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ANÁLISIS DE LOS MERCADOS MUNDIALES DE METALES: COMOVIMIENTOS E IMPACTO DE LOS PRINCIPALES EVENTOS ECONÓMICOS RECIENTES

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GLOBAL METALS MARKETS ANALYSIS: COMOVEMENTS AND IMPACT OF THE MAIN RECENT ECONOMIC EVENTS

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Lista de Símbolos, Abreviaturas y Siglas

ADF. Augmented Dickey Fuller

AFRO. African Region

AIC. Akaike information criterion

Al. Aluminum

AMM. America Metals Market

BIC. Bayesian information criterion

Brexit. Salida del Reino Unido de la Unión Europea

BRICS. Brazil, Russia, India, China and South Africa

BUKHI50P. Cboe Brexit High 50 Index price detail and constituents' financial data

CBOE. Chicago Board Options Exchange

CEE. Central and eastern european countries

CO_2. Dióxido de Carbono

CoC. Cost of Carry

COMEX. New York Commodities Exchange

COTR. LME's Commitments of Traders Report

COVID-19. Coronavirus disease of 2019

CRB. Commodity Research Bureau

Cu. Copper

CVAR. Conditional value at risk

DCC GARCH. Dynamic conditional correlation GARCH model

EMRO. Eastern Mediterranean Region

EPUCBREX. Economic uncertainty index due to Brexit

EPUCCEUM. European economic uncertainty index

EPUCUK. U.K. Economic uncertainty index

ETFs. Exchange traded funds

EU. European Union

EUR. Euro currency

EURO. European Region

EV. Electric vehicle

FAVG. Factor average

FCVAR. Fractional conditional value at risk

FOREX. Global electronic marketplace for trading international currencies and currency derivatives

FQGLS. Feasible Quasi Generalized Least Square

FTSE 100. Index consisting of the shares of the 100 biggest companies by market capitalisation on the London Stock Exchange

GDP. Gross domestic product

GHG. Greenhouse gases

HKEX. Hong Kong exchange

IAA. International Aluminum Association

ICA. The International Copper Association

ICSG. International Copper Study Group

INSG. International Nickel Study Group

IZA. International Zinc Association

KPSS. Kwiatkowski–Phillips–Schmidt–Shin

LME. London Metal Exchange

MTs. Metric Tonnes

NASAAC. North American Special Aluminum Alloy Contract

Ni. Nickel

OLS. Ordinary least squares

OMS. Organización Mundial de la Salud

PAHO. Region of Americas

Pb. Lead

PIMCO. Pacific Investment Management Company, LLC

PP. Phillips Perron

PVC. Policloruro de vinilo

QE. Quantitative easing

Quandl. Portal de datos libres

RWWD. Random walk with drift

S&P 500. Standard & Poors 500

SEARO. South-East Asia Region

SEE. South and eastern european countries

SHFE. Shanghai Forex Exchange

Sn. Tin

TVP-VAR. Time-Varying Parameter Vector Autoregressions

UK. United Kingdom

US. United States of America

USD. United States Dollars

VAR. Autoregressive vectors

WHO. World Health Organization

WPRO. Western Pacific Region

Zn. Zinc

Resumen y conclusiones

1. Mercados de materias primas. Metales básicos

Las materias primas se han convertido hoy en día en un tema de enorme interés, tras los peores momentos de la Pandemia del *COVID-19*, la reactivación de las economías, la reordenación logística del trading, la involución de la globalización en favor del negocio de proximidad, la crisis geopolítica entre Rusia y Ucrania y la escasez general de las materias primas. Todo ello, preparando la situación macroeconómica para el acuciante súper ciclo de los metales.

Los ciclos temporales que ha evidenciado el sector de los metales en general siempre han estado ligados a circunstancias y movimientos de consumo mundial y por ende a ciclos económicos. En la literatura relacionada, tienden a asociarse con las llamadas "*Kondratiev waves*", que son evidencias de las subidas de precios en los mercados de las *commodities* con momentos económicos a largo plazo (Marañón & Kumral, 2019). En dichas referencias de ciclos económicos a largo plazo han sido muchos los estudios que tienden a acotarlos en periodos, de 20-70 años (Cuddington & Jerret, 2008), 30-40 años (Erten & Ocampo, 2012) o 28-30 años (Rossen, 2015), pero la realidad es que la reciente historia nos deja impactos mucho más trascendentales que los estrictamente estadísticos, que golpean el mundo económico y por ende los sectores de *commodities* y sus precios. La estacionariedad dentro de un ciclo anual siempre ha sido objeto de análisis, intentando extrapolar al mundo de los metales lo que históricamente siempre ha ocurrido en las *commodities* más relacionadas con la agricultura como son las *soft commodities* (Sharon & Girish, 2021).

¿Dónde nos encontramos ahora mismo dentro de estos ciclos? Claramente, estamos en una situación de inventarios de metales en las distintas bolsas a niveles mínimos históricos, de precios a valores récord y con una revolución industrial, de servicios necesarios y de consumo, con enormes crisis geopolíticas, que nos hacen estar en los albores de lo que se ha venido a llamar, un inminente súper ciclo de los metales, por esperarse una elevada demanda sostenida durante un periodo prolongado (diferente para cada metal como se explicará más adelante) y su implicación en los precios y, por desbordamiento, en el resto de la economía.

Los patrones comunes, como el comportamiento de la economía china a inicios de los años 2000 con los años 2020, añadido a todo el proceso de no inversión industrial desde la crisis financiera, hacen esperar que dicho súper ciclo de los metales sea algo absolutamente inminente, sólo pudiendo estar en peligro por los actuales desarrollos geopolíticos como es la crisis de Ucrania y Rusia, desencadenando un conflicto bélico que puede influir de manera determinante en dicho súper ciclo, bien dinamitándolo definitivamente o bien ralentizándolo.

Surgen gran cantidad de preguntas relacionadas con dicho súper ciclo ¿qué metales serán los más demandados? ¿se quedará el mundo sin metales? ¿los altos precios darán paso a productos o materiales alternativos? ¿cómo afectarán las políticas medioambientales al sector de los metales?

La respuesta combinada a todas estas preguntas genera en sí misma la previsión de este ciclo al que todo apunta se caracterizará, durante un largo periodo, por la fuerte demanda y una intensa presión alcista sobre los precios.

Todos los metales parecen ser críticos en esta situación de movimiento económico al alza en la que las bases del consumo cambian rápidamente: hará falta más plomo para las baterías, más cobre y aluminio para los conductores eléctricos, más acero para infraestructura, maquinaria y útiles en general, más estaño para aislamientos especiales y aleaciones, más níquel para el aumento de la producción de aceros inoxidables, etcétera. Es por ello que no se puede considerar ningún metal menos necesario que otro para los próximos años y décadas.

Desde el punto de vista de la oferta, todo parece ligado al precio, es decir, existen reservas naturales mineras para suministrar el mercado completo, siempre que el precio de las *commodities* sea lo suficientemente alto como para poder ser rentable su extracción (ya que las leyes[1] más bajas de metales son las menos extraídas por ser más costosas). Es por todo esto que consideramos que el caldo de cultivo existe para el desarrollo de este súper ciclo de metales incipiente, pero, sobre todo, venidero; en el mundo del cobre, se esperan horizontes de consumo masivo por el desarrollo del coche eléctrico y con el año 2400 como previsión de desaparición de disponibilidad, Jones et al. (2020) y Sverdrup et al. (2014). Por otro lado, en el aluminio, Li et al. (2021) proponen aumentos de consumo para reducir la emisión de los gases de efecto invernadero. En el níquel, Olafsdottir & Sverdrup (2021) hacen un estudio sobre el incremento de consumo en las baterías y por ende, generando una tensión en la demanda, aproximación similar a la de Baars et al. (2021) en el plomo, aunque en este caso asociado al reciclado de las baterías. En referencia a la escasez de zinc, Sverdrup et al. (2019) y Tokimatsu et al. (2017) realizan estudios en base al horizonte de disponibilidad del metal en el año 2100 y la situación asociada a la extracción, respectivamente. Por último, en el estaño, Li et al. (2021) realizan un estudio de la capacidad de extracción que evidencia la falta de disponibilidad a medio plazo.

Otros autores, como Yokoi et al. (2021), Simon et al. (2020), Lee et al. (2020), Lèbre et al. (2019) y Schmidt (2018), modelizan la evolución de oferta-demanda por regiones y periodos, en metales básicos y no básicos, y la previsible escasez de oferta futura, incrementos de precios de venta para justificar dicha reducción de disponibilidad, así como transiciones hacia la reducción de emisiones de CO_2 a la atmósfera.

Para entender mejor el posible súper ciclo de los metales, se ha de tener en cuenta, también, aquellos efectos que pueden ir a la contra de la existencia de éste, tales como:

- El efecto de los productos sustitutivos y,
- El impacto de las políticas medioambientales

[1] Ley: porcentaje de metal contenido dentro del mineral o concentrado extraído.

En referencia al primero, la historia reciente nos indica cómo, por ejemplo el PVC ha sustituido al cobre en tuberías para conducir el agua, la fibra de vidrio al mismo metal para la conducción de señales (cable telefónico), o el uso de cerámicas en lugar de aceros en el mundo de la construcción, pero de una manera o de otra, las características de los metales, por su dureza, conductividad, resistencia, etcétera, hacen que sea difícil ser sustituidos de manera masiva por otro tipo de materiales no metálicos.

Por otro lado, son innumerables los intentos de los distintos gobiernos de frenar el calentamiento global y el cambio climático y, como buena muestra de ello es la reciente adhesión, en 2021, de Estados Unidos al Acuerdo de París (que entró en vigor en noviembre de 2016[2]), con un impacto definitivo en el cumplimiento de sus objetivos, especialmente en lo relativo a las medidas relacionadas con las industrias extractivas y transformadoras. La industria minera ha sido siempre una industria considerada como contaminante, y aunque los esfuerzos para conseguir reducir sus emisiones han sido innumerables, no se ha conseguido, y es sin duda su gran asignatura pendiente. Es en este sentido que existen grandes movimientos para empujar el mercado hacia la sostenibilidad, forzando los organismos reguladores a mantener cuotas de emisión de CO_2 controladas y dando mayor valor a aquellos productos que menores emisiones hayan generado en su producción. Dentro del marco de la sostenibilidad, también se engloban las soluciones de reciclado de metales que cada vez están adquiriendo más fuerza a nivel mundial y que se conoce como la Minería del Siglo XXI o Minería Urbana.

Éste es el contexto general empleado en esta tesis doctoral, para la que hemos tomado como objeto de análisis los elementos que más han removido todos los mercados en estos últimos años (y el del sector de las commodities en particular), como han sido la crisis asociada a la pandemia del *COVID-19* o el desarrollo del *Brexit,* estudiando sus implicaciones en los mercados de metales básicos, materias primas fundamentales para los sectores industriales tales

[2] https://www.un.org/es/climatechange/paris-agreement#:~:text=El%20Acuerdo%20de%20Par%C3%ADs%20brinda%20un%20marco%20duradero,en%20aumentar%20las%20ambiciones%20clim%C3%A1ticas%20de%20los%20pa%C3%ADses

como automoción, construcción y electrónica. Son materiales que se comercializan en las bolsas de materias primas de metales de las distintas localizaciones geográficas, LME (*London Metal Exchange*), COMEX (*Commodity Exchange, division of New York Mercantile Exchange*) y SHFE (*Shanghai Futures Exchange*). En dichas bolsas, se establece una compleja red de almacenamiento intermedio (almacenes) que forma parte esencial del modelo financiero del mercado de futuros y cobertura.

La formación de precios de estas materias primas, a presente y a futuro, así como la influencia bidireccional con las principales variables macroeconómicas y microeconómicas, son, así, el objeto de este estudio.

A continuación, en este capítulo introductorio, se describirán, en primer lugar, los dos tipos de fuerzas de cuya interacción se realiza la formación de precios (por un lado, los fundamentales de los mercados, vinculados a la oferta y demanda de metales físicos y, por otro, las generadas por los propios mercados financieros financieros -financiarización de las materias primas-), así como los mecanismos de cobertura -*hedging*- que emplean los agentes para optimizar el resultado de su participación en los mercados de *commodities*. Seguidamente, en el epígrafe 1.2 se mostrarán los eventos específicos que se han seleccionado por ser los que más intensamente han condicionado los mercados (Brexit y la pandemia del COVID-19), junto con el funcionamiento de la estructura de precios en un contexto de precios altos de los metales. El epígrafe 1.3 describe los objetivos de cada uno de los tres trabajos que se proponen en esta tesis. En el epígrafe 1.4, se expone la metodología empleada y en el epígrafe 1.5, las principales aportaciones. El epígrafe 1.6, concluye.

1.1. Financiarización, efectos fundamentales y *hedging*

Transversalmente, todas las materias primas sobre las que se ha trabajado en esta Tesis se encuentran determinadas e impactadas por aspectos fundamentales y por causas financiarizadoras, además de ser una herramienta para estrategias de *hedging* o cobertura de la volatilidad del precio.

Aquellos aspectos que se consideran fundamentales son los estrictamente asociados a las leyes de la oferta y de la demanda física. La producción de las materias primas y su disponibilidad en almacenes intermedios (regulados o no por órganos bursátiles) pueden considerarse como los principales componentes de la oferta, siendo los consumos de las diferentes industrias la base fundamental de la demanda. En el mundo de los fundamentales, nos encontramos actualmente en una situación en la que existe una demanda exacerbada de materias primas, proveniente principalmente de la reactivación económica posterior a la peor situación de la Pandemia, añadido a una necesidad de productos industriales como apoyo al desarrollo de las energías renovables y a equipos específicos, como puede ser el coche eléctrico. Del lado de la oferta, aunque los recursos naturales para la generación de dichas materias primas pueden considerarse como suficientes para las próximas décadas, los costes de dichas extracciones, su distribución geográfica, los efectos de sustitución entre las mismas y en general su modelo de sostenibilidad generan cierta tendencia hacia la escasez y, por tanto, al defecto de oferta. Cabe resaltar en el aspecto de la oferta, la enorme repercusión que los efectos de la crisis geopolítica de Ucrania y Rusia está generando, con la reducción de movimientos de determinadas materias primas hacia áreas de consumo, sanciones bidireccionales entre las zonas implicadas en el conflicto bélico y precios de la energía (gas natural, electricidad y combustible) que llevan al límite la continuidad de los negocios clásicos (transporte e industria), desembocando en una inflación en Europa sin precedentes.

