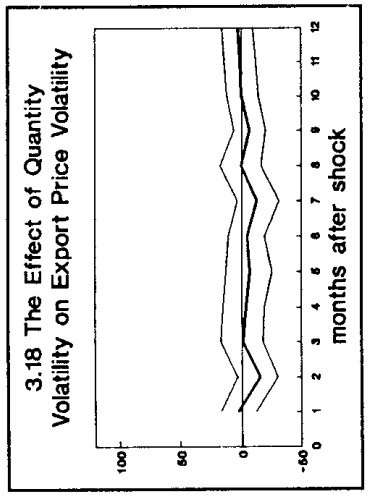
3.15 The Effect of Export Price Volatility on Stock Volatility



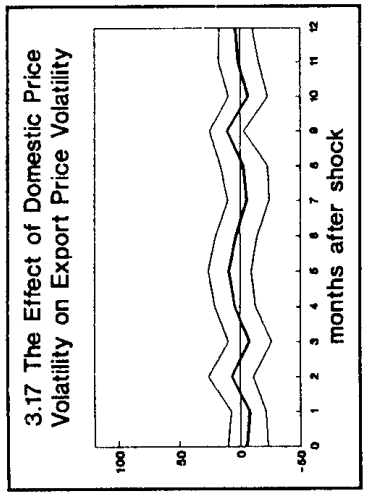
3.14 The Effect of Exchange Rate Volatility on Stock Volatility



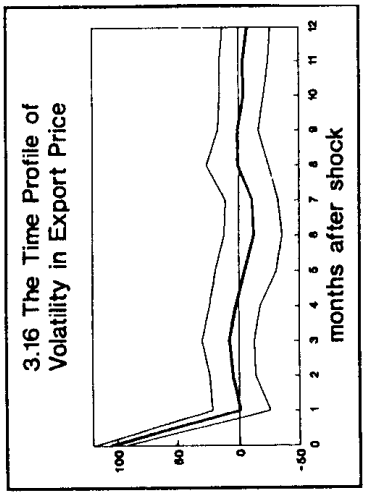
3.13 The Effect of Quantity Volatility on Stock Volatility



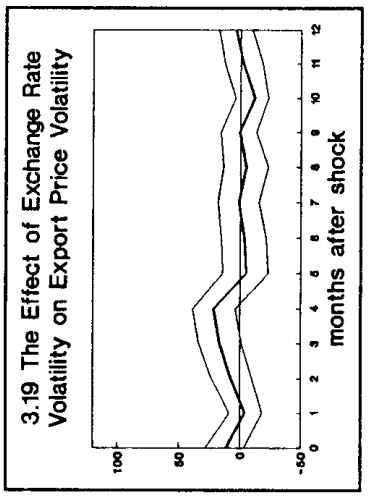
3.18 The Effect of Quantity Volatility on Export Price Volatility

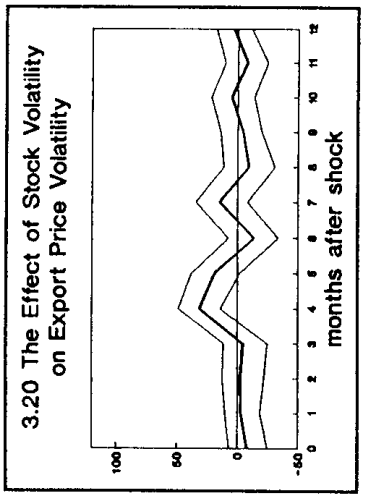


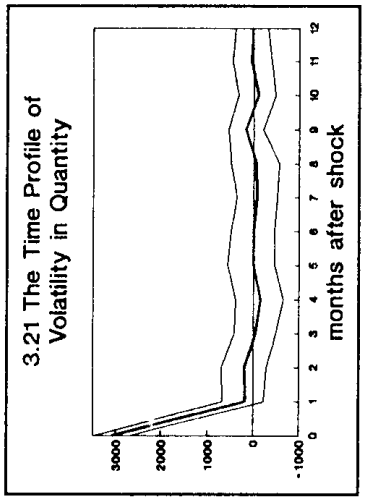
3.17 The Effect of Domestic Price Volatility on Export Price Volatility

