The Impact of Terms of Trade Volatility on Economic Growth and Investment in Australia

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Abstract

Terms of trade volatility has often been associated with poor economic performance in commodity dependent developing countries, but little research has been done for commodity dependent developed countries such as Australia. This paper examines the effect of terms of trade volatility on economic growth and investment in Australia over the past 50 years. On theoretical grounds the uncertainty associated with terms of trade volatility has a negative impact on growth by deterring investment spending. This paper uses real options theory to show that when investment is irreversible and can be delayed, an increase in uncertainty will generally lead to lower investment spending. However, opposing theories assert that in some instances, uncertainty can increase investment spending. Thus there is scope to explore the relationship empirically. This paper first examines the data and constructs a measure of terms of trade uncertainty based on a GARCH (1,1) model. A bivariate VAR process is then selected to model the relationship between uncertainty and economic growth and investment. Expectations and implications for results are also discussed.
1. Introduction

Terms of trade volatility has often been associated with poor economic performance in commodity dependant developing countries.\(^1\) When a poor country with undeveloped markets is dependant on one or two commodities for its export income, and these commodities exhibit volatile price fluctuations, their foreign exchange earnings will be unpredictable. This can impact on growth and investment through a variety of channels. For governments, volatile foreign exchange earning can complicate budgetary planning and destabilise fixed exchange rate regimes. For firms, terms of trade variability increases the price volatility of exported outputs and imported inputs, contributing to overall cash flow variability. This in turn reduces the collateral value of inventories, increases the costs of borrowing and deters future investment spending. For smallholder agriculture producers with poor access to credit or savings instruments, crop diversification is one of the only ways to cope with volatile output prices. Thus they forgo the potential benefits obtainable through specialisation. For these broad reasons terms of trade volatility is likely to impede economic growth in commodity dependent developing countries.

The relevance of this argument for a commodity dependant developed country has yet to be thoroughly examined. Australia presents an interesting case study in that it is dependant on primary commodities for export,\(^2\) exhibits periods of extreme terms of trade volatility, yet has in place the developed business systems, sophisticated financial markets and advanced production techniques characteristic of a developed economy. This paper undertakes a thorough examination of the effect of terms of trade volatility on economic growth and investment in Australia using quarterly data over the past 50 years. The implications of the results are important for other commodity dependant countries. A significant negative relationship between terms of trade volatility and economic growth and investment in Australia would suggest that the characteristics of a developed economy do not insulate a country from world price fluctuations, while a nil-result would suggest that this may indeed be a relevant factor and an important area for future research.

With the above argument as the motivating factor, this paper conducts the following analysis. Part 2 examines a prominent theoretical model on the effect of uncertainty on investment. The model uses real options theory to show that when investment is irreversible and can be delayed, an increase in uncertainty will generally lead to lower investment spending. Part 2 also interprets the relevance of this model for our case study and considers opposing theories which assert that in some instances, uncertainty can increase investment spending. This lack of theoretical consensus suggests that there are grounds to explore the relationship empirically, which occurs in Part 3. Here I first examine the data and construct a measure of terms of trade uncertainty based on a GARCH (1,1) model. A bivariate VAR process is then selected to model the relationship between uncertainty and economic growth and investment. Expectations and implications for results are also discussed. Part 4 concludes.

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\(^2\) Over the past 50 years primary commodities have averaged three-quarters of Australia’s goods exports.
2. **A Theoretical Model**

The general consensus from the literature is that terms of trade volatility (and volatility in general) affects economic growth through investment. This paper applies real options theory to the problem to explain the relationship. Consider an irreversible investment opportunity under the framework of a financial call option. A call option gives the owner the right, but not the obligation to pay an exercise price and in return receive some asset that has an uncertain value. Exercising the option is irreversible; although the asset can be sold to another investor at a price determined by the market, the option itself and the money paid to exercise it can never be recovered (Pindyck and Solimano 1993).

