WP/16/218

IMF Working Paper

To Bet or Not to Bet: Copper Price Uncertainty and Investment in Chile

By Fabio Comelli and Esther Pérez Ruiz

INTERNATIONAL MONETARY FUND

 WP/16/218

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Western Hemisphere Department

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Prepared by Fabio Comelli and Esther Pérez Ruiz

Authorized for distribution by Stephan Danninger

November 2016

Abstract

A strand of research documents Chile's copper dependence hence significant exposure to terms of trade shocks. Copper prices' sharp decline and forecast uncertainty since the end of the commodity super-cycle has rekindled the debate on Chile's adjustment capacity to external shocks. Following Malz (2014), this paper builds a time-varying measure of copper price uncertainty using options contracts. VAR analysis shows that the investment response to an uncertainty shock of average magnitude in the sample is strong and persistent: the cumulative fall in investment from trend at a one-year horizon ranges 2–5.8 percentage points; and it takes between 1½ and 2 years for investment to return to its trend level. Empirical ranges depend on alternative definitions for investment, uncertainty, and options' maturing time.

JEL classification: D92, E22, D8, C23
Keywords: copper price, exchange rate, uncertainty, investment, option contracts, vector autoregression, Chile
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"No existe consenso en las proyecciones del precio del metal rojo en el corto y mediano plazo que permita a la gran minería tomar decisiones con certeza"

Joaquín Villarino, Presidente del Consejo Minero
El Diario Financiero, 26 de abril de 2016

I. Introduction[1]

Copper and the Chilean economy (Figure 1). Dubbed "Chile's lifeblood" by leader Salvador Allende, the country is the largest producer of copper (30 percent of market share), sending the red metal across the Pacific to China. Copper plays a major role in the Chilean economy: as of 2015, the mining sector accounted for 10 percent of GDP, originated half of exports, and represented 30 percent of total investment. CODELCO, the state company that manages the public copper mines, contributed fiscal revenues of almost 7 percent of GDP of the central government revenues. Copper's physical characteristics make it appealing for a wide range of applications while the substitution of new materials is only imperfect, hence the metal will likely remain relevant to the Chilean economy in the future.

Challenges posed by copper specialization (Figure 2). While Chile reaps the benefits of copper, natural resource abundance represents, as in many other small open commodity exporting economies, important challenges for growth. Chile has historically been exposed to considerable terms of trade swings, resulting into significant business cycle volatility (see, e.g., Díaz and Wagner, 2014). A solid macroeconomic framework of fiscal savings, credible inflation targeting, and exchange rate flexibility has gone a long way in dampening the output response to copper since 1999 (De Gregorio and Labbé, 2011). However, copper prices' sharp decline since the end of the commodity super-cycle (a 50 percent drop between 2011Q1 and 2016Q1, or almost 20 percent in real terms relative to 2006−11) and the ensuing contraction in mining investment over 2014−15 (projected to extend also into 2016) have rekindled the debate on the adjustment capacity of the Chilean economy to external shocks. Moreover, increasing uncertainty embedded in copper price forecasts is perceived by the mining community as a key obstacle to investment decisions.[2]

Purpose. The main purpose of this paper is to examine the impact of copper price uncertainty on investment decisions in Chile. Movements in copper prices have been highly volatile since the early 2000s, and their projection by professional forecasters subject to considerable uncertainty. Going forward, major global developments such as China's rebalancing and the U.S. liftoff will likely involve first-order changes to the demand and supply of copper, hence the focus on price uncertainty.

[1] We are grateful to Stephan Danninger for support and guidance. We are indebted to Ehab Tawfik for excellent research assistance.

[2] The Mining Council has been vocal about price uncertainty. Its president Joaquín Villarino recently stated that *"En cuanto a la proyección, en el corto y mediano plazo, existe una amplia dispersión, la que ha estado marcada por los vaivenes de las cifras de la economía China."* El Diario Financiero, April 26, 2016.

Investment and uncertainty in the economic literature. It has been proposed that uncertainty generates reductions in real activity since at least Keynes (1937), who suggested that investment is the most volatile component of aggregate demand precisely because it relies most heavily on opinions about future events, which are necessarily ill-informed. Arrow and Fisher (1974) and Bernanke (1983) formalized the idea that, when projects are irreversible, the presence of uncertainty about future returns generates an option value of waiting that lowers the rate of current investment, even when agents are risk-neutral. Empirical work on the topic has made progress on estimating the economic significance of this mechanism, with some evidence in support of a relationship between investment and uncertainty. IMF (2015) highlights the role of policy uncertainty in retarding investment in some advanced economies, particularly euro area economies with high borrowing spreads during the 2010–11 sovereign debt crisis. Servén (1998) estimates private investment equations for a large number of developing countries and finds evidence of a negative link between exchange uncertainty and investment. For Chile, recent evidence finds a significant negative link between uncertainty and investment decisions (Justel and Saravia, 2014, Albagli and Luttini, 2015).

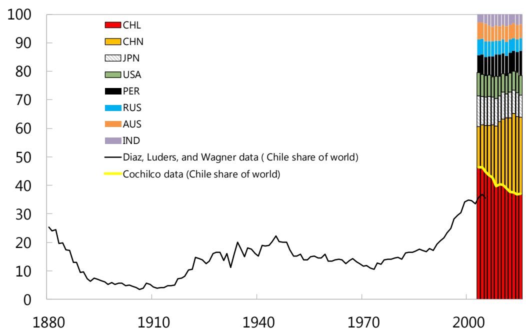
Methodology and main results. We contribute to the previous literature with a novel measure of uncertainty. Following Malz (2014), we construct a time-varying measure of copper price uncertainty using options contracts. The uncertainty measure is subsequently used to simulate an exogenous shock to investment. VAR analysis then explores the investment response to copper price uncertainty. The VAR analysis suggests that investment growth is reduced considerably in the face of uncertainty. Investment displays a sizable and persistent response to copper price uncertainty.

Structure of the paper. Section II discusses stylized facts on copper prices, investment, and GDP growth in Chile. Section III reviews the basic tenets of investment in a context of uncertainty. Section IV discusses the data and the notion of uncertainty retained in the analysis. Section V presents VAR evidence on the impact of copper price uncertainty on investment. Section V concludes.

