Empirica **31:** 137–162, 2004.
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Investment Under Monetary Uncertainty: A Panel Data Investigation★

ANDREW HUGHES HALLETT★★
CEPR and Department of Economics, Vanderbilt University, Nashville, TN 37235, USA
E-mail: a.hugheshallett@vanderbilt.edu

GERT PEERSMAN
Department of Financial Economics, Gent University, Gent, Belgium and Bank of England, Threadneedle Street, London EC2R 8AH, UK
E-mail: gert.peersman@ugent.be

LAURA PISCITELLI
Bank of England, Threadneedle Street, London EC2R 8AH, UK
E-mail: laura.piscitelli@bankofengland.co.uk

Abstract. There is a presumption in the literature that price or exchange rate uncertainty, or uncertainty in the monetary conditions underlying them, will have a negative effect on investment. Some argue that this negative effect will be extended by imperfect competition. However, models of "irreversible" investment show that the situation is more complicated than that. In these models, investment expenditures are affected by the scrapping price available on world markets and also by the opportunity cost of waiting rather than investing. The impact of uncertainty is therefore going to depend on the type of industry and hence on the industrial structure of the economy concerned. In addition, it may depend on the persistence of any price "misalignments" away from competitive equilibrium. In this paper, we put these theoretical predictions to the test. We estimate investment equations for 13 different industries using data for nine OECD countries over the period 1970–2000. We find that the impact of price uncertainty is negative or insignificant in all but one case whereas the impact of (nominal) exchange rate uncertainty is negative in only six cases, positive in four cases, and insignificant in three others. In addition, there are conflicting effects from the real exchange rate. The net effect depends on whether the source of the uncertainty is in domestic markets or in foreign markets.

Keywords: Investment expenditures, price and exchange rate uncertainty, PMGE estimators

JEL codes: E22, F21

I. Introduction

In Darby et al. (1999, 2002) we estimated investment equations for the major G7 countries including exchange rate volatility and misalignment terms. We

★ We thank Hashem Pesaran, Joe Byrne, Andrew Bailey, Simon Price, Peter Pedroni, Jean-Pierre Urbain, Matt Canzoneri, three anonymous referees and seminar participants at the 2003 Austrian Economic Association Annual meeting for helpful comments and suggestions.

★★ Author for correspondence.

found that, on average and for most countries in the sample, exchange rate volatility has had a negative and significant impact on the level of investment, confirming conventional wisdom on the negative relationship between investment and exchange rate volatility. A second result was that, for some countries, the investment decision is affected by the degree of misalignment of the exchange rate in a measure depending on the degree of underlying volatility.

This type of aggregate empirical analysis fails, however, to capture differences at the industry level, which the theoretical analysis developed in those two papers proved could be important. In the present paper, we extend the empirical analysis of Darby et al. (1999, 2002) to the micro-level, using a panel data approach in order to capture cross-industry differences. We are also able to explicitly incorporate the effects of price uncertainty for the first time and to distinguish the effects when price uncertainties arise at home from the case when they arise in foreign markets.

The structure of the paper is as follows: in Section II we briefly recall the theoretical analysis and its results as derived in Darby et al. (1999, 2002). In Section III, we describe the methodology adopted to conduct the empirical analysis. In Section IV, we discuss the results of such analysis. Section V concludes.

II. Theory: The Impact of Price and Exchange Rate Volatility on the Level of Investment

The theoretical analysis conducted in Darby et al. (1999, 2002) showed that the way in which individual investment programs react to uncertainty depends on that investment's scrapping value and on the opportunity cost of waiting. Specifically, if the scrapping price is low, then rising price or exchange rate volatility tends to increase investment because extra volatility reduces the chances of being stuck with an (ex-post) unwanted investment. Price uncertainty therefore reduces the potential for "hold up" problems.

Similarly, if the opportunity cost of waiting is low and the scrapping price high, producers prefer to wait rather than invest. It therefore takes comparatively large or frequent increases in prices (or the exchange rate) to persuade producers to invest. Increases in price volatility create exactly that situation with the result that increasing price variability increases investment. But if the opportunity cost of waiting is high, and the scrapping price is also high, producers are inclined to invest rather than to wait. In this case, an increase in either the possibility or the frequency of higher prices fails to make them want to invest more at the upper end of the price distribution. But, at the same time, it increases the risk of a mistaken investment at the bottom end of the price distribution. So, in this case, an increase in price volatility leads to a fall in investment expenditures.

1. THE THEORETICAL MODEL

The theoretical framework for this study is provided by the Dixit and Pindyck option value model of irreversible investment (Dixit and Pindyck, 1994). According to this model, taking an investment decision is analogous to buying an option. The decision is based on an evaluation of the expected future stream of revenues the investment project is going to produce over its lifetime (assumed to be infinite). Given sunk entry/exit costs and running costs, the decision to invest is taken only if the value of the project is "high enough" in terms of a certain threshold. The alternative is to wait until the entry condition is verified. The problem is symmetric: a firm currently investing will decide to disinvest if the value of the investment project becomes "too low". Otherwise it will wait to disinvest.

Note that the firm's optimization problem is a genuine stochastic problem. The future value of the investment project is indeed uncertain because of the uncertainty concerning the future value of the exchange rate and, consequently, the producer price (used to evaluate the investment project).[1] We maintain the same assumption as in the Dixit and Pindyck model that the exchange rate (and therefore the prices received in domestic currency) follows a Brownian motion specified as $de = \alpha \cdot e\,dt + \sigma \cdot e\,dz$, where e denotes the exchange rate, α and σ are parameters and dz is a random process, normally distributed with zero mean and variance dt (t being the time index). Note that if $\alpha = 0$, $de/e = \sigma\ dz$, and thus, integrating between time 0 and 1, $\log(e/e_0) = \sigma$, which makes σ a measure of the exchange rate volatility. On the other hand, $\alpha > 0$ means that the exchange rate index is expected to rise ($E(de) = \alpha \cdot e \cdot dt > 0$) and, conversely, $\alpha < 0$ indicates that it is expected to fall. This makes α a measure of the current (or perceived) misalignment in the exchange rate.[2]

The major implication of introducing uncertainty in the firm's investment problem is that uncertainty makes waiting costly. If, today, the firm decides to wait and does not invest, then it might well end up losing some profits should prices become more favorable at a later stage. This cost of waiting therefore has to be considered as an additional structural parameter/variable in the firm's optimization problem. Following Dixit and Pindyck, we denote the cost of waiting as δ and include it in the model as the discount rate for future prices.

The solution to the firm's optimization problem (maximizing the present discounted value of expected future revenues) now provides upper and lower trigger values for prices which are functions of sunk and running costs, the parameters defining the monetary uncertainty α and σ, and of the cost of waiting δ[3]. We denote these thresholds P_{H} and P_{L}, and note that the latter also represents the firm *scrapping* price.[4] The range of prices between P_{L} and P_{H} is a zone of inactivity in the sense that when prices fall within this interval and the firm is not investing, it will remain out of the market. Similarly, if it is already investing, it will stay in the market as originally planned.