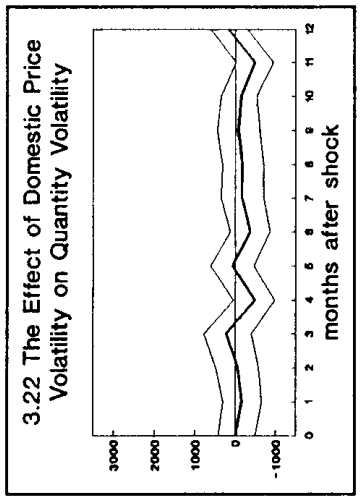


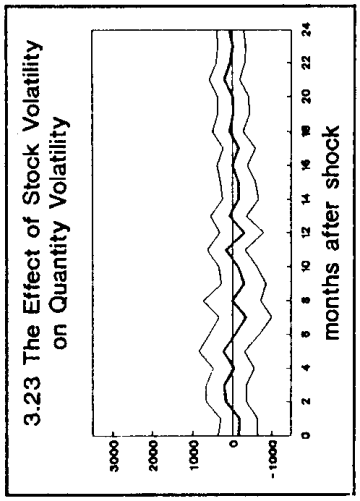
3.16 The Time Profile of Volatility in Export Price

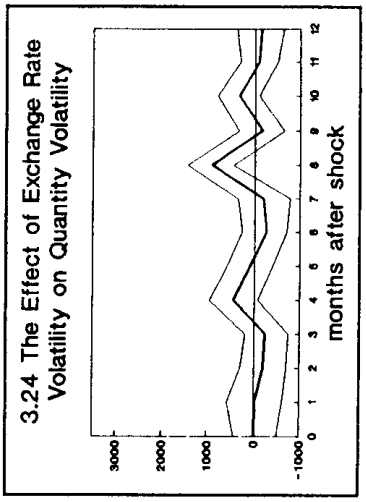

3.19 The Effect of Exchange Rate Volatility on Export Price Volatility
100
50
0
-50
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock

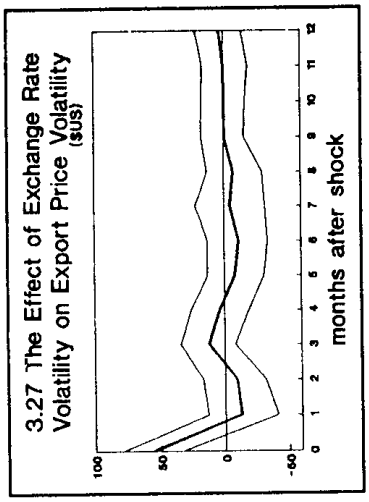

3.20 The Effect of Stock Volatility on Export Price Volatility
100
50
0
-50
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock

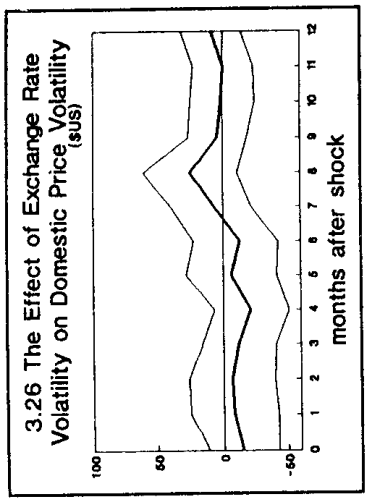

3.21 The Time Profile of Volatility in Quantity
3000
2000
1000
0
-1000
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock

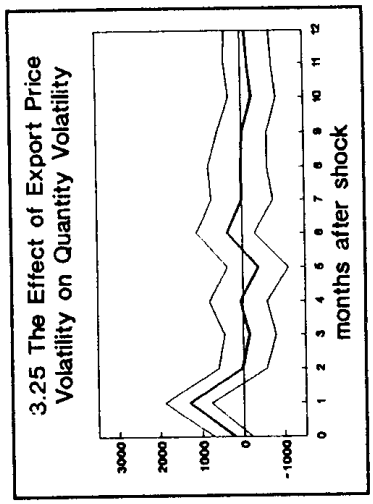

3.22 The Effect of Domestic Price Volatility on Quantity Volatility
3000
2000
1000
0
-1000
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock


3.23 The Effect of Stock Volatility on Quantity Volatility
3000
2000
1000
0
-1000
0 2 4 6 8 10 12 14 16 18 20 22 24
months after shock


3.24 The Effect of Exchange Rate Volatility on Quantity Volatility
3000
2000
1000
0
-1000
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock


3.27 The Effect of Exchange Rate Volatility on Export Price Volatility ($US)
100
50
0
-50
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock


3.26 The Effect of Exchange Rate Volatility on Domestic Price Volatility ($US)
100
50
0
-50
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock


3.25 The Effect of Export Price Volatility on Quantity Volatility
3000
2000
1000
0
-1000
0 1 2 3 4 5 6 7 8 9 10 11 12
months after shock

was rejected in each case at the 5% level and it was concluded that the variance of each equation followed a multivariate ARCH process.