Por el lado de la financiarización, encontramos que los mercados de las materias primas han sido el refugio de inversores (fondos de inversión, traders y especuladores) durante décadas, que han operado de una manera reglada, pero orientada, a optimizar sus posiciones, quedándose cortos esperando una bajada de precios o posicionándose largos de materiales, en espera de futuras subidas. Centrándonos en los análisis de liquidez de todos los metales básicos, encontramos algunos muy financiarizados, tales como el aluminio y el cobre, a la vez que encontramos metales muy poco financiarizados, como son el estaño y el plomo. Dicha financiarización ha sido medida de varias maneras, teniendo en cuenta los lotes que las instituciones financieras soportan en la Bolsa de Metales de Londres (LME), arrojando en este orden la financiarización de los metales básicos: Al-Cu-Ni-Zn-Pb-Sn[3] o por valor en dólares de dichos lotes, cambiando algo el orden de los mismos: Ni-Cu-Al-Zn-Sn-Pb, pero manteniendo al cobre y al aluminio como los más financiarizados.

En los mercados financieros de materias primas, las operaciones en las distintas bolsas anteriormente mencionadas (LME, COMEX, SHFEX) se realizan con fechas teóricas en las que se compran (y por lo tanto se han de recoger), o se venden (y por lo tanto se han de entregar).

Dichas bolsas, también se utilizan como mercados en los que realizar coberturas (*hedging*), utilizando fechas en las que finalmente ni se entregan ni se recogen materiales y, por tanto, son fechas en las que realizar el *offset* (operaciones contrarias a las realizadas para cerrar la posición).

Estas operaciones de *hedging* se realizan y perfeccionan en fechas concretas, siendo algunas más líquidas que otras como han demostrado varios autores, como Otto (2011).

La fecha de referencia en el mundo de los metales básicos es la de 3 meses desde el momento actual y es la base para la determinación de la llamada “estructura del precio de los metales”, que se define como la diferencia entre el precio contado del momento (o *cash*) y el precio de referencia a 3 meses:

[3] Al: Aluminio, Cu: Cobre, Ni: Níquel, Zn: Zinc, Pb: Plomo y Sn: Estaño

Estructura precio metales = (precio a 3 meses) – (precio a contado)

Cuando dicha estructura adquiere un valor negativo, se consdiera que el mercado está en una situación de *backwardation*, siendo la contrario una posición llamada *contango*.

Ambas referencias pueden ser usadas por los distintos actores del mercado, tales como: productores, consumidores, *traders*, bancos, fondos, etc. para establecer sus posiciones y obtener rentabilidad.

Entender cuándo ocurren ambas situaciones (*contango* y *backwardation*) y qué influye en ellas, es una herramienta clave y el objeto de esta tesis doctoral.

Una vez contextualizados *contango* y *backwardation*, nos enfocamos a entender qué significan en la literatura relacionada y en la economía en general, elementos como la *"normal backwardation*"; Dicha teoría consiste en la asociación de valores de *backwardation* con situaciones de escasez, determinadas por defectos de oferta o excesos de demanda física, donde la regulación que hacen las distintas bolsas a través de sus stocks en almacenes juega un papel determinante en el modelado del precio a presente y a futuro. Dicha "*normal backwardation*" puede tomarse en cuenta con un valor de *backwardation* de signo contrario, conceptuándose en *contango* dentro de dicha teoría.

Las evidencias de la existencia de la *"normal backwardation*" son tácitas en momentos tales como la primera ola de la pandemia del *COVID-19*, ejemplo que estudiamos en esta tesis, donde el defecto de la demanda fue un hecho y donde los stocks de los almacenes de las distintas bolsas de materias primas aumentaron y los precios a presente se desplomaron, también respecto a su mismo precio a futuro.

1.2. Contextualización y eventos específicos

En este entorno de cobertura o *hedging* y en consonancia con la estructura de futuros del precio de los metales, contango y *backwardation*, los eventos relevantes (ya sean microeconómicos o macroeconómicos) tienen una influencia determinante en dicha estructura. En esta tesis se analizan distintos tipos de eventos relevantes como el *Brexit* y la pandemia del *COVID-19*, así como el vínculo entre los precios altos y la *backwardation* en metales financiarizados, dentro de un entorno de tensión entre una demanda al alza y una oferta mantenida.

1.2.1. *Brexit*

En el conjunto de factores macroeconómicos, el *Brexit* ha sido sin duda uno de los elementos más influyentes para el flujo global de todos los mercados en la historia reciente.

El *Brexit*, entendido como una declaración que confirmaba el abandono del Reino Unido como país miembro de la Unión Europea, ha roto con un modelo de circulación estandarizado de mercancías durante décadas y de economía en general. Desde la decisión de dicha salida en 2016, la confirmación por parte del Gobierno británico en 2019, las prórrogas durante el mismo año y hasta la confirmación de su salida en enero de 2020, han sido muchos los movimientos políticos de las instituciones de Reino Unido y la Unión Europea para regular sus relaciones en todos los ámbitos.

En referencia a las materias primas en general y los metales básicos en particular, el *Brexit* ha sido sin duda un factor influyente y motivador, ya que ha generado inestabilidad política que los tensionados mercados de metales no han pasado por alto.

Para medir la repercusión económica del *Brexit* hemos empleado el índice BUKHI50P, parte del CBOE *(Cboe Global Markets)*, que engloba a las 50 compañías con mayor capitalización en Reino Unido en las que sus ingresos dependen de la balanza de comercio en libras esterlinas, siendo, por tanto, un barómetro del *Brexit*. Las fluctuaciones de este índice son tomadas como referencia para medir el impacto sobre diferentes materias primas, tales como el cobre. La entrada y salida de empresas dentro de dicho índice depende de su mayor o menor capitalización en libras esterlinas, siendo por tanto un índice muy vivo que refleja en todo momento cuál es la relación del *Brexit* con la actividad económica.

1.2.2. Precios en alza y desarrollo de la *backwardation*

Dentro del más que evidente súper ciclo de los metales, los precios y la estructura a futuro toman especial importancia. La mayoría de la literatura en este campo está ligada en exclusiva a la formación de precios y a la influencia de distintos eventos en los mismos. Por ello, nuestro objetivo se ha enfocado en la estructura a futuros del precio de los metales básicos y su funcionamiento en un contexto de aumento de precios, como elemento diferenciador sobre la literatura, poniendo el foco en los metales más financiarizados.

Dichas relaciones entre los precios altos y el desarrollo de la estructura a futuros del precio de los metales básicos, se agudizan en situaciones de mercado tensas, por falta de suministro o por aumento de la demanda. En un entorno como el actual y en circunstancias de eventos macroeconómicos extremos, dicha tensión se agudiza y por lo tanto la relación entre los precios altos y el desarrollo de la *backwardation* se evidencia más.

El ejemplo actual más determinante lo encontramos con la situación que está generándose a partir del conflicto bélico entre Rusia y Ucrania, en la que los precios de determinadas *soft commodities*, los metales básicos y la energía están alcanzando máximos históricos.

1.2.3. *COVID-19*

A finales del año 2019, empezó a hablarse de una enfermedad de rápida transmisión e importantes efectos en la salud de los enfermos de esta patología en Wuhan-China. Sólo se necesitaron algunos meses para que la OMS[4] declarase esta enfermedad como pandemia, hecho que sucedió el 11 de marzo de 2020, ante los datos que se arrojaban en ese momento de 118.000 casos en 114 países y 4.291 personas que habían perdido la vida[5], 600 días después, el número de casos en el mundo era de más de 250 millones y más de 5 millones de muertes.

El cómo cada país, de manera individual, así como las distintas organizaciones gubernamentales europeas y mundiales han afrontado esta situación epidemiológica desde el punto de vista sanitario y económico, ha sido muy diferente, con una pauta económica común: los cierres físicos de fronteras, tanto perimetrales como globales, las paradas temporales de los centros productivos y los puntos de conjunción de personas, las ayudas económicas para reactivaciones posteriores, una crisis económica materializada durante y posterior a los distintos confinamientos, así como una recuperación desordenada.

Dichos movimientos económicos son los que han evidenciado una vital importancia de las materias primas, generando grandes problemas de almacenamiento en los momentos de menor consumo mundial, llegando a generar situaciones de precios negativos del petróleo (Le et al., 2021), con caídas generalizadas en el precio de todas las materias primas y grandes problemas en los productores para ubicar sus productos en almacenes, tanto los oficiales de las bolsas de *commodities,* como fuera de ellos.

Durante la primera fase de la pandemia, la alarma por el desabastecimiento de determinados bienes de consumo básico generó una sobredemanda para almacenamiento, neutralizando en cierta medida la falta de comercio a nivel mundial. Pero esto sólo era el principio de un incipiente desorden y desalineación de los canales de comercio mundiales que iba a generar varias crisis que un año

[4] Organización Mundial de la Salud www.who.int
[5] https://www.who.int/es/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020

y medio después mantenía una situación descompensada en la cadena de suministro global (Béné et al., 2021).

En la siguiente fase de la pandemia, una vez que la situación sanitaria mejoró y las economías se reactivaron, las cadenas de comercio tendieron a reactivarse, generándose problemas en la situación logística mundial, con el desplazamiento de unidades de producción hacia China y, por tanto, una basculación de recursos hacia esa geografía (Tegbrant & Karlander, 2021).

La fase de asentamiento de la pandemia del *COVID-19* a finales de 2021, sigue teniendo grandes efectos sobre la escasez de materias primas en general, bien por efectos de previsión de desabastecimiento (Sadus et al., 2021), por la limitación de componentes tecnológicos (Wu et al., 2021) o la aparición de nuevos consumos por la aparición de nuevos modelos de sostenibilidad (Arribas-Ibar et al., 2021).

1.3. Objetivos del trabajo

El entorno de este trabajo describe la situación actual de los mercados de los distintos metales básicos, a la vez que busca relaciones entre eventos macroeconómicos (tales como el Brexit y el COVID-19) y el desarrollo de las estructuras a futuros de sus precios.

En esta tesis se han estudiado las siguientes tres relaciones entre mercados:

- La influencia del *Brexit* en un mercado tenso de demanda como en el que se encontraba el cobre, desarrollando su estructura de futuros de precio en base a la LME hacia una situación de *backwardation*.
- Cómo precios altos de referencia de los metales se ligan con desarrollos de *backwardation*, siendo más evidentes en metales más financiarizados.
- Cómo se relacionan los stocks en almacenes de bolsa (LME) con estructuras de futuros de precio en *contango* (evidencia por tanto de la teoría de la "*normal backwardation")* en el periodo de desarrollo de la pandemia del *COVID-19* especialmente en las regiones europeas.

1.4. Metodología

Las bases de precios y las variables económicas se estructuran en series temporales, por lo que, para su estudio, se han utilizado métodos de análisis de estacionariedad de series temporales, tales como los ADF, PP y KPSS tests, así como el uso de la prueba de Durbin-Watson para el análisis de la estacionariedad de los residuos lineales de las series y su consistencia. Todo ello usando, cuando ha sido necesario, las transformaciones exponenciales de Box-Cox de las series.

Para los estudios de cointegración y por lo tanto de chequeo de comovimientos entre las series temporales, se ha utilizado la teoría de Causalidad de Engle y Granger, bajo la aproximación de Johansen, previo análisis de los retardos de las series siguiendo los criterios BIC y AIC. Es en este entorno donde se ha hecho uso de la determinación de la λ_{max} y las pruebas de la Traza.

Con el objetivo de encontrar subintervalos dentro de las series temporales en los que analizar con más detalle posibles comovimientos, se ha hecho uso de los análisis de *structural breaks*, bajo los *Chow tests* y *Wald Statistics*.

Por último, también se han utilizado análisis de datos de panel para encontrar una mayor representatividad de los datos, ampliando las series de datos hacia matrices de datos de análisis, utilizando los datos de panel bajo los *tests* de Kao, Pedroni y Westerlund.

1.5. Aportaciones de la tesis doctoral

Hemos conseguido ahondar en los objetivos buscados, obteniendo los siguientes resultados:

- El índice BUKHI50P (empresas cuya facturación está ligada al balance comercial de Reino Unido) del CBOE (Chicago Board Options Exchange), está cointegrado con la estructura a futuros del precio del cobre. Los eventos Brexit, por tanto, generan un impacto negativo en dicha estructura. Así, este tipo de eventos, cuya importancia se refleja de inmediato en el mercado, permite a los agentes establecer estrategias basadas en la estructura de precios, utilizando fechas valor para sus operaciones.

- En un entorno de precios altos en los metales básicos, la estructura a futuros del precio y sus precios actuales se encuentran cointegrados, siendo dicha cointegración consistente en los metales más financiarizados como son el cobre y el aluminio. Este estudio nos provee de un patrón más fidedigno y basado en la econometría, de manera que cuando los precios tienden a valores más altos, los mercados tienden a su vez a una estructura de precios en *backwardation*. Los resultados proveen a aquellos participantes del mercado que hacen cobertura de sus posiciones en bolsa o físicas, de una teoría para recolocar sus posiciones de “*stop loss*” o “*profit taken*” en escenarios tensos y de precios altos, para obtener más valor de sus posiciones.

- Durante la llamada primera ola de contagios del COVID-19 en Europa, se desarrolla la llamada “normal backwardation”, obteniendo una cointegración entre el aumento de las muertes y el desarrollo del contango en metales básicos como es el caso del cobre. Las principales implicaciones de este estudio nos llevan a entender un cambio en la estructura de futuros, pasando de la backwardation al contango, demostrándose el peso del efecto de los elementos fundamentales. Por tanto, aquellos componentes de mercado que entiendan a tiempo dicho cambio, pueden tomar posiciones para beneficiarse del margen que dicha estructura a futuro les puede generar.

Hay actores de mercado que acuden a la Bolsa de Metales, para especular y buscar situaciones en la que los precios tiendan a subir o a bajar, para optimizar su posición o mejorar la rentabilidad de sus operaciones. Otros actores utilizan las Bolsas de Metales para hacer *hedging*, e intentar que sus negocios no sean dependientes de los precios sino de las transformaciones de las Materias Primas. Nuestros resultados adquieren valor para estos últimos agentes, ya que pueden:

- Posicionarse de manera que, ante eventos macroeconómicos adversos, se optimicen sus posiciones de cobertura, a corto o a largo plazo. Bien en un sentido, como es el caso del *Brexit* y el desarrollo de la *backwardation,* o bien como en el caso del *COVID-19,* posicionándose a favor del *contango*.
- Considerar la situación real del precio en el momento de trabajo (de subida constante o de ralentización de precios), para acompañar sus posiciones con la llamada *“normal backwardation*”.

Mineros, fondos y transformadores industriales pueden utilizar las anteriores recomendaciones para solicitar fijación de precios de sus mercancías a corto o a largo plazo e intentar obtener valor de sus posiciones.