Similarly, an irreversible investment opportunity gives a firm the option to spend money (pay the exercise price) at some point in time in return for an asset with an uncertain value (the investment project). Although the project’s assets may then be sold to another firm, the investment itself is irreversible. When a firm makes an irreversible investment it effectively exercises the option, giving up the possibility of waiting for new information that might affect the profitability of the investment. It can not retrieve its costs should economic conditions change unfavourably (Dixit and Pindyck 1995).

Viewing investment opportunities in this way an important role for uncertainty becomes apparent. Effectively, uncertainty regarding the future value of the asset gives an option value. This notion is standard to traditional option theory. With a financial option, a volatile price of the underlying asset gives the option more value and increases the incentive to wait and delay exercising the option. This is because of the asymmetry of the options payoffs: as the asset price increases the value from exercising the option also rises, but if the asset price falls the investor only looses the price paid for the option. Similarly, if volatile economic conditions cause the value of the project to increase, the payoff to the firm from investing rises. If the value falls, the firm can choose not to invest and they only loose the money spent in obtaining the investment opportunity. It is easy to deduce then that any increase in uncertainty will increase the value of waiting and thus the value of the option to delay.

2.1 Irreversibility and the Ability to Delay

Before constructing the theoretical model I first clarify the concepts of irreversibility and the ability to delay. Investment spending is irreversible when it is specific to a firm or an industry. For example, the decision to invest in advertising and marketing is common among all types of firms. However, once the capital has been spent it can not be recovered as advertising and marketing are firm specific and not marketable assets. In the same way a steel plant is industry specific as it can only be used to produce steel. Theoretically a steel plant could be sold to another steel producing company. In reality however, if a company is forced to sell its steel plant because of unfavourable economic conditions, and if the industry is reasonably competitive, other steel companies will be facing the same conditions so that the value of the plant is the same for all firms, leaving little incentive to sell it (Dixit and Pindyck 1994). In this way firm and industry specific investments are clearly sunk costs, that is, incurred costs that can not be recovered.

The ‘market for lemons’ theory developed by Akerlof (1970) can be applied to show that even investments that are not firm or industry specific remain to a large extent irreversible. Consider an IT firm which has expanded its capital investment in computer
hardware only to find less than favourable demand conditions in the following period. The firm will find it difficult to recover the cost of the computers due to asymmetric information in the market for used computers. When buyers are unable to evaluate the quality of an item (such as a used computer) they will offer a price corresponding to the average quality of the market. Sellers, who know the quality of the item they are selling, will be reluctant to sell an above average item. The low quality goods drive out the high quality goods, lowering the average quality of the market and therefore the market price. Other examples of non-specific yet largely irreversible investments include office furniture, personnel training, and vehicles. Even if they are sold relatively new, their market value will be well below their purchase cost.

Government regulation can also add to the irreversibility of investments. For example inflexible workplace relations laws make investing in personnel a largely irreversible cost by increasing the sunk costs of hiring, training and firing. Strict financial regulations and capital controls (although more prevalent in developing countries than Australia) can make reallocating funds between countries difficult (Dixit and Pindyck 1994).

Now that it has been established that investment opportunities are irreversible, it is also necessary for our analogy with financial call options to show that they can be delayed for some period of time. For some firms the option to delay may be minimal; for example, when operating in a highly competitive market where firms need to invest quickly to pre-empt investment by other firms. However, in most instances firms have the option of delaying. Even if this incurs some cost (such as the risk of entry by other firms), the benefits of waiting for more information in an uncertain environment can be substantial.

2.2 A Model of Irreversible Investment under Uncertainty

Our analysis so far has shown that when investment is irreversible the ability to delay an investment can greatly affect the decision to invest. Effectively, the value of the real option constitutes the opportunity cost of investing now and as such should be included in the total cost of the investment. As a result, the simple net present value (NPV) rule that forms the basis of neo-classical models: ‘invest in a project when the present value of its expected cash flows is at least as large as its cost’ is invalidated. The value of the investment must now exceed the cost of the investment by at least the value of keeping the option alive (Pindyck and Solimano 1993). Below I construct a continuous time model of irreversible investment, based on the work of McDonald and Siegel (1986) and Dixit and Pindyck (1994), to capture this modification of the NPV rule.