Figure 1. Copper and the Chilean Economy

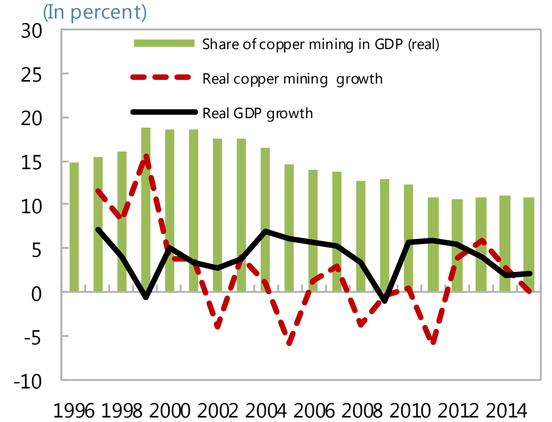
Chile is the largest copper producer....

Chile Production of Copper 1/
(In percent of world production)



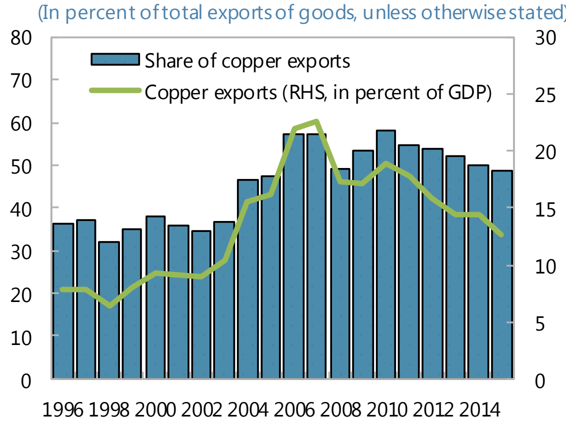
Copper production still represents around 11 percent of real GDP....

Real GDP and Copper Output
(In percent)



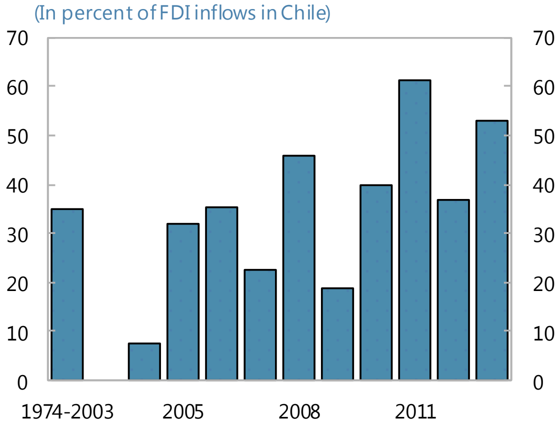
Copper accounts for half of exports...

Copper Exports
(In percent of total exports of goods, unless otherwise stated)



....and about half of FDI inflows

Mining Foreign Direct Investment 2/
(In percent of FDI inflows in Chile)



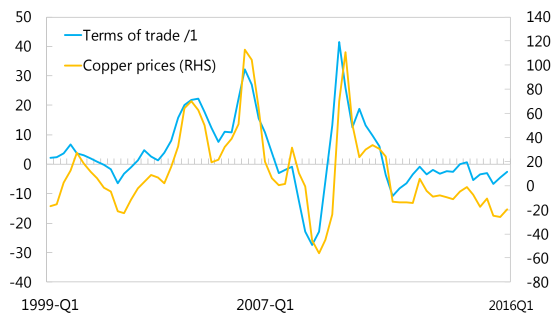
Source: Central Bank of Chile; Chilean Copper Commission (CoChilco); Foreign investment committee; Diaz, Luders, and Wagner (2010); and IMF Staff calculations.
1/ Includes extraction and smelter.
2/ FDI under Decree-Law 600.

Figure 2. Macroeconomic Effects of Copper Prices in Chile

Given its relatively high copper dependence, Chile is exposed to considerable terms of trade swings

Copper Prices and Terms of Trade

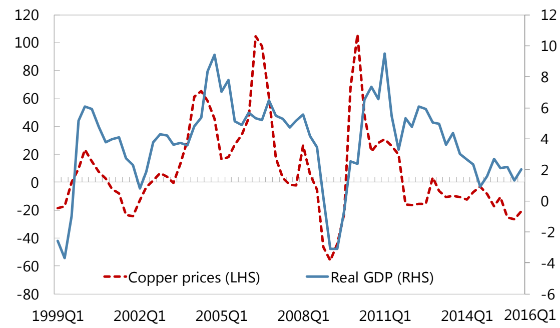
(In percent, y/y)



GDP growth and copper price growth display a strong co-movement in the short run…

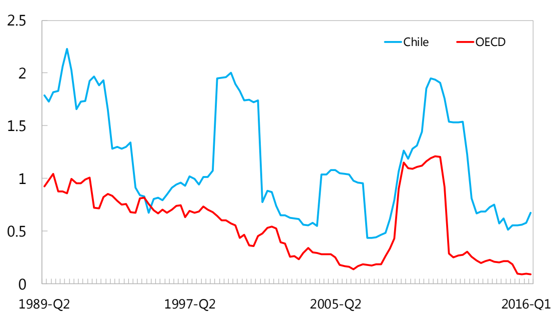
Real GDP and Copper Prices

(In percent, y/y)



…resulting in high business cycle volatility relative to peers

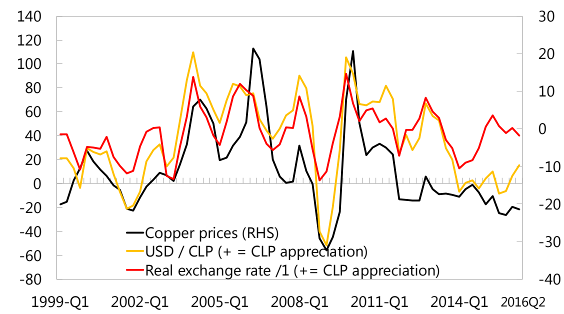
Volatility of GDP Growth /2



Copper prices are a key driver of the exchange rate

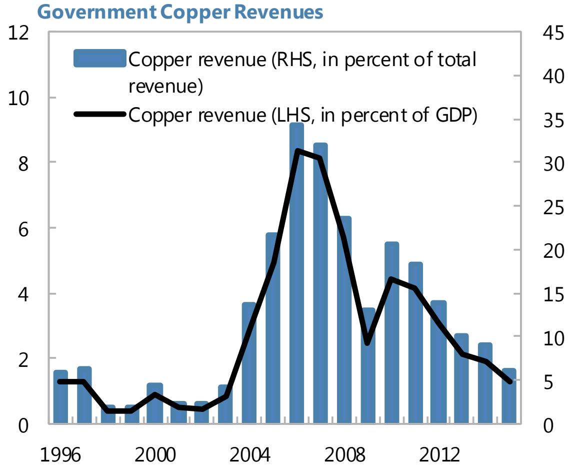
Copper Prices and the Exchange Rate

(In percent, y/y)