1.6. Conclusiones y resumen del capítulo

En esta tesis, hacemos un estudio sobre varias *commodities*, identificando comovimientos entre variables macroeconómicas y estructura de precios de metales a futuro, de igual manera que la misma se adentra en las conexiones existentes entre los precios altos y los desarrollos de estructuras de *backwardation*, pudiéndose identificar vehículos para dirigirnos hacia el llamado súper ciclo de los metales ya que las situaciones de *backwardation* se asocian con situaciones de escasez, de mayor demanda, de oferta controlada y por ende de precios altos, base fundamental y por tanto evidencia de la llamada "n*ormal backwardation*".

Los resultados (cointegraciones) obtenidos demuestran que, en un mercado con tendencia a la escasez de disponibilidad como en el caso del cobre, los eventos asociados al *Brexit* intensifican la tensión en el mercado de la *commodity*. Por otro lado, evidenciando la teoría de la *"normal backwardation*", también se obtiene una importante influencia de los efectos fundamentales (oferta y demanda físicas) en presencia de eventos extremos, como es el caso del inicio de la Pandemia del *COVID-19* en Europa, en su primera ola de contagios.

Podemos determinar, por tanto, que ante la inminente llegada del nuevo súper ciclo de los metales, hay que tener en cuenta todos los efectos financiarizadores y fundamentales en cada momento, para posicionar estrategias de estructura de precio y maximización de resultado o al menos dirigir posiciones de cobertura para reducir el riesgo.

Tras el estallido de la guerra entre Rusia y Ucrania, los precios de las materias primas se han disparado aún más, entrando muchas de ellas en situación de clara backwardation, en alineación con los resultados de esta investigación. Los últimos eventos corroboran lo demostrado en esta Tesis Doctoral acerca de la backwardation en situaciones de precios altos y de acontecimientos que aumentan la tensión de los mercados económicos globales.

2. Cointegration between the structure of copper futures prices and *Brexit*[6]

2.1. Abstract

In copper futures trading, '*contango*' (or '*forwardation*') is the condition in which the futures price enjoys a premium over the spot price on the London Metal Exchange at the close of the second ring and '*backwardation*' the contrary. That spread or difference between the two prices is affected by fundamentals such as supply and demand as well as by political, social, environmental and macroeconomic risks, hereafter grouped under the term '*financialisation factors*'. Based on analysis of variations in the BUKHI50P stock index that monitors the impact of *Brexit* on UK companies, this study shows that in the context of a market shortage, *Brexit*-related macroeconomics and their effect on local companies are cointegrated with the structure of copper futures prices. Guidelines are also provided for traders on when to short- and when to long-sell to capitalise on the structure of copper futures prices under simultaneous market shortage and adverse macroeconomic circumstances.

2.2. Keywords

Brexit; *commodities*; structure of copper futures prices; cointegration; *contango*; *backwardation*

2.3. Introduction

Commodity markets are used by investors as financial markets to diversify their exposure to securities (Aepli et al., 2017). So-called fundamentals and their effects on *commodity* prices are strictly associated with the law of supply and demand and investor bullish (positive) or bearish (negative) sentiment. Financialisation, in contrast, defined here to mean the growing market

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[6] *Artículo publicado en la revista Resources Policy, volumen 71, accesible en el enlace:* https://www.sciencedirect.com/science/article/pii/S0301420721000155.

involvement of investment funds and other interest groups, it is related to their tendency to buy or sell shares in keeping with what is most beneficial for their respective positions. The outcome is a situation in which players' actual positions are difficult to determine and a market sensitive to international trading, international finance and trading technology, all of which are contended by Valiante (2015) to drive physical trading.

A market's local (microeconomic) impact, the conditions that specifically affect a given security, the effect of geopolitical and global (macro-) economic indicators, fundamentals and financial factors vary with the market cycle. The extent of such effects differs in bull and bear markets as well as when there is an excess or shortage of supply or demand. The greater or lesser impact of financialisation and market fundamentals was explored by Paraschiv et al. (2015), who identified situations in which *commodity* prices would be driven by the former and structural breaks by the latter. Figuerola-Ferreti et al. (2015), in turn, found periods of mild volatility to be associated with financial bubbles and others when prices were driven by tight physical markets.

Commodity market contracts, generally traded on futures markets and formalised on exchanges, are primarily used to hedge price exposure, with a mere 1 % subsequently materialising as physical movements of goods to or from warehouses. Kleinman (2013) noted that in the London Metal Exchange's (LME) prompt date system, which envisages different contract durations, some terms are more liquid than others and positions can be hedged in advance of the purchase or sale date contracted.

In non-ferrous LME markets such as copper, timing is a major issue due to its high price and volume of futures trading. Three-month transactions are the most liquid and the ones to which most LME contracts are referenced by traders and brokers (Otto, 2011). Against that backdrop, a term of 3 months may be adopted as the reference for the structure of copper futures prices, defined as the differences between the 3-month futures and spot prices. When the forward price is higher (difference >0), the result is known as *contango* and when the spot or cash price is higher, *backwardation*.

Where there is a physical shortage of a *commodity* on the near-term market, the situation is generally termed ‘normal *backwardation*’. One review of *backwardation* not strictly attributable to physical shortage found that the prevalence of ‘speculator’ over producer / consumer behaviour had a significant effect on the futures price curve of some *commodities* (ap Gwilym et al., 2019). The perception of physical shortage may be induced by high market demand, supply problems affecting a specific player or production cutbacks intended to force prices upward (Go and Lau, 2017). *Contango*, in contrast, is generally associated either with a balanced market or sufficient availability reserves to ensure short- and medium-term supply.

Contango and *backwardation* are likewise deemed to be a reaction to investor demand, in turn, heavily impacted by producers/manufactures and traders who attempt to deviate these trends in favour of their own positions. In a bear market, for instance, financial investors may tend to sell their *commodity* market positions to lower the cash or spot price to beneath the forward value, whereas producers/manufacturers who seek to prevent the price from dropping may buy those positions to neutralise that effect (raising the price and generating *backwardation*). A third type of player may also be present, however, such as traders in need of *backwardation* because they hold a contract with a near-term maturity or simply seek a dominant strategic position. Such actors would conclude more short-term contracts or even buy at the spot price in an attempt to induce *backwardation*.

The *commodity* studied here, copper, is a metal heavily traded worldwide with a direct effect not only on the economic environment in Chile, the world’s number one producer, where interest and currency exchange rates are affected by the demand for copper (Pedersen, 2019), but also on the Peruvian, Mexican, Congolese and Zambian economies. Copper is not alone as such an influential *commodity*; Cashin et al. (2004) detected co-movements between 44 *commodities* and exporting countries’ economic indicators.

Park and Lim (2018) showed that forward prices cannot be predicted by spot prices alone, contending that they may be impacted by financialisation factors, the inference being that *contango* and *backwardation* are also induced by such factors. That has informed the present attempt to identify possible correlations, co-movements or contagion between the structure of copper futures prices and macroeconomic events such as *Brexit*.

As mining is characterised by short numbers of large-scale transactions which must be optimised, the findings may prove to be of particular interest to the industry for they would provide traders with better insight into when to capitalise on the structure of copper futures prices.

This research makes several contributions to the state of the art:

- identification of the effects of macroeconomic events, and not merely the spot price, on the structure of copper futures prices as has been observed for other *commodities* such as gold or oil (Akbar et al., 2019; Kagraoka 2016);
- use of BUKHI50P, CBOE's alternative index to analyse the effect of *Brexit*-related events;
- determination of how macroeconomic events may modify the cost of carry (CoC) as theorised by Watkins and McAleer (2002), affecting price volatility and risk, particularly in a context of shortage of supply such as studied here, with a copper market deficit due to predictions of higher global demand than global output and when the leading exchanges' (LME, SHFE and COMEX) warehouses stood at historical lows;
- comparison of financialisation in the copper and other non-ferrous metal markets such as aluminum, zinc, tin and lead.

The remaining five sections into which this article is divided are: literature review in section 2.4; data and methodology in section 2.5; description of results and analytical review in section 2.6; discussion in section 2.7; and policy recommendations by way of conclusions in section 2.8.

2.4. Literature review

2.4.1. Co-movement

Co-movements involving macroeconomic variables and *commodity* prices have been observed for metals such as gold, silver, platinum and palladium (Batten et al., 2010), although some of those metals are less dependent than others on global macroeconomic indicators such as GDP and real interest rates (Chen 2010). Such relationships have been identified not only in metals or hard *commodities*, but also in soft *commodities*, whose price has been shown to be cointegrated with S&P 500 returns, more obviously in volatile environments such as financial crises (Creti et al., 2013). The price of copper has been linked to China's economic activity and the returns on its stocks (Guo 2018). Co-movements between prices and macroeconomic variables have also been found in freight markets (Lim et al., 2019).

Macroeconomic events could either attenuate or exacerbate two Watkins et McAleer´s 2002 theories regarding the relationship between metal spot prices and the nearest maturity date prices: Price volatility and risk.

Backwardation has traditionally been associated with a physical shortage of the *commodity* at issue, whether attributable to actual market availability or geopolitical issues. In a study of the (soft *commodity*) soya bean market, Lambrechts and Muganiwa (2019) observed shortage and low warehouse levels to concur with speculative forward purchases to guarantee supply. That is consistent with the theory of "normal *backwardation"* extensively studied by Benbachir and Lembarki (2018) applied to the near-term oil price curve as well as by Ames et al. (2020) to the long-term curve for that *commodity*. The two theories, *backwardation* and storage, were also combined in a model developed by Ekeland et al. (2019).

The literature review of co-movements also revealed reports of significant bidirectional Granger causality among the world's three leading metal futures markets, the Shanghai Futures Exchange (SHFE), London Metal Exchange

(LME) and New York *Commodities* Exchange (COMEX) (Rutledge et al., 2013). At this time, however, *backwardation* cannot be as readily associated with shortage due to the prevalence of financialisation.

2.4.2. *Brexit*

The substantial impact of *Brexit* on the world economy can be attributed to the United Kingdom's position as a major actor in the European Union and a world power. On 27 June 2016, the start date for *Brexit*, David Cameron confirmed that the people of the United Kingdom had voted to leave the European Union, triggering a series of worldwide economic events. Despite the short time lapsing in the interim, the literature includes many studies of the effect of that outcome on financial markets.

Gu and Hibbert (2018) found that highly volatile stocks were more sensitive to *Brexit* than those exhibiting greater price stability. Bohdalová and Greguš (2017), using the EPUCCEUM, EPUCUK and EPUCBREX indices, ruled out any association between *Brexit* and FTSE 100 volatility. In contrast, Davies and Studnicka (2018) observed that the worst daily post-referendum results were posted not only by companies highly exposed to the UK and the EU, but also by businesses reliant on imported intermediates. Breinlich et al. (2018) reported that stocks and sterling were both adversely affected when expectations around changes in UK-EU trading arrangements (tariffs and non-tariff barriers) were updated. Alkhatib and Harasheh (2018) observed an impact on ETFs and Nasir and Morgan (2018) on sterling. Škrinjarić (2019), obtained mixed results for the effect of *Brexit*-related events on the abnormal cumulative return series in Central and Eastern European (CEE) and South and Eastern European (SEE) securities markets, but observed a significant impact on the respective volatility series. Dao et al. (2019) proved that the *Brexit* vote had a sizeable effect on FOREX, the world's largest financial market, in light of the correlation between intraday values and the transmission of volatility to certain currencies. An analysis authored by Shaikh (2018) of the major implicit volatility indices in the Eurozone, Asia-Pacific, Africa, Canada and the US revealed positive abnormal returns and cumulative positive abnormal returns for the volatility index, along with negative returns for stocks, in most global equity markets.

Brexit was also observed to have a heavier adverse impact in countries with a high debt/GDP ratio, including Greece, Ireland, Italy, Portugal and Spain (Burdekin et al., 2018), and on companies with high domestic as opposed to international revenues (Oehler et al., 2017).

Post-*Brexit* European financial markets tended to be negatively correlated in the long run (Bashir et al., 2019). In addition, volatility contagion was observed in 43 emerging countries' stock exchanges following on the June 2016 referendum (Aristeidis and Elias, 2018).

2.5. Data and Methodology

2.5.1. Data

The copper price data for this study were sourced from the contracts used by the London Metal Exchange[7] to establish the price structure upon official daily close of the second ring which included 1042 price observations in the sessions held between 31/12/2015 and 27/12/2019. The Chicago Board Options Exchange's (CBOE) BUKHI50P[8] stock index that monitors the performance of the 50 UK companies most severely impacted by *Brexit* (those with the highest proportion of earnings in sterling), was the basis for determining the effect of *Brexit* events. Those events (listed in Annex 2.1), in turn, were drawn from the UK Parliament's House of Commons Library (2019)[9].

[7] see www.lme.com
[8] see www.cboe.com/indexeurope/*Brexit*
[9] see www.hansard.parliament.uk/commons/2016-06-27/debates/1606275000001/OutcomeOfTheEU Referendum

2.5.1.1. Structure of copper futures prices

The LME, an HKEX (Hong Kong Exchange Group, Hong Kong Exchanges and Clearing Market[10]) company, is the benchmark exchange for the international market price of non-ferrous metals (copper, zinc, aluminum, lead, tin and nickel), precious metals, the NASAAC (North American Special Aluminum Alloy Contract[11]), cobalt and molybdenum. Its system is used by all market participants to formulate and monitor prices and arrange for physical delivery via a global network of warehouses.

The structure of copper futures prices is defined as the difference between the London Metal Exchange's cash price and the 3-month forward price (the most liquid, according to Otto 2011) at official second ring closing, the latter constituting both, the reference price for physical trading and the official market price. In this context:

$$copper\ price\ structure = copper\ price_{3\ months} - copper\ price_{spot}$$
$$copper\ price\ structure\ > 0\ \rightarrow contango$$
$$copper\ price\ structure < 0\ \rightarrow backwardation$$

2.5.1.2. Copper market fundamentals

Copper market fundamentals show that physical supply and demand were fairly well balanced in 2016 to 2019, although balance on this market induces substantial industry concern around the possibility of a copper shortage generating a situation akin to market deficit.

Copper availability is determined by three sub-markets: refined product (mining) output, scrap (circular economy) output and warehouse inventories.

[10] see www.hkex.com.hk/?sc_lang=en
[11] see www.lme.com/en-GB/Metals/Non-ferrous/NASAAC#tabIndex=0

According to the International Copper Study Group's (ICSG) Copper Factbook 2018[12], copper consumption on the refined product market has been consistently higher than production since 2010 (Figure 2.1).