A firm has the option to invest in a project with a known, fixed and irreversible cost of C, in return for expected future net cash flows with a present value of V, which follows a geometric Brownian motion:

$$dV = \alpha V dt + \sigma V dz$$

(2.1)

where t is time and z is a standard Wiener process. What we are now interested in is the point at which an optimizing firm will invest, that is, pay the irreversible cost C. Using the NPV rule, the firm will invest when V > C. But as has been discussed, this method fails to account for the opportunity cost of investing today. The decision rule thus
becomes: `invest only when V is at least as large as some critical value V* that exceeds C by the value of the option` (Dixit and Pindyck 1994). Given a constant C and a variable V, the payoff from investing is Vt – C. Thus the firm’s optimizing decision involves maximising the expected present value of this payoff:

\[
F(V) = \max E[(V_T - C)e^{-pT}]
\]  
(2.2)

subject to equation (2.1) and the assumption that \( \delta = p - \alpha > 0 \), where T is the unknown future time in which the investment takes place and p is the discount rate.

A complete proof of this model using dynamic programming is beyond the scope of this paper but can be found in chapter five of Dixit and Pindyck (1994). Below I present the relevant results of the model:

\[
V^* = \frac{\beta C}{\beta - 1}
\]  
(2.3)

where \( \beta \) is a known constant determined by \( \sigma, p \) and \( \alpha \) such that \( \beta > 1 \). Since \( \beta > 1 \), it is clear that \( V^* > C \). The combination of uncertainty and irreversibility act to create a wedge between the critical value \( V^* \) and the cost \( C \). Some of the limiting properties of \( \beta \) are also informative. Dixit and Pindyck find that as \( \sigma \to \infty \), we have \( \beta \to 1 \), and thus \( V^* \to \infty \). In words, this means that as uncertainty increases, the critical value at which the firm will invest also increases, decreasing the overall level of investment spending. Under infinite uncertainty, investment will never take place.

Thus we can see the negative impact of uncertainty on investment. In fact McDonald and Siegel (1986) show that for reasonable levels of uncertainty it is optimal to wait until V is at least twice as large as C.

2.3 Interpretation of the Model

There are a number of clarifications required of this model to make it relevant for our case study. Firstly, I justify the interpretation of terms of trade volatility as a relevant measure of uncertainty. As we are working with aggregate level data we are interested in an aggregate measure of uncertainty. Terms of trade volatility is one such variable likely to have a pervasive effect across all industries; not only commodity exporting industries where output prices are notoriously volatile, but industries which rely on imports of capital and manufactures goods. Non-exporting and non-importing industries may still be vulnerable to terms of trade volatility indirectly. Firstly through their interaction with other firms in these industries and secondly to the extent that terms of trade volatility contributes to overall macroeconomic uncertainty. Furthermore, the terms of trade is useful in that it is determined exogenously to Australia. This means we do not have to worry about changes in investment or economic growth feeding back into the uncertainty variable, which would complicate theoretical and empirical conclusions.

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3 If the growth rate of the investment (\( \alpha \)) exceeds the discount rate (p) the value of the investment opportunity \( F(V) \) will increase indefinitely by choosing a larger optimal investment time (T) and a solution will not exist.

4 Where \( B = \frac{1}{2} - (p - \delta)/\sigma^2 + \left\{[(p - \delta)/\sigma^2 - \frac{1}{2}]^2 + 2p/\sigma^2\right\}^{\frac{1}{2}} \)
Secondly, I consider the implications of applying a microeconomic model to macroeconomic data. The model above examines the investment decision of the firm. For our case study however, we are interested in the aggregate economy. The uncertainty created by a volatile terms of trade is not likely to impact firms individually, but industries as a whole. Thus we are only interested in aggregate uncertainty rather than idiosyncratic, firm-specific uncertainty. One might expect that at the industry level, where firms no-longer enjoy monopoly rights to invest and must consider the possible entry or expansion of other firms, the opportunity to wait would be reduced to zero. However, price uncertainty still plays a role because of its asymmetric effect; the impact on profitability of favorable aggregate shocks is limited by the entry of new firms (in a competitive industry) or the expansion of existing firms, while irreversibility still prevents exit when unfavorable shocks occur. Thus higher aggregate uncertainty increases the critical level at which a firm will invest and therefore reduces firm as well as industry-wide investment. The full development and proof of this extension to the theory can be found in Caballero and Pindyck (1996).