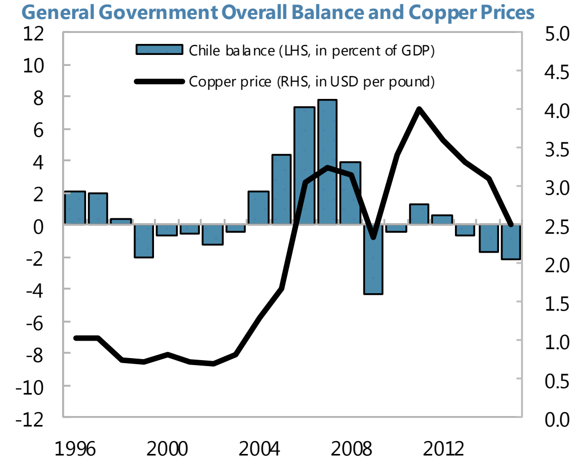
Copper contributes a significant share of government revenues…

Government Copper Revenues



…thus the fiscal position is closely related to copper prices.

General Government Overall Balance and Copper Prices



Sources: Haver Analytics, Central Bank of Chile, and IMF Staff calculations.

/1 Implied terms of trade from nominal and real exports and imports.

/2 Volatility defined as the standard deviation of 10 quarter rolling window of seasonally adjusted Q/Q growth rates.

II. COPPER PRICE UNCERTAINTY AND INVESTMENT: THEORY

Copper price volatility. Volatile copper prices stem from rigid supply and demand, especially in the short run. On the demand side, copper's physical characteristics make it appealing for a wide range of applications, with aluminum and plastic being only imperfect substitutes. On the supply side, investment reacts with a lag to higher demand given the technical complexity involved in the prospection and construction of a project. Once in train, investment becomes largely irreversible given the amount of capital involved. Furthermore, existing capacity is price inelastic given large fixed costs and high sunk costs from market exit. By implication, production is *optimally* kept at price levels well below total costs. Even if operating losses occur, if they are expected very short term, or if they are lower than the sum of maintenance costs and the costs of resuming production, firms will avoid market exit. In sum, the large amount and specificity of capital committed in mining investment projects makes for a rigid supply both *ex ante* (wait-and-see attitude in the face of price uncertainty) and *ex post* (the decline in prices must be large and perceived as durable for market exit to occur, delaying adjustment).

Investment and uncertainty. Theory holds that investment on long maturity projects such as mining[3] need to take into account the permanent component in prices. This is confirmed for investment long-term dynamics for Chile (Fornero and Kirchner, 2014, and Kulish and Rees, 2014). However, movements in copper prices are currently subject to considerable uncertainty, reflecting both micro-economic arguments (previous paragraph) as well as major developments affecting global demand (notably, China's economic transformation). This raises the question whether uncertainty hinders investment decisions beyond what would be warranted by depressed prices. There are two assumptions in the literature why uncertainty could adversely affect investment:

- *Risk aversion*. With risk aversion, investors care about the variance of the returns distribution alongside its mean. Risk averse investors may claim some *compensation* to undertake the riskiest project (the project with the higher variance), average returns being equal. Under risk aversion, the relationship between the expected marginal revenue product of capital and the uncertainty variable is positive through a convex profit function.

- *Irreversibility in investment.* With investment irreversibility (for instance, when sector specific capital makes it difficult reallocation across sectors), *delaying* investment can be *optimal* in presence of uncertainty. As investors face irreversible investment opportunities, a wait-and-see option gets a positive value in a depressed returns environment, such that the higher the level of uncertainty, the greater the value of postponing investment. Under investment irreversibility, the positive link between investment and returns is broken, and a range of inaction is created within which investment does not respond to the conventional net present value criterion (Dixit and Pindyck, 1995, Abel and Eberly, 1993).

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[3] The average maturity period of mining projects is seven years.

The high degree of capital specificity alongside the long maturity of mining investment projects gives prominence to the irreversibility hypothesis, which therefore underlies the analysis conducted in Section IV.

III. Lower and More Uncertain Copper prices: Measurement

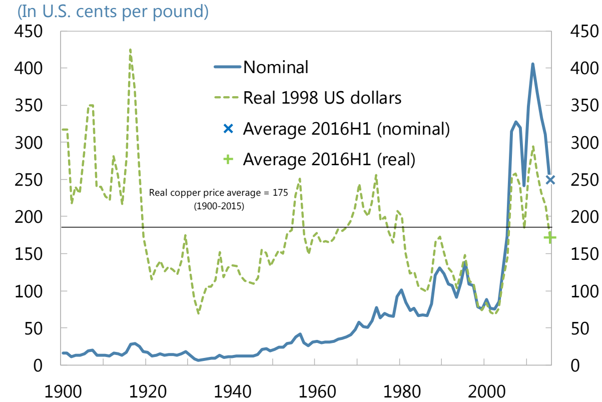
A. Facts

Working hypothesis. Following the end of the commodity super-cycle in 2012, investment has contracted in Chile over 2014−15. The main hypothesis we mean to test is whether the second-moment of copper prices (that is, *uncertainty* over the evolution of copper prices) has a bearing on investment alongside the first-moment (that is, the *level* of copper prices).

First-moment developments: the copper price super-cycle (Figure 3). Starting in 1900, copper price displays three long cycles, which can be associated with global demand booms: the industrialization of the late 19th century, the reconstruction period after World War II, and the urbanization of the Chinese economy since the 1990s (Eyraud, 2015). The commodity super-cycle appears to have plateaued around 2012. Since their 2011 peak, copper prices have fallen dramatically by about 50 percent (in both nominal and real terms).

Figure 3. Historical Price of Copper

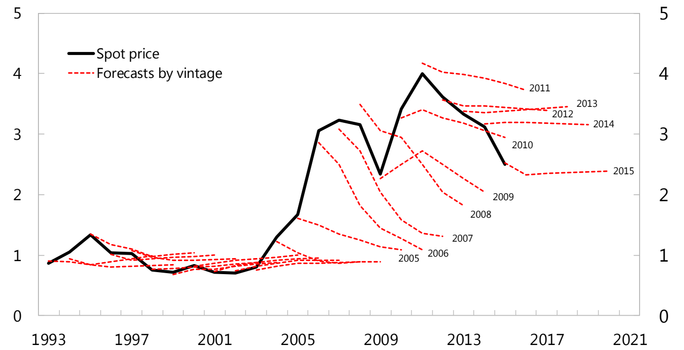
(In U.S. cents per pound)



Source: U.S. Geological Survey.

