The Effects of Foreign Price Uncertainty on Australian Production and Trade

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Abstract

This paper provides a framework for the empirical analysis of the role of uncertain international prices for the Australian economy's production sector and its international trade. We model the movement of traded goods prices via a bivariate GARCH model and embed this within an expected utility maximizing model of the production sector. We find that the empirical results are consistent with expected utility maximization and that the hypothesis of risk neutrality is soundly rejected. Estimates of the effects of changes in expected prices and volatility of traded goods prices upon production decisions and the return to capital are presented and discussed, as are the impacts of changes in output growth of Australia's major trading partners. The overall conclusion is that price uncertainty matters for the Australian production sector.

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1 Introduction

Conventional wisdom suggests that many small open economies are subject to large and uncertain swings in the prices received for their (often resource- and agricultural-based) export commodities and in the prices paid for their imports, such as manufactures and oil. The volatility of the terms of trade is likely to have significant implications for the domestic economy and its trade with the rest of the world, since many important production decisions need to be made before prices are known. Furthermore, these implications become even more significant when uncertainty is greater. The purpose of this paper is to provide a framework for empirical analysis of the role of such price volatility in the Australian economy's production sector. Since the Australian economy is a resource and agricultural based small open economy, foreign price uncertainty is potentially very important.

The theoretical framework that we use to empirically examine the effects of foreign price uncertainty on a small open economy, such as Australia, is very general and is based firmly on the theory of choice under uncertainty. We assume that the production sector makes production decisions before the prices of imports and exports are known and that it does this by maximizing an expected utility function. We use the resulting indirect utility function to derive the supply functions of export, consumption and investment goods and the demand functions for labour and imports from the indirect utility function in a very simple fashion. We also use it to obtain the return to capital, a stochastic variable in our model. Finally, we use the model to check for consistency of the data with the expected utility maximization hypothesis.[1]

The derived supply and demand functions are expressed in terms of the exogenous variables and the moments of the price distribution, therefore providing a natural and simple framework for empirical analysis. Thus, although producers face uncertain foreign prices, we can still obtain a system of demand and supply equations, using a properly defined indirect utility function. Since this system of demand and supply functions depends on the moments of the underlying price distributions, for empirical applications it is required that we first obtain information on these moments. We propose that this be done by using a multivariate generalized autoregressive conditional heteroskedasticity model of the time series movement of import and export prices. Once estimated, the moments can be used in the theoretical model to study the effects of uncertainty.

Following the early theoretical work by Sandmo (1971), there have been numerous studies on the role of uncertainty in production decisions. Empirical studies of the role of price uncertainty in production decisions include, among others, Appelbaum (1991) on the textile industry in the U.S., Chavas and Holt (1996) on field crops in the U.S., Appelbaum and Ullah (1997) on U.S. printing and publishing and the stone, clay and glass industries, Kumbhakar (2002) on salmon

[1] This framework can also be applied to non-expected utility cases. See Appelbaum (1997) and Appelbaum (2006) for a general discussion.

farms in Norway, Satyanarayan (1999) on British chemical firms and Wolak and Kolstad (1991) on the Japanese steam-coal import market. Overall, the empirical literature is largely focused on studies of the role of price and output uncertainty in agricultural markets and among agricultural firms. This area of research has recently been reviewed by Just and Pope (2003).

There have been few empirical studies that deal explicitly with the roles that uncertainty in import and export prices play in the production sector or, more generally, the domestic economy for small open economies. One such area of application has been the impact that import price uncertainty has on production and income distribution, which has been studied for the U.S. and Switzerland by Appelbaum and Kohli (1997, 1998). The impact of traded goods prices on the New Zealand economy was examined empirically by Wells and Evans (1985), who use a reduced form vector autoregressive model. However, they do not explicitly model the impacts of price uncertainty. In the Australian context, attention has concentrated upon the macro-economic effects of terms of trade and exchange rate uncertainty as in the studies by Pitchford (1993), Gruen and Shuetrim (1994), Gruen and Wilkinson (1994) and McKenzie (1998). To our knowledge, there has been no work done on the impact of world trade prices on the Australian production sector. This paper is intended to rectify this deficiency in the literature.

Our model has three distinctive features. First, unlike Chavas and Holt (1996), for example, we do not specify functional forms for either the utility function or the production technology. Rather, we follow the approach outlined in Appelbaum (1993), Appelbaum and Ullah (1997), Satyanarayan (1999) and Appelbaum (2006)[2] and apply a dual approach to derive supply and demand functions. Specifically, we specify a quadratic approximation to the indirect utility function to obtain a set of empirically estimable supply/demand functions expressed in terms of the first two moments of the price distribution (and other exogenous variables). Second, the model can be used to study the effects of uncertainty in foreign prices on the distribution of the return to capital (which is stochastic in our model). Third, in contrast to most of the literature, the price distribution is modeled as a bivariate generalized conditional heteroskedasticity model that allows for time-varying means, variances and covariances.

The model is estimated by the method of maximum likelihood using aggregate quarterly Australian data on exports, imports and the production sector, drawn primarily from the Australian National Accounts. We find that the empirically estimated model satisfies monotonicity properties (of the indirect utility function) and yields plausible slopes of demand and supply functions. We also find that the data are consistent with the hypothesis of expected utility maximization, but we reject the null hypothesis that Australian producers, in aggregate, are risk neutral.

We illustrate and discuss our empirical model by estimating the effects of changes in the underlying price distribution, foreign aid/transfers, output growth rates of foreign trading partners

[2] Within a nonexpected utility framework.

and several other exogenous variables. We do this by calculating the corresponding elasticities. We also estimate the effects of the changes mentioned above on the distribution of the rate of return on capital. In examining the effects of uncertainty, we consider both marginal and non-marginal ("large") changes in uncertainty. We find that both marginal and non-marginal changes in the variances of import and export prices and their covariance have statistically significant effects upon the outputs chosen by the Australian production sector and upon the expected return to capital and its variance. Finally, we also find that changes in foreign aid and foreign growth rates will have a significant effect on the Australian production sector.

2 Theoretical Framework

Consider an economy in which inputs of capital, labour and imports are used to produce outputs of export, consumption and investment goods. The net output vector is specified as $y = (y_T, y_N)$, where $y_T = (y_c, y_I)$ and $y_N = (y_x, y_m, y_l)$ denote traded goods (exports, x, and imports, m) and non-traded goods (consumption, c, investment, I, and labour, l).[3] The quantity of capital, k, is assumed given. The technology is given by the production possibilities set $\mathcal{T}$, which is assumed to be non-empty, monotonic, convex and closed. The prices of k and y are denoted as r and $p = (p_T, p_N) \equiv [(p_x, p_m), (p_c, p_I, p_l)]$ respectively.