TABLE 4
Testing for ARCH Processes

Base Variable	R^2
E	0.448
P	0.395
S	0.447
Π	0.295
Q	0.331

To analyse second-stage interactions, Granger causality tests are presented in Table 5 for the second-stage estimates denominated in $A. It can be seen from this table that there are significant transmission effects of volatility between the variables. Own lags are significant for the domestic price and stocks, suggesting that volatility will be self-generating for these variables, as in single-equation ARCH processes. When indirect effects are considered, there is substantial bi-directional interaction between the volatility of stocks and both export and domestic price volatility. Causality also runs from domestic price volatility, and indirectly from export price via domestic price volatility, to exchange rate volatility.

TABLE5
Tests for Granger Causality in Volatility

Equation	Variable				
	E	P	S	Π	Q
E	1.93	7.72	1.01	0.41	1.84
P	1.05	2.27	0.40	4.16	1.15
S	0.30	3.83	4.07	1.28	0.93
Π	1.40	1.66	3.35	0.45	0.66
Q	2.98	0.79	0.49	2.60	0.27

The 5% critical value of F is 2.0 at the 5% level..

Exchange rate volatility has no Granger causal effect on the volatility of either price series denominated in $A. Furthermore, causality tests for the same model denominated in foreign currency

indicated that exchange rate volatility is not transmitted to the volatility of prices denominated in $US. However, the correlation between residuals from the exchange rate volatility and the $A-denominated domestic price volatility equations is 0.22, suggesting that volatility is contemporaneously transmitted. A similar result occurs for volatility of the exchange rate and the $US-denominated export price, with a correlation of 0.37.

Second-stage impulse response functions

In the second-stage analysis, if impulse response functions are not strictly positive, there are circumstances under which negative conditional variances could be generated. Although all significant response functions are predominantly positive, some point estimates are negative. These could have been removed by imposing non-negativity constraints on the covariance matrix. However, for the purpose of this study, this approach was not necessary but the resulting estimates are inefficient. The 25 impulse response functions for a twelve-month time period are presented in Figure 3.

For exchange rate volatility, the own effect in the causality test is just below the 5% critical value. This may partly be due to the low power of the test induced by the long lag length of the model. The impulse response function (Fig. 3.1) is almost significant at lag 1 implying that volatility in the exchange rate will, indeed, be self-generating. Both domestic (Fig. 3.2) and export price (Fig. 3.4) volatility cause the exchange rate to be more volatile. This is consistent with the first-stage analysis that found the $A to be a commodity-driven currency. Although the causality test was not significant at the 5% level for the effect of quantity volatility on exchange rate volatility, the impulse response function (Fig. 3.5) is significant and relatively large.

Volatility in the domestic price responds to exchange rate volatility (Fig. 3.9). Both the Granger causality test and the impulse response function are insignificant for a response of $US-denominated domestic price volatility to exchange rate volatility (Fig. 3.26). Therefore, volatility registers in the $A-denominated series alone. The impulse response function of the exchange rate suggests that the transmitted volatility reaches a peak after seven months. A comparison of the response of domestic price to innovations in all of the other variables, indicates that the exchange rate volatility, although significant, has a relatively small effect.

Domestic price volatility is also self-generating (Fig. 3.6) and is directly affected by export price (Fig. 3.7). The own-effect for domestic price volatility is much greater in magnitude than the effect from export price. Although the first period effect is zero by construction, the full effect from export price volatility takes four months to filter through.

For stock volatility, the own-effect (Fig. 3.11) and domestic price volatility (Fig. 3.12) are significant, the latter profile being the best-determined of all of the interaction effects. The transmission to stock volatility from domestic prices builds to a peak after 2-4 months. Exchange rate volatility does not impact on the volatility of stocks (Fig. 3.14). The innovations of both export price volatility (Fig. 3.15) and quantity volatility (Fig. 3.13) are also insignificant.