To analyze the impact of exchange rate uncertainty on the level of investment, it is sufficient to analyze how the size of the inactivity zone changes as α and σ change. In other words, the conventional wisdom that increasing uncertainty reduces investment can be translated into "*increasing* α *and* σ *increases the size of the inactivity zone*". Consequently, to answer the question "*how do investment decisions respond to monetary uncertainty?*" becomes an exercise in comparative statics to be resolved by assessing the signs of $\frac{\partial(P_H - P_L)}{\partial\sigma}$ and $\frac{\partial(P_H - P_L)}{\partial\alpha}$. In Darby et al. (1999, 2002) we derived the conditions under which each of these partial derivatives is either positive or negative.[5] We found that firms react differently to the exchange rate/price uncertainty in the sense that as volatility is reduced and/or the currency becomes more aligned to its medium/long-run value, some firms will invest more – but others will not. It depends on the opportunity cost of waiting, as well as on the scrapping price. In addition, the impact of a reduction in misalignment on investment also depends on the underlying degree of exchange rate/price volatility.

A formal derivation of these results follows from the conditions for investment to increase or decrease with price/exchange rate uncertainty in the Dixit–Pindyck model. These conditions are set out in the Appendix in this paper.

2. THE IMPORTANCE OF DIFFERENT INDUSTRIAL CHARACTERISTICS

Based on the theoretical analysis conducted in Darby et al. (1999, 2002), it is possible to identify three classes of industries:

- *Group 1*: industries with a low scrapping price. These industries are characterized by having investments with a low resale value. If they invest, they stand a high chance of getting stuck with an (ex-post) unwanted investment. Consequently, they are likely to respond to a fall in uncertainty by waiting.
- *Group 2*: industries with a high scrapping price and high opportunity cost of waiting. Contrary to the industries in the previous group, industries in this group stand a low chance of getting stuck with an ex-post unwanted investment. However, as waiting is very costly for them, they are even likely to respond to a rise in volatility by continuing to invest. Similarly, in an environment characterized by a highly volatile and misaligned currency, they will respond to any increase in misalignment by investing more. But, if the underlying volatility is low, they will react to an increase in misalignment by waiting.
- *Group 3*: industries with a high scrapping price and low opportunity cost of waiting. For these industries waiting is not costly and retooling, in the sense of adjusting their infrastructures to the production of a different

product, is not expensive. Consequently, they are likely to respond to an increase in volatility by waiting and, conversely, to any fall in volatility by investing. The same type of decision (i.e. waiting) will appear in response to an increase in misalignment, in a high volatility environment. But if the underlying volatility is low, then these firms are likely to respond to a rise in misalignment by investing more.

To reiterate therefore, Group 1 includes industries where investment has a low scrapping price – such as power plants, mines, utilities – or industries that involve high tech manufacturing with high development costs. Here, price uncertainty should have a positive effect on investment. Group 2 includes those industries with high scrapping prices and a high opportunity cost of waiting, such as financial services as well as those with high margins and which are cyclically sensitive or depend on patents or technical innovations. In these cases too, price volatility would have a positive effect on investment. Group 3 consists of the remaining industries, with high scrapping prices and low waiting costs. This group would consist mainly of conventional manufacturing involving medium skills and technology, or service industries where retooling is relatively easy and the cycle is unimportant. Table I summarizes the differences in reaction across industries.

III. Empirical Tests

In this section, we investigate whether the theoretical intuitions set out in the previous section are confirmed by the data.

To do this, we estimate investment equations for 13 different industries (listed in Table II), using 13 panels of data obtained from nine OECD countries over the period 1970–2000. The results of our panel estimations are summarized in Tables III–VI, covering the pooled estimates of the long-run (equilibrium) relations for each industry (Tables III–V) and the short-term, country specific, deviations from those equilibrium relationships (Table VI). These tables report the signs of the coefficients and are designed to be compared with the theoretical results quoted above.[6]

1. THE DATA

Our data relate to nine countries and to 13 industries in each country. The countries we consider are Austria, Canada, Finland, France, Germany, Italy, Sweden, the U.K. and the U.S. The industrial sectors, which are defined according to the International Standard Industrial Classification, are reported in Table II (together with the terminology adopted in the tables and charts). The industries are organized in the three groups identified at the previous section and correspond to data at the 2-digit level of industrial activity.

Table I. Different industries have different investment reactions

Industry type	Examples	Reaction to a fall in volatility	Reaction to a fall in misalignment
Group 1: low scrapping price	Power plants/utilities	Fall in investment (+ve)	Fall in invest. (+ve)
Group 2: high scrapping price/high opportunity cost of waiting	Financial services/cyclically sensitive industries	Fall in investment (+ve)	With high vol.: fall in invest. (+ve). With low vol.: rise in invest. (−ve)
Group 3: high scrapping price/low opportunity cost of waiting	Medium or low skills manufactures	Rise in investment (−ve)	With high vol.: rise in invest. (−ve). With low vol.: fall in invest. (+ve)

Note: + ve denotes a positive reaction; -ve denotes a negative reaction.

Table II. Industrial sectors

Group 1	
CHEM	Chemical, rubber, plastics and fuel products
UTIL	Electricity, gas and water supply
Group 2	
TEXT	Textiles, textile products, leather and footwear
TRANS	Transport equipment
PAP	Pulp, paper, paper products, printing and publishing
FIN	Finance, insurance, real estate and business services
Group 3	
BM	Basic metals, metal products, machinery and equipment
FOOD	Food products, beverages and tobacco
MACH	Machinery and equipment
MIN	Mining and quarrying
NEC	Manufacturing NEC (non-electronic components)
NMET	Other non-metallic mineral products
WOOD	Wood and wood and cork products

Table III. The long run (equilibrium) relationships

Specification	Model type
Price and nominal e/r volatility	
$linv = \alpha_0 ly + \alpha_1 p_vol + \alpha_2 p_mis\ (+\alpha_3 p_mis_{+ve}) + \beta_1 eer_vol$ $+ \beta_2 eer_mis\ (+\beta_3 eer_mis_{+ve})$	(a)
$linv = \alpha_0 ly + \alpha_1 p_vol + \alpha_2 p_mis + \alpha_4 p_msp + \beta_1 eer_vol$ $+ \beta_2 eer_mis + \beta_4 eer_msp$	(b)
Real e/r volatility	
$linv = \gamma_0 ly + \gamma_1 reer_vol + \gamma_2 reer_mis\ (+\gamma_4 reer_mis_{+ve})$	(c)
$linv = \gamma_0 ly + \gamma_1 reer_vol + \gamma_2 reer_mis + \gamma_4 reer_msp$	(d)

Second, our data are measured at an annual frequency and cover the period 1970–2000. For each sector and each country, the dataset includes time series of investment (gross fixed capital formation), production and measures of producer price volatility and misalignment. The latter are used as industry-specific proxies for exchange rate volatility and misalignment. However, alternative models directly involving nominal and real exchange rate volatility and misalignment measures are also examined. Our main data source is the OECD STAN database and the OECD Indicators for Industry and Services. However, producer prices for the sectors MACH, MIN, NEC,

Table IV. Pooled results

Industry	*eer_vol*	*p_vol*	*eer_mis*	*p_mis*	*eer_msp*	*p_msp*	eer_mis_{+ve}	p_mis_{+ve}
(a) *Nominal exchange rates and producer prices*								
CHEM	+	+	+	None	−	None	None	None
UTIL	None	None	None	None	None	None	None	None
TEXT	+	None	None	None	None	None	None	None
TRANS	−	None	None	None	None	None	None	None
PAP	+	None	−	None	None	None	None	None
FIN	−	None	+	None	None	None	−	None
BM	+	−	±	None	+	None	+	None
FOOD	−	−	−	−	+	+	+	+
MACH	−	None	None	None	None	None	None	None
MIN	−	−	None	None	−	None	None	None
NEC	−	None	None	None	+	None	None	None
NMET	−	−	+	None	−	None	None	None
WOOD	None	None	None	None	None	None	None	None
(b) *Real exchange rates*								
	reer_vol		*reer_mis*		*reer_msp*		$reer_mis_{+ve}$	
CHEM	±		+		−		−	
UTIL	−		−		None		None	
TEXT	−		+		−		+	
TRANS	+		−		None		+	
PAP	+		+		+		+	
FIN	−		+		None		−	
BM	+		−		+		None	
FOOD	+		−		+		None	
MACH	None		None		None		None	
MIN	None		None		None		None	
NEC	None		None		None		None	
NMET	−		+		None		−	
WOOD	−		+		−		−	

NMET, TRANS and UTIL are taken from the Eurostat database. The source of the nominal effective exchange rate series is the Bank of England FST. The real effective exchange rate series were provided by the OECD.