Thirdly, in order to capture any broader effects of terms of trade volatility we extend the implications of the model to the relationship between uncertainty and economic growth. In addition to the effect of uncertainty on investment discussed above, significant terms of trade volatility can be destabilising and can affect economic efficiency. That is, if consumers and producers are not able to diagnose the extent and duration of a change in the terms of trade, efficient resource movements are likely to be impeded as price signals are misread. And this tends to inhibit both productivity growth and economic growth. Furthermore, terms of trade volatility increases cash flow variability for businesses by affecting their input and output prices. This in turn reduces the collateral value of inventories; increases the costs of borrowing, as lenders charge higher premiums to account for risk; and thus has an additional detrimental affects on investment spending. High levels of volatility in the terms of trade can therefore seriously disrupt an economy, increasing the volatility of its growth rate and price level making monetary policy more difficult to implement. This tends to increase the volatility of inflation, adding to general economic instability. The operation and control of fiscal policy can be similarly more difficult under such circumstances.

Finally, we also extend the implications of the model to include the hypothesis that the characteristics of a developed economy help to insulate it from terms of trade volatility. Even though a developed, commodity dependent country may be better equipped to manage macroeconomic risk and have more developed financial markets, it is unclear as to how relevant these factors are to the relationship between terms of trade volatility and economic growth and investment. In other words, one would expect that a developed economy is better able to protect itself against terms of trade volatility, yet to this author’s knowledge, this hypothesis has yet to be investigated theoretically or empirically.

3.4 Alternative Theories
In reviewing the theoretical literature it becomes clear that take as a whole, the theoretical predictions on the relationship between uncertainty and investment are ambiguous. Depending on the approach and assumptions, some theories purport a negative relationship, some a positive relationship and others an indefinite relationship. As such,
the following is a brief discussion of alternate theories to the McDonald and Siegel model.

Hartman (1972) finds that current investment by competitive firms would increase in the face of uncertainty. He develops a dynamic, discrete time model under standard neoclassical conditions: a constant returns, perfectly competitive firm in which capital is the only fixed factor and labour can be costlessly adjusted in each period. The firm must choose its capital input for a period before knowing the output price or wage rate. The choice of labour is made subsequently, once the output price and wage rate are observed. Additionally, Hartman assumes increasing marginal costs to investment, I, and that these costs vary randomly according to output and input prices. When the firm disinvests, I is negative and the firm receives revenue from the sale of unused capital. Thus we can denote \( C(I_t) \) as the adjustment cost to investment (either positive or negative) which is increasing and strictly convex in I.\(^5\)

The analysis is based on a model in which the firm chooses an investment strategy to maximise expected profit subject to the original capital stock:

\[
H = E \sum_{t=0}^{\infty} r[K_t g(p_t, w_t) - C(I_t)]
\]

where \( H \) is the profit function, \( r \) is the discount rate, \( t \) is time, \( K \) is the capital input, \( g \) is convex, \( p \) and \( w \) are output price and the wage rate and \( C(I_t) \) is defined as before.\(^6\) Under the optimal investment strategy, the marginal cost of investment will equal the increase in profits; \( C' = H' \).

Hartman’s approach to including uncertainty involves a multidimensional generalisation of a mean preserving spread.\(^7\) This is obtained by adding a random variable with conditional mean zero to the original random variables. Hartman finds that the addition of uncertainty in this way causes \( H' \) to increase, since Jensen’s inequality holds. As \( C' \) is monotone increasing, the increase in \( H' \) requires an increase in \( I \) for the firm to remain profit maximising. Thus Hartman reaches the conclusion that an increase in the uncertainty associated with \( p \) and/or \( w \) will increase the value of a marginal unit of capital so that an optimizing firm will increase its investment in that period and thus its overall level of capital stock.