Export price volatility is not affected by its own past (Fig. 3.16). Stock volatility has a direct effect (Fig. 3.20) causing export price to be most volatile after four months. The effect from domestic price volatility, which is transmitted indirectly through stocks, is relatively small and is insignificant everywhere. Exchange rate volatility (Fig. 3.24), export price volatility (Fig. 3.25) and the own-effect (Fig. 3.21) all increase the volatility of the quantity series.

Conditional impulse response functions

Given that Ω and, hence H, was considered constant in the first-stage analysis, the first-stage innovations amount to describing unconditional, or average, behaviour. The second-stage model attempts to describe how the diagonal elements of the conditional covariance matrix, Ω_t, evolve so that some insight can be gained into how the unconditional impulse response functions might behave. Although these first-stage innovations are uncorrelated, even in the conditional sense, non-zero higher-order moments imply that the innovations are no longer independent.

In principle, the off-diagonal elements of Ω_t could be modelled so that this covariance matrix could be decomposed at each point in time: $\Omega_t = H_t H_t'$. Under such circumstances, conditional impulse response functions could also be generated at each point in time. However, even in this 5-equation model, there are 20 off-diagonal terms in Ω_t which, if a 'complete' second-stage VAR were contemplated, degrees of freedom would be exhausted.

Naturally, restrictions could be placed on Ω_t and its time series properties but this degree of complexity is outside the focus of this paper.

The second-stage results imply that the volatilities of stocks and the exchange rate increase with the volatility in domestic prices. Since the relative sizes of the innovations are given by their standard errors (the square root of the diagonal elements of Ω_t) increased domestic price volatility magnifies the size of subsequent innovations in both stocks and the exchange rate but, importantly, with a multiplier of less than one half in the case of the exchange rate. The exchange rate shock in turn impacts on attempts to stabilise domestic prices. Thus, to focus on the exchange rate-price interaction, the AWC makes significant attempts to dampen exchange rate shocks on domestic prices but volatility that does arise in domestic prices, either through these exchange rate shocks or from other sources, causes a second-round,

dampened increase in the magnitude of subsequent exchange rate shocks.

Conclusions

Time series methods have been employed to analyse the relationships between the exchange rate, the domestic and export prices, quantity and AWC stocks. The principle of the method is that, for example, the currency is more likely to remain volatile if it is currently volatile than if it has recently been relatively stable. This concept is extended to each variable in the model and to allow volatility in one variable to affect volatility in another.

The analysis was conducted in two stages. In the first, unconditional, or average, responses of each variable to a shock in each other are considered. The second stage permits the strength of these shocks to evolve over time and in response to increased volatility in other shocks.

Many significant relationships were established in the first stage. It was found that domestic (auction) prices were found to take about 4-9 months to have full impact on export returns. Evidence of the commodity driven nature of the currency was seen from the impact of shocks, or innovations, to stocks on the exchange rate and prices, and the innovations of prices to the exchange rate. This finding was corroborated by the second-stage analysis with $A-denominated domestic price volatility causing a more volatile period for the exchange rate.

The analysis was conducted in both local and foreign (US) prices to determine the degree of success of the AWC in smoothing producer prices. When the $A-denominated results are compared for prices denominated in $US, it can be seen that an exchange rate shock affects both the domestic price of wool denominated in $A and in $US, with approximately two thirds of an exchange rate shock instantaneously registering in $A prices. After a one month delay, the $A price is completely insulated from such changes. This has implications for the distribution of benefits from the RPS. Risks associated with price variations are important for investment decisions of both wool producers, exporters and importers who process the raw product. From Quiggin (1983), if price stabilisation is complete and supply fluctuations dominate, the associated risk of price fluctuations is borne by producers. If demand or exchange-rate fluctuations dominate, risk will be borne by importers.

For a given currency movement, demand will shift in terms of $A and supply will shift in terms of foreign currency. Hence, if prices moved freely, the risk associated with exchange-rate fluctuations would be distributed between producers and importers dependent on the relative elasticities of supply and demand. However when price is stabilised in $A terms, the risk associated with currency fluctuations is borne by importers. Given that demand and exchange rate fluctua-

tions typically dominate the wool market [Myers *et al.*] and that first-stage exchange rate shocks register mostly in $A domestic prices, the AWC has been only partially successful in stabilising prices in $A from one form of demand shock, changes in the exchange rate. Both wool producers and exporters face most of the risks associated with exchange rate fluctuations that register in $A-denominated auction price.