In Darby et al. (1999, 2002), two different measures of exchange rate volatility were used. They both involved rolling estimates of the standard deviation of the variable under consideration, either in level terms or in the form of deviations from a time-varying equilibrium path. That is, volatility was defined as

Table V. How the empirical results compare with the theoretical predictions

Industry type	Example	Reaction to a fall in volatility	Reaction to a fall in misalignment
Group 1: low scrapping price	Power plants/mines/ utilities	Fall in invest. (+ve) CHEM[a,b],UTIL[c]	Fall in invest. (+ve) CHEM[b,c]
Group 2: high scrapping price/ high opportunity cost of waiting	Financial services/cyclically sensitive industries	Fall in invest. (+ve) TEXT[b], PAP[b,c], TRANS[c]	With high vol.: fall in invest. (+ve) FIN[b,c], TEXT[c], PAP[c]
			With low vol.: rise in invest. (−ve) PAP[b,c], TRANS[c]
Group 3: high scrapping price/low opportunity cost of waiting	Medium or low skills manufacturing	Rise in invest. (−ve) BM[a], FOOD[a,b], MIN[a,b], NMET[a,b,c], MACH[b], NEC[b], WOOD[c]	With high vol.: rise in invest. (−ve) BM[b,c], FOOD[a,b,c]
			With low vol.: fall in invest.(+ve) NMET[b,c], WOOD[c]

[a] Producer price.
[b] Nominal exchange rate.
[c] Real exchange rate.

$$V = \left[\frac{1}{m}\sum_{i=1}^{m}(\ln(Z_{t-i}) - \ln(Z_{t-i-1}))^2\right]^{1/2} \quad (1)$$

with Z denoting the real exchange rate either in levels (Darby et al., 1999) or as deviation from a trend extracted using a HP filter (Darby et al., 2002). In this paper, we use both definitions of volatility, the Z variable being in turn producer prices, or the nominal or real effective exchange rate (either in levels, in the case of the first definition, or as a deviation from the HP trend in the case of the second definition).[7]

We then use three measures of misalignment. The first one, denoted in what follows as *p_mis*, *eer_mis* and *reer_mis* for producer prices, the nominal and the real effective exchange rate respectively, is simply defined as the deviation of the producer price (exchange rate) from its trend. The second, denoted *p_msp*, *eer_msp* and *reer_msp* for producer prices, the nominal and the real exchange rate, is a sign-preserving measure of misalignment, defined as the squared deviation of the producer price (exchange rate) from the trend, with a positive (negative) sign when the producer price (exchange

Table VI. Short-run country-specific coefficients on volatility[a]

Industry	*eer_vol*	*p_vol*	*reer_vol*
CHEM	−UK;US−Sweden[b]	−France; US	+ UK−Italy
UTIL	None	None	+ Sweden
TEXT	−France; US; Italy	None	+ Sweden[c]
TRANS	+ France	None	−France; Finland; Sweden
PAP	−Italy	None	−France; US; Italy; Sweden
FIN	−Canada + France	None	None
BM	+ UK−Finland/Sweden	None	−France; Austria; Sweden
FOOD	+ Austria; Canada; Sweden−Italy; Finland	None	−Italy
MACH	+ UK	None	None
MIN	+ Italy	+ Finland−Sweden	None
NEC	None	None	None
NMET	+ Finland	+ France; UK−Sweden	None
WOOD	None	None	+ Finland; Italy

[a] The reported signs are those of the coefficients on the first difference of nominal exchange rate, price and real exchange rate volatility. They represent the short-run impact multipliers, country by country, of an increase in price or exchange rate volatility on investment expenditures in each industry.
[b] The sign of the effect turns positive if the sign preserving measure of misalignment is added to the long run relationship.
[c] The sign of the effect turns negative if a term in positive misalignments is added to the long run relationship.

rate) is above (below) the trend. This measure is used to test for the presence of the effects of asymmetry in size. A third measure, denoted p_mis_{+ve} eer_mis_{+ve} and $reer_mis_{+ve}$ for producer prices, the nominal and the real exchange rate, is a dummy variable assuming the value of the misalignment in the case of positive misalignments and zero otherwise. It is used to test for the presence of sign asymmetries in the impact of misalignment on investment spending.

Finally, our data are divided into 13 panels, one for each industry. Each panel pools together data for a specific industrial sector across a set or subset of the countries considered.[8]

2. THE EMPIRICAL METHODOLOGY

In the investment model set up in the previous section, two error processes are being modeled: one in the prices or exchange rates upon which the investment decisions are conditioned, and one in the investment decisions

themselves. The theoretical model also makes clear that $\alpha > 0$, for example, implies that markets expect prices to rise, which means that P_{H} would rise too and hence (under the conditions discussed above and formally derived in the Appendix) that investment will fall if the upper tail of the price/exchange rate distribution does not increase in size. The results derived in Darby et al. (1999, 2002) show that that will not happen. Consequently, the price/exchange rate disturbances necessarily create a negative feedback loop in this model. In other words, our investment model implies mean reverting (error correction) behavior in the investment decisions. Thus, to tie the empirical work to our theoretical model, we have to incorporate an error correction mechanism in the former and test it for mean reversion. This is what was done in Darby et al. (1999, 2002) using aggregate data. It is further developed here using disaggregated data in order to test the industrial structure implications, which lie at the heart of our theory. Those implications were reported in Section II.2.

The main constraint faced when estimating an investment model at the industry level is the lack of disaggregated data covering all the variables of potential interest. For this reason, the model we estimate in the following section has to be simpler than those estimated in previous studies of investment under uncertainty. In contrast to Darby et al. (1999, 2002), for example, our investment model includes only industrial production and the measures of volatility and misalignment described above.[9]

However, as in Darby et al. (1999, 2002), the estimation methodology is still essentially an error correction model approach. In a panel context, this is implemented in the form of a pooled mean group estimation (PMGE) procedure for heterogeneous panels, as introduced by Pesaran et al. (1999). The choice of this methodology is dictated by the size of our panels. With a maximum time dimension of $T = 31$ and maximum cross-section dimension of $N = 9$, the panels are too small for the application of more sophisticated methodologies. In fact, more elaborate techniques are usually designed for panels having at least one "large" dimension.[10] Hsiao et al. (1998) have shown that if at least one of the dimensions is small, the mean group estimator (MG) [which consists of the mean of the estimates obtained estimating separate equations for each group] although consistent, is not a good estimator. The next best approach is the PMGE estimator, which remains consistent for $T \rightarrow \infty$ (Pesaran et al., 1999).[11]

The main benefit of the PMGE procedure is that, for a given panel, it constrains only the long-run coefficients to be identical. Intercepts, short-run coefficients and error variances can vary across groups. In fact, Pesaran et al. (1999) have shown that this weak homogeneity assumption is preferable to the strong homogeneity assumption required by alternative estimation procedures such as fixed effects, IV or GMM – if only because the latter may provide very misleading estimates if the underlying coefficients are indeed

different across groups. In the context of investment models, similarity between the technologies in use in a given industry across countries could justify having specified identical long-run relationships across countries. Moreover, there are no strong priors suggesting that the adjustment dynamics in the investment equation for a specific industry should also be identical across countries. Indeed, the impact of uncertainty could still be very different, even if of the same sign, for a variety of institutional or structural reasons.