Abel (1983) extends Hartman’s model to the case where uncertainty is reflected by continuous output and factor prices which shift stochastically through time, rather than being discrete random variables in each period. He finds that Hartman’s result continues to hold regardless of whether the adjustment function is convex or concave. All that is required is that the profit function is convex in prices.

Wong (2007) examines the effect of uncertainty on investment in a real options model based on McDonald and Siegel (1986) as discussed above. He finds that the critical value of a project that triggers the investment \( V^* \), exhibits a U-shaped pattern

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\(^5\) This convexity may be the case due to the firm’s monopsony power in the capital goods market, internal adjustment costs which must be met before new investment takes place, or due to economies of scale in installing capital and training workers. When the firm disinvests, the strict convexity of \( C \) reflects the difficulty of selling a large amount of capital quickly.

\(^6\) For full derivation of the model see Hartman (1972).

\(^7\) Essentially, for the one-dimensional case this involves moving some of the probability mass close to the center of a distribution farther out into the tails. In this way the mean remains unchanged but the variance increases.
against uncertainty. This non-linear relationship is due to two countervailing factors: when volatility goes up, the risk factor enhances the value of the investment option, making waiting more beneficial and producing a negative relationship between uncertainty and investment. On the other hand, the return factor arising from the upward adjustment of the discount rate makes waiting more costly and results in a positive relationship between uncertainty and investment. A U-shape is created as the positive relationship dominates for low levels of uncertainty, while the negative relationship dominates when uncertainty is high. Wong also finds that the U-shaped pattern is inherited by the relationship between the expected time to exercise the investment option and uncertainty. This means that for relatively safe projects, greater uncertainty will shorten the expected exercise time and thus lead to more investment, while for riskier projects the opposite will occur. Therefore, at the aggregate level the relationship between uncertainty and investment is indefinite.

3. The Empirical Facts
Owing to the lack of a theoretical consensus on the affect of uncertainty on investment or economic growth, I find reason to explore this relationship empirically. To do so I use the EViews software package and a large time series data set comprising 185 quarterly observations from 1960 to 2006. All data is sourced from the Australian Bureau of Statistics or the Reserve Bank of Australia. The variables of interest are the terms of trade, the uncertainty associated with the terms of trade, gross domestic product, and various measures of investment. All series are seasonally adjusted.

3.1 Data analysis
Figure one shows the pattern of the terms of trade over the last 100 years. Two broad characteristics are apparent: a trend decline and periods of considerable volatility. It is the pattern of extreme volatility followed by relative stability which is of interest to this paper. Examining the causes of this pattern, it is apparent that the most dramatic changes in the terms of trade can be explained by world wide shocks to global markets. For example, periods of high volatility in figure one can be explained by: increasing commodity prices in the early 1920s; the great depression in the early 1930s; the Second World War in the mid 1940s; and the boom and bust of wool prices over the period of the Korean War in the early 1950s. In figure two we can see the effect of more recent world events such as: the oil price spike in the mid 1970s which cause a rapid decline in Australia’s terms of trade; a period of weak commodity prices in 1986; the world recession in the early 1990s; the Asian Financial Crisis in the late 1990s; and the recent commodity price boom (Australian Treasury 2003).

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8 These include: total gross fixed capital formation (GFCF), private GFCF and total business GFCF.
Figure One

Australia's Terms of Trade
2002/03 = 100, log scale

Source: Gillitzer and Kearns (2005) data set, author’s calculations

Figure Two

Australia's Terms of Trade
2004/05=100

Source: ABS, author’s calculations

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9 Yearly data
10 Quarterly data
Table one also illustrates the changing pattern of Australia’s terms of trade. It summarises the mean and standard deviation of the terms of trade and economic growth in Australia over the past five decades. Our findings from the graphical analysis that Australia’s terms of trade exhibits periods of extreme volatility it also evident in this simple statistical analysis. That is, periods in which the terms of trade was rapidly changing, such as the 1970s and the past 5 years, have larger standard deviations. Finally, figure three also allows us to examine Australia’s changing terms of trade volatility. It measures the conditional variance of the terms of trade data series (discussed in part 3.2) and again reflects periods of volatility and relative stability.