Second-moment developments: anecdotal evidence (Figure 4). Volatile copper prices can make it difficult for economic agents to distinguish between persistent and transitory price movements. In this context, agents may only learn over time about the true persistence of the shock. Indeed, looking into the differences between forecast and effective copper prices points to a persistent downside bias embedded in projections running into the commodity super-cycle (and a persistent upside bias since 2012). Further, the analysis in Section III.B shows that such projection bias has, on occasion, come along with heightened copper price uncertainty.

Figure 4. Price of Copper versus Projections
(In U.S. dollars per pound)



Source: IMF Global Assumptions Live and Vintages 1993-2015, and IMF Staff calculations.
Note: Forecasts at t+5 by Autumn WEO vintages. No overlap of red /black lines indicates WEO projections for the first projection year *t* differ from the actual average price for *t*.

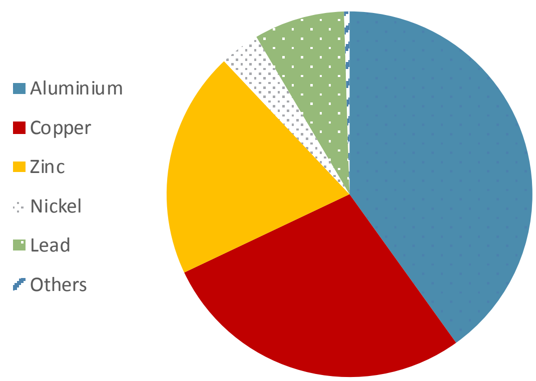
B. Measuring Copper Price Uncertainty

Previous literature. Uncertainty can be measured in many different ways, and there is no consensus on what constitutes the correct method of measurement. The naive approach involves treating all price movements as indicative of uncertainty by using the standard deviation of the series at stake. This is likely to overstate uncertainty, as it does not control for predictable trend/cyclical movements. In an important contribution, Bloom (2009) showed that measures of (observed and implied) stock-market volatility are strongly correlated with other micro- and macro-level measures of uncertainty, such as bond spreads, disagreement among professional forecasters, and the distributions of firm/industry profits/productivity. This has motivated the use of implied volatilities, derived from stock market options, as a measure of forward-looking, *global* uncertainty. Sudden changes to global uncertainty have then been shown to be an important shock driving the business cycle in the U.S. (Bloom, 2009), G7 countries (Gourio and others, 2013), or a broader group of developed economies and emerging markets (Carriere-Swallow and Céspedes, 2013).

Our contribution. Unlike the previous literature, which establishes a link between investment and *global* measures uncertainty, this paper constructs an indicator of uncertainty specific to the Chilean economy. To measure copper price uncertainty, we rely primarily on the standard deviation of the risk-neutral probability density function implied by a six-month option on the CLP/USD exchange rate. For the post-commodity super-cycle period we are most interested in, the analysis below shows that this indicator tracks reasonably well our benchmark measure of uncertainty based on copper price options, which we nevertheless disregard given data constraints. Reassuringly, there is an ample body of empirical literature documenting the strong link between copper prices and the exchange rate for Chile.

Hedging in copper's derivatives market. In generating copper price uncertainty measures from options instruments, one important observation is in order. Inadequate market depth and liquidity and/or substantial changes in the representative portfolio of risks being hedged may result in volatile PDFs for reasons other than genuine changes in market uncertainty. The over-thecounter (OTC)[4] nature of the options on the CLP/USD exchange rate used in this paper prevents us from assessing the volume of operations actually being traded. By contrast, the options on copper prices used in our empirical analysis are standardized contracts traded in the London Metal Exchange (LME). The LME is the world center for industrial metals trading: the prices settled on the LME trading platforms are used as the global reference price and both the metal and investment communities use the LME to transfer or take on risk 24 hours a day. For derivatives contracts as a whole, copper ranks second by volume traded (chart).

Derivatives Contracts Traded in the LME 1/
(Volume in Millions of Tons)



Source: LME monthly trading report, October 2016.
1/ Includes futures, traded options, and Traded Average Price Options (TAPOs).

Malz procedure: intuition. Following Malz (1997, 2014), the proposed methodology extracts from option prices[5] the probability density function (PDF) for future values of the underlying asset (copper price, the CLP/USD exchange rate). Specifically, we use as a measure of uncertainty the standard deviation of the risk-neutral implied PDF for copper price/ the CLP/USD exchange rate. According to options theory, options are traded at different strike prices such that the difference between options' prices at a given expiry date and the strike price reflects the market expectation about the price of the underlying asset. By implication, the prices at which options are traded contain information about the expected change and uncertainty surrounding the future price of the underlying asset. This information can be expressed in terms of the probability assigned by market participants that the price of the underlying asset will lie within particular ranges of the strike price.

Malz procedure: formalization (for a detailed description of the methodology, see Appendix A). We apply Malz's procedure to extract the risk-neutral implied PDF for expected copper prices and the CLP/USD exchange rate at a six-month horizon. We use monthly data for the period 1998M1−2016M1. The first step involves deriving the implied volatility σ by solving the equation:

$$0 = \sigma - atm + 2rr(\Delta - 0.5) - 16str(\Delta - 0.5)^2 \quad (1)$$

where atm denotes the price of an at-the-money straddle option, rr denotes the price of a risk-reversal option, str denotes the price of a strangle option and Δ denotes the derivative of the value of the call option with respect to the price of the underlying asset (copper prices, the CLP/USD exchange rate). The implied volatility is the volatility of an asset price that market

[4] OTC contracts are tailored to suit individual business needs and they are not listed on an exchange.

[5] An option contract gives the holder the right, but not the obligation, to buy (in a call option) or sell (in a put option) a specified asset (the underlying asset) at specified price (the exercise price or strike price).

participants expect to prevail at the expiry date of the option. It can be used to calculate the price of a European call option (that is, an option giving the right to buy a specified asset at certain price on a certain date) using the *Black and Scholes (BS)* model:

$$c(t,X,\tau) = S_t e^{-r_t^* \tau} \Phi \left[\frac{log\left(\frac{S_t}{X}\right) + \left(r_t - r_t^* + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \right] - X e^{-r_t \tau} \Phi \left[\frac{log\left(\frac{S_t}{X}\right) + \left(r_t - r_t^* - \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \right] \quad (2)$$

where c denotes the price of the European call option, τ is the remaining time to maturity of the option, S_t is the price of the underlying asset at time t, X is the strike price of the underlying asset, r_t^* is the foreign risk-free interest rate, r_t is the domestic risk-free interest rate, σ is the implied volatility derived in (1), and $\Phi[\quad]$ denotes the cumulative probability distribution function for a standardized normal distribution.