A final benefit of the PMGE methodology is that it does not require stationarity of the regressors. As Pesaran et al. (1999) demonstrate, pool mean group estimators are consistent and asymptotically normal (as T, and therefore T/N, tends to ∞) in the case of either stationary or non-stationary regressors.[12] Panel unit root tests of the variables involved in the estimations that follow, both in levels and first difference (available from the authors on request[13]), suggest that these variables are either $I(0)$ or $I(1)$. In particular, volatility and misalignment measures of both prices and exchange rate appear to be stationary. From a time series analysis perspective, their role in the error correction term is therefore to provide information on the adjustment process to the long-run value of the investment to production ratio. In other words, their insertion in the error correction term could be considered redundant and they could well be relegated to the short-run dynamics only. However, the real reason for including them in the error correction term is to capture the fact that, in the continuous time space in which we locate our analysis, prices and exchange rate volatility and misalignments all affect the individual firm's *probability* of no action.

3. THE ESTIMATING EQUATIONS

In this paper we compute PMGE estimators using the GAUSS program distributed by Pesaran and Shin. The starting point is the estimation of an ARDL(p, q) model in the form

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{it-j} + \sum_{j=0}^{q} \delta'_{ij} x_{it-j} + \mu_i + \varepsilon_{it} \qquad (2)$$

with x_{it}, the vector of regressors for group i; μ_i, the fixed effects; λ_{ij}, scalars and δ_{ij}, the vector of coefficients. By re-parameterizing and stacking time series observations together, the model can be rewritten in the following error correction form:

$$\Delta y_i = \varphi_i y_{i,-1} + X_{i,-1}\beta_i + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta y_{i,-j} + \sum_{j=0}^{q-1} \Delta X_{i,-j} \delta^*_{ij} + \mu_i \imath + \varepsilon_i \qquad (3)$$

where $y_i = (y'_{i1} \ldots y'_{iT})'$ and $X_i = (X'_{i1} \ldots X'_{i1T})'$ are the stacked vector of dependent variables and the stacked matrix of regressors respectively; and

where λ^* and δ^* are linear combinations of the parameters in (2) specified as follows:

$$\lambda^*_{ij} = -\sum_{m=j+1}^{p} \lambda_{im} \quad j = 1, 2, \ldots, p-1 \quad \text{and} \quad \delta^*_{ij} = -\sum_{m=j+1}^{q} \delta_{im} \quad j = 1, 2, \ldots, q-1 \tag{4}$$

Assuming that a long-run relationship[14] exists between y_{it} and x_{it} with coefficients identical across groups, and assuming that disturbances ε_{it} are normally and independently distributed across countries, the parameters in Equation (3) are estimated using a maximum likelihood approach which involves maximizing the log-likelihood function by means of the Newton–Raphson algorithm. Further details can be found in Pesaran et al. (1999).

Table III summarizes our equilibrium specifications. For each industry, we estimate a suite of models and apply a general to specific approach to derive a parsimonious (but statistically significant) specification. Model (a) supposes the logarithm of production (*ly*), producer price volatility (*p_vol*) and misalignment (*p_mis*) as well as exchange rate volatility (*eer_vol*) and misalignment (*eer_mis*) as the only determinants of (the logarithm of) investment expenditures (*ly*). A term in positive misalignment ($p_mis_{+\text{ve}}$ for prices and $eer_mis_{+\text{ve}}$ for exchange rate) is also added to test for the presence of asymmetric responses of investment to prices or exchange rate misalignments. Model (b) then adds the sign-preserving measure of misalignment (*p_msp* for prices, and *eer_msp* for the exchange rate).[15]

Models (c) and (d) are analogous to models (a) and (b), the difference being the use of real effective exchange rate volatility (*reer_vol*) and misalignment measures (denoted *reer_mis*, where $reer_mis_{+\text{ve}}$ indicates as before the term in positive misalignment and *reer_msp* denotes the sign-preserving measure of misalignment) in place of producer prices and nominal exchange rate volatility and misalignment.

For some panels, the estimation was conducted using data expressed as deviations from their respective cross-sectional means. This procedure allows us to eliminate or reduce the impact of common time-specific effects. In some cases, these effects indeed appear to be the predominant ones, overshadowing the effects of other variables. Therefore, they need to be netted out in order to be able to single out the impact of exchange rate/producer prices volatility and misalignment on the level of investment.

In each panel, we test for homogeneity of the long-run coefficients and the error correction term using the Hausman test. Pesaran et al. (1999) argue that pooled mean group estimators are consistent and efficient only if homogeneity holds. Conversely, if the hypothesis of homogeneity is rejected, the PGME estimates are not efficient. In that case the mean group estimators would normally be preferred.

IV. Results

Table IVa and IVb contain the general results from the long-run pooled estimation (PMGE) procedure for each group of industries in turn. These estimates correspond to the various equilibrium relationships summarized in Table III. Table V compares these results with the theoretical predictions outlined in Section II. Table VI then sets out any country-specific deviations in those coefficients in the short run – including any changes in sign – corresponding to the short-term dynamic relationship given in Equation (3).[16]

1. THE LONG-RUN IMPACT OF PRICE AND EXCHANGE RATE UNCERTAINTY

Table IVa and IVb show that conventional wisdom – namely that the impact of price or exchange rate uncertainty on investment is likely to be negative in the long run – is *not* well supported in the data. As far as domestic price uncertainty is concerned, it has remarkably little impact on investment. Only five industries out of 13 actually show any significant effect: four of them negative and one positive. The majority (that is 8 out of 13 or 60%) shows no significant effect.

It is true that the negative impacts belong to the medium skills and technology category (Basic Metals, Mining/quarrying, and Non-Metal Products) where retooling might be easy and the state of the economic cycle relatively unimportant. Conversely the positive impacts belong to industries that are technologically developed with high sunk costs (Chemical, Plastics and Fuels Production and Processing). To that extent, these results confirm our theoretical predictions exactly.

But the interesting finding is that the majority of industries shows no systematic impact from price uncertainty, and for those that do, the impact is relatively small and (mostly) less significant than the impacts of exchange rate uncertainty. There are two exceptions: the Mining sector and the Basic Metal sector. In the former, the impact of price volatility is larger than that of nominal exchange rate volatility while the latter is the only industrial sector that shows a significant interaction between price volatility and exchange rate volatility. Furthermore, the two impacts are differently signed. Thus price uncertainties are clearly less important than exchange rate uncertainty, and it would be a mistake not to separate these two effects (although few studies have done so in the past).