### Table One

<table>
<thead>
<tr>
<th>Decade</th>
<th>Terms of Trade</th>
<th>GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Level</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>1960s</td>
<td>92.0</td>
<td>4.3</td>
</tr>
<tr>
<td>1970s</td>
<td>90.9</td>
<td>8.7</td>
</tr>
<tr>
<td>1980s</td>
<td>80.6</td>
<td>5.2</td>
</tr>
<tr>
<td>1990s</td>
<td>78.2</td>
<td>3.2</td>
</tr>
<tr>
<td>1990s (1st half)</td>
<td>78.1</td>
<td>4.2</td>
</tr>
<tr>
<td>1990s (2nd half)</td>
<td>78.2</td>
<td>1.9</td>
</tr>
<tr>
<td>2000s</td>
<td>92.1</td>
<td>11.5</td>
</tr>
<tr>
<td>full sample</td>
<td>86.3</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Source: ABS, author’s calculations

### Figure Three

**Terms of Trade Uncertainty**

GARCH volatility estimates

Source: ABS, author’s calculations
Before conducting our empirical analysis I consider the order of integration of our variables. Simple observation of the GDP and investment series over time suggests they all exhibit a stochastic trend. Augmented Dickey Fuller (ADF) tests with a liner trend, intercept and anywhere from one to twelve lags never reject the null hypothesis of a unit root. Additionally the null hypothesis of a unit root is always rejected conducting the same test on the first difference of the variable. As we would expect, these tests confirm our initial observation that all three variables are integrated of order one [I(1)]. Observing the time path of the terms of trade series suggests that the variable follows a random walk. On conducting the same ADF tests as above we also confirm this observation and conclude that the terms of trade is [I(1)].

3.2 Measuring Uncertainty

In constructing a measure of uncertainty it is important to distinguish between sample variability and ‘true’ uncertainty; we need a measure which reflects only the unpredictable innovations in the terms of trade. A simple sample volatility is not acceptable as it may overstate uncertainty by including cyclical movements and trends, which are partly predictable from past data. Additionally, in order to examine the effect of uncertainty on our dependent variable we need a time variant level of uncertainty.

We generate a variable conceptually comparable to this notion of uncertainty by applying a generalized autoregressive conditional heteroskedasticity (GARCH) model to the innovations in the terms of trade. More specifically, following the work of Bollerslev (1986) I estimate the following univariate GARCH(1,1) model:

\[
\Delta \text{tot}_t = a_0 + a_1 t + \beta_1 \Delta \text{tot}_{t-1} + \epsilon_t \\
\sigma^2_t = \gamma_0 + \gamma_1 \epsilon^2_{t-1} + \delta \sigma^2_{t-1}
\]

(3.1) (3.2)

where tot denotes the terms of trade, \( \Delta \text{tot} \) is the first difference of the terms of trade and \( \sigma^2_t \) is the variance of \( \epsilon_t \) conditional on information up to period \( t \). Thus we have our measure of uncertainty which is dependent on both time and the predictable movements in the terms of trade embodied in \( \epsilon_t \).

3.3 Set-up of the Model

I estimate a bivariate VAR model of the following form:

\[
Y_t = \theta_0 + \sum \theta_\rho Y_{t-\rho} + \sum \Phi_\rho \sigma^2_{t-\rho} + \sum \Pi_1 X_t + \nu_t
\]

(3.3)

where \( Y \) is our dependent variable of interest (economic growth, or measures of investment), \( \sigma^2_t \) is our measure of uncertainty as defined above, \( \rho \) is the number of lags on the endogenous variables and \( \theta, \Phi, \text{ and } \Pi \) are coefficients determined by the model. \( X \) is a vector of exogenous control variables yet to be defined. Theory discussed above suggests some likely candidates. Controlling for investment in the economic growth equation would illustrate whether terms of trade uncertainty effects economic growth directly or indirectly through investment. Controlling for the volume of derivative trading in Australia’s main commodity exports may indicate whether the existence of
sophisticated futures markets helps to mitigate the effect of terms of trade uncertainty on the economy. Furthermore, controlling for inflation or the real exchange rate would suggest whether terms of trade volatility impacts on the economy directly or through a transitive price mechanism. Estimation of the model also produces a corresponding VAR with $\sigma_t^2$ as the dependant variable. As the effect of GDP and investment on terms of trade uncertainty is not theoretically viable and of no interest to our hypothesis the results and equations for this relationship can be ignored.