We assume that the prices of the traded goods are unknown when production decisions are made, but domestic prices are known. Let the prices of the traded goods be given by the continuous bounded random variables $p_T \in [0, \widetilde{p}_T]$, whose distribution is given by the distribution function G, with the finite support $\mathcal{A} \equiv (p_T : p_T \in [0, \widetilde{p}_T])$. Since the random variable p_T is concentrated on the compact interval $[0, \widetilde{p}_T]$, the moments exist and uniquely determine the distribution.[4] Let θ denote all of the moments of the distribution. The moment vector θ includes the expectations of p_T,given by $\overline{p}_T$, and the covariance matrix, Σ, and all higher order moments. The distribution whose moments are θ can, therefore, be denoted as G_θ.

We assume that the equilibrium of the production sector of the economy can be obtained from an aggregate choice problem. Specifically, choice under uncertainty can be represented by expected utility maximization.[5] For any given k, the equilibrium of the production sector of the economy is

[3] From the definition of y as a vector of net outputs, it follows that $y_m < 0$ and $y_l < 0$ since imports and labour are inputs to the production sector. Thus, $-y_m > 0$ and $-y_l > 0$ denote the quantities of imports and labour inputs.

[4] Bounded support is a sufficient condition for the distribution function to be uniquely determined by the moments. This is the so-called "moments problem". See, for example, Wilks (1964), Theorem 5.5.1, p.126 or Kendall (1969), Corollary 4.22, p.110.

[5] Assuming that preferences are rational, continuous and satisfy the independence axiom.

obtained by the solution to the problem

$$V(\theta, p_N, w, k, b) \equiv \max_{y_T, y_N, l} \{ \int_{p \in \mathcal{A}} U(p_T\ y_T + p_N\ y_N - b)\ dG_\theta(p_T) : (y, k) \in \mathcal{T} \}, \tag{1}$$

where b is the exogenously given cost/transfer (negative income), U is a continuous von Neumann-Morgenstern utility function.

The indirect expected utility function, V, has several interesting properties that are particularly pertinent to the construction of our econometric model. First, it can be shown[6] that V is convex in θ, satisfies certain monotonicity conditions,[7] but is linear homogeneous if and only if we have risk neutrality.[8] Convexity in moments is, therefore, a necessary condition for the validity of expected utility maximization, hence providing a simple test for this hypothesis, as well as a requirement to be used in specifying a functional form for V. Similarly, the conditions for risk neutrality also provide a simple testable hypothesis, as noted below.

Second, the net supply functions can be derived directly from V using the envelope theorem.[9] Using equation system (**??**), the supply and demand functions (conditional on the capital stock, k) are given by

$$\begin{aligned} y_T &= -\frac{\partial V(\theta, p_N, w, k, b)}{\partial \bar{p}_T} / \frac{\partial V(\theta, p_N, w, k, b)}{\partial b} \equiv y_T(\theta, p_N, w, k, b) \\ y_N &= -\frac{\partial V(\theta, p_N, w, k, b)}{\partial p_N} / \frac{\partial V(\theta, p_N, w, k, b)}{\partial b} \equiv y_N(\theta, p_N, w, k, b). \end{aligned} \tag{2}$$

This provides a very convenient method for the specification of a set of supply and demand functions - specify a suitable functional form for the indirect utility function V and then obtain the supply and demand functions by differentiation.[10]

The supply and demand functions, in turn, have several interesting and useful properties. Some of these are as follows. First, it is well known that with risk neutrality (or without uncertainty), changes in Σ or b will not affect production decisions. Conversely, if such changes do affect deci-

[6] For a general discussion and proof of convexity and other properties, within the context of non-expected utility, see Appelbaum (1997) and Appelbaum (2006).

[7] Specifically, V is increasing with respect to the expected price of exports and the prices of non-traded outputs, but it is decreasing with respect to the price of imports, the wage rate and fixed costs. The effects of changes in the volatility of foreign prices on V are, however, unknown. Thus, theory gives no guidance on the effect of greater price volatility upon expected utility; increased volatility in foreign prices may increase or decrease expected utility.

[8] With risk neutrality, $\overline{p}_T y_T + p_N y_N - wl - b$ is linear in $\overline{p}_T, p_N, w$ and b, thus leading to linear homogeneity of V in $\overline{p}_T, p_N, w$ and b. Conversely, since $U(\lambda py - \lambda wl - \lambda b) \neq \lambda U(py - wl - b)$ unless U is linear, V cannot be homogeneous of degree one in $\overline{p}_T, p_N, w$ and b (or in $\overline{p}_T, p_N, w, b, \sigma_x$ and σ_m).

[9] Note that if the optimal solution is unique (in addition to being upper semi-continuous), the indirect utility function is once differentiable.

[10] Note that when the fixed cost/transfer is zero we simply evaluate the system of demand and supply functions at the point $b = 0$.

sions, we cannot have risk neutrality. These properties provide a simple econometric test for risk neutrality, which may be expressed in terms of the parameters of the system of supply and demand functions. Second, we observe that if V is linearly homogeneous (with risk neutrality) then the supply and demand functions are homogeneous of degree zero in expected prices. On the other hand, when V is not linearly homogeneous (without risk neutrality), input demand functions are not homogeneous of degree zero in expected prices (of all goods and labour) and b.[11] Again, this provides us with a testable hypothesis on the parameters of the supply and demand functions.

In the above model, it is assumed that the producer chooses inputs of labour and imports and outputs of exports, consumption and investment goods to maximize expected utility of net revenue before foreign prices are realized. After this production decision is made, foreign prices are realized and the realized return to capital is determined. Given realized prices, p_T, the realized net revenue earned by capital is

$$F(p_T, p_N, \theta, k, b) \equiv p_T\, y_T(\theta, p_N, k, b) + p_N\, y_N(\theta, p_N, k, b) - wl(\theta, p_N, k, b). \tag{3}$$

Then, the realized rental rate on capital, $r(p_T, p_N, \theta, k, b)$, is defined by[12]

$$r(p_T, p_N, \theta, k, b) \equiv F(p_T, p_N, \theta, k, b)/k. \tag{4}$$

The return to capital is stochastic in our model since it depends upon stochastic prices for traded goods, p_T. Given the production sector's choices of net outputs and labour demand (y_T, y_N and l), the realized return to capital is $R = p_T\, y_T + p_N\, y_N$. Its expectation is $E(R) = \overline{p}_T\, y_T + p_N\, y_N$ and its variance is $V(R) = y_T'\, \Sigma\, y_T$, where Σ is the variance-covariance matrix for p_T. The distribution of the random variable R, being a linear function of jointly distributed log-normal variables, is not log-normally distributed. Its distribution can be determined via simulation, as we will do in the empirical section below.

Cut section 2 much more; list the properties and write an appendix as Martin suggests. Done enough?

[11] To see this, note, for example, that the first order conditions for traded goods yield $\frac{\beta_i + \overline{p}_i}{\beta_j + \overline{p}_j} = \frac{T_i}{T_j}$, where $\beta_h = Cov(U', p_h), h = x, m$ and where the technology is given by the transformation function $T(y, l, k) = 0$. For a general utility function, the output mix will be unaffected by proportionate changes in expected prices if and only if $\beta_i = \beta_j = 0$, for all i, j, which is the case under risk neutrality. Thus, in general, supply functions are not zero-homogeneous in expected prices. Since $V_i/V_j = y_i/y_j$, this means that the slopes of the level surfaces of V along a ray through the origin are not constant; in other words, V cannot be homothetic either.