The risk-neutral implied PDF is then obtained as the second difference of the price of the call option with respect to the strike price:

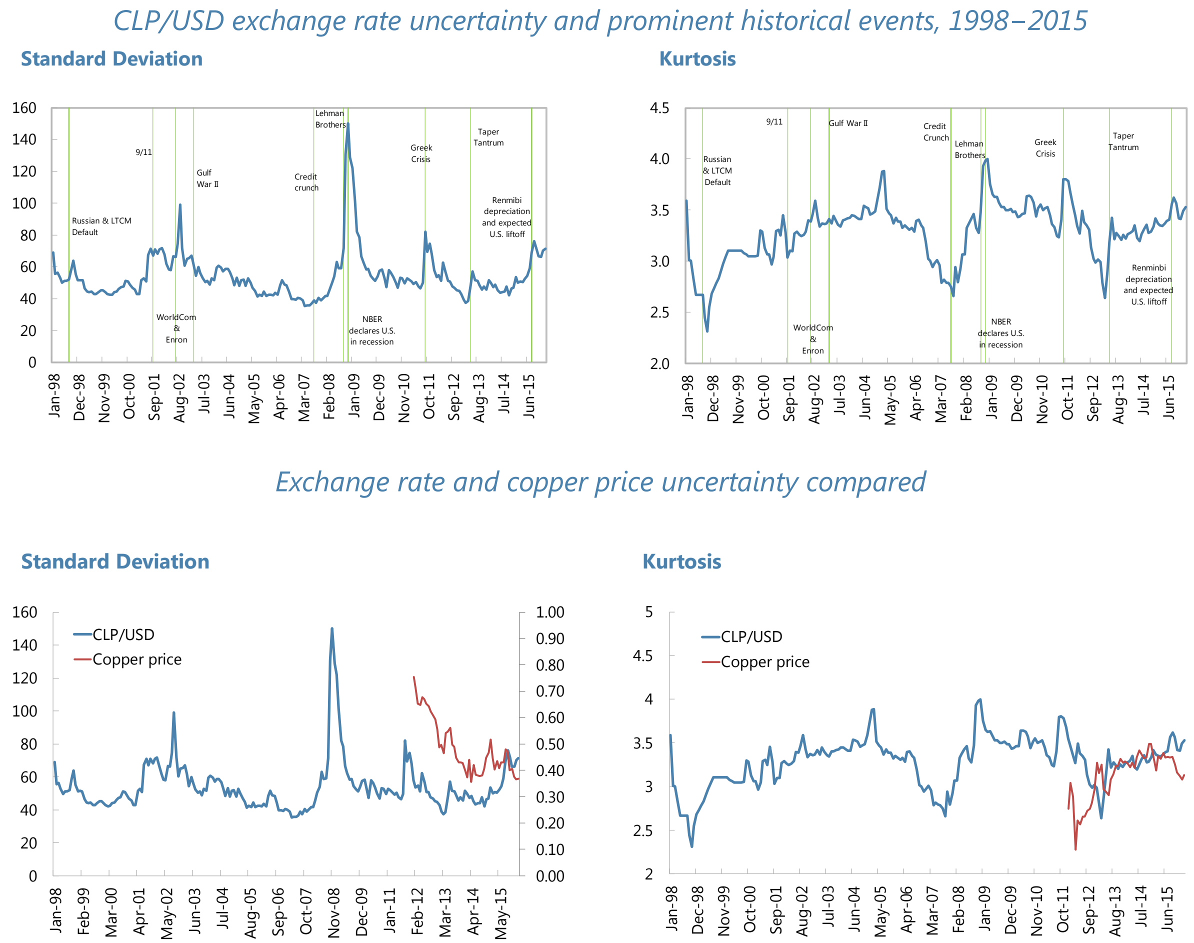
$$\tilde{\pi}_t(X) = e^{r_t \tau} \frac{\partial^2}{\partial X^2} c(t,X,\tau) \quad (3)$$

Measures of copper price uncertainty. Uncertainty about future copper prices can be appraised from either the standard deviation or kurtosis obtained from the risk-neutral implied PDF on the underlying asset (copper prices, the CLP/USD exchange rate). The *standard deviation* (that is, the square root of the second moment of the risk-neutral implied PDF) is expressed in the same units as the underlying asset and measures the dispersion of market expectations about the underlying price. The *kurtosis* (that is, the fourth moment of the risk-neutral implied PDF standardized by the fourth power of the standard deviation) has not units and measures market expectations of extreme changes in the underlying asset price. The higher the kurtosis, the higher the probability concentrated in the tails of the distribution. In particular, a normal distribution has kurtosis of 3, thus a distribution with kurtosis <3 (>3) displays shorter and thinner (higher and sharper) tails than the normal.

C. Results

Uncertainty: A walk through memory lane. Exchange rate uncertainty appears to jump after major economic and geopolitical shocks (Figure 5, top charts). These include the Asian crisis, the Russian and LTCM default, September 11, the WorldCom and Enron corporate governance scandals, the Gulf War II, the 2008−09 global financial crisis, the 2011−12 euro area crisis, the taper tantrum episode during summer 2013, and the financial market volatility following the renminbi depreciation and expected U.S. monetary normalization during summer 2015. These events, which can be deemed exogenous to local fundamentals, would have impacted Chile and other commodity exporters mostly via two distinct channels, dollar appreciation (insofar as most commodities, particularly copper, are traded in dollars) and higher financing costs (affecting investment projects on commodities). For the post-commodity super-cycle period 2012−15 where copper price uncertainty data is also available, the two uncertainty metrics are tied together (Figure 5, bottom charts), with some misalignment occurring at the end of the sample, where currency increasing uncertainty contrasts with more subdued uncertainty for the red metal.[6]

Figure 5. Uncertainty Measures

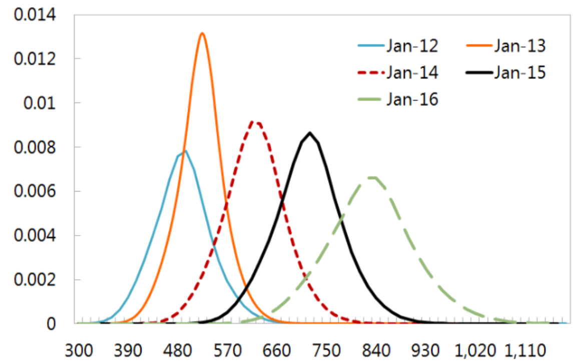


Source: Haver Analytics, Bloomberg, and Staff calculations.
Note: All statistics obtained from risk-neutral PDFs implied by option prices for the CLP/USD exchange rate at 6 months. Kurtosis is the fourth central moment of the risk-neutral implied PDF standardized by the fourth power of the standard deviation. The higher the kurtosis the higher the concentration of probabilty in the distribution tails.