The model is non-standard in that it is estimated using levels of variables rather than their first difference. This is in order to exploit the additional information contained in the low frequency movements of the series. Additionally, this methodology has the advantage in that it doesn’t necessitate pre-testing of the times series to acquire an I(0) variable. Although this is a simple procedure using unit root tests such as the Augmented Dickey Fuller test or Phillips and Perron test, the power of these tests are known to be very low against the alternative hypothesis of stationarity (Toda and Yamamoto 1995). This implies that the traditional strategy of estimating a VAR with differenced variables may suffer from severe pretest bias.

Alternate model forms which may be pursued include (3.4), a simpler version of (3.3), where the uncertainty measure is treated as an exogenous variable within the VAR. Similarly, (3.5) is also a simpler version in that it negates the problem of estimating with an I(1) dependant variable by taking the first difference.

\[ Y_t = \theta_0 + \sum \theta \rho Y_{t-p} + \Phi_1 \sigma_t^2 + \sum \Pi_1 X_t + \nu_t \] (3.4)

\[ \Delta Y_t = \theta_0 + \sum \theta \rho \Delta Y_{t-p} + \sum \Phi_1 \sigma_{t-p}^2 + \sum \Pi_1 X_t + \nu_t \] (3.5)

As a precursor to constructing the above models it is necessary to select the number of lags on the endogenous variables. There are a number of procedures available. One possible method is to start from a model with the maximum feasible lag length $\rho_{\text{max}}$ and apply sequential tests to determine a suitable lag order. In this case theoretical intuition may be used to select $\rho_{\text{max}}$, that is, due to the inertia inherent in investment we might want to start with at least two years worth of lags. Instead of sequential testing there are a number of information criteria which can be used to select lag length. The usual approach is to fit a VAR model of order $\rho_{\text{max}}$ and then to choose the lag length that minimises the specific criteria. Two common criteria are the Akaike Information Criterion (AIC) and the Schwarz Criterion. We are interested in examining both criteria as the AIC asymptotically overestimates the model with positive probability while the SC tends to underestimate the true lag order. All methods for lag selection discussed are applicable to models with both I(0) and I(1) variables (Lütkepohl and Kratzig 2004).

### 3.4 Testing the Model

Firstly we test for stability (stationarity) which is necessary for certain results to be valid. The process (3.3) is stable if the polynomial defined by the determinant of the autoregressive operator has roots with modulus less than one which lie inside the unit circle (Lütkepohl and Kratzig 2004). For our model there are $k\rho$ roots where $k$ is the number of endogenous variables (in our case two) and $\rho$ is the number of lags. Early testing of the model reveals that the process is not stable, that is, the polynomial has a
unit root. As a result, some or all of the variables are integrated, which is to be expected as we are working with levels.

Sims et al. (1990) show that OLS estimators for correctly specified VAR models, which include some variables integrated of an order greater than zero, are consistent and asymptotically normally distributed. However, the covariance matrix will be singular. Specifically, if there are integrated variables, some coefficient estimates will converge faster than the normal rate of \( T^{1/2} \), but standard \( t \), \( \chi^2 \), and F-tests for those coefficients may not be valid. Consequently, care must be taken with the interpretation of Granger-causality tests in this framework.