[12] Note that, at realized prices, p_T, the national income identity holds. That is, $kr(p_T, p_N, \theta, k, b) = p_T\, y_T(\theta, p_N, k, b) + p_N\, y_T(\theta, p_N, k, b) - wl(\theta, p_N, k, b)$.

3 Empirical Application

Having provided the theoretical framework, we now provide an empirical specification of the model. To implement the model empirically, we have to specify a functional form for the indirect utility function $V(\theta, p_N, w, k, b)$, derive the implied demand-supply system for commodities, and embed them in a stochastic framework. Since this system depends on the unknown first two moments of the price distribution, namely $\bar{p}_x, \bar{p}_m, \sigma_x, \sigma_m$ and σ_{xm}, these are estimated in a GARCH model.[13] Given the specified functional form and the moments, the system of equations (2) can be easily estimated.

3.1 Econometric Specification

We assume that the indirect utility function can be approximated by the quadratic function

$$V(\bar{p}_x, \bar{p}_m, \sigma_x, \sigma_m, \sigma_{xm}, p_c, p_I, w, k, b) = a_0 + \sum_i a_i i + \frac{1}{2}\sum_i \sum_j a_{ij} ij,$$

where $i, j = \bar{p}_x, \bar{p}_m, \sigma_x, \sigma_m, \sigma_{xm}, p_c, p_I, p_l, k, b, z$, where z is a time shift variable and where the symmetry restrictions, $a_{ij} = a_{ji}$, hold. The demand and supply functions may be derived using equation (2) and are, therefore, given by

$$\begin{aligned} y_i &= -[a_{\bar{p}_i} + \sum_j a_{\bar{p}_i j} j]/D, \quad i = x, m \\ y_i &= -[a_{p_i} + \sum_j a_{p_i j} j]/D, \quad i = c, I, l \end{aligned} \tag{5}$$

where $D = a_b + \sum_j a_{bj} j$ and the summations are over $j = \bar{p}_x, \bar{p}_m, \sigma_x, \sigma_m, \sigma_{xm}, p_c, p_I, p_l, k, b$ and z. Since the equations in (5) are homogeneous of degree zero in the parameters, we use a normalization for the parameters ($a_b = -1$). Assuming that there are no fixed costs we need to evaluate this system of equations at the point $b = 0$.

To ensure expected utility maximization, we need to impose convexity in all of the moments (a necessary condition for expected utility). Unfortunately, due to the differentiation in obtaining the supply and demand functions, the parameters of the indirect utility function that do not involve $\bar{p}_T, p_N$ and b do not appear in our estimated system. Consequently, we cannot impose convexity in all moments; we can impose convexity only in $\bar{p}_x, \bar{p}_m$. These convexity restrictions are given by the parametric equalities $a_{\bar{p}_x,\bar{p}_x} = c_{xx}^2$, $a_{\bar{p}_m,\bar{p}_x} = a_{\bar{p}_x,\bar{p}_m} = c_{xx}c_{xm}$ and $a_{\bar{p}_m,\bar{p}_m} = c_{mm}^2 + c_{xm}^2$.

[13] For examples of applications where higher moments are used, see Appelbaum and Ullah (1997).

For empirical implementation, the model has to be imbedded within a stochastic framework. To do this, we assume that the supply and demand equations in (5) are stochastic due to "errors in optimization". We define the errors in the i^{th} equation at time t as $v_i(t),\ i = x, m, c, I$ and l. We denote the column vector of disturbances at time t as $v(t)$ and assume that the vectors of disturbances are identically and independently, joint normally distributed with mean zero and non-singular covariance matrix

$$E[v(s)v(t)] = \begin{cases} \Omega & \forall s, t \text{ if } t = s \\ 0 & \text{if } t \neq s, \end{cases} \tag{6}$$

where Ω is a 5×5 positive definite matrix of parameters.

3.2 Stochastic Process for Prices

Implementation of the econometric model of production choice under foreign price uncertainty described above requires knowledge of the moments of the foreign price distribution for each time period t. To this end, a stochastic model of the distribution of the prices of imports and exports was specified and estimated to provide time-varying estimates of the means, variances and covariances of these price variables.

Specifically, the log changes in traded goods prices, $P_{m,t} = 100 * \ln(p_{m,t}/p_{m,t-1})$ and $P_{x,t} = 100 * \ln(p_{x,t}/p_{x,t-1})$, are assumed to follow a bivariate GARCH process. The model for the resulting traded goods price vector P_{Tt} is expressed as $P_{Tt}|I_{t-1} \backsim NI(\mu_t, H_t)$, where I_t is the information set, μ_t is the vector of means and H_t is the variance-covariance matrix at time t. In our empirical model, the means for the growth rates of traded goods prices are assumed to depend linearly upon the lagged values of these variables to allow for time dependence. Moreover, real GDP of the U.S.A. and Japan (in time difference in natural logs or approximate percent changes) are included as explanatory variables that represent a measure of economic activity of Australia's major trading partners. Accordingly, the price growth model may be expressed as

$$\begin{aligned} P_{m,t} &= \beta_{m0} + \beta_{mm} P_{m,t-1} + \beta_{mx} P_{x,t-1} + \beta_{mJP} JPRGDP_t + \beta_{mUS} USRGDP_t + \epsilon_{mt} \\ P_{x,t} &= \beta_{x0} + \beta_{xm} P_{m,t-1} + \beta_{xx} P_{x,t-1} + \beta_{xJP} JPRGDP_t + \beta_{xUS} USRGDP_t + \epsilon_{xt} \end{aligned}$$

where ϵ_{mt} and ϵ_{xt} are random disturbances.

The bivariate GARCH specification for the time-varying variance-covariance matrix is given by

$$H_t \equiv V(\epsilon_t \mid I_{t-1}) = \Theta + A\epsilon'_{t-1}\epsilon_{t-1}A' + BH_{t-1}B', \tag{7}$$

where Θ is a symmetric, positive definite matrix of parameters and A and B are square matrices of parameters, and where $\epsilon_t \equiv P_{Tt} - \mu_t$ is a row vector of disturbances. This model, due to Engle and Kroner (1995), is sometimes referred to as the BEKK GARCH model with single lags in the ARCH (A) and GARCH (B) components. The conditional variances and covariances depend upon past disturbances in every equation and upon past values of the conditional variances and covariances. Specifically, the two variances and the covariance in period t are linear functions of the cross-products $\epsilon^2_{m,t-1}$, $\epsilon_{m,t-1}\epsilon_{x,t-1}$ and $\epsilon^2_{x,t-1}$ of the disturbances in period $t-1$ and of the variances and covariances $H_{m,t-1}$, $H_{mx,t-1}$ and $H_{x,t-1}$ in period $t-1$, as follows:

$$\begin{aligned} H_{m,t} &= \Theta_{mm} + a^2_{mm}\epsilon^2_{m,t-1} + 2a_{mm}a_{mx}\epsilon_{m,t-1}\epsilon_{x,t-1} + a^2_{mx}\epsilon^2_{x,t-1} \\ &\quad + b^2_{mm}H^2_{m,t-1} + 2b_{mm}b_{mx}H_{mx,t-1} + b^2_{mx}H^2_{x,t-1} \\ H_{mx,t} &= \Theta_{mx} + a^2_{mm}\epsilon^2_{m,t-1} + 2a_{mm}a_{mx}\epsilon_{m,t-1}\epsilon_{x,t-1} + a^2_{xx}\epsilon^2_{x,t-1} \\ &\quad + b^2_{mm}H^2_{m,t-1} + 2b_{mm}b_{mx}H_{mx,t-1} + b^2_{xx}H^2_{x,t-1} \\ H_{x,t} &= \Theta_{xx} + a^2_{xm}\epsilon^2_{m,t-1} + 2a_{xm}a_{xx}\epsilon_{m,t-1}\epsilon_{x,t-1} + a^2_{xx}\epsilon^2_{x,t-1} \\ &\quad + b^2_{xm}H^2_{m,t-1} + 2b_{xm}b_{xx}H_{mx,t-1} + b^2_{xx}H^2_{x,t-1}. \end{aligned} \tag{8}$$

While the parameters in A and B are difficult to interpret, this formulation ensures the positive definiteness of the covariance matrices H_t provided Θ is positive semi-definite.

The parameter matrices β, Θ, A and B were estimated by the method of maximum likelihood.[14] The GARCH model maximum likelihood estimates were then used to compute the estimates of the means, conditional variances and conditional covariances for the growth rates in traded goods prices for every observation. These were then used to compute the time-varying means, conditional variances and conditional covariances for the traded goods prices themselves. Specifically, the distribution of the log price vector, $\ln p_{Tt}$, conditional upon the information set, may be expressed as

$$\ln p_{Tt}|I_{t-1} \backsim N(\mu_t/100 + \ln p_{Tt-1}, H_t/100^2), \tag{9}$$

which means that $p_{Tt}|I_{t-1}$ has a (joint) lognormal distribution. Given μ_t and H_t, it is then straightforward, using the result that the moments of a log-normally distributed vector may be obtained by evaluations of the moment generating function for a normally distributed vector, to compute

[14] The likelihood function is ....

the means, conditional variances of the import and export prices and their conditional covariance at time t as $\bar{p}_{x,t}, \bar{p}_{m,t}, \sigma_{x,t}, \sigma_{m,t}$ and $\sigma_{xm,t}$.

3.3 Data

For empirical implementation to the Australian production sector, GNP data measured from producers' perspective are required. The nation's total output (GNP) is disaggregated into three goods - consumption goods, investment goods and export goods. To produce these goods, the production sector uses domestic primary factors in the form of capital, labour and imports. Thus, the required data comprise times series for the prices and quantities of imports, exports, consumption, investment, labour and capital.

The core data used in the paper are drawn from Australian National Accounts (ANA) published by the Australian Bureau of Statistics (ABS). The principal source is the National Income, Expenditure and Product Catalogue (No. 5206.0), but the data series are downloaded from the AusStats website at www.abs.gov.au. Some unpublished data are sourced directly from the ABS. The data series are all original[15] quarterly observations and cover the period 1966:3-2000:2. The start date is chosen as the third quarter of 1966 because from this date all variables of interest are readily available. The cut off date is intentionally chosen to be June 2000 to exclude the effects of goods and services taxes introduced in July of 2000. Summary statistics for the price and quantity data series are provided in Table 1.

Because we are modeling the production sector, all values and prices are required to be those facing the producers. Accordingly, all prices of outputs and inputs (drawn mainly from the ANA expenditure method and the income method of computing GNP) are corrected for taxes and government subsidies. As an example, the current dollar value of imports is inclusive of taxes or customs duties paid on imports. On the other hand, the current dollar value of exported goods is exclusive of any taxes on exports but inclusive of production subsidies provided by the government. Thus, GNP is measured at producer prices and according to the identity $GNP = consumption + investment + exports - imports \equiv wages + rentals\ of\ capital\ stock$. Further details on the sources of the data series and on the adjustments made to them are available in Sen (2004), from which the data are drawn.

Real GDP data for U.S.A. and Japan are sourced from the OECD statistical database at www.oecd.org. The figures are seasonally adjusted.

[15] That is, the data are not adjusted for seasonal or trend effects.

4 Empirical Results

4.1 Distribution of Foreign Prices

The Maximum Likelihood Estimates (MLEs) of the BEKK GARCH model for the growth rates in foreign prices are reported in Table 2. The block on the left hand side provides estimates of the parameters of the mean equations along with estimates of their asymptotic standard errors and indicators of the significance of the estimates. The right hand side block provides the same information for the estimates of the variance and covariance equations.[16]

The results show that the mean growth rate for import prices depends positively and significantly upon the lagged growth rates for both import and export prices, indicating a positive time persistence. The mean growth rate in import prices is higher the higher was the lagged growth rate in import prices and, also, in export prices. On the other hand, while the mean growth rate in export prices depends positively and significantly upon the lagged growth rate for export prices, it depends negatively, but insignificantly, upon the lagged growth rate for import prices. Overall, the lagged growth rate effects upon the means are statistically significant, the p-value for the likelihood ratio test being 0.0000.

By contrast, the growth rates in the real GDPs of Japan and the U.S., introduced to measure the role of economic activity amongst Australia's most important trading partners, are individually statistically insignificant in their effects on mean growth rates for import and export prices. Their signs are, however, consistent with one interpretation of the roles of the GDP variables. The coefficients of the GDP growth rates in the import price equation are both negative, suggesting that higher growth rates of real GDP in Japan and the U.S. indicate greater productive capacity in those economies, thus generating supplies and lower growth rates in the prices of Australia's imports. By contrast, the positive coefficients in the export price equation suggest that greater production capacity in Japan and the U.S. increases the demand for inputs to their production sectors and thereby raises the growth rates in the prices of Australia's exports. The p-value for the likelihood ratio test of their joint significance is 0.017, indicating that the joint role of the real GDP variables is evident in the data.

The growth rates in both import and export prices have variances exhibiting time-variability. This is clearly demonstrated by the observation that all except two of the ARCH and GARCH coefficient estimates are significantly different from zero. Given the complex nature of the way that the parameter matrices A and B enter the variance/covariance formula in equation (7), it is generally not possible to associate a particular parameter uniquely with the effect of a lagged disturbance or variance/covariance upon the current variances and covariance. It is more informative to examine

[16] Estimates of standard errors for the constant parameters, Θ, in the variance/covariance equations are not provided in Table 2. In the estimation, positive seimdefiniteness of Θ was ensured by writing it as $\Theta = UU'$, where U is an upper triangular matrix. Estimates of standard errors for the elements of U are available.

joint effects. The statistical significance of the GARCH effects (lagged disturbance effects) may be jointly tested by testing the null hypothesis that $B = 0$, while the ARCH effects (lagged variance and covariance effects) may be jointly tested by testing the null hypothesis that $A = 0$. Likelihood ratio tests of these hypotheses yield p-values that are both effectively zero. Thus, we can conclude that the GARCH parameters are significantly different from zero, as are the ARCH parameters. The joint hypothesis that $A = 0$ and $B = 0$ is also soundly rejected (again the p-value is effectively zero). Thus, we conclude that the growth rates in Australia's foreign trade prices have statistically significant time-varying volatility.