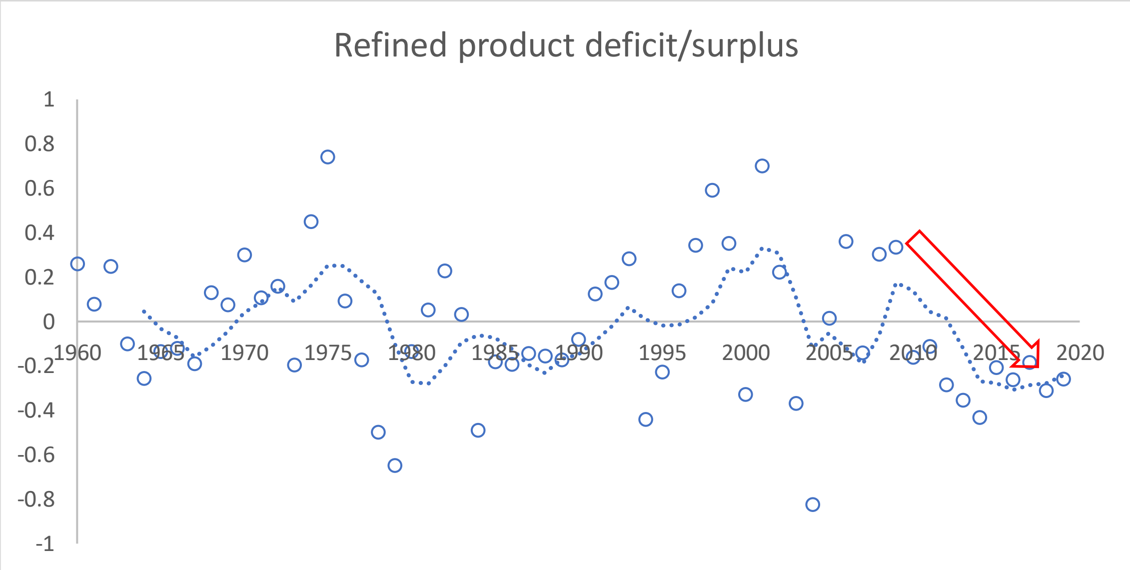


Figure 2.1. Refined product deficit (-) or surplus (+) (source: formulated by the authors from ICSG Copper Factbook 2018 and Economist Intelligence Unit N.A. data)

Consumption on scrap markets has held fairly steady for years (Figure 2.2), for despite the growing demand for recycled materials, greater industry efficiency has lowered the amount of scrap generated in the manufacture of all products. As a result, neither availability nor consumption has risen exponentially. That notwithstanding, recycling is one of the major factors in copper supply, as explained by Gómez et al. (2017).

[12] see www.icsg.org/

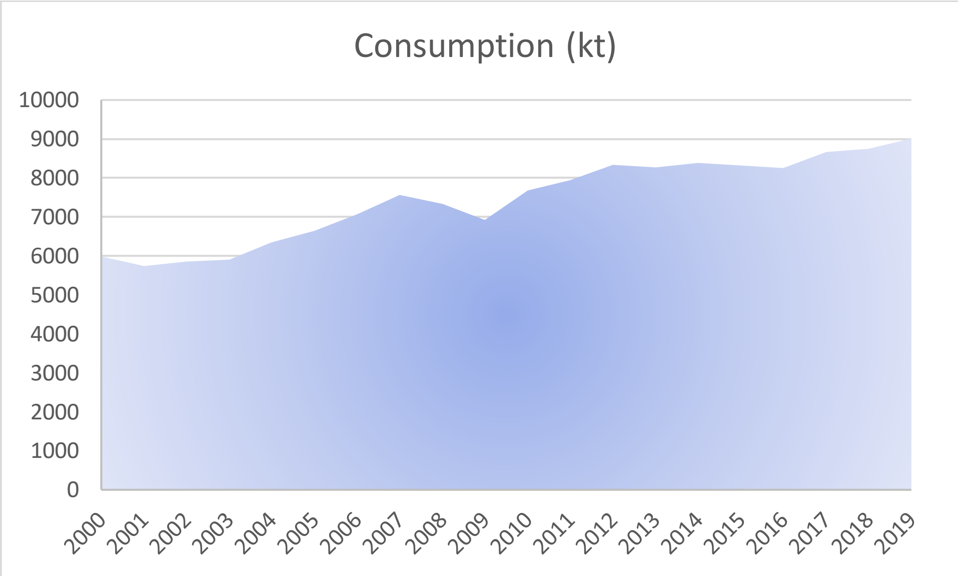


Figure 2.2. Total scrap consumption (thousands of metric tonnes) (source: formulated by the authors from ISRI[13] and ICSG data)

Warehouse inventories have declined significantly since 2016, to 25% of the peak volume recorded in the period studied (Figure 2.3).

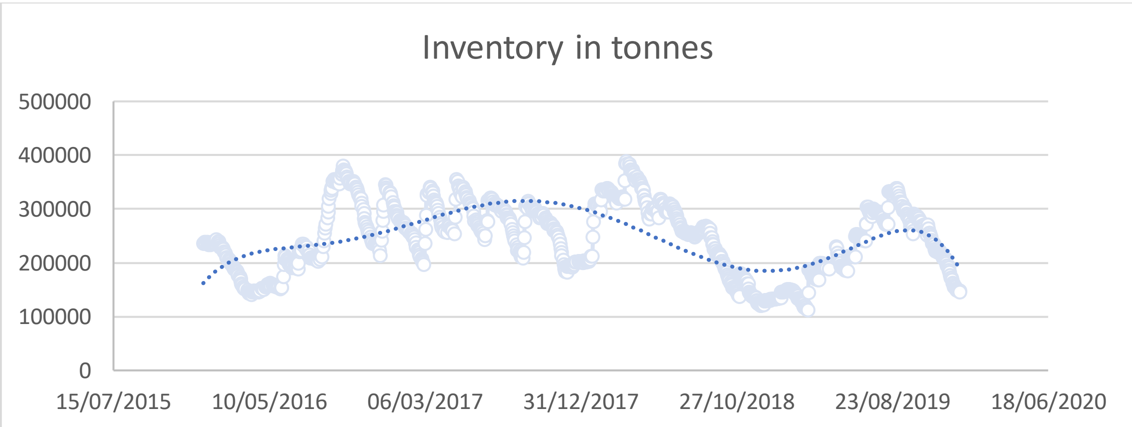


Figure 2.3. Copper inventory in LME warehouses

Figure 2.4, in turn, graphs the gradual decline in copper stocks as well as the progressive decrease in warehouse inventories (associated with specific customer demand) characteristic of shortage. That was attendant upon abrupt

13 see www.isri.org

large-scale inflows resulting from speculation by major players with short positions in an attempt to keep prices from rising too far.

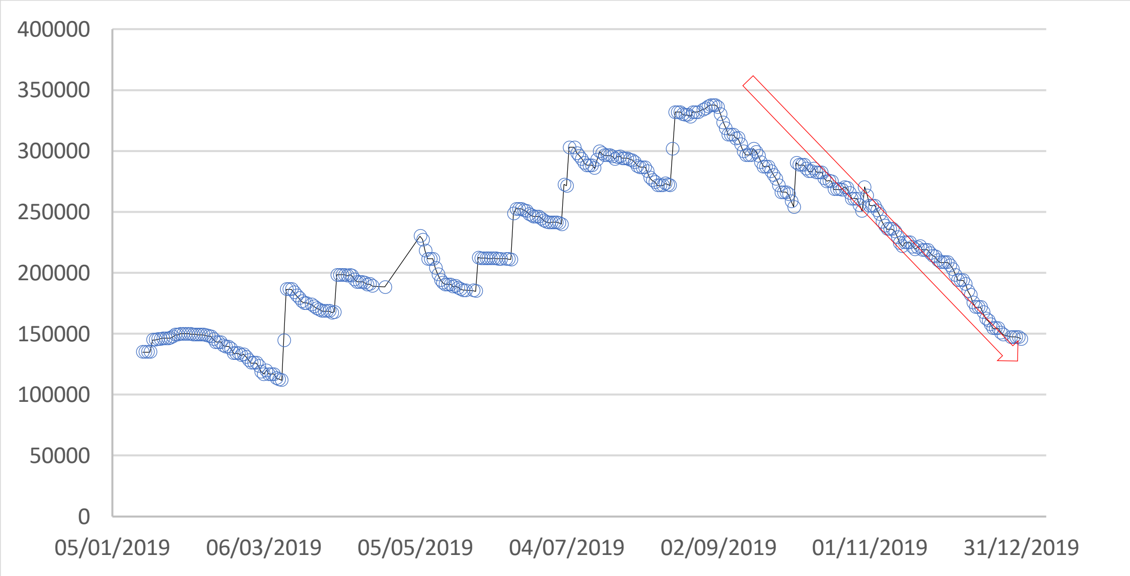


Figure 2.4. Copper stocks in LME warehouses (metric tonnes) in 2019

On the grounds of the information about the three sources of supply cited (refined product, scrap output and warehouse inventories), market supply and demand in the period were well balanced or exhibited a deficit, prompting fears of shortage.

An alternative approach to measuring copper shortage consists in the long-term netting of physical market positions and financiarization. Further to the LME's Commitment of Traders Report (COTR) on the activity of LME members and their clients, that calculation revealed a net market shortage. The report analysed (Quandl[14] database) both physical market (producer / merchant / processor / user) and financial market (money managers: primarily institutional investors) positions. A comparison of the two attested to a global historic net shortage of physical positions and a surplus of financial positions, due essentially to overbuying to keep the *commodity* price as high as possible (Figure 2.5).

[14] see www.quandl.com

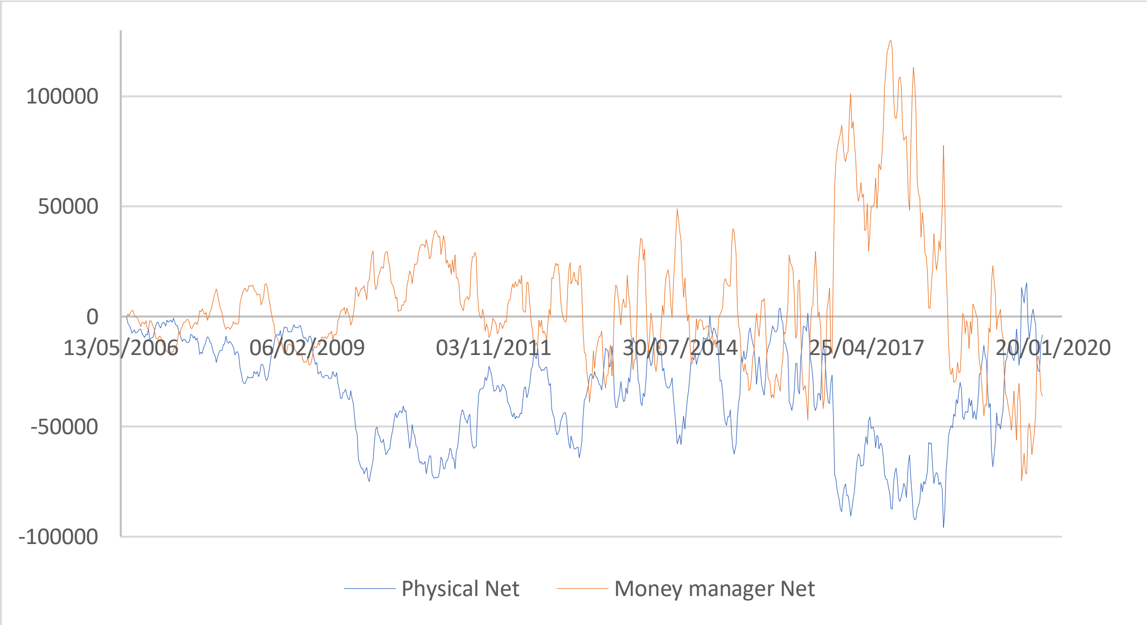


Figure 2.5. Physical and financial positions in copper on the LME by number of lots (Quandl)

An analysis of the overall position of the *commodity* based on all elements addressed in the report (including physical and speculative swaps and other transactions not cited in the foregoing) showed a deficit in the worldwide market in the period studied (Figure 2.6).

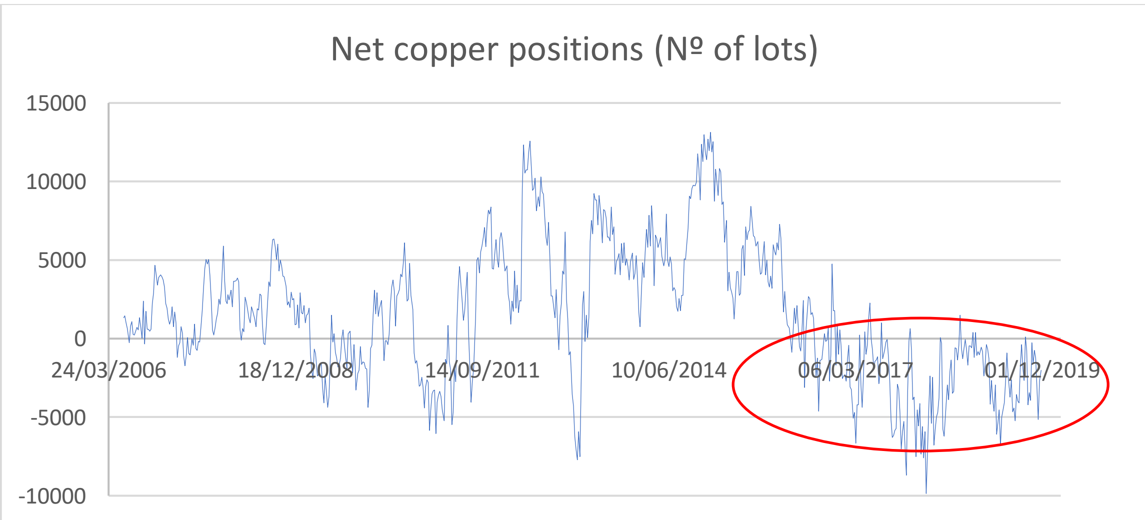


Figure 2.6. LME. Net copper positions in number of lots (Quandl).

2.5.1.3. Copper market financialisation

The LME's Commitment of Traders Report[15] was analysed to compare LME copper market financialisation to that of other LME non-ferrous metal markets, including aluminum, zinc and lead.

The number of lots held by each type of financial actor extracted from all the reports for the period was then multiplied by the metal price in the respective session. That exercise showed copper to be the major non-ferrous metal traded by value (Table 2.1).