[6] For both standard deviation- and kurtosis-based uncertainty, copper price-based uncertainty is found to lead exchange rate-based uncertainty (up to the second lag).

After the end of the commodity super-cycle. The mean market expectation for the CLP/USD exchange rate at a six-month horizon has been on the rise since 2012, reflecting depreciation pressures on the peso (rightward shift of the risk-neutral implied PDF, figure 6). Likewise, market uncertainty about the value of the currency has been growing (higher concentration of probability in the tails of the risk-neutral implied PDF). This likely reflects major unprecedented global developments, such as China's economic transformation and the U.S. liftoff from unconventional monetary policy—the implications of which would seem, to market participants, difficult to assess *ex ante.*

Figure 6. Market Expectations on the CLP/USD Exchange Rate
(Probability Density Functions)



Sources: Haver, Bloomberg, and Staff calculations.
Note: Probability density functions obtained from option prices for the CLP/USD exchange rate at 6 months.

IV. VAR ANALYSIS

VAR configuration. To study the impact of copper price uncertainty on investment,[7] we estimate a VAR, which takes the standard reduced-form:

$$Y_t = c + \sum_{i=1}^{p} \Phi_i Y_{t-1} + \sum_{i=0}^{p} \Phi_i X_{t-1} + \varepsilon_t \qquad (4)$$

where Y_t, X_t , c, Φ_i , and ε_t respectively denote the vector of endogenous variables, the vector of exogenous variables, the vector of constants, the matrices of autoregressive coefficients, and the vector of white noise processes.

Y_t is a vector of endogenous variables:

$$Y_t = \{cop_t, \sigma cop_t, r_t, p_t, inv_t, ymin_t\} \qquad (5)$$

where $cop_t, \sigma cop_t, r_t, p_t, inv_t, ymin_t$ respectively denote log copper prices, the CLP/exchange rate uncertainty indicator, the monetary policy rate, the log consumer price index, the log gross fixed capital investment, and the log mining production. The inclusion of copper prices in equation (5) is meant to control for first-moment shocks to returns, such that our uncertainty analysis can be

[7] Ideally, the exercise should consider investment mining only, in order to isolate the effects of copper price uncertainty on investment. Unfortunately, there are no quarterly series available for mining investment. For this reason, the VAR is conducted for two variants of investment, overall gross fixed capital investment, and machinery and equipment only, the latter showing a tight correlation with mining investment.

regarded as the sole impact of uncertainty shocks.[8]

X_t is a vector of exogenous variables:

$$X_t = \{gd_t, i^{US}_t\} \qquad (6)$$

Where gd_t, i^{US}_t respectively denote the log global demand addressed to Chile and the U.S. 3-month Treasury bill. The VAR uses seasonally-adjusted monthly data 1999−2015.[9] All variables are Hodrick-Prescott detrended in the baseline simulations and enter the VAR with two lags.[10]

Identification. Identification of the structural shocks is achieved via a Cholesky recursive scheme, which attributes all of the effect of any common component to the variable that comes first in the VAR system. Put simply, Cholesky-identified shocks contemporaneously affect their corresponding variables and those ordered at a later stage, but have no impact on variables that are ordered before. This needs the most exogenous (endogenous) variables be placed first (last) in the VAR. Specifically, the Cholesky ordering retained in the analysis features:

$$cop_t \rightarrow \sigma cop_t \rightarrow r_t \rightarrow p_t \rightarrow inv_t \rightarrow ymin_t \qquad (7)$$

This ordering is based on the assumption that shocks instantaneously influence the copper market (levels and volatility), then prices (the consumer price index and interest rates), and finally quantities (investment and mining production) (Bloom, 2009). Conceptually, the key identifying assumption is that commodity price fluctuations and uncertainty are predetermined with respect to Chile's small open economy.

Results (Figure 7, top left chart). We inspect the response of investment to an uncertainty shock of average magnitude over the sample. The response of investment to copper price uncertainty is strong: the cumulative fall in investment from trend at a one-year horizon amounts 3 percentage points by standard deviation uncertainty (1½ percentage points by kurtosis uncertainty). Investment takes considerably long to return to its trend level (between 1½ and 2 years depending on the uncertainty indicator considered). By the standard deviation measure, investment would mildly overshoot over the medium-term, once uncertainty has fallen sufficiently.

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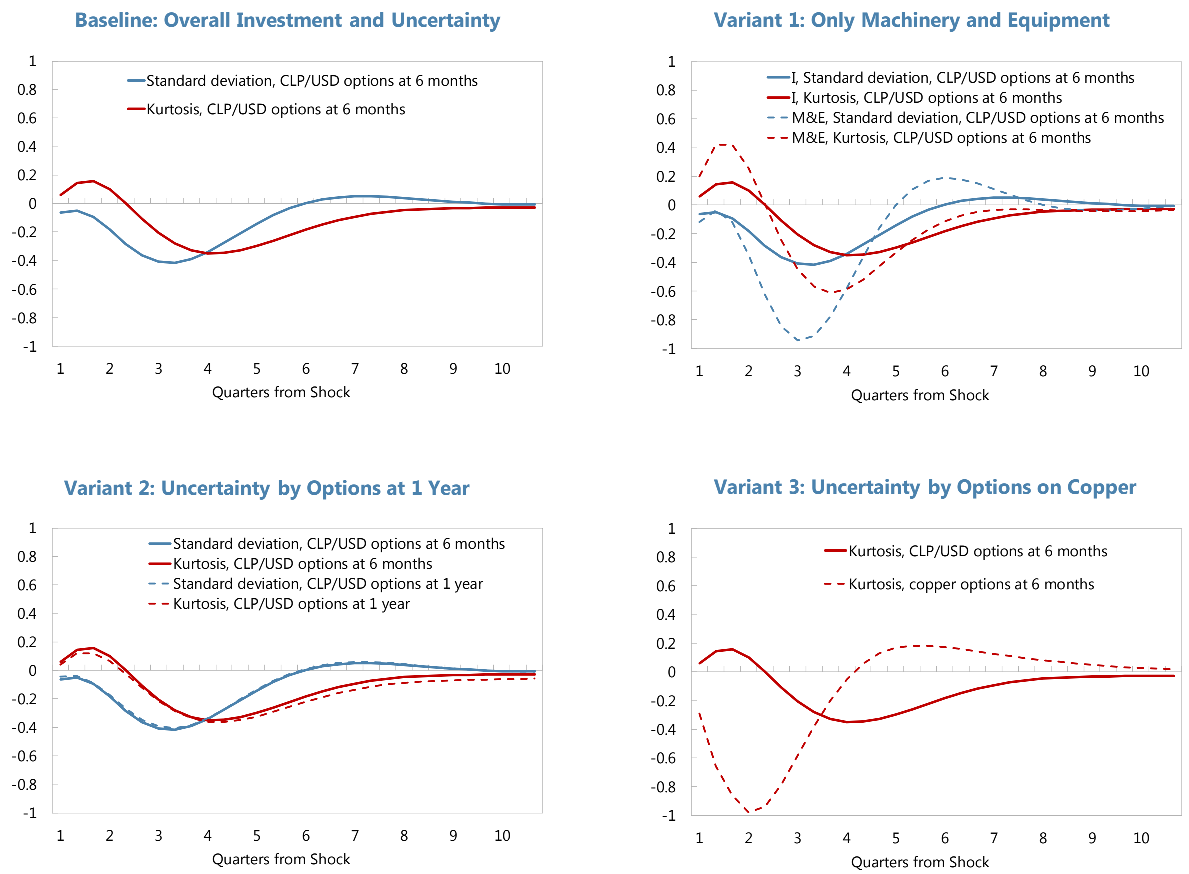
[8] Using the CLP/USD exchange rate in the place of copper prices to control for first-moment shocks to returns barely affects the results.