To describe the conditional volatility of foreign prices visually, Figures 1-3 plot the estimates of the conditional variances of the growth rates in import prices and export prices and their conditional correlation coefficients, respectively. Overall, the variance plots in Figures 1 and 2 show that the conditional variances vary substantially over time and that there is significant volatility during the mid 1970s and in the period 1985-87, with intermittent periods of high volatility from the mid 1980s. They also show that the growth rates for import prices exhibit significantly higher volatility than the growth rates for export prices, except during the 1960s and early 1970s. Figure 3 plots the conditional correlation coefficients between the growth rates for import and export prices and shows that there exists a strong correlation in the two price series and that the conditional covariance is time-varying, increasing over time on the whole. In other words, import price growth and export price growth are strongly positively correlated in that they tend to rise and fall together.

The relative stability in the growth rates for Australia's export and import prices in the last decade can be attributed to greater diversification of Australia's trade in both the goods traded and its range of trading partners.

Overall, our results show that the means and variances for the prices of Australia's exports and imports are significantly time-varying and that the prices exhibit significant volatility. We now investigate how, and to what extent, the moments of the price distribution influence production decisions by Australian producers.

4.2 Production Sector

We estimate the system of equations using the maximum likelihood technique, with the symmetry, normalization and convexity (in $\bar{p}_x, \bar{p}_m$) restrictions imposed.[17] The parameter estimates, together with their asymptotic standard error estimates, are given in Table 3. We note that many of the parameter estimates are significantly different from zero. Moreover, the R^2 values for the individual equations are quite high (.909, .965, .976, .726 and .921, for the export, import consumption,

[17] The convexity restrictions are given by the parametric equations $a_{\bar{p}_x,\bar{p}_x} = t_{xx}^2$, $a_{\bar{p}_m,\bar{p}_x} = a_{\bar{p}_x,\bar{p}_m} = t_{xx}t_{xm}$, $a_{\bar{p}_m,\bar{p}_m} = t_{mm}^2 + t_{xm}^2$. These restrictions are evaluated at the point $b = 0$.

investment and labour equations respectively).[18] However, rather than focusing on the parameter estimates themselves, it is more informative to use these estimates to check the properties of the model as set out in the theory section above.

First, we test for the convexity restrictions in $\bar{p}_x, \bar{p}_m$ and find that the null hypothesis of convexity in these moments cannot be rejected.[19] Convexity is a necessary condition for expected utility maximization. In this sense, the model estimate is, indeed, consistent with expected utility theory.

Next we check for monotonicity conditions in $\bar{p}_x, \bar{p}_m, p_c, p_I, w$ and b. We find that the estimate of V is non-decreasing in $\bar{p}_x, p_c, p_I$ and non-increasing in $\bar{p}_m, w, b$ at every sample point, as required by economic theory (we also test and find that the slopes of the indirect utility function at the point of normalization are all significantly different from zero).

As discussed above, under risk neutrality changes in $\sigma_x, \sigma_m, \sigma_{xm}$ and b will not affect production decisions. Supplies and demands are locally unaffected by $\sigma_x, \sigma_m, \sigma_{xm}$ and b if and only if, at a given data point, the corresponding derivatives, $\frac{\partial y_i}{\partial j}$, satisfy the condition that $\frac{\partial y_i}{\partial j} = 0$ for all $i = x, m, c, I, l$ and $j = \sigma_x, \sigma_m, \sigma_{xm}, b$. We test for this joint hypothesis at the point of normalization and obtain a p-value of 0.0045 ($\chi^2 = 40.380$, $\chi^2_{(20,.01)} = 37.566$), thus rejecting the null hypothesis of local risk neutrality. Given that the local restrictions are rejected, it is clear that global risk neutrality will be rejected as well. We therefore reject the hypothesis of risk neutrality.

4.3 Elasticities

To examine the effects of the exogenous variables on exports, imports, consumption, investment and labour, we calculate the corresponding elasticities (given in the equations in (**??**)). The calculated elasticities, evaluated at the point of normalization (the last sample point), are given in Table 4.[20]

As Table 4 shows, all the own-price elasticities have the normally expected sign at the point of normalization.[21] The elasticity estimates show that the exports, consumption and investment supply functions are positively sloped functions of own price, whereas the labour and imports demand functions are negatively sloped. In the case of exports and imports, these elasticities indicate the responses to changes in the expected prices of imports and exports.

The effects of uncertainty are, partially, captured in Table 4 by the elasticities with respect to the second moments of the price distributions. We find that an increase in the variance of export prices will increase all supplies and demands except for investment, but the individual effects are insignificant. Similarly, an increase in the variance of import prices will also increase all supplies and

[18] The Durbin-Watson statistics, however, are rather low, suggesting the possible presence of serial correlation in the distrubances.

[19] We obtain $\chi^2 = 2.311$, while $\chi^2_{(3,.01)} = 11.345$.

[20] Note that cross-price elasticities of demand are usually not symmetric, even under complete price certainty. Under price uncertainty, however, the cross-price elasticities do not even have to be of the same sign.

[21] Note that with uncertainty (and assuming expected utility maximization) demand/supply functions do not necessarily have to be downward/upward sloping.

demands except for investment, with insignificant individual effects. We also find that an increase in the covariance between export and import prices will decrease all supplies and demands. It is useful to note that, in general, it is impossible to determine the effects of an increase in a variance even in a one-output, one-random-variable model. For example, in the standard firm's expected utility maximization problem, for an increase in variance to have a negative effect on output (in a one-output, one-random-variable model) it is necessary to assume that, in addition to risk aversion, the utility function exhibits decreasing absolute risk aversion. In our model we do not make such an assumption and, furthermore, we have more that one random variable and we also have several outputs. Consequently, it is not clear, a priori, what the effect of higher variances should be.

While the individual effects of the second moments are insignificant, the overall effects of uncertainty (the effects of *all* second moments) are significant: the p-value for the joint hypothesis that $\varphi_{z,q} = 0$ for all $z = x, m, c, i, l$ and $q = \sigma_x, \sigma_m, \sigma_{xm}$ is 0.0030. Overall, therefore, uncertainty does affect the production sector.

As one illustrative example of the implications of our elasticity results, consider the effects of a change in the distribution of exports prices (keeping in mind the qualification that the individual effects are not precisely estimated). We obtain that an increase in the expected price of exports leads to an increase in exports and also an increase in imports - they are complementary. It also yields lower outputs of consumption and investment and a lower demand for labour - there is a move away from the non-traded goods sector. On the other hand, an increase in the variance of the price of exports also raises exports but reduces imports and investment. This result is in contrast with that of Pozo (1992), who finds in a quite different model that increased exchange rate risk causes a reduction in British exports.