Second, the exchange rate uncertainty results also confirm our theoretical intuition, irrespective of whether the exchange rate variability is in real, nominal or misalignment terms. Thus, Chemical Products and Fuels, Textiles and Footwear, Food Manufacturing, Transport and Paper/Printing/Publishing all show evidence of a positive impact of exchange rate uncertainty on investment as we might expect from the theoretical analysis since these are

high tech/high skill industries, or those with substantial entry and development costs, or industries which are dependent on the cycle.[17]

The interesting cases, however, are Chemicals, Food, Textiles and Transport, which reveal a sign switch depending on whether the uncertainty is measured in real or nominal terms. Chemicals and Textiles are industries where uncertainty has a positive impact in the nominal case but a negative impact for real exchange rates. In contrast, Food and Transport are industries that show the opposite result. In fact, it is possible to demonstrate that such sign reversals can occur when the degree of price uncertainty in domestic and foreign prices is very different. In particular, having greater uncertainty in foreign prices will show the kind of sign reversal we see in the Chemical and Textile industries, while having greater uncertainty in domestic prices will produce the sign reversal we see in the Transport and Food results. In either case, the relative price uncertainty needs to exceed that in the nominal exchange rate. However, that is exactly what we would expect: Chemicals and Textiles, being widely traded, will react more to "foreign" (i.e., rest of the world) price uncertainty – but they are not large enough as industries to dominate the exchange rate in most OECD economies. Food and Transport, on the other hand, would respond more to domestic price uncertainty in most industrialized economies. For transport that is perhaps obvious but for Food, it is important to bear in mind that processed foods are generally culture specific and not widely traded. This is in contrast to agricultural products (not analyzed here) which include many primary commodities and which are widely traded internationally.[18]

2. THE LONG-RUN IMPACT OF MISALIGNMENT EFFECTS

There are two aspects of the results to consider here: the fact that misalignments may affect (either reduce or encourage) investment expenditures and that large misalignments may matter more (i.e., have a more than proportionate impact) than small misalignments. These two effects are captured by the terms "*-mis*" and "*-msp*" in each regression. From the results in Table IVa and IVb we can see that:

(a) Misalignments do matter; departures from the trend by exchange rates or prices affect investment in excess of any of the effects that volatility or other explanatory variables would cause on their own. Investment is either reduced or encouraged by such price or exchange rate misalignments in 10 out of 13 industries.
(b) Price misalignments on their own do not matter; they show up only in the Food industry. Real exchange rate misalignments, however, affect investment in 10 industries, and are the only kind of misalignments that matter in four of them (Textiles, Transport, Utilities and Wood). Finally, nominal exchange rate misalignments matter in another six cases, leaving

only three industries (Machinery, Mining and Manufacturing, Non-Electronic Components) which are unaffected by misalignments altogether. Thus, if misalignments matter, it is through exchange rates and competitiveness effects – not domestic pricing.

(c) Departures from the trend in the sense of a currency overvaluation (nominal exchange rate above the trend, and hence *e* below it) enhance investment in only three cases (Chemicals, Financial and Non-Metal Products), and reduce it in two cases (Food and Paper). Conversely, an undervaluation increases investment in two cases and reduces it in 3. There are therefore three industries unaffected by real or nominal misalignments in exchange rates. In as far as we can allocate industries to the groups defined in Section II.2, these results support the theoretical predictions for Chemicals or Financial Products but not those for the Food and Paper industries.

(d) More interestingly perhaps, the non-proportionality tests ("-*msp*") suggest large misalignments matter in four industries – those with a plus sign in the "_*msp*" columns – but small misalignments are more important in five cases (those with a minus sign). Hence, the impact of uncertainty and misalignments is non-linear in most cases. As a result, we have included an explicit asymmetry test: the "$_mis_{+\mathrm{ve}}$" variables in Tables IVa and IVb. For nine sectors out of 13 the impact coefficient of a plus misalignment (an overvaluation) appears to be quantitatively different from that of a minus misalignment (an undervaluation). Positive misalignments therefore appear to increase investment in the OECD's less widely traded products (Textiles, Food, Transport, Paper and Basic Metals); but to decrease it in the more widely traded goods (Chemicals, Financial Services, Non-Metal Products and Wood Products).

Given the results reported in Section II, these outcomes support our theoretical predictions reasonably well for the traded goods that belong to group 1 industries (e.g., Chemicals), or group 2 industries with volatile prices (e.g., Financial services), or group 3 industries with stable prices (Non-Metal and Wood Products). The same is true for the less traded goods in group 2 if prices tend to be stable (Food, Transport), or those in group 3 with unstable prices (Basic Metals). We have summarized the extent to which our empirical results confirmed our theoretical predictions in Table V. For volatility, the theory is confirmed in 12 out of 13 cases. For misalignments, there is confirmation for nine out of 13 industries.

3. COUNTRY-SPECIFIC AND SHORT-TERM DEPARTURES FROM THE EQUILIBRIUM RELATIONSHIPS

Table VI summarizes the various short-term, country-specific departures from the estimated equilibrium relationships in Table III which we have used

so far. These dynamic relationships take an error correction form with an autoregressive distributed lag specification with up to three lags; see Equation (3). The length of the lags was determined separately for each industry in each country by one of the information criteria available (Schwartz, Akaike or Hannan-Quinn Selection Criterion), and only the significant coefficients are retained in the final estimated relationship.[19]

In the short term, a number of countries show deviations from the sign pattern established in Table IVa and IVb. There is a little more evidence of price uncertainty having some short-term influence on investment – but positive this time in the Mining sector in Finland and Sweden; and positive in Non-Metal manufacturing for France and the U.K., but negative for Sweden. Only the French and British results are strong enough to produce a sign reversal for the impact of long-run uncertainty on investment.

There are a larger number of short-term deviations in the impact of nominal exchange rate uncertainty, although only in the case of the Food industry does that involve a majority of countries. Furthermore, only 17 out of the 117 possible country-specific coefficients display a sign reversal in the short-term impact of nominal exchange rate uncertainty. The industries most affected are Basic Metals/Machinery, Chemicals and Textiles, where the positive impact of exchange rate uncertainty would be overturned in one case each; and Food, Machinery, Non-Metal Manufacturing and Paper, where the negative impact would be reversed in one case each.

In terms of real exchange rates, there are even fewer short-term departures from the general sign pattern: 14 out of a total of 117 possible country-specific coefficients. Taking all these results together, plus the fact that there seem to be no significant departures from the pattern of misalignment effects in Table IVa and IVb, we find that our results appear to be remarkably robust across countries and across time periods.

Two further results are of interest in this context. First, one might suppose that a higher degree of openness would imply that industries are trying to diversify their input services and export markets. That would reduce the impact of volatility. However introducing an openness variable into our regressions yielded insignificant results in each case, so that turns out not to be an issue in practice.

Second, one might suppose that the nature of the shocks might affect the impact which volatility has on investment. But since the Dixit–Pindyck model just indicates two trigger prices for any type of shock, in this framework it would not matter what kind of shock disturbed the output price. However, there is the possibility that industry specific vs. economy wide shocks would make a difference. This has yet to be investigated because it depends on finding a satisfactory way of decomposing aggregate shocks into their (exclusive) industry and economy-wide components, a subject for further research.