In the second-stage analysis, significant interactions between prices and stocks were established. The transmission of volatility from the exchange rate to prices was found to occur contemporaneously, with producers and exporters bearing the full risk from domestic price volatility. In conjunction with the first-stage findings, it appears that the AWC has been partially successful in sheltering $A prices from a shock to the level of the exchange rate, but has apparently not used flexible reserves to shelter prices from a shock to the level of volatility in the exchange rate.

References

Adam, C. M., and Bewley, R. A. (1990), 'Positive Evidence for Purchasing Power Parity', BEFG Working Paper 90/1, University of New South Wales.

Bernanke, B. S. (1986), 'Alternative Explanations of the Money-Income Correlation', *Carnegie-Rochester Conference Series on Public Policy* 25, 49-100.

Blanchard, O. J. (1989), 'A Traditional Interpretation of Macroeconomic Fluctuations', *American Economic Review* 79 (5), 1146-1164.

Bollerserv, T., Engle, R. F. and Wooldridge, J. M. (1988), 'A Capital Asset Pricing Model with Time-varying Covariances', *Journal of Political Economy* 96(1), 116-131.

Box, G. E. P. and Pierce, D. A. (1970) 'Distribution of Residual Autocorrelations in Autoregressive-Integrated Moving Average Time Series Models', *Journal of the American Statistical Association* 65, 1509-1526.

Breusch, T. S., and Pagan, A. R. (1979), 'A Simple Test for Heteroscedasticity and Random Coefficient Variation', *Econometrica* 47(5), 1287-1294.

Dornbusch, R. (1986), 'Exchange Rate Economics: 1986', *Economic Journal* 97, 1-18.

Engle, R. F. (1982), 'Autoregressive Conditional Heteroscedasticity With Estimation of the Variance of United Kingdom Inflations', *Econometrica 50(4)*, 987-1007.

Engle, R. F., Granger, C. W. J. and Kraft, D. (1984), 'Combining Competing Forecasts of Inflation Using a Bivariate ARCH Model', *Journal of Dynamics and Control* 8(2), 151-165.

Granger, C. W. J. (1984), 'Wholesale and Retail Prices: Bivariate Time-Series Modelling with Forecastable Error Variances', in Belesley, D. A. and Kuh, E. (eds) *Model Reliability* (MIT Press, Mass.), 1-16.

Han, D. B., Jansen, D. W. and Penson, J. B. (1990), 'Variance of Agricultural Prices, Industrial Prices, and Money', *American Journal of Agricultural Economics* 72, 1066-1072.

Judge, G. C., Griffiths, W. E., Hill, R. C., Lütkepohl, H., and Lee, T.-C. (1985), *The Theory and Practice of Econometrics*, 2nd Edition, Wiley, New York.

Matthews, K., and Valentine, T. (1986), 'The Australian Foreign Exchange Market 1983-86', *Economic Record* (Supplement), 4-11.

Myers, R. J., Piggott, R. R., and Tomek, W. G. (1990), 'Estimating Sources of Fluctuations in the Australian Wool Market: An Application of VAR Methods', *Australian Journal of Agricultural Economics* 34(3), 242-262.

Orden, D. and Fackler, P. L. (1989) 'Identifying Monetary Impacts on Agricultural Prices in VAR Models', *American Journal of Agricultural Economics* 71(2), 495-502.

Quiggin, J. C. (1983), 'Wool Price Stabilisation and Profit Risk for Wool Users', *Australian Journal of Agricultural Economics* 27(1), 31-43.

Riley, D. (1988), AUTOBOX, Hatboro, Penn.: AFS)

Rogoff, K. (1985), 'Can Exchange Rate Predictability be Achieved without Monetary Convergence: Evidence from the EMS', *European Economic Review* 28(2), 93-115.

Sims, C. A. (1980), 'Macroeconomics and Reality', *Econometrica* 48(1), 1-48.

Sims, C. A. (1986), 'Are Forecasting Models Usable for Policy Analysis?' *Federal Reserve Bank of Minneapolis Quarterly Review* Winter, 2-16.

University of New England (1988), 'Exporting Australian Wool – the Changing Role of the Wool Exporter', Rural Development Centre Paper, May.

White, H. (1980), 'A Heteroscedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity' *Econometrica* 48(4), 817-838.