Finally, it is interesting to look at the implications of our model estimates for the demand for labour by the production sector. We observe from Table 4 that an increase in the expected prices of traded goods will have an adverse effect on the demand for labour. Similarly, an increase in the covariance between the prices of traded goods will have a negative effect on labour demand. On the other hand, an increase in all other prices, or in the variances, will have a positive effect. Overall, changes in "other prices" $(\bar{p}_x, \bar{p}_m, p_c, p_I)$ and second moments $(\sigma_x, \sigma_m, \sigma_{xm})$ have a significant effect on the demand for labour with a p-value of 0.00001 ($\chi^2 = 35.797$, $\chi^2_{(7,.01)} = 18.475$) for the joint hypothesis that there is no effect.

4.4 Traded Good Prices and the Return to Capital

As indicated in the theory section, the realized return to capital is a random variable since it depends upon the realized outcomes for the prices of traded goods. The estimates of the mean and variance for the return to capital may be calculated from the model estimates for each observation in the sample. As an illustration, the mean and standard deviation for R are calculated to be

41.933 and 0.574 for the last sample observation, leading to a coefficient of variation of 0.014.[22] These compare with values of 4.787, 0.032 and 0.007 at the beginning of the sample.

The distribution for R was empirically estimated via simulation for the last observation and is illustrated in Figure 4. Although R is a linear function of jointly distributed log-normal variables, the empirical distribution depicted in the figure looks approximately normal. This figure illustrates the role that the volatility of traded goods prices plays in the determination of the distribution of the return to capital; volatility of the former affects the expected return to capital and also the volatility of the return to capital.

To capture these individual effects we use the parameter estimates to calculate the effects of changes in the expectations, variances and covariances of traded goods prices, as well as all the other exogenous variables, on the expected value and variance of the return to capital ($r = R/k$). These effects, (evaluated at the point of normalization) are reported in Table 5. As Table 5 shows, an increase in the expected price of exports will have a statistically significant positive effect on the expected return on capital, whereas a higher expected price of imports will have the opposite effect. Higher variances of either export or import prices, on the other hand, have the same effect: each change leads to a higher expected rate of return. Finally, while higher prices of consumption goods or of labour increase the expected return on capital, a higher price of investment or a higher covariance between export and import prices will decrease it. Note that, although the individual effects are insignificant with the exception of the effect of $\bar{p}_x$, the overall effects of changes in prices, variances and the covariance are significant (p-value = 0.036).

Table 5 also shows the effects of the exogenous variables on the variability of the rate of return on capital. As the table indicates, the variation in the return is primarily explained by the changes in the variances and covariance of traded good prices: changes in variances have a positive effect, whereas a change in covariance has a negative effect. These effects of changes in the volatility of traded goods prices are, individually, all statistically significant. While the effects of changes in the prices of domestic commodities and in the expected prices of traded goods are not significant individually, their joint effect is statistically significant (p-value = 0.0015).

4.5 Other Effects

Finally, using simulations, we also examined the effects of non-marginal changes in uncertainty, transfers, or foreign aid and changes in the rate of growth of output of Australia's trading partners on production decisions.[23] We find that: (i) while the effects of non-marginal changes in uncertainty may be large, they are not statistically significant (ii) an increase in transfers, or foreign aid will (statistically significantly) decrease all supplies and demands; that is, it will shrink the overall level

[22] Since $R = rk$, it is easy to obtain the distribution of r from the distribution of $R:$ they differ by the constant k.

[23] Details of these results can be obtained upon request.

of economic activity, with a particularly strong effect on the investment sector (iii) increased growth in Japanese and U.S. production serves to raise (there is evidence of mild joint significance) both the demand for Australian exports, thereby raising export prices, and the supply of Australian imports, thereby reducing import prices;[24] thus, the Australian production sector shifts further into the traded goods sector and away from the nontraded goods sector.

5 Conclusions

The impacts of the uncertainty of traded goods prices faced by small open economies are potentially very important. To investigate the extent of volatility in traded goods prices and its impact on the Australian production sector we proposed a theoretical model of expected utility maximization based on microeconomics principles and implemented it using Australian data. In our model, the production sector chooses outputs (consumption, investment and exports) and inputs (labour and imports) to maximize the expected utility of profits, assuming that traded goods prices are stochastic. Producers are further assumed to predict the means, conditional variances of the prices of imports and exports and their conditional covariances using a bivariate conditional heteroskedastic regression model.

Our empirical model results are broadly consistent with the hypothesis of expected utility maximization. We also find that the hypothesis of risk neutral behaviour is soundly rejected by the data. As a result, it appears that production decisions (levels of outputs and inputs) are statistically significantly affected by changes in the variance of import prices, the variance of export prices or their covariance. This is true for both marginal and non-marginal changes in uncertainty. This result further implies that the expected return to capital, a residual in our model, and its variance are also significantly affected by the volatility of traded goods prices. Estimates of these effects have been presented in the paper. For example, our results show that an increase in the variance of the price of either imports or exports will raise the expected return to capital, but will also raise the variance of the return to capital. In short, uncertainty in traded goods prices does matter for the Australian economy.

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Table 1: Summary Statistics of Prices and Quantities

Variable	Mean	St. Dev.	C.V.	Min	Max
Prices normalized such that 2000:2 = 1					
p_m	0.63716	0.322	0.505	0.16449	1.03898
p_x	0.62750	0.292	0.465	0.18202	1.00000
p_i	0.63460	0.314	0.495	0.17262	1.00364
p_c	0.52703	0.308	0.584	0.12042	1.00000
p_l	0.47945	0.311	0.649	0.06616	1.05375
p_k	0.53854	0.292	0.542	0.14964	1.10384
Quantities normalized such that 2000:2 = 1					
$-y_m$	0.40976	0.225	0.549	0.15343	1.01435
y_x	0.41399	0.246	0.594	0.13000	1.01559
y_i	0.54272	0.191	0.352	0.28688	1.09970
y_c	0.58218	0.190	0.326	0.28827	1.03833
$-y_l$	0.69981	0.119	0.170	0.55303	1.00061
x_k	0.59169	0.216	0.365	0.25722	1.00000

Notes: (1) y_j, $j = m, x, i, c, l$ denotes the net output quantities.
(2) C.V. = coefficient of variation.