Table 2.1. Financial institutions' holdings of LME metals by value

	Lot	Total Zn	Total Sn	Total Pb	Total AH	Total Cu
Investment firms or credit institutions	Long	164 670.98	13 153	95 226.83	710 566.22	258 192.84
	Short	137 691.60	9 814	74 858.49	521 487.79	231 266.00
Investment funds	Long	22 080.37	488	5 595	44 967.28	15 549.99
	Short	31 978.55	486	8 291	79 168.28	23 707.99
Other financial institutions	Long	52 837.87	1 723	51	124 930.71	41 445.68
	Short	36 474.93	1 269	83	94 559.98	31 115.88
All in	SUM	445 734.3	26 933	184 105.32	1 575 680.26	601 278.38
LME official price on 15/04/2020	Per mt	$1 909	$15 340	$1 664	$1 470	$5 055
All-in price ($)	Per mt	$850 683 912	$413 152 220	$306 351 252	$2 315 462 142	$3 039 161 572

2.5.1.4. BUKHI50P Index

The CBOE's (Cboe Global Markets) Europe Equities BUKHI50P index was used to analyse the effect of *Brexit* events on the copper market. That reference, a barometer of the impact of *Brexit* on local companies whose economic performance is determined by their business in the UK, is based on earnings

[15] https://www.lme.com/Market-Data/Reports-and-data/Commitments-of-traders#tabIndex=0

geography. The BUKHI50P index comprises the companies in the Cboe 100 UK index of the country's largest companies by market capitalisation deriving the highest portions of their revenues from the UK on a specific date, in this case 15/07/2019 (Annex 2.2).

Correlations between *Brexit* events and the BUKHI50P index values were sought separately for three periods: 2016-2017; 2018; and 2019.

Brexit events were consequently observed here to be closely correlated to changes in BUKHI50P index trends. That contrasts with findings reported by Bohdalová and Greguš (2017) based on the EPUCBREX, which ruled out any association between *Brexit* and FTSE 100 volatility. Yao and Memon (2019), however, observed the referendum to have a post-*Brexit* positive impact on that index.

2.5.2. Methodology

Granger causality theory (Granger 1969), was used to analyse the relationship between these two non-stationary time series, i.e., the structure of copper futures prices and the BUKHI50P index.

These series used $(y_t)_{t=1}^{N}$ are defined below:

- Structure of copper futures prices, $(y_t)_{t=1}^{N}$: $(stru_t)_{t=31-12-2015}^{27-12-2019}$ (Equation 2.1a)
- BUKHI50P (CBOE), $(z_t)_{t=1}^{N}$: $(BUK_t)_{t=31-12-2015}^{27-12-2019}$ (Equation 2.1b)

The series $\mathrm{stru_t}$ and $\mathrm{BUK_t}$ are non-stationary (mean and variance are not constant, and the covariance between any two points depends only on the distance between them but not on their specific locations in time, Tsay, 2010) (see Figure 2.7).

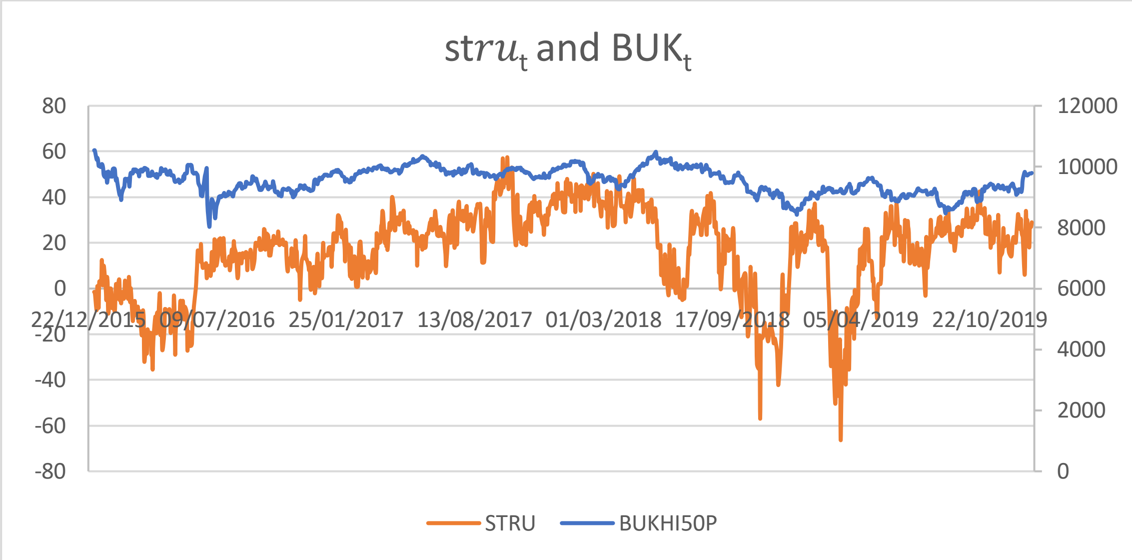


Figure 2.7 $stru_t$ and BUK_t over the time period studied

A number of tests are in place to verify time series stationarity: those where the stationarity of the series is the null hypothesis H0, such as KPSS (Kwiatkowski et al. 1992), used by Chen and Pun (2019), who found it to be more effective in bootstrap-based time series, the Leybourne tests and McCabe tests (Leybourne and McCabe, 1994) used in Otero and Smith (2012). In contrast, in other approaches, the null hypothesis assumes non-stationarity such as the Dickey-Fuller test (Dickey and Fuller, 1979), the Phillips-Perron test (Phillips and Perron, 1988) and the DF-Generalized Least Square tests (Elliot et al., 1996). The number of lags complies the Bayesian Information Criterion (BIC), as suggested by Yao (1988), and the Akaike information criterion (AIC), Akaike (1974) and extended in Bai and Perron (2003); Other processes could have been used to determine the optimum number of lags like referred in Ng and Perron (2001), we have used the proposition given by the software, being certified for the above theory.

The augmented Dickey-Fuller (ADF) tests have been recently deployed by de Souza et al. (2019) and Khalfaoui et al. (2019).

In the case of non-stationary result, Box-Cox transformations (Box and Cox 1964), a family of power transformations, can be performed (as in Habib, 2018) to look for the stationary of the series and going on with the stationary tests. This transformation is one of the most widely used methods for transforming the curves for non-normal variables into a normal shape. It is deemed ‘best practice’, for other procedures are not based on specific patterns but randomly iterated until they yield the best normalisation (Osborne, 2010).

Such transformations cannot be applied to negative values because they may involve logarithms. As the objective here was to find co-movements (trend curves) rather than to pair data, the structure of copper futures prices was assigned a fixed value to elude the presence of negative values.

After this transformation in keeping with the above procedures, the resulting series had to be tested for stationarity; where affirmative (running again ADF tests) they would be deemed to be integrated of order 1, denoted I(1).

Even if we have used integer integration, most tests in fact fail to reject the null of a unit root (Abbritti et al., 2016). Unit root methods have been extended, so, in the last years to the case of fractional integration (Gil-Alana and Robinson, 1997). In fact, many authors have shown that the classical unit root methods have lower power if the true data are fractionally integrated, see, e.g., Diebold and Rudebusch (1991), Hassler and Wolters (1994), Lee and Schmidt (1996).

Thereafter, a unit root of the same order as the transformed series (here order 1 I(1) for BUKHI50P and stru) has been then calculated, using the Engle and Granger (1987) causality-based cointegration tests. In the case where fractional integration would be applied, cointegration could be also extended to the same fractional idea like in recent years, see, e.g., Robinson and Marinucci (2003), Robinson and Yajima (2002) or more recently to the fractional CVAR, FCVAR approach of Johansen (2008) and Johansen and Nielsen (2010, 2012).

Based on Engle and Granger causality cointegration, the autoregressive vectors (VAR) can be calculated and for instance the basis for the Trace test and λ_{max} using Johansen’s approximation (1988) to find at least one cointegration relationship between the two series.

Engle and Granger cointegration tests were conducted to estimate the two equations shown below from the two series of data transformed using OLS (ordinary least squares):

$$stru_t = \alpha_0 + \alpha_1 \, stru_{t-1} + \cdots + \alpha_1 \, stru_{t-l} + \beta_1 \, stru_{t-1} + \cdots + \beta_1 \, BUK_{t-l} + \varepsilon_t, \qquad \text{(Equation 2.2)}$$

$$BUK_t = \alpha_0 + \alpha_1 \, BUK_{t-1} + \cdots + \alpha_1 \, BUK_{t-l} + \beta_1 \, BUK_{t-1} + \cdots + \beta_1 \, stru_{t-l} + u_t \qquad \text{(Equation 2.3)}$$

where: $stru_t \, and \, BUK_t$ are the time series for which cointegration was to be determined, l the number of delays used, α and β the parameters to be studied and ε_t and u_t the errors or random disturbance, which are normally uncorrelated.

Briefly, if βl = β1 = 0 there is no inter-series causation whereas if βl ≠ β1 ≠ 0 the two are co-integrated as defined by Granger.

The Johansen approximation yields α and β as the vectors:

α = |p,r| and   β = |m,r|

where r is the number of cointegrating vectors and p and m are the series vector components.

Examples of the current use of the Granger model can be found in Eross et al. (2019), who applied the methodology to study a highly topical subject, bitcoins, and in Qadan (2019) and Rutledge et al. (2013) in analyses of the same market environment as explored here. Other authors adopting a similar approach including Hossain and Mitra (2017), Alam (2017), Hadi et al. (2019), Dong (2017), Chalmers et al. (2019) and Samsi et al. (2019).

2.6. Results

2.6.1. Link between *Brexit*-related events and the structure of copper futures prices

This descriptive study shows four clearly distinct phases in $stru_t$ and BUK_t joint movements. This 4-period selection has been specified based on the authors´ experience on the copper market, strongly linked with different behaviours of the *contango* and *backwardation* periods in the studied time-frame, intense *backwardation* followed by an incremental *contango*, a stable *contango* and finally falling into a series of ups and down alternating *contango* and *backwardation* (see Figure 2.8). This descriptive study could be also improved through standard structural breaks tests like those of Bai and Perron (2003) introduced in the methodology.

Consequently, the characteristics of the four periods are:

Phase 1: consistently high BUKHI50P values were observed, attendant upon intense *backwardation* across the period due to the copper market shortage and the absence of adverse *Brexit*-related news.

Phase 2: change from *backwardation* to *contango* in conjunction with stabilisation of the BUKHI50P index

Phase 3: consistent contagion with the decline in BUKHI50P and change to *backwardation* with the rise in the index

Phase 4: variable ups and downs in both indices and *backwardation* consistently appearing with improvements in BUKHI50P

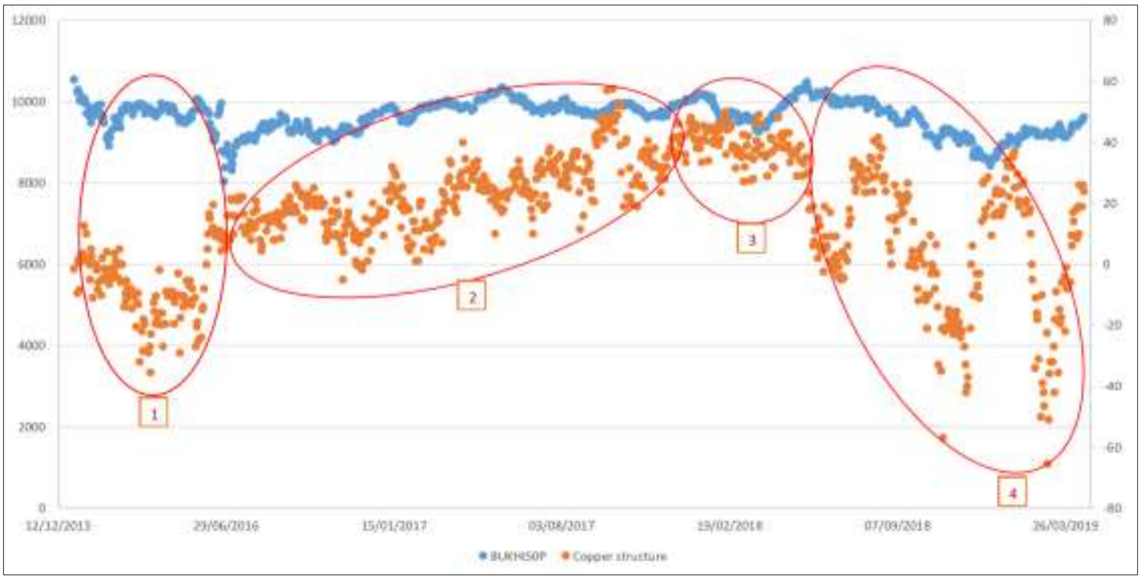


Figure 2.8. Structure of copper futures prices in USD and BUKHI50P index values (source: authors' formulation

A joint analysis of the stru and BUK series showed *Brexit* events to impact both in the whole range studied.

- *Brexit*-related events induced changes in the BUKHI50P index, which is based on the stock market value of the UK companies with highest exposure to the domestic economy and consequently to the country's political situation.
- When warehouse inventories are low in a context of output shortfalls, the structure of copper futures prices may be impacted by any geopolitical event able to prompt short-term shortage, which would favour *backwardation* or narrow the *contango*.

The graphs in Figures 2.9 to 2.11 illustrate the short-term changes in the copper price curve induced by *Brexit* events (text in red, list in Table 2.2). All the events favouring the United Kingdom's exit from the European Union raised political uncertainty and with it the perceived risk of shortage.

Table 2.2. Most prominent *Brexit*-related events by period analysed

	Date	*Brexit* event
2016-2017	22/02/2016	The Prime Minister announces the EU referendum date – 23 June 2016.
	03/10/2016	In her Party Conference speech, Theresa May announces a 'Great Repeal Bill' and confirms Article 50 will be triggered before the end of March 2017.
	16/03/2017	The European Union (Notification of Withdrawal) Act receives Royal Assent.
	29/03/2017	The Prime Minister triggers Article 50 of the Treaty on European Union.
	30/03/2017	The Government publish the Great Repeal Bill White Paper
	08/06/2017	The outcome of the general is a hung Parliament, with the Conservatives win of a simple majority enabling Theresa May to form a Government.
2018	16/05/2018	The European Union (Withdrawal) Bill passes House of Lords stages with ensuing parliamentary ping pong.
	23/08/2018	The Government publish the first series of technical notices providing guidance on how to prepare for a no-deal *Brexit*.
	19/09/2018	EU leaders hold an informal summit in Salzburg.
	14/11/2018	The Withdrawal Agreement is passed and published.
	15/11/2018	*Brexit* Secretary resigns as Secretary of State for Exiting the European Union and is replaced by Stephen Barclay the following day.
2019	15/01/2019	The Prime Minister loses the 'Meaningful Vote' and the Leader of the Opposition tables a motion of no confidence in the Government.
	16/01/2019	The Prime Minister wins a vote of confidence in the Government.
	29/03/2019	The Prime Minister loses 'Meaningful Vote 3'.
	01/04/2019	On the second day of indicative votes, all four options are defeated.
	02/04/2019	The Prime Minister announces she will seek a further extension to the Article 50 process and offers to meet with the Leader of the Opposition to finalise a deal that will win the support of MPs.
	30/10/2019	The Government table the Early Parliamentary General Election Bill, setting the 12 December as the date for a general election. The Bill passes all its Commons stages.