[9] With quarterly data, the trough in investment following an uncertainty shock of average magnitude is one lagged one quarter relative to, and slightly more pronounced than obtained at, a monthly frequency.

[10] The lag structure of the VAR is determined by means of lag exclusion and lag length criteria.

Figure 7. Investment and Uncertainty

Impulse Response Functions



Source: IMF staff calculations.

Note: Charts show the investment's percentage points deviation from trend following an uncertainty shock of average magnitude. Uncertainty is measured as the standard deviation/kurtosis of the risk-neutral implied PDF on the CLP/USD exchange rate (copper prices) based on options at 6 (12) months.

Robustness. VAR results seem robust to a range of alternative approaches over investment definitions (machinery and equipment), uncertainty metrics (standard deviation versus kurtosis), options' maturing time for contracts, and exchange rate versus copper price for underlying assets. Overall, the investment response to an uncertainty shock of average magnitude in the sample is strong and persistent: the cumulative fall in investment from trend at a one-year horizon ranges 2–5.8 percentage points; and it takes between 1½ and 2 years for investment to return to its trend level. There is some evidence of overshoot from the original trend for investment in machinery and equipment (CLP/USD-standard deviation-based uncertainty, options at 6 months) and for overall investment (copper price-kurtosis-based uncertainty, options at 1 year).

Caveats. Our results should be interpreted with caution. First, the implicit assumption throughout the paper is that the foreign exchange option market in Chile is deep and liquid. While this is likely a valid claim for copper price options (Section III.B), specific information on trading operations for the CLP/USD exchange rate options (used as a proxy in our empirical analysis) is not available. With more information about the microstructure of the foreign exchange options market, our indicators of uncertainty may differ from those we have derived in this paper. Second, unlike lower-order moments of PDFs (standard deviation), higher-order moments such as the kurtosis-informed uncertainty measure, can be sensitive to alternative procedures to estimate options-implied PDFs and to changes in the observed options prices (see, e.g., Datta and others, 2014, and papers therein). It is therefore reassuring that, for many of the experiments conducted in this paper, the kurtosis- and standard deviation-informed IRFs deliver similar investment dynamics. Still, it is important to acknowledge that the confidence bands around these estimates are large.

V. Conclusion

Key findings. This work builds on the existing literature on the link between uncertainty and investment. We contribute a measure of uncertainty specific to Chile and show that an uncertainty shock has significant and persistent effects on investment. This result is robust to different uncertainty metrics (standard deviation versus kurtosis of the implied PFD; alternative expiry dates for options contracts underlying the analysis), investment definitions (overall gross fixed capital formation versus machinery and equipment), and sample periods (longer, 1999−2015, time horizon versus shorter post-commodity super-cycle episode 2012−15).

Rationale and prospects. When investors face irreversible investment opportunities, as is the case for mining investment in Chile, periods of high uncertainty may lead more firms to choose a wait-and-see attitude, *optimally* putting their investment plans on hold. This may constitute one key reason for the contraction in investment over 2014−15. The upside of this analysis is that, as long as uncertainty dissipates and business conditions can be better ascertained, many firms who have so far postponed their investment plans may find themselves far from their optimal levels of capital, hence carrying out the adjustment required to relieve their pent-up factor demand and generating an expedite investment recovery.

Policy implications. Policy has an important role to play during periods of elevated uncertainty. In particular, the implementation of Chile's vast structural reform agenda should focus on enhancing private investment. This includes fast-tracking the adoption of the new infrastructure fund, facilitating the allocation of risk capital, and enhancing the resilience of the financial sector and corporates' balance sheets. Further, by facilitating access to financing to firms seeking to invest, monetary policy accommodation can go a long way in mitigating the adverse effects of uncertainty and speeding up the return of investment to its trend level.

Appendix A. Using Malz Methodology to Generate Options-Implied Probability Density Functions for the Peso/USD Exchange Rate and for Copper Prices

Unlike the previous literature, which establishes a link between investment and *global* measures uncertainty, this paper constructs an indicator of uncertainty specific to the Chilean economy. In particular, we derive from option prices indicators of uncertainty surrounding i) the expected copper price at six months and ii) the expected CLP/USD exchange rate at six months.[1] We use option prices because options contain information about the probability, assigned by market participants, that financial assets will assume a range of possible prices at some future date.[2] More specifically, we are primarily interested in extracting from option prices the probability density functions (PDFs) for future values of our underlying financial assets of interest (copper and the CLP/USD exchange rate), using monthly option prices data.[3] Then, to measure the uncertainty surrounding the expected price of copper and the CLP/USD exchange rates over the following six months, we calculate the standard deviation and kurtosis of the extracted PDFs. Changes in the dispersion (or standard deviation) of the PDFs can inform us about changes in market uncertainty about future asset prices, while changes in the kurtosis of the PDFs can help us assess market expectations for extreme changes in the underlying asset price in the future (Bank of England, 2016).