Table 2: ML Estimates of the GARCH Model of Foreign Prices

Parameter Mean equations	Estimate	S.E.	Parameter Covariance equations	Estimate	S.E.
Import Prices					
Constant, β_{10}	1.1982***	0.2323	Constant, θ_{11}	1.8320	
Lagged Import Price, β_{11}	0.2106*	0.1087	Constant, θ_{12}	1.5295	
Lagged Export Price, β_{12}	0.1710***	0.0592	Constant, θ_{21}	1.5295	
JPRGDP, β_{13}	-0.1697	0.1150	Constant, θ_{22}	1.2769	
USRGDP, β_{14}	-0.1987	0.1872	ARCH, a_{11}	0.9652***	0.1902
Exports Prices			ARCH, a_{12}	0.1032	0.0841
Constant, β_{20}	0.6099**	0.2989	ARCH, a_{21}	0.7002***	0.1475
Lagged Import Price, β_{21}	-0.1166	0.1039	ARCH, a_{22}	-0.2290***	0.0857
Lagged Export Price, β_{22}	0.3636***	0.0891	GARCH, b_{11}	0.3421***	0.1050
JPRGDP, β_{23}	0.2809*	0.1648	GARCH, b_{12}	0.0121	0.0810
USRGDP, β_{24}	0.2023	0.2492	GARCH, b_{21}	-0.3304***	0.0839
Ln Likelihood	−602.11		GARCH, b_{22}	0.9424***	0.0573

*** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

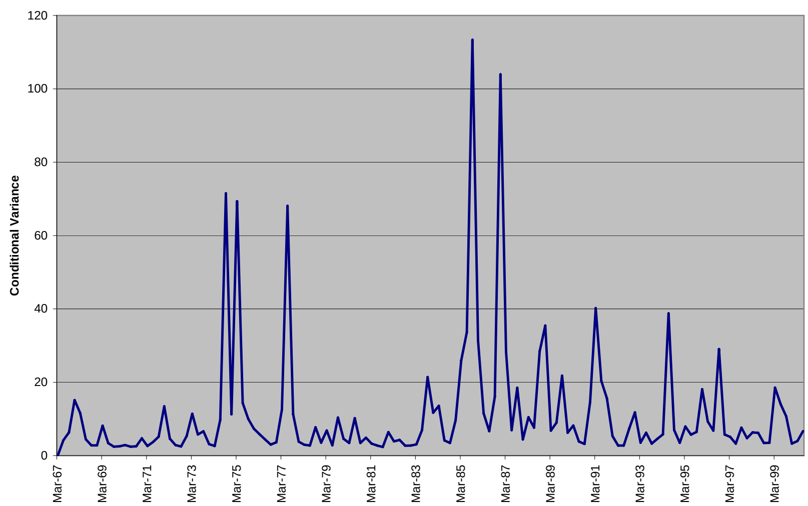

Figure 1: Estimated Conditional Variances for Import Price Growth Rates

Table 3: Parameter Estimates of Demand and Supply Functions

Parameter	Estimate	t-Statistic	Parameter	Estimate	t-Statistic
α_x	9.994	3.238	α_{mt}	-14.994	-1.745
α_m	-2.672	-.673	α_{cc}	-32.458	–1.288
α_c	45.509	7.079	α_{cI}	-28.332	-3.018
α_I	14.227	2.718	α_{cl}	13.857	.737
α_l	-32.983	-7.275	$\alpha_{c\sigma_x}$	-2.269	-.160
t_{xx}	1.496	1.202	$\alpha_{c\sigma_m}$	-2.130	-.391
t_{xm}	.047	.025	$\alpha_{c\sigma_{xm}}$	9.634	.729
α_{xc}	-5.408	–.811	α_{cb}	.562	1.485
α_{xI}	-6.843	-1.729	α_{ck}	-1.178	-1.891
α_{xl}	12.052	2.086	α_{ct}	102.837	5.247
$\alpha_{x\sigma_x}$	-.612	-.137	α_{II}	-2.113	-.438
$\alpha_{x\sigma_m}$	-.645	-.414	α_{Il}	8.614	1.239
$\alpha_{x\sigma_{xm}}$	2.013	.525	$\alpha_{I\sigma_x}$	-1.721	-.252
α_{xk}	-.424	-2.027	$\alpha_{I\sigma_m}$	-1.017	-.444
α_{xb}	.058	.418	$\alpha_{I\sigma_{xm}}$	3.780	.655
α_{xt}	23.919	3.031	α_{Ib}	.320	1.668
t_{mm}	.958	.584	α_{Ik}	-.171	-.451
α_{mc}	12.317	1.568	α_{It}	27.073	1.867
α_{mI}	7.523	2.467	α_{ll}	4.407	.271
α_{ml}	-4.244	-.678	$\alpha_{l\sigma_x}$	2.077	.206
$\alpha_{m\sigma_x}$	1.675	.358	$\alpha_{l\sigma_m}$	1.684	.435
$\alpha_{m\sigma_m}$	.835	.489	$\alpha_{l\sigma_{xm}}$	-7.391	-.784
$\alpha_{m\sigma_{xm}}$	-3.071	-.739	α_{lb}	-.193	-.615
α_{mk}	-.207	-.691	α_{lk}	.361	.659
α_{mb}	-.119	-.882	α_{lt}	-48.576	-2.477
$\alpha_{b\sigma_x}$	.071	.369	$\alpha_{b\sigma_m}$	.042	.574
$\alpha_{b\sigma_{xm}}$	-.176	-.964	α_{bk}	.020	2.270
α_{bt}	-1.281	-3.224			
Equation	R^2	D.W.-Statistic	Equation	R^2	D.W.-Statistic
Exports	.909	.263	Investment	.726	.511
Imports	.965	.380	Labour	.921	.655
Consumption	.976	.651			

Table 4: Elasticity Estimates (Evaluated at the Point of Normalization)

Elasticity	Estimate	t-Statistic	Elasticity	Estimate	t-Statistic
φ_{x,p_x}	.344	.928	φ_{c,p_l}	-.085	-.240
φ_{x,p_m}	-.257	-.993	φ_{c,σ_x}	.102	.567
φ_{x,p_c}	.728	1.062	φ_{c,σ_m}	.040	.734
φ_{x,p_I}	.054	.146	$\varphi_{c,\sigma_{xm}}$	-.152	-1.069
φ_{x,p_l}	.729	1.188	φ_{I,p_x}	-.518	-1.042
φ_{x,σ_x}	.099	.288	φ_{I,p_m}	.448	1.269
φ_{x,σ_m}	.031	.300	φ_{I,p_c}	-1.432	-1.377
$\varphi_{x,\sigma_{xm}}$	-.197	-.732	φ_{I,p_I}	.512	.744
φ_{m,p_x}	.124	.453	φ_{I,p_l}	.386	.412
φ_{m,p_m}	-.327	-1.362	φ_{I,σ_x}	-.004	-.008
φ_{m,p_c}	.397	.661	φ_{I,σ_m}	-.003	-.020
φ_{m,p_I}	.192	.476	$\varphi_{I,\sigma_{xm}}$	-.033	-.075
φ_{m,p_l}	-.135	-.258	φ_{l,p_x}	-.300	-1.709
φ_{m,σ_x}	-043	.160	φ_{l,p_m}	-.112	-.883
φ_{m,σ_m}	.035	.424	φ_{l,p_c}	.753	2.070
$\varphi_{m,\sigma_{xm}}$	-.179	-.839	φ_{l,p_I}	.404	1.561
φ_{c,p_x}	-.005	-.026	φ_{l,p_l}	-.585	-2.123
φ_{c,p_m}	.041	.278	φ_{l,σ_x}	.084	.567
φ_{c,p_c}	.443	1.069	φ_{l,σ_m}	.033	.744
φ_{c,p_I}	.009	.034	$\varphi_{l,\sigma_{xm}}$	-.127	-1.097