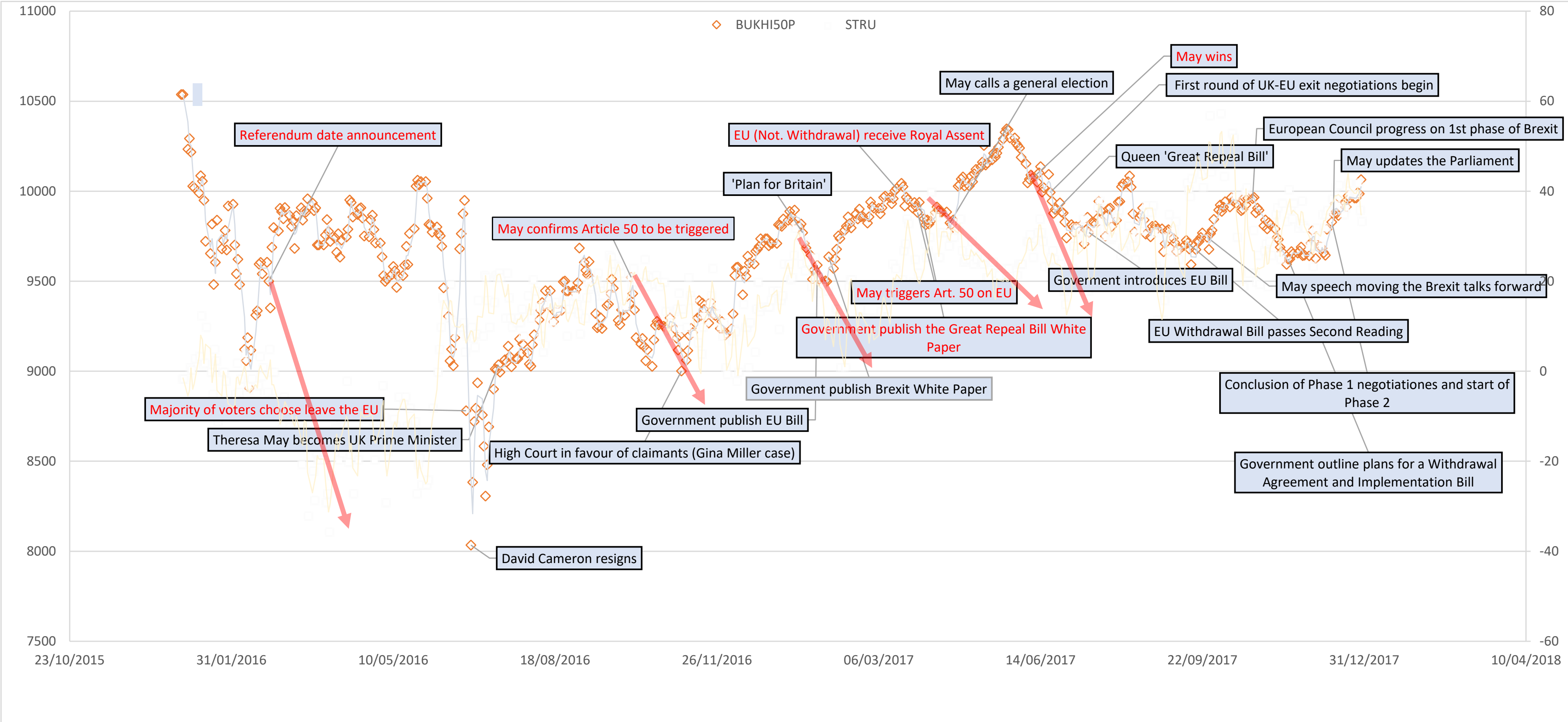


Figure 2.9. Variations in the structure of copper futures prices and BUKHI50P in the wake of *Brexit*-related events (2016-2017)

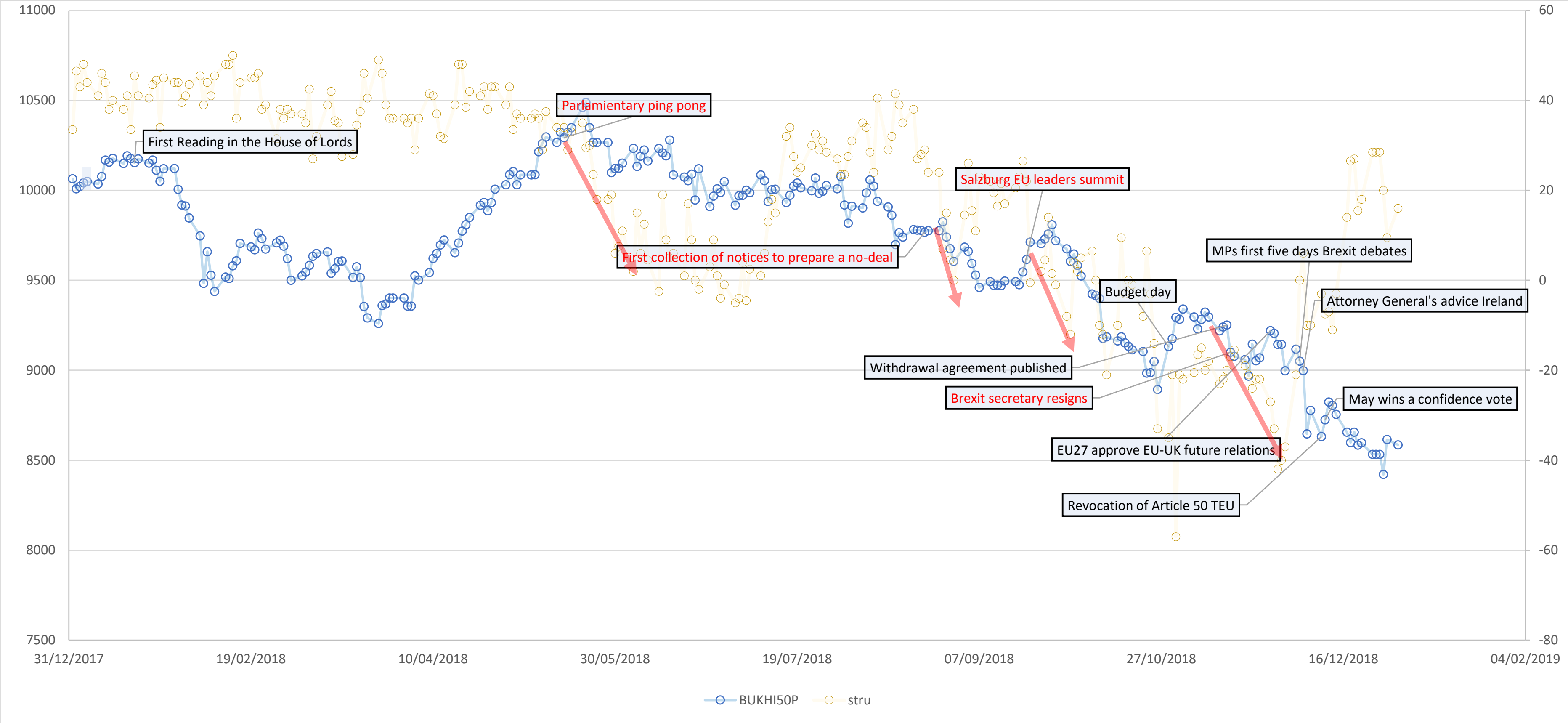


Figure 2.10. Variations in the structure of copper futures prices and BUKHI50P in the wake of *Brexit*-related events (2018)

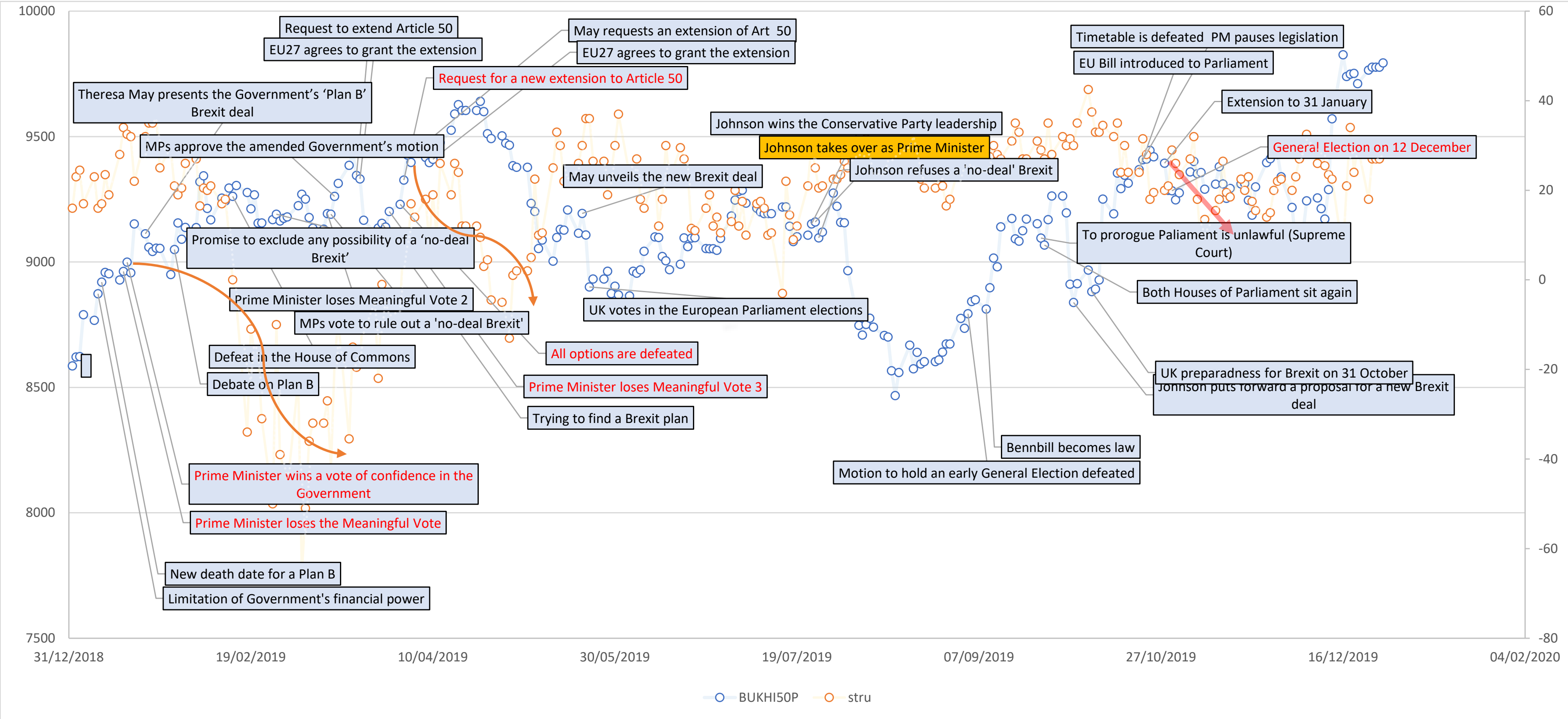


Figure 2.11. Variations in the structure of copper futures prices and BUKHI50P in the wake of *Brexit*-related events (2019)

BUKHI50P - structure of copper futures prices causality test

Applying Box-Cox transformation to λ values of ½ and λ_{max} to analyse $stru_t$ and BUK_t series stationarity yielded similar results.

Table 2.3. ADF p-value for $stru_t$ and BUK_t

			Augmented Dickey-Fuller		
	Period	Transformed serie (through Box-Cox)	Significance	Significance using λ = ½	Significance using λ_{max}
BUK_t	2016-2019	I(0)	7%*		
	2016-2017	I(0)	4%**		
	2018	I(0)	87%		
	2019	I(0)	65%		
	2016-2019	I(1)		**7%***	7%*
	2018	I(1)		88%	82%
	2019	I(1)		64%	68%
$stru_t$	2016-2019	I(0)	5%**		
	2016-2017	I(0)	1%***		
	2018	I(0)	40%		
	2019	I(0)	21%		
	2016-2019	I(1)		**4%****	6%*
	2018	I(1)		39%	37%
	2019	I(1)		20%	22%

Notes: *** rejection of the null hypothesis at the 1% significance level

** rejection of the null hypothesis at the 5% significance level

* rejection of the null hypothesis at the 10% significance level

The augmented Dickey-Fuller tests for the period as a whole showed stationarity at 5 % significance for $stru_t$ and at 7 % for BUK_t.

Box-Cox transformations applied to the two series also verified Dickey-Fuller stationarity, with 4 % significance for $stru_t$ and 7 % for BUK_t when a λ value of ½ was used. With λ_{max}, 6 % significance was observed for $stru_t$ and 7 % for BUK_t.

The analysis by period (2016-2017, 2018 and 2019) revealed stationarity for the 2016-2017 series, but for neither the 2018 nor the 2019 series (with or without transformation). Given that discrepancy in stationarity, comparing periods in pursuit of differences in patterns was deemed futile.

Focusing on the whole range 2016-2019, Box-Cox transformation with λ=½ yielded the data with the best p-values arriving to two stationary series of order 1, I(1), where the statistical parameters are listed in Tables 4 and 5.

Table 2.4. ADF test for BUK stationary series after Box-Cox transformation with λ =½

Descriptive statistics

Variable	*BUK*
Observations	1042
Obs. with lost data	0
Obs. without lost data	1042
Minimum	8034.46
Maximum	10537.3
Average	9545.39
Standard deviation	420.142

Dickey-Fuller (ADF stationarity) / k: 10 / *BUK*):

Tau (observed value)	-3.241
Tau (critical value)	-3.394
p-value (one-sided)	0.074
alpha (α)	0.1

H_0: There is a unit root for the series.

H_a: There is no unit root for the series. The series is stationary

The *p*-value as calculated is lower than significance level α=0.1.

Null hypothesis H_0 must be rejected and alternative hypothesis Ha accepted.

Table 2.5, ADF test for stru stationary series after Box-Cox transformation with λ =½

Descriptive statistics	
Variable	*stru*
Observations	1042
Obs. with lost data	0
Obs. without lost data	1042
Minimum	-65.5
Maximum	57.5
Mean	16.545
Standard deviation	18.974

Dickey-Fuller (ADF stationarity) / k: 10 / *stru*):	
Tau (observed value)	-3.417
Tau (critical value)	-3.394
p-value (one-sided)	0.048
alpha (α)	0.05

H_0: There is a unit root for the series.
H_a: There is no unit root for the series. The series is stationary.

The *p*-value as calculated is lower than significance level α=0.1.
Null hypothesis H_0 must be rejected and alternative hypothesis

As the two series found to be of the same order, they were tested for cointegration. Applying AIC criteria delivered a VAR order of 5 (Table 2.6).