V. Conclusions

The results of the cross-industry empirical investigation conducted in this paper have provided six new conclusions about the impact of uncertainty on investment behavior:

(1) There can be no general presumption that increasing price or exchange rate uncertainties reduce investment. For some industries the effect will be negative but for others it will be positive. The overall effect, in a specific economy, will therefore depend on the precise industrial structure of that economy.
(2) In the 13 industries studied here, price uncertainty played little role independently of exchange rate effects. That said, price uncertainty depressed investment in four cases and enhanced it in one case, leaving eight industries unaffected. In contrast, nominal exchange rate uncertainty depressed investment in seven cases, but enhanced it in four while real exchange rate uncertainty depressed it in five industries, but increased it in five. Thus, while the negative impacts are in the majority, they are only in a small majority and several industries show a positive impact.
(3) The sign pattern of these uncertainty effects supports our theoretical predictions rather well. Those industries with obviously low scrapping costs or high development and entry costs, show a positive impact of price or exchange rate uncertainty on investment – as do those with higher scrapping costs, but a high opportunity cost of waiting. Those with lower waiting costs show a negative effect, as predicted.
(4) Real and nominal exchange rate uncertainty can produce contrary effects, or the same effects, on investment depending on whether the underlying price uncertainties are at home or abroad.
(5) Price or exchange rate misalignments are also important but price misalignments alone are seldom significant. Thus it seems likely that the issue of imperfect competition, which has been so important in the literature, is in fact quantitatively unimportant in practice. Exchange rate misalignments, on the other hand, appear to be important in most cases, implying that undervaluations will encourage domestic investment. That is consistent with the theory for markets where group 1 industries or group 2 industries with stable prices predominate. But the effects are likely to be both asymmetric (undervaluations have more impact than overvaluations) and disproportionate (large misalignments are more important than small misalignments).
(6) And finally, we have introduced an important caveat to aggregate studies that conclude that greater exchange rate stability will, in itself, lead to increased investment expenditures (for instance, Byrne and Davis, 2003). This is a consequence of the disaggregated, industry level approach that we

use here. There are several reasons for this conclusion. First exchange rates are seldom fixed against the rest of the world as a whole. This is an important qualification to the assumption that the nominal *effective* exchange rate will be less volatile than before. Second, even if the effective exchange rate is stabilized, some industries will see rising investment – but others falling investments, depending on their actual scrapping value and opportunity cost of waiting. Thus the net effect could go either way. Third, there are possible misalignments to take into account as firms base their investment decisions not only on the underlying degree of volatility in the economy but also the current position of the exchange rate with respect to its long-run value. Fourth, the sign of the nominal exchange rate uncertainty effect can easily become reversed by uncertainty in real exchange rates or in the degree of competitiveness. That effect therefore depends on whether the uncertainty is caused by events at home or abroad.

Lastly, we have maintained the conventional assumption of the Dixit–Pindyck model that the firm is a price taker in the product and foreign exchange markets throughout this paper. There are therefore no pricing decisions. An interesting extension of this work would be to examine the impact of uncertainty on investment if the firm can decide between local and domestic currency pricing. Endogenous pricing decisions in the style of those recently analyzed in Bacchetta and van Wincoop (2001) would be the next natural stage of research.

Appendix

THE DIXIT–PINDYCK INVESTMENT MODEL

Consider a firm evaluating an investment decision that, if taken, will involve producing a certain amount of output forever. There is a sunk cost to the investment that the firm must pay once it decides to invest. The firm's inverse demand function may be written as

$$P = eD(Q) \tag{A1}$$

where e is the exchange rate and $D(Q)$ is the firm's revenue in units of a numeraire or foreign currency. Hence P is the output price received, measured in domestic currency units, while $P_f = P/e$ is the foreign currency price, or the price in a competing sector. The firm is a price taker in both the product and the currency markets.

For convenience we take P_f to be normalized at unity. That means e represents the price of domestic currency per unit of "foreign" currency and P and e are interchangeable as far as analyzing the impacts of uncertainty are concerned while $D(Q)$ remains fixed. Now suppose domestic prices follow a Brownian motion

$$dP = \alpha P\,dt + \sigma P\,dz \tag{A2}$$

where dz is normally distributed with zero mean and variance dt. That reduces the problem to one of price uncertainty, whether that uncertainty arises in the domestic market or through the foreign markets. The key parameters are: α, a measure of the predictable movements in prices away from their current values, and σ, a measure of their potential volatility.

Note that the term in α implies some persistence in prices, but in the following sense: because (A2) ensures stochastic separability between time periods, first period certainty equivalence will apply to each output and each investment decision. That means the current state of a project's profitability will be known, but its future state and its future rate of return remain uncertain. Multiperiod certainty equivalence will be able to take care of that in due course. However, in the current period, $\alpha > 0$ means that firms think that prices are more likely to go down than up in the next period (and *vice versa* if $\alpha < 0$; Pindyck, 1988). That would be a market definition of a misalignment in prices: an overvaluation if $\alpha < 0$ because prices are either falling or are expected to fall. Hence prices must be above trend. Conversely, we will have an undervaluation if $\alpha < 0$. Only if we have no information on which way prices are more likely to move next would we expect to have $\alpha = 0$.

With exchange rates however, we get the opposite interpretation. Given that e is defined as the price of domestic currency per unit of foreign currency, $\alpha < 0$ in the equivalent relationship for e would imply a predicted fall in e – and hence an appreciation. Hence $\alpha < 0$ implies an undervaluation of the exchange rate and $\alpha > 0$ an overvaluation from the domestic stand point with e itself having been below trend.

The Dixit–Pindyck analysis now proceeds by maximizing the expected discounted value of the project per unit of output

$$V(P) = P/\delta \quad \text{where} \quad \delta = \mu - \alpha$$

with μ, the firm's discount rate, and δ, the opportunity cost of waiting. The firm will only invest if the present value of the expected revenues is higher (by an amount equal to the value of waiting) than the sunk cost of entry I. Likewise it will only disinvest if expected revenues fall below the exit cost, E. In other words, two threshold prices P_{H} and P_{L} have to be computed such that the decision becomes "invest if the price P rises above P_{H}, but abandon if P falls below P''_{L}. The investor should wait between P_{H} and P_{L}.

MODEL SOLUTION

Let $V_0(P)$ be the value of the option of waiting to invest and $V_1(P)$ the value of the active firm – i.e. the sum of the profits expected from being active plus the value of the option to abandon. The threshold values, P_{H} and P_{L}, can now be determined using the value matching and smooth pasting conditions:

$$V_0(P_{\mathrm{H}}) = V_1(P_{\mathrm{H}}) - I \quad V_0'(P_{\mathrm{H}}) = V_1'(P_{\mathrm{H}}) \tag{A3}$$

$$V_1(P_L) = V_0(P_L) - E \quad V_1'(P_L) = V_0'(P_L) \tag{A4}$$

Dixit and Pindyck show that the solution to (A3) and (A4) can be obtained from

$$\left.\begin{aligned} &-A_1 P_H^{\beta_1} + B_2 P_H^{\beta_2} + P_H/\delta - C/r = I \\ &-\beta_1 A_1 P_H^{\beta_1 - 1} + \beta_2 B_2 P_H^{\beta_2 - 1} + 1/\delta = 0 \\ &-A_1 P_L^{\beta_1} + B_2 P_L^{\beta_2} + P_L/\delta - C/r = -E \\ &-\beta_1 A_1 P_L^{\beta_1 - 1} + \beta_2 B_2 P_L^{\beta_2 - 1} + 1/\delta = 0 \end{aligned}\right\} \tag{A5}$$

where (i) $0 < P_L < P_H$; (ii) A_1 and B_2 are nonnegative variables; and (iii) where

$$\begin{aligned} \beta_1 &= \frac{1}{2} - (\rho - \delta)/\sigma^2 + \sqrt{\left[(\rho - \delta)/\sigma^2 - \frac{1}{2}\right]^2 + 2\rho/\sigma^2} > 1 \\ \beta_2 &= \frac{1}{2} - (\rho - \delta)/\sigma^2 - \sqrt{\left[(\rho - \delta)/\sigma^2 - \frac{1}{2}\right]^2 + 2\rho/\sigma^2} < 0 \end{aligned} \tag{A6}$$

In this we assume α and σ are known, but not necessarily constant, at each time t, and that ρ is the private sector's discount rate: $\mu = r + \phi\rho\sigma$.