Table 5: Effects of Exogenous Variables on the Mean and Variance of the Return to Capital (Evaluated at the Point of Normalization)

Effect on $E(r)$	Estimate	S.E.	Effect on $Var(r)$	Estimate	S.E.
$\frac{\partial E(r)}{\partial \bar{p}_x}$	.5687**	.2475	$\frac{\partial Var(r)}{\partial \bar{p}_x}$	.0222	.0438
$\frac{\partial E(r)}{\partial \bar{p}_m}$	-.0849	.1924	$\frac{\partial Var(r)}{\partial \bar{p}_m}$	-.0622	.0379
$\frac{\partial E(r)}{\partial \sigma_x}$	.0785	.5519	$\frac{\partial Var(r)}{\partial \sigma_x}$	.1612*	.0689
$\frac{\partial E(r)}{\partial \sigma_m}$	.0091	.1658	$\frac{\partial Var(r)}{\partial \sigma_m}$	.3035**	.0271
$\frac{\partial E(r)}{\partial \sigma_{xm}}$	-.1005	.5910	$\frac{\partial Var(r)}{\partial \sigma_{xm}}$	-.4658**	.0798
$\frac{\partial E(r)}{\partial p_c}$	.7810	.5632	$\frac{\partial Var(r)}{\partial p_c}$	.0822	.0957
$\frac{\partial E(r)}{\partial p_I}$	-.6119	.3160	$\frac{\partial Var(r)}{\partial p_I}$	-.1274	.0708
$\frac{\partial E(r)}{\partial w}$	.0324	.5527	$\frac{\partial Var(r)}{\partial w}$	-.0323	.0815

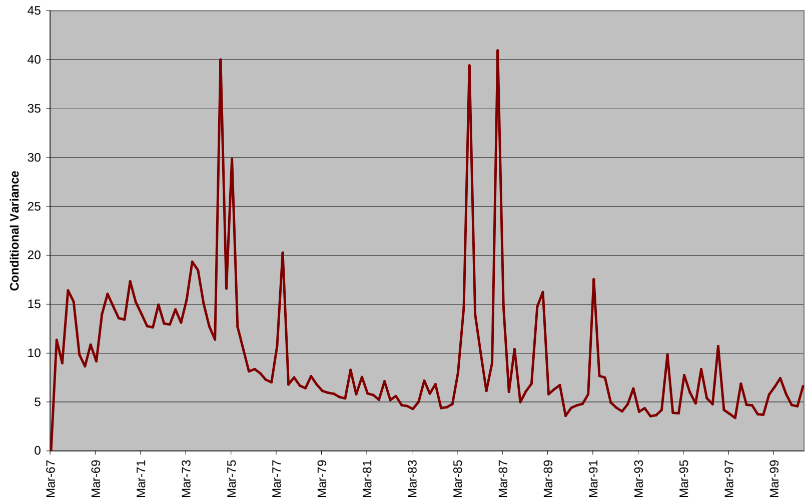

Figure 2: Estimated Conditional Variances for Export Price Growth Rates

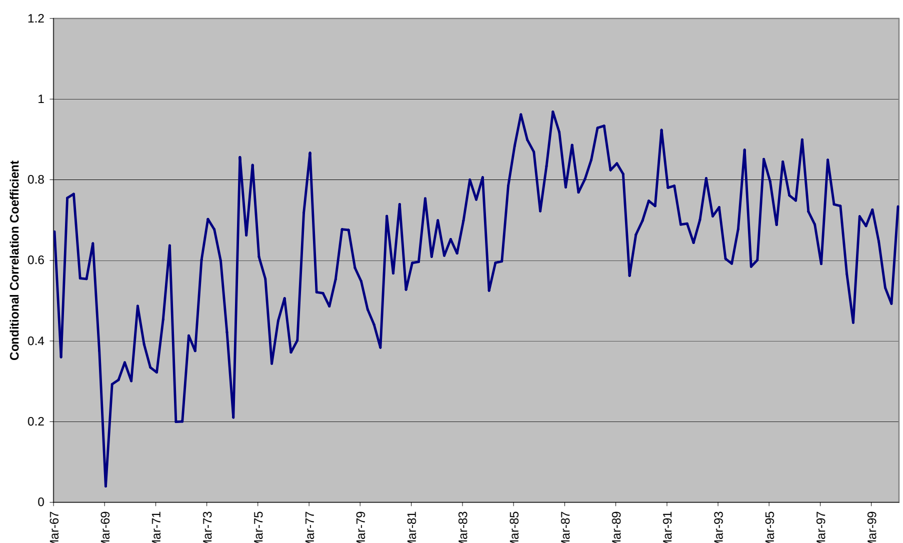

Figure 3: Estimated Conditional Correlation Coefficients between Import and Export Price Growth Rates

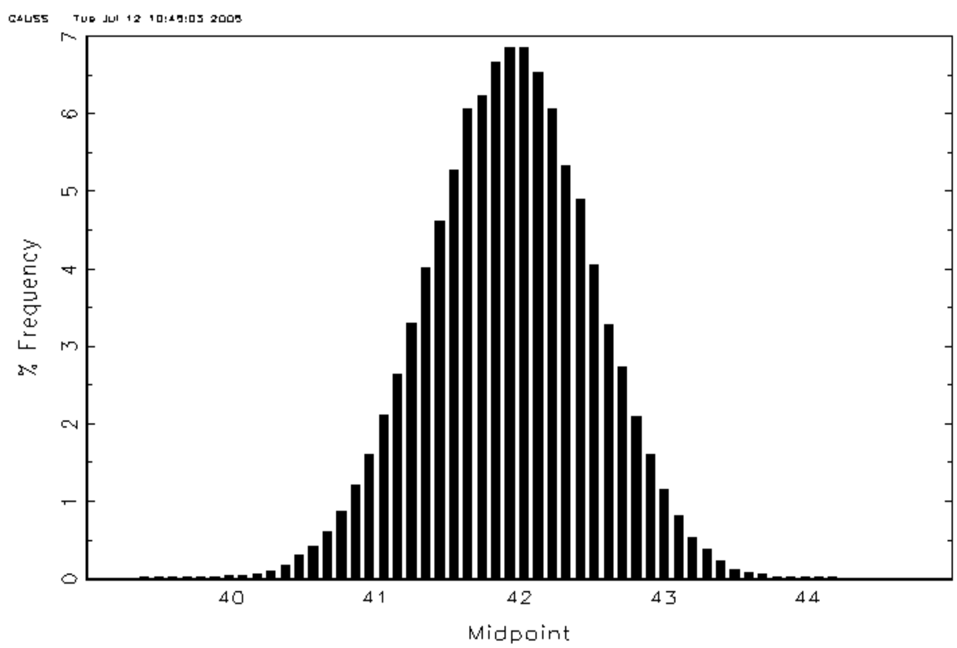

Figure 4: Simulated Distribution for Return to Capital (Evaluated at the Point of Normalization)