Table 2.6. VAR order calculations for series stru and BUK

Descriptive statistics		
Variable	*BUK* Box-Cox	Box-Cox stru + 70
Observations	1042	1042
Obs. with lost data	0	0
Obs. without lost data	1042	1042
Minimum	177.27	2.243
Maximum	203.303	20.583
Mean	193.353	16.472
Standard deviation	4.32	2.23

VAR order Significance level (%): 5

Number of temporary lags	AIC	HQ	BIC	FPE
1	-0.244	-0.237	-0.225	0.783
2	-0.362	-0.348	-0.324	0.696
3	-0.39	-0.368	-0.333	0.677
4	-0.395	-0.366	-0.319	0.673
5	**-0.418**	-0.382	-0.323	0.658

AIC-estimated *VAR* order = 5.

The λ_{max} and trace tests revealed at least one cointegration relationship at a significance level of 5 % (Table 2.7).

Table 2.7. Results of λ_{max} and trace tests for BUK and stru time series

H_0 (Number of cointegrating equations)	Eigenvalue	λ_{max}	Critical value	p-value
None	0.017	17.255	11.225	0.004
At most 1	0	0.011	4.13	0.931

Further to the $\boldsymbol{\lambda_{max}}$ test there is 1 cointegration relationship at a significance level of 0.05.

Trace test

H_0 (Number of cointegrating equations)	Eigenvalue	Trace	Critical value	p-value
None	0.017	17.266	12.321	0.007
At most 1	0	0.011	4.13	0.931

Further to the **trace** test there is 1 cointegration relation at a significance level of 0.05.

The values of fitting coefficients α and β for the cointegrating equations are given in Table 2.8.

Table 2.8. Fitting coefficients for the cointegrating equations

Fitting coefficient α:		
BUK BC	-0.067	-0.003
BC stru + 70	0.097	-0.001

Fitting coefficient β:		
BUK BC	0.041	0.002
BC stru + 70	-0.477	0.033

The findings showed that the time series associated with the BUKHI50P (BUK) stock index was cointegrated with the structure of copper futures prices (stru) at a 5 % level of significance in the period studied: 31/12/2015 to 27/12/2019. The inference is that *Brexit*, a major macroeconomic event, had a significant effect on the structure of copper futures prices in a tight marketplace. That information may prove useful to agents trading lots whose size is linked to the immediate market cycle, such as mining companies that engage in high-volume transactions impacted by developments not strictly related to the demand for copper.

That the performance of companies with high exposure to *Brexit* is cointegrated with variations in the structure of copper futures prices implies a close relationship between the two series. Monitoring *Brexit* events may consequently provide good insight into the behaviour of the structure of copper futures prices in a tight market.

2.6.2. BUKHI50P and the price structure for other metals

The robustness of the present results was tested by applying the procedure described for copper to less financialised metals (as discussed in the section on data) such as aluminum (Al), lead (Pb), tin (Sn) and zinc (Zn).

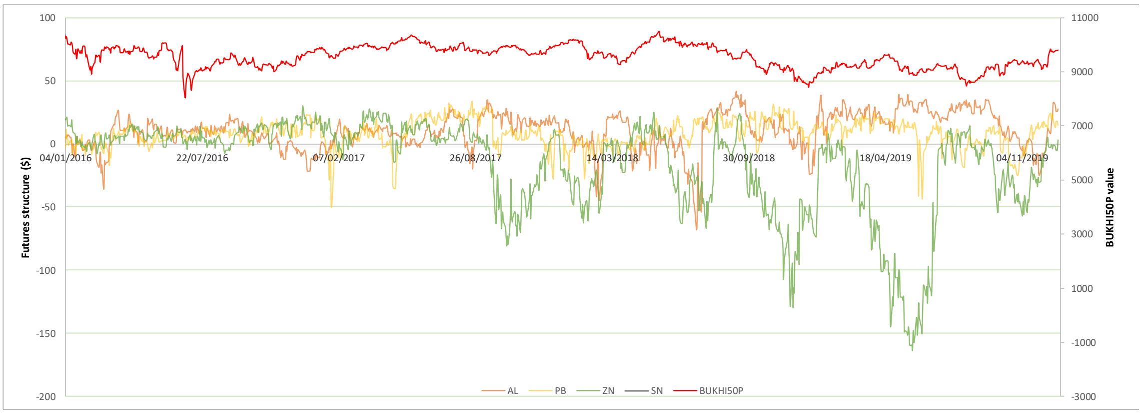


Figure 2.12. Al, Pb, Zn, Sn price structures and BUKHI50P index value

The series for three of the four metals, Al, Pb and Sn, were found to be stationary (further to ADF) in the period studied, in which their price structures were determined to the same criterion as described for copper. The results exhibited a much better level of significance, with no need for transformation, than observed for BUKHI50P and Zn (Figure 2.12). The two non-stationary series, BUKHI50P and Zn, were transformed using the values of λ found with ADF and the levels of significance shown in Table 2.9.

Table 2.9. Calculation of Al, P, Sn, Zn and BUKHI50P time series stationarity

Variable/Period		Transformed serie (through Box-Cox)	Significance (DAF)
BUK_t		I(0)	7%*
		I(1)	7%*
$stru_t$	Al	I(0)	1%***
	Pb	I(0)	1%***
	Sn	I(0)	1%***
	Zn	I(0)	5%*
		I(1)	5%*

The Engle and Granger cointegration findings for the Zn price structure and BUKHI50P after one transformation are given in Table 2.10, finding no cointegration.

Table 2.10. Cointegration values for the Zn and BUKHI50P series

H0 (Number of cointegrating equations)	Eigenvalue	λ_{max}	Critical value	p-value
None	0.009	9.578	11.225	0.096
At most 1	0.000	0.126	4.130	0.770

Further to the λ_{max} test there is no cointegration relationship at a significance level of 0.05.

H0 (Number of cointegrating equations)	Eigenvalue	Trace	Critical value	p-value
None	0.009	9.704	12.321	0.132
At most 1	0.000	0.126	4.130	0.770

Further to the λ_{max} test there is no cointegration relationship at a significance level of 0.05.

2.7. Discussion

In the context of the influence of macroeconomic events on *commodity* prices, the present findings confirm the existence of a relationship between *Brexit* and the structure of copper futures prices, measured on the grounds of BUKHI50P data.

Commodity financialisation has been addressed in the literature, with authors such as Batten et al. (2010), Chen (2010) and Creti et al. (2013) associating volatility with macroeconomic movements. Whereas those authors included copper as part of a general study, others such as Guo (2018) explored volatility and Shao et al. (2013) and Guzmán & Silva (2018) the variation in price for that metal separately.

The present analysis adopts a different approach. Rather than volatility or price, often the object of *commodity* market research based on the S&P 500, the U.S. Dollar Index or similar, it explores the dependence of the structure of copper futures prices, along with *contango* and *backwardation*, on worldwide economic developments and more specifically on *Brexit*, one of the most impactful economic developments in recent history.

Despite that difference in approach, however, the analysis was based on the same methodology, namely Granger causality, and the same copper market environment as applied by other authors (Guzmán & Silva, 2018).

2.8. Conclusions and Policies

Behaviour patterns differ substantially among the various types of copper market actors. The present study is intended to provide guidance to players conducting small numbers of large-scale transactions, such as mining firms, seeking to optimise their trading. It consequently focuses on fluctuations in the structure of copper futures prices (*contango* and *backwardation*) as a physical market driver. The decision to engage in a cash or a 3-month forward transaction may be informed by which is believed to deliver higher value. This paper aims to support decision-making based not only on fundamentals such as supply and demand but also on macroeconomic events such as *Brexit* in a tight market or one on the brink of shortage.

Our contribution has proven that the evolution of companies with high exposure to *Brexit* is cointegrated with variations in the structure of copper futures prices. The conclusion drawn is that just as *Brexit*-related events imply a weakening of the UK economy, they have a detrimental effect on the structure of copper futures prices.

Given that the structure of copper futures prices is defined by the difference between the LME spot price and the 3-month forward price, in a context such as the current one, of shortage of supply, *Brexit*-related events that may be perceived as negative geopolitical impacts will lead to short-term stockouts, which would lower copper futures prices relative to spot prices. The outcome is, thus, a rise in the copper spot relative to its forward price (narrower *contango* or advent of *backwardation*).

As *Brexit* events generate a negative impact on the structure of copper futures prices, these events (whose importance perceived by the market is immediately observed in it), should induce bidders (miners and metal holders) to carry out operations according to a price-structure oriented strategy instead of prompt or long term due dates strategies.

Watkins and McAleer (2002) identified a number of elements that affect the relationship between a *commodity*’s cash and its future value. One they cited is ‘price volatility and risk’. In that context, the effect of *Brexit*-associated events on the structure of copper futures prices addressed in this article may merit further analysis as an element that raises or lowers volatility and risk.

Another line of study might be the impact of other macroeconomic events not only on the structure of copper futures prices but also on those of less financialised metals, either in periods of shortage or of lower market stress.

Additionally, one more relevant issue to be addressed in future research would be to analyse other sub-periods to the descriptive-based ones, since the moment of each break is not known. A suitable methodology can be the Robinson (1994) tests, as in Gil-Alana (2002).

Finally, the study of volatility is a topic of the utmost importance and being able to provide solutions to reduce or manage volatility in the market would be an important contribution, which we would like to work on next.

2.9. Annexes

Annex 2.1

Date	Key event
17/12/2015	The European Union Referendum Act providing for a referendum on the UK's future membership of the EU receives Royal Assent.
22/02/2016	The Prime Minister announces the EU referendum date – 23 June 2016.
23/06/2016	The UK referendum on membership in the EU results in a majority vote in favour of exit (51.9% versus 48.1% of voters).
24/06/2016	Prime Minister David Cameron announces his intention to resign.
13/07/2016	Theresa May becomes the new UK Prime Minister.
03/10/2016	In her Party Conference speech, Theresa May announces a 'Great Repeal Bill' and confirms Article 50 will be triggered before the end of March 2017.
03/11/2016	The High Court rules in favour of the claimants in the Gina Miller case. The Government announce they will appeal the decision.
17/01/2017	The Prime Minister delivers her Lancaster House speech, setting out the Government's 'Plan for Britain' and the priorities that the UK will use to negotiate *Brexit*.
24/01/2017	The Supreme Court rejects the Government's appeal of the Gina Miller case.
26/01/2017	The Government publish European Union (Notification of Withdrawal) Bill.
02/02/2017	The Government publish the *Brexit* White Paper, formally setting out the strategy for the UK to leave the EU.
16/03/2017	The European Union (Notification of Withdrawal) Act receives Royal Assent.
29/03/2017	The Prime Minister triggers Article 50 of the Treaty on European Union.
30/03/2017	The Government publish the Great Repeal Bill White Paper
18/04/2017	The Prime Minister calls a General Election for 8 June 2017.
08/06/2017	The General election results in a hung Parliament, the Conservatives' win of a simple majority enable Theresa May to form a Government.
19/06/2017	The first round of UK-EU exit negotiations begin.
21/06/2017	The Queen's Speech at the State Opening of Parliament includes a reference to the 'Great Repeal Bill'.
13/07/2017	The Government introduce the European Union (Withdrawal) Bill, commonly referred to as the 'Great Repeal Bill'.
12/09/2017	The EU Withdrawal Bill passes Second Reading in the House of Commons.
22/09/2017	The Prime Minister delivers her key *Brexit* speech in Florence, setting out the UK's position on moving the *Brexit* talks forward.
20/10/2017	The European Council hold a meeting to assess progress on the first phase of *Brexit* negotiations.
13/11/2017	The Government outline plans for a Withdrawal Agreement and Implementation Bill.
08/12/2017	The UK and EU publish a Joint Report on progress made during Phase 1 of negotiations. This concludes Phase 1 of negotiations and both sides move to Phase 2.
11/12/2017	The Prime Minister updates Parliament on *Brexit* negotiations.
18/01/2018	The European Union (Withdrawal) Bill has its First Reading in the House of Lords.
02/03/2018	The Prime Minister gives a speech at Mansion House on the UK's future economic partnership with the European Union

Date	Key event
14/03/2018	European Parliament endorses a resolution laying out a possible association agreement framework for future EU-UK relations after *Brexit*.
19/03/2018	The amended Draft Withdrawal Agreement is published.
16/05/2018	The European Union (Withdrawal) Bill passes House of Lords stages with ensuing parliamentary ping pong.
26/06/2018	The European Union (Withdrawal) Bill receives Royal Assent and becomes an Act of Parliament: the European Union (Withdrawal) Act.
06/07/2018	The Cabinet meets at Chequers to agree a collective position for the future *Brexit* negotiations with the EU.
09/07/2018	David Davis resigns as Secretary of State for Exiting the European Union and is replaced by Dominic Raab.
24/07/2018	The Government publish the White Paper on future UK-EU relations.
23/08/2018	The Government publish the first collection of technical notices providing guidance on how to prepare for a no-deal *Brexit*.
19/09/2018	EU leaders hold an informal summit in Salzburg.
29/10/2018	The last budget before the UK leaves the EU is passed on Budget Day.
14/11/2018	The Withdrawal Agreement is passed and published.
15/11/2018	The *Brexit* Secretary resigns as Secretary of State for Exiting the European Union and is replaced by Stephen Barclay the following day.
26/11/2018	At a special meeting of the European Council, EU27 leaders endorse the Withdrawal Agreement and approve the political declaration on future EU-UK relations.
04/12/2018	MPs begin the first of five days of *Brexit* debates, leading up to the 'Meaningful Vote' on 11 December.
05/12/2018	The Government publish the Attorney General's legal advice to Cabinet on the Protocol to the Withdrawal Agreement on Ireland and Northern Ireland.
10/12/2018	The CJEU rules on the Wightman case, finding unilateral revocation of Article 50 TEU to be a sovereign right for any Member State. The Prime Minister pulls the final vote on her *Brexit* deal planned for the next day.
11/12/2018	Theresa May wins a vote of confidence in her leadership of the Conservative Party.
08/01/2019	In the Report Stage and Third Reading of Finance (No. 3) Billthe Prime Minister is defeated, with MPs approving an amendment that would limit the Government's financial powers in the event of a no-deal *Brexit*.
09/01/2019	As five days of *Brexit* debates begin – leading to a 'Meaningful Vote' on 15 January – an amendment to the business motion is passed, giving the Prime Minister only three days, as opposed to the original 21, to present a 'Plan B' *Brexit* plan if she loses meaningful vote.
15/01/2019	The Prime Minister loses the 'Meaningful Vote' and the Leader of the Opposition tables a motion of no confidence in the Government.
16/01/2019	The Prime Minister wins a vote of confidence in the Government.
21/01/2019	Theresa May presents the government's 'Plan B' *Brexit* deal.
29/01/2019	MPs debate the Prime Minister's 'Plan B' deal, which is then approved following two amendments.
14/02/2019	The Government's *Brexit* plan suffers a defeat in the House of Commons.
26/02/2019	The Prime Minister promises MPs a vote on ruling out a no-deal *Brexit* or delaying *Brexit* if she loses the second 'Meaningful Vote' next month
12/03/2019	The Prime Minister loses 'Meaningful Vote 2'.
13/03/2019	In a defeat for the Prime Minister, MPs vote to rule out a 'no-deal *Brexit*'.
14/03/2019	MPs approve the amended Government's motion, instructing the Government to seek permission from the EU to extend Article 50.