If increasing volatility or systematic misalignments were to reduce investment, we should expect to find that

$$\frac{\partial(P_H - P_L)}{\partial\sigma} > 0 \quad \text{and} \quad \frac{\partial(P_H - P_L)}{\partial\alpha} > 0 \tag{A7}$$

These inequalities imply that the zone of inactivity, i.e. the range of prices over at which there is no new investment, will widen with increasing values of α and σ. In practice, however, we have to check that the frequency with which the upper trigger price is exceeded does not also increase at the same time. If it did, a widening of the band in which no investment is undertaken might not lead to less investment overall. To do that we have to check that $\partial G(P_H)/\partial\sigma \leq 0$ holds, where $G(\cdot) = 1 - F(\cdot)$ and $F(\cdot)$ is the probability *distribution* function of prices or the exchange rate. This condition is demonstrated in Darby et al. (1999). Similarly, the condition for the frequency with which P_H is exceeded when the degree of misalignment increases, is not increased is $d\alpha \leq d\log(P_H)$, i.e. the proportional increase in any undervaluation must be no greater than the increase in P_H itself (Darby et al., 2002). These restrictions need to be incorporated to ensure that a widening of the zone of inactivity necessarily implies lower investment spending.

CONDITIONS UNDER WHICH INCREASING PRICE/EXCHANGE RATE VOLATILITY REDUCES INVESTMENT EXPENDITURES

We can evaluate the partial derivatives for $P_H - P_L$ with respect to σ using (A5) to define the model's solution, plus the inequality constraints

$P_H > P_L \geq 0$ and $(A_1, B_2) > 0$ from Dixit (1989). After some algebra we have

$$\frac{\partial P_H}{\partial \sigma} = \left[A_1 \frac{\partial \beta_1}{\partial \sigma} P_H^{\beta_1 - 1}(1 + \beta_1 \log(P_H)) - B_2 \frac{\partial \beta_2}{\partial \sigma} P_H^{\beta_2 - 1}(1 + \beta_2 \log(P_H)) + \beta_1 P_H^{\beta_1 - 1} \frac{\partial A_1}{\partial \sigma} - \beta_2 P_H^{\beta_2 - 1} \frac{\partial B_2}{\partial \sigma} + \varphi\rho/\delta^2 \right] / C_1 \tag{A8}$$

and

$$\frac{\partial P_L}{\partial \sigma} = \left[A_1 \frac{\partial \beta_1}{\partial \sigma} P_L^{\beta_1 - 1}(1 + \beta_1 \log(P_L)) - B_2 \frac{\partial \beta_2}{\partial \sigma} P_L^{\beta_2 - 1}(1 + \beta_2 \log(P_L)) + \beta_1 P_L^{\beta_1 - 1} \frac{\partial A_1}{\partial \sigma} - \beta_2 P_L^{\beta_2 - 1} \frac{\partial B_2}{\partial \sigma} + \varphi\rho/\delta^2 \right] / C_2 \tag{A9}$$

where

$$C_1 = -A_1\beta_1(\beta_1 - 1)P_H^{\beta_1 - 2} + B_2\beta_2(\beta_2 - 1)P_H^{\beta_2 - 2}$$
$$C_2 = -A_1\beta_1(\beta_1 - 1)P_L^{\beta_1 - 2} + B_2\beta_2(\beta_2 - 1)P_L^{\beta_2 - 2}$$

We can also deduce that $\partial\beta_1/\partial\sigma < 0$ and $\partial\beta_2/\partial\sigma > 0$ directly from (A6). In addition, $\partial A_1/\partial\sigma > 0$ and $\partial B_2/\partial\sigma > 0$ follows directly from (A5) for smaller values of ϕ. The signs of $\partial P_H/\partial\sigma$ and $\partial P_L/\partial\sigma$ remain uncertain. However, we can determine sufficient conditions to guarantee $\partial(P_H - P_L)/\partial\sigma > 0$. They are:

$$P_H, P_L \geq e^{-1/\beta_2} > e^{-1/\beta_1} \tag{A10}$$

to make

$$1 + \beta_1 \log P_H > 0, 1 + \beta_1 \log P_L < 0 \quad \text{and}$$
$$1 + \beta_2 \log P_H < 0, 1 + \beta_2 \log P_L < 0$$

$$P_H, P_L > \left[\frac{B_2\beta_2(\beta_2 - 1)}{A_1\beta_1(\beta_1 - 1)} \right]^{1/(\beta_1 - \beta_2)} \tag{A11}$$

to make C_1 and $C_2 < 0$.

$$B_2\beta_2(\beta_2 - 1) > A_1\beta_1(\beta_1 - 1), \tag{A12}$$

$$P_H^x(1 + \beta_2 \log P_H) - P_L^x(1 + \beta_2 \log P_L) < P_H(1 + \beta_1 \log P_H) - P_L(1 + \beta_1 \log P_L), \tag{A13}$$

where $\rho \leq \delta$ and $x = \beta_2 - \beta_1 + 1 \leq 0$. These are the simplest, but not necessarily the only conditions showing when price/exchange rate volatility is guaranteed to depress investment. They can further be reduced to the condition that (A10) shall hold. That is to say: if (A10) holds, then (A13) holds; as do (A11) and (A12) also provided $\rho \leq \delta$ and $P_L \geq 1$.

Sufficient conditions: Thus our sufficient conditions boil down to $P_L > e^{-1/\beta_2}$, i.e.

$$\frac{1}{\sigma^2}\left[\frac{\rho(\log P_L + 1) - \delta}{\log P_L}\right] > \frac{\log P_L + 1}{2(\log P_L)^2} \tag{A14}$$

That leaves three cases to consider. Investment will fall with price or exchange rate uncertainty (but rise otherwise) if:

(i) $\log P_L > 0$ and $\rho(\log P_L + 1) > \delta$, which implies we need

$$\sigma^2 < 2 \log P_L\left(\rho - \frac{\delta}{1 + \log P_L}\right). \tag{A15}$$

(ii) $\log P_L > 0$ and $\rho(\log P_L + 1) < \delta$, which will require (A15) with the inequality reversed.

(iii) $\log P_L < 0$, in which case those sufficient conditions will always be broken.

Necessary conditions: Following the same arguments, the corresponding necessary conditions for investment to fall as exchange rate volatility/uncertainty rises is

$$\frac{\sigma^2}{\rho - \delta} > 2 \log P_L \tag{A16}$$

which is very similar to (A15) but for the term in δ. Conversely, if $\rho > \delta$, the sufficient conditions will always be violated in cases (i) and (ii) and (A16) shows investment will certainly rise with volatility if σ^2 is small or the scrapping price high.