More formally, we follow Malz (1997, 2014) to extract from option prices the implied PDFs of the expected price of the underlying asset at a given horizon in the future (in our case six months). We proceed as follows. First, for both the underlying assets of interest, we derive the implied volatility as a function of Δ, which denotes the sensitivity of an option price to small changes in the underlying asset price:

$$\sigma(\Delta) = atm - 2rr(\Delta - 0.5) + 16str(\Delta - 0.5)^2 \quad (1)$$

where atm denotes the price of an at-the-money straddle option, rr denotes the price of a risk-reversal option, str denotes the price of a strangle option. Intuitively, the implied volatility is the volatility of an asset price that market participants expect to prevail over a certain period of time in the future.[4] Put differently, implied volatility is a measure of uncertainty of the underlying

[1] An option contract gives the holder the right, but not the obligation, to buy (in a *call option*) or sell (in a *put option*) a specified asset (“the underlying asset”) at specified price (the “exercise price” or “strike price”).

[2] See Bank of England (2016), Blake and Rule (2015), and Clews et al. (2000).

[3] Specifically, we derive implied PDFs of the CLP/USD exchange rate during the period January 1998–February 2016, while we derive implied PDFs of copper prices during the period June 2011–February 2016.

[4] More formally, the implied volatility is that value of volatility which equates the observed market price of the option with the price of a European call option predicted by the Black and Scholes pricing formula (see Blake and Rule, 2015).

asset price at the expiry date of the option.[5] Equation (1) is a linear combination of the most common option trading strategies. The first term on the RHS, atm, denotes an at-the-money straddle option.[6] The straddle is a strategy whereby the investor purchases one put option (which gives the holder of the option the right to purchase an asset) and one call option (which gives the holder of the option the right to sell an asset). Both options have the same strike price.[7] Essentially, the straddle generates positive payoffs each time that the price of the underlying asset moves away (in either direction) from the strike price. The reason why the straddle in included in (1) is because it captures changes in the dispersion of the PDF, which can be informative about changes in market uncertainty surrounding future asset prices.

The second term on the RHS, rr is the risk reversal option. It consists in a hedging strategy, popular in the foreign exchange market, whereby the investor purchases a call option and sells a put option (which imposes to the holder the obligation to buy the underlying asset in case the holder of the put option decides to exercise it). Both options have a different strike price. The price of the risk reversal (quoted in volatility) gives information about the degree of asymmetry, or skewness, of the implied PDF. The skewness provides information on whether the market expects an appreciation of the underlying asset or a deprecation.

The third and last term in (1) is a strangle option. Like a straddle, the strangle is a strategy whereby the investor purchases one put option and one call option. However, in a strangle both options have different strike prices and are out-of-the-money. Holding a strangle yields positive payoffs each time when the price of the underlying asset moves away considerably from the strike price. The presence of the strangle strategy in (1) is justified by the fact that its price gives information about the kurtosis of the implied PDF. Put differently, it provides information on the probability assigned by market participants to observe extreme movements in the underlying asset price in future.

Second, once the implied volatility as a function of Δ, $\sigma(\Delta)$, has been derived from (1), we can express the implied volatility σ as a function of the strike price X. This allows us to derive the implied volatility smile, $\sigma(X)$. Then, once obtained $\sigma(X)$, we can calculate the price of a European call option (which is an option giving the right to buy a specified asset at maturity at a certain price) using the *Black and Scholes (BS)* pricing formula:

[5] Unlike realized volatility, implied volatility is a forward-looking measure of the variability of an asset price, as it is derived from option data rather than from historical data.

[6] An option is said to be *in-the-money* when the difference between the price of the underlying asset and the strike price means it would be beneficial for the holder to exercise the option. An option is said to be *out-of-the-money* when the difference between the price of the underlying asset and the strike price means it would not be beneficial for the holder to exercise the option. Finally, an option is said to be *at-the-money* when the price of the underlying asset is equal to the strike price (see Blake and Rule, 2015).

[7] In a straddle, both options are said to be at-the-money, as for both options the strike price is equal to the spot price.

$$c(t,X,\tau) = S_t e^{-r_t^* \tau} \Phi \left[\frac{log\left(\frac{S_t}{X}\right) + \left(r_t - r_t^* + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \right] - X e^{-r_t \tau} \Phi \left[\frac{log\left(\frac{S_t}{X}\right) + \left(r_t - r_t^* - \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \right] \quad (2)$$

where c denotes the price of the European call option, τ is the remaining time to maturity of the option, S_t is the price of the underlying asset at time t, X is the strike price of the underlying asset, r_t^* is the foreign risk-free interest rate, r_t is the domestic risk-free interest rate, σ is the implied volatility derived in (1), and Φ[ ] denotes the cumulative distribution function for a standardized normal distribution.

To extract the implied PDFs from copper option prices, we still apply the Malz methodology illustrated above. However, in the Black and Scholes formula (2) instead of the domestic risk-free interest rate, r_t, we use an estimated convenience yield for the copper price, c_t. The convenience yield is defined as the benefit associated with holding an underlying physical good, rather than a financial derivative product. More specifically, the convenience yield c_t is defined as follows:

$$c_t = r_t^* + \frac{1}{T}\left(1 - \frac{F_t}{S_t}\right) \quad (3)$$

where r^*_t is the international borrowing rate, T is time to maturity expressed in fraction of year, F_t is the forward price of copper while S_t denotes copper spot price.

As a third step, we derive the implied PDF by taking the second difference of the price of the European call option, c(t,X,τ), with respect to the strike price X:

$$\tilde{\pi}_t(X) = e^{r_t \tau} \frac{\partial^2}{\partial X^2} c(t,X,\tau) \quad (4)$$

At this stage, for each PDF extracted from currency (CLP/USD) and commodity (copper) option prices, we calculate the standard deviation *s*

$$s = \sqrt{\sum_{i=1}^{n} p_i (x_i - \mu)^2} \quad (5)$$

The standard deviation, the square root of the variance, is expressed in the same units as the underlying asset and measures the dispersion of market expectations about the underlying price.

For each PDF, we also calculate the kurtosis *k*

$$k = \frac{\sum_{i=1}^{n} p_i (x_i - \mu)^4}{\left[\sum_{i=1}^{n} p_i (x_i - \mu)^2\right]^2} \quad (6)$$

The *kurtosis* (the fourth moment of the distribution standardized by the fourth power of the standard deviation), which has not units, measures market expectations of extreme changes in the underlying asset price. The higher the kurtosis, the higher the probability concentrated in the tails of the distribution. In particular, a normal distribution has kurtosis of 3, thus a distribution with kurtosis <3 (>3) displays shorter and thinner (higher and sharper) tails than the normal distribution.

For both underlying assets (CLP/USD and copper), we produce time series of standard deviation (s_t^{clp} and s_t^{cu}) and kurtosis (k_t^{clp} and k_t^{cu}) of the implied PDFs. These series will be included in the vector auto-regression.

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