This paper draws on the work of Toda and Yamamoto (1995) to overcome the above problem. As discussed the inclusion of I(1) variables is problematic in that the resultant covariance matrix will be singular. This singularity can be removed by over-fitting the VAR model. That is, having chosen the true lag length \( \rho \), estimate a \( \rho+1 \) order VAR. Toda and Yamamoto then show that simply estimating this new model and ignoring the extra lagged vector (since it is regarded as zero) allows for standard granger causality tests to be performed.\(^{11}\)

3.5 *Expectations, Implications and Scope for Further Research*

For testing the theoretical hypothesis the key coefficient is \( \Phi_i \), the effect of uncertainty on the dependant variable. A standard Granger causality test can be undertaken to test for negative and jointly significant value of \( \Phi_i \). Rejection of the null hypothesis, that \( \sigma^2_t \) does not Granger cause \( Y_t \), would indicate that terms of trade volatility does not effect economic growth or investment.

As yet no such test has been undertaken. Below I consider the implications for both a significant and nil result. A negative and significant result would confirm the theoretical model discussed and broadly support the body of cross-sectional empirical work on the relationship between terms of trade volatility and economic growth and investment. Additionally, it would suggest that the developed economy and sophisticated financial markets of a developed country such as Australia are not able to insulate an economy from the effect of exogenous movements in its terms of trade.

Subsequently, we consider the implications of a nil result. This could indicate a number of things. Firstly, that terms of trade volatility does not effect economic growth or investment in Australia. This in turn could be the result of many factors such as: readily accessible and developed futures markets in Australia which allow firms to hedge the price risk associated with their exports or imports, mitigating the effect of uncertainty on investment decisions; good macroeconomic management (including inflation targeting over the last fourteen years) to minimise the uncertainty associated with price changes; or substantial diversification of the composition and destination of goods exports over the past forty years.\(^{12}\) As such there may be scope to test this hypothesis by using an earlier data set from Australia so that the economic and financial conditions more accurately reflect those of developing countries.

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\(^{11}\) Toda and Yamamoto point out that this approach suffers from some loss of power since the model is over-fitted. However, for a model with a small number of variables with relatively large numbers of lags (as is most likely the case for our model) the inefficiency in adding one more lag will be small.

\(^{12}\) In particular, Australia has diversified its exports away from food and wool, and away from a Europe dominated market.
Secondly, failure to find a significant result may be an indication of data problems. Working with time series data (as opposed to the cross-sectional and panel data of previous studies) may produce a weaker relationship as there is less variation between observations. Additionally, the data may be a problem because it is only quarterly. Quarterly data is likely to grossly understate the true nature of price volatility in Australia’s commodity exports. As such there may be scope to test the hypothesis by using higher frequency data series such as exports (released monthly) or commodity prices (available on spot markets).

Thirdly, a nil result may also reflect problems with our theoretical model. As was discussed in section 2.4, some economists purport that uncertainty can have a positive, neutral or non-linear effect on investment. If their models are relevant for the Australian economy then uncertainty may impose conflicting effects on investment, so that no clear empirical result is achieved.

Finally, a lack of significant results may reflect a misspecified model or incorrect methodology. As with any empirical investigation, a number of problems may occur throughout the process. For example: the true relationship may require a different number of lags; a non-linear specification may be more appropriate; or our measure of uncertainty may not reflect the true proportion of unpredictable volatility in the terms of trade. Clearly, there is scope for further empirical research using different technique to those employed by this paper.

4. Conclusion
This paper presents a summary of my work so far into the effect of terms of trade volatility on economic growth and investment in Australia. On theoretical grounds I found that the uncertainty associated with terms of trade volatility has a negative impact on the economy by deterring investment spending. This paper used real options theory to model the critical value of a project at which investment takes place. It was then shown that an increase in uncertainty increases this critical value so that overall, less investment takes place. This theory was then extended so as to be relevant for our broad investigation into the effect of terms of trade volatility on economic growth and aggregate investment in Australia. Opposing theories were also discussed to show that there is no overall theoretical consensus on the affect of uncertainty on investment or economic growth. Thus I found scope to explore the relationship empirically. I began by examining the terms of trade data to illustrate a pattern of time-variant volatility. To measure the uncertainty associated with this volatility I constructed a variable based on a GARCH (1,1) model. A bivariate VAR process was then selected to model the relationship between uncertainty and economic growth and investment. As yet no formal empirical work has been completed. Accordingly, I finished by discussing my expectations for results and the implications for both a significant and nil result.
Bibliography