CONDITIONS UNDER WHICH A MISALIGNMENT WILL REDUCE INVESTMENT EXPENDITURES

The effects of a misalignment can likewise be computed from:

$$\frac{\partial P_H}{\partial \alpha} = \left[A_1 \frac{\partial \beta_1}{\partial \alpha} P_H^{\beta_1 - 1}(1 + \beta_1 \log P_H) - B_2 \frac{\partial \beta_2}{\partial \alpha} P_H^{\beta_2 - 1}(1 + \beta_2 \log P_H) + \beta_1 P_H^{\beta_1 - 1}\frac{\partial A_1}{\partial \alpha} - \beta_2 P_H^{\beta_2 - 1}\frac{\partial B_2}{\partial \alpha} - 1/\delta^2\right] / C_1 \tag{A17}$$

and

$$\frac{\partial P_L}{\partial \alpha} = \left[A_1 \frac{\partial \beta_1}{\partial \alpha} P_L^{\beta_1 - 1}(1 + \beta_1 \log P_L) - B_2 \frac{\partial \beta_2}{\partial \alpha} P_L^{\beta_2 - 1}(1 + \beta_2 \log P_L) + \beta_1 P_L^{\beta_1 - 1}\frac{\partial A_1}{\partial \alpha} - \beta_2 P_L^{\beta_2 - 1}\frac{\partial B_2}{\partial \alpha} - 1/\delta^2\right] / C_2 \tag{A18}$$

where C_1 and C_2 have been defined above, and where $\partial\beta_1/\partial\alpha < 0$ and $\partial\beta_2/\partial\alpha < 0$, and $\partial A_1/\partial\alpha > 0$ and $\partial B_2/\partial\alpha > 0$ all follow from (A5), (A6) and $\rho \leq \delta$. One set of sufficient conditions such that $\partial(P_H - P_L)/\partial\alpha > 0$ is that C_1 and C_2 should be negative that $1 + \beta_1 \log P_H$, $1 + \beta_1 \log P_L$ are positive; and that $1 + \beta_2 \log P_H$ and $1 + \beta_2 \log P_L$ are negative. Hence, the zone of inactivity widens when

$$P_H, P_L \geq e^{-1/\beta_2} > e^{-1/\beta_1} \tag{A19}$$

$$P_H, P_L > \left[\frac{B_2\beta_2(\beta_2 - 1)}{A_1\beta_1(\beta_1 - 1)}\right]^{1/(\beta_1 - \beta_2)} \tag{A20}$$

Since (A19) implies (A20), investment will fall with increasing undervaluations ($\alpha > 0$) if $P_L > e^{-1/\beta_2}$, i.e. if

$$\frac{1}{\sigma^2}\left[\frac{\rho(\log P_L + 1) - \delta}{\log P_L}\right] > \frac{\log P_L + 1}{2(\log P_L)^2} \tag{A21}$$

That means we again face three possible outcomes:

(i) $\log P_L > 0$ and $\rho(\log P_L + 1) > \delta$, which implies we need

$$\sigma^2 < 2 \log P_L\left(\rho - \frac{\delta}{1 + \log P_L}\right) \tag{A22}$$

(ii) $\log P_L > 0$ and $\rho(\log P_L + 1) < \delta$, investment will rise if the inequality in (A22) holds – but fall if it is reversed.

(iii) $\log P_L < 0$, in which case investment will always rise since (A22) is always violated ($\beta_2 < 0$).

These conditions depend on both the trigger prices and the level of price (or exchange rate) volatility.

Notes

1. Note that exchange rate uncertainty would affect not only decisions to invest in a foreign country but also domestic investment decisions because of the presence of vertical integration, for example, or because firms might be able to switch between producing for (or in) the domestic or the foreign market.
2. Note that including σ and α as separate parameters means that our model treats pure volatility (σ) and predictable variations (α) as separate components in the overall degree of variability of prices or the exchange rate.
3. Note that in this paper we adopt a similar definition of mean preserving price (exchange rate) uncertainty to Caballero (see Caballero, 1991). Specifically, we focus solely on the type of uncertainty originating in a volatile and misaligned currency. Nonetheless, there might be a range of different sources of uncertainty affecting investment decisions. Carruth et al. (2000) review some of approaches used in the literature to proxy the uncertainty affecting investment decisions (e.g., stock market volatility, real wages volatility, long and short bond risk premia). However, they also point out "*a lack of consensus about best practice*" and that each measure bears a number of shortcomings. Importantly, they also stress that "*correlation with a volatility measure ... may reveal more about correlation with*

some omitted underlying "fundamentals'"". Nevertheless, this kind of risk should be significantly reduced in the type of disaggregated empirical analysis conducted in this paper.

4. Details of the optimization problem and its solution can be found in the Appendix.
5. This was shown in Darby et al. (1999) for changes in σ and in Darby et al. (2002) for changes in α. In each case we had to show that an increase in the width of the inactivity zone was not matched by an increase in the area of the price distribution above P_L. If that had happened, a wider range of conditions with no investment could have been offset by a higher frequency of prices which trigger investment.
6. See Hughes Hallett et al. (2004) for detailed numerical estimates of these coefficients, standard error and all the regression diagnostics. Note that these results are derived from an extensive specification search within the general framework defined by Equations (2)–(4) below. However we only report the final results: where only coefficients that are significant at the 5% level have been retained, and where the standard diagnostic tests are satisfied. Estimates for the remaining models and coefficients are available from the authors on request, as are the model estimates obtained when the volatility measures are computed as in Darby et al. (1999).
7. To compute these volatility measures we start from monthly data, which are then rolled over according to Equation (1) using a 5-month window ($m = 5$). Finally, annualized measures of volatility are computed by averaging the result over the year.
8. In some panels, countries with only a limited number of observations available were excluded from the sample.
9. Admittedly, the STAN database contains data on other variables that could have been included in the investment model. However, these data are not available for all the countries and all the sectors considered. Including those extra variables would mean severely reducing the already small size of the panels in use, thus undermining the validity of the empirical analysis performed.
10. Given the possibility that industrial production and price volatility are endogenous with respect to investment, a GMM approach would, for example, be more appropriate. Also, note that a cross-section dimension of 9 is usually considered too large for SUR or other system estimations techniques to be applicable.
11. Although large values of T are not a feature of our data, it is, however, true that the time series dimension of our panels is at least three times as large as the cross-sectional one.
12. Pesaran et al. (1999) contains an extensive comparison of the PMGE with other dynamic panel estimation procedures.
13. We conducted Levin-Lin and IPS tests.
14. In the paper we follow the convention, usually adopted when conducting PMGE estimations, of not testing for the existence of such long-run relationships. However panel unit root tests of the residuals of the long-run relationships for each sector, available from the authors on request, suggest that this hypothesis cannot be rejected.
15. Producer price volatility and misalignment are included alongside nominal exchange rate volatility and misalignment to account for any possible interaction effect. However, the interaction is not rejected by the data in only one sector (Basic Metals).
16. For the numerical details that lie behind these qualitative results, including the coefficient values and their standard errors, see Hughes Hallett et al. (2004).
17. Only the results for the Basic Metal sector contravene our theoretical intuition.
18. For a comprehensive description of these industrial sectors, ISIC rev. 3.1, *Detailed structure and explanatory notes*.
19. For the detailed numerical results that lie behind Table VI see Hughes Hallett et al. (2004).

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