Date	Key event
20/03/2019	The Prime Minister writes to European Council President Donald Tusk, asking to extend Article 50 until 30 June 2019.
21/03/2019	Following a meeting of the European Council, EU27 leaders agree to grant an extension comprising two possible dates: 22 May 2019, should the Withdrawal Agreement gain approval from MPs next week; or 12 April 2019, should the Withdrawal Agreement not be approved by the House of Commons.
27/03/2019	Commons debates and votes on eight indicative votes, in an attempt to find a *Brexit* plan that wins the support of the majority of MPs. All options are defeated.
29/03/2019	The Prime Minister loses 'Meaningful Vote 3'.
01/04/2019	In the second day of indicative votes, all four of the selected options are defeated.
02/04/2019	The Prime Minister announces she will seek a further extension to the Article 50 process and offers to meet with the Leader of the Opposition to finalise a deal that will win the support of MPs.
05/04/2019	Theresa May formally writes to Donald Tusk, requesting a further extension to the Article 50 process to the end of June 2019.
10/04/2019	The European Council meets. The UK and EU27 agree to extend Article 50 until 31 October 2019.
21/05/2019	The Prime Minister unveils her new *Brexit* deal.
23/05/2019	The UK votes in the European Parliament elections.
23/07/2019	Boris Johnson wins the Conservative Party leadership race.
24/07/2019	Boris Johnson formally takes over as Prime Minister.
25/07/2019	Prime Minister Johnson makes a statement in the House of Commons and commits to the October date for *Brexit* and – while hoping for a renegotiation of the Withdrawal Agreement – refuses to rule out the possibility of a 'no-deal' *Brexit*.
04/09/2019	With the Commons passing Hilary Benn's European Union (Withdrawal) (No. 6) Bill, the Prime Minister moves to hold an early General Election. The motion is defeated.
09/09/2019	The Benn bill becomes law: the European Union (Withdrawal) (No. 2) Act 2019 and parliament prorogues
24/09/2019	The Supreme Court unanimously rules that the decision to prorogue Parliament was unlawful. The Speaker of the House of Commons announces that the House will sit again the next day.
25/09/2019	Both Houses of Parliament sit again.
03/10/2019	The Prime Minister delivers a statement to Commons outlining the Government's proposals for a new *Brexit* deal.
08/10/2019	The Government publish the No-Deal Readiness Report, detailing the UK's preparedness ahead of *Brexit* on 31 October.
19/10/2019	At a rare Saturday sitting of Parliament the Prime Minister presents his new *Brexit* deal, but is defeated when the Letwin amendment is passed. The PM later writes to Donald Tusk, in accordance with the Benn Act, to ask for a *Brexit* extension.
21/10/2019	The European Union (Withdrawal Agreement) Bill is introduced to Parliament.
22/10/2019	The EU (Withdrawal Agreement) Bill passes its second reading, but the programme motion setting out the timetable is defeated. The PM pauses the legislation.
28/10/2019	EU Ambassadors agree to a *Brexit* extension to 31 January 2020. The Prime Minister confirms the UK's agreement to this extension.
30/10/2019	The Government table the Early Parliamentary General Election Bill, which sets the date for a general election on 12 December. The Bill passes its Commons stages.

Annex 2.2

Companies conforming BUKHI50P, *Brexit* CBOE High 50

Code	Name
IIIl	3i Group
ADMl	Admiral Group
ABFl	Associated British Foods
AUTOl	Auto Trader Group
AVl	Aviva
BAl	BAE Systems
BARCl	Barclays
BDEVl	Barratt Developments
BKGl	Berkeley Group Holdings
BPl	BP
BLNDl	British Land Co /The
BTl	BT Group
CNAl	Centrica
DCCl	DCC
DLGl	Direct Line Insurance Group
EXPNl	Experian
FLTRl	Flutter Entertainment
HLl	Hargreaves Lansdown
IAGl	International Consolidated Airlines Group SA
ITVl	ITV
SBRYl	J Sainsbury
JDl	JD Sports Fashion
JMATl	Johnson Matthey
JEl	Just Eat
KGFl	Kingfisher

Code	Name
LANDl	Land Securities Group
LGENl	Legal & General Group
LLOYl	Lloyds Banking Group
LSEl	London Stock Exchange Group
MKSl	Marks & Spencer Group
NGl	National Grid
NXTl	Next
OCDOl	Ocado Group
PSNl	Persimmon
PHNXl	Phoenix Group Holdings
RMVl	Rightmove
RBSl	Royal Bank of Scotland Group
SGEl	Sage Group /The
SDRl	Schroders
SGROl	Segro
SVTl	Severn Trent
SSEl	SSE
STJl	St James's Place
SLAl	Standard Life Aberdeen
TWl	Taylor Wimpey
TSCOl	Tesco
TUIl	TUI AG
UUl	United Utilities Group
WTBl	Whitbread
MRWl	Wm Morrison Supermarkets

3. Cointegration between high base metals prices and *backwardation*: getting ready for the metals super-cycle

3.1. Abstract

The objective of some agents in *commodity* markets is to manage future price structures to hedge their positions rather than to speculate on prices. In this paper, we demonstrate that markets tend to backwardate in rising price scenarios and that this cointegration tends to be linked with the most financialized metals: copper and *aluminum*. In this study, a triple analysis was performed: cointegration on the time series, panel data and structural breaks over the full time series. The connection between high prices and negative-futures price structure (*backwardation*) in tin, copper, *aluminum* and zinc is demonstrated for the full series and with structural breaks. Using panel data analysis, the base metal full matrix (price and futures price structure) is cointegrated. The results of this study are important for *commodity* traders, brokers and others to maximize their profits on their *hedging* positions.

3.2. Keywords

Normal *backwardation*; cointegration; base metals; hard *commodities*; futures price structure

3.3. Introduction

Since the beginning of the century, world metal markets have experienced a period of sustained strong demand. The first big metal shortage occurred between 2003 and 2008 (Humphreys, 2010; Ciner et al., 2020), followed by other periods of more balance. Metal markets have now become tense, primarily due to the revolution on metal markets between 2016 and 2020 but also with the appearance of electrical vehicles and their charging infrastructure as well as developing country electrification through minigrids (Boait et al., 2015), public policies (Best, 2017) and finally with the development of renewable energies (Vikström, 2020).

However, over this long period of strong demand, there have been two breaks in the growing trend of supply shortages: the global financial crisis (2008-2009), studied by Al-Yahyaee et al. (2019); and the recent *COVID-19* pandemic (Umar et al., 2021; Borgards et al., 2021). The *COVID-19* pandemic started as an epidemic in China, and markets did not react sharply, but once the virus had spread to different regions in Europe, and the pandemic was declared by the World Health Organization (WHO), lockdowns led the global economy to decline sharply. The effect on worldwide production and global trade has been studied in Zeshan (2020) and Guan et al. (2020); the difference between soft and hard *commodities* has also been explored by Sifat et al. (2021), and Zhang (2020) described how supply chains have readapted to the lack of products in different areas. The specific effect of the *COVID-19* crisis on the development of *contango* in some markets has been analyzed by Corbet et al. (2020), focusing on the oil market. The timing of the *COVID-19* pandemic has been studied in many papers; for example, Allam (2020) has done it in intervals of 50 days. One of the only possible temporal solutions to the economic situation is government economic stimulus, which has been studied by Narayan et al. (2021), even if the way each country reacted through economic stimulus has been different (Perasolo et al., 2020). As the worldwide *COVID-19* vaccination progressed, the general demand for metals increased due to the economic stimulus in every country and the infrastructure improvements to use that money, and, conversely, from the breaks in the supply chains coming from trying to recover part of the lost production during the lockdown and the pandemic's worst time periods. The global market and the needs of metals by geography have had different rates of use during the pandemic, and trading activity has attempted to equate them, a process that has been difficult, as the world was working as a sole market for a long time. The threats appearing in the market with the lack of chips and components, primarily in the automotive industry, have markedly increased the world's metal demand, making supply chains struggle up to limits where some of the primary corporations, such as Tesla or Volkswagen, have been pushed to invest upstream in acquisitions to guarantee raw materials for their core business.

These, among other reasons, have led to the presence of new agents with an eye on hard *commodities* markets.

Commodity market contracts are generally referenced to future points in time. Raw materials could be required currently or over a specific period to finance or for storage, which may not be affordable for the buyer. Thus, contractually, these steps are performed on futures markets. In metal markets, more liquid timing bases exist, meaning that actors in the market tend to buy, sell and allocate transactions around those dates. Based on Otto (2011), a 3-month basis is a liquid reference, and a 15-month basis is particularly liquid, too, which is why we chose a 3-month basis for this study. The London Metal Exchange (LME) also states that "the foundation of liquidity and price discovery is found in the 3-month rolling prompt date, while most of the open interest sits on 3rd Wednesday "monthly" contracts"16. The spot or cash price in addition to the 3-month basis are the two references that consolidate metal future price structures. This metal structure is thus defined as *backwardation* when spot prices are higher than 3 months, and therefore, the futures price structure is negative. Also, *contango* refers to the opposite, both are described below:

$$\text{metal futures price } structure = \text{metal } price \text{ 3-mo}nths - \text{metal } price\ spot$$

$$\text{metal futures price } structure > 0 \rightarrow contango$$

$$\text{metal futures price } structure < 0 \rightarrow backwardation$$

In *commodities* markets, a backwardated situation is normally linked with a shortage of offers, a high demand, or a combination of both. This situation is called *"normal backwardation*", a situation in which participants are trading more due to real needs than to either speculation or financialization. This theory, introduced by Keynes (1930), has been evolving during recent decades, when financialization (Günter and Karner, 2020) and macroeconomic events are increasingly taking over. For example, Galán-Gutiérrez and Martín-García (2021)

[16] https://www.lme.com/Education-and-events/Online-resources/LME-insight/What-are-implied-markets

show how *Brexit*, a macroeconomic event, can influence the copper futures price structure.

In this article, we consider theories that link high prices and *backwardation*, and identify evidence of normal *backwardation*. Using cointegration methods, we consider the different metals priced in the LME, evaluating prices and future price structures. The analysis is based on time series cointegration with and without structural breaks and on a data panel structure. This high price-*backwardation* linkage can be a good tool for speculators, miners, funds and market players who do not speculate and try to leverage their hedged positions.

The primary contribution of this research is the finding of co-movements between the future price of base metals and spot prices, referenced through their futures price structure. Also, we report the usage of cointegration tests through time series and through data intervals, which are obtained through structural breaks, as well as strengthen these results via the study of data panel cointegration. In addition, we study whether there is a relation between the metal level of liquidity or financialization and *backwardation*.

The remainder of this paper is organized as follows. Section 3.4 reviews the relevant literature on co-movements and base metal introduction. Data and methodology are reviewed in Section 3.5. A description of the results and an analytical review is presented in Section 3.6. Finally, conclusions and recommendations are discussed in Section 3.7.

3.4. Review of the literature

3.4.1. Co-movements in the literature

There is a wide compendium of papers that relates the prices between the different *commodities* through co-movements, and many report important findings. Ma et al. (2021) found that linkages across energy *commodities* are stronger than those among agricultural or metal *commodities*. Mensi et al. (2020) studied precious metals and primary energy futures price returns, and concluded that the global financial crisis followed by the great oil price bust in 2014 intensified return co-movements. Cai et al. (2020) studied relationships between crude oil, precious metals, and agricultural *commodities*, and found a strong joint evolution during the crisis from 2007 to 2012. In addition, similarity in evolution occurs in the mid-term and the long term (Madaleno and Pinho, 2014, for oil markets and, again, Cai et al.,2020).

Focusing on metals, Al-Yahyaee et al. (2020) use the spillover index to find strong multiscale co-movements among nonferrous metals. Additionally, *aluminum* is the highest contributor to shocks in other metal markets, while lead and copper contribute the least. In the specific case of copper markets, Rutledge et al. (2013) found Granger causality among the world's three major metal futures markets: the Shanghai Futures Exchange (SHFE), the London Metal Exchange (LME), and the New York *Commodity* Exchange (COMEX).

Co-movements between metal prices, which are shocks in prices that occur due to changes in other metals, have recently become of interest to researchers, as reported by Ding and Zhang (2020), Cai et al. (2019), Adhikari and Putnam (2020) and Yu et al. (2021). The literature refers to shocks and co-movements even in food prices, which are focused on certain periods where governments fell, and humans suffered (Carter et al., 2011).

Other co-movements that involve hard *commodities* have been studied by Alquist et al. (2020), who analyzed the dependence structure between *commodities* and are typically categorized into 5 sectors: agriculture, energy, industrial metals, livestock, precious metals. Co-movements between metals (e.g., gold, silver, platinum and palladium) and macroeconomics were studied by Boako et al. (2020), specifically considering the evolution of African stocks and *commodities*. Golosnoy et al. (2018) identified two common factors that relate to nonferrous and precious metals using distinct autoregressive dynamics; these results agreed with those of Cai et al. (2019).

Other economic variables that can influence *commodity* markets have also been investigated, as shown in Table 3.1.

Study	Data	Method	*Commodities*	Other variables	Key findings
Batten et al., 2010	1986-2006	Conditional standard deviations	Gold, silver, platinum and palladium	Business cycle, monetary environment and financial market sentiment	Different responds on Gold volatility, Platinum and Palladium, and Silver
Chen 2010	1900-2007	Cross-sectional standard deviations	Al, Bo, Cr, Co, Cu, Au, steel, Fe ore, Pb, Mg, Mn, Mo, Ni, Pt, Si, Ag, S, Sn, Tg, Vn, Zn	Volatility	Macroeconomic factors dependence 34%, 66% depending on *commodities*-specific risk
Ge and Tang 2020	1993-2016	Panel regression	27 *commodity* futures traded in CRB	GDP	Prediction of GDP growths on next quarters by *commodity* price
Creti et al., 2013	2001-2011	DCC GARCH	Independent and aggregate *Commodity* price index	S&P 500 index	Correlations between comm. and stock markets are highly volatile
Guo 2018	1991-2015	DCC GARCH	Copper	Stock returns	Correlation between copper prices and China's activity
Lim et al., 2019	2008-2017	Regression and Unit Root tests	Freight prices	CBOE VIX, CSPOT, CSLOPE, CVOL, CORDER, CFLEETG, CCONTR, OECD, IPPRC, PRCIRON, PRCCOKE	Correlation between freight markets, VIX and other macroeconomic variables
Liu et al., 2020	1975-2015	FAVG, Predictive Regression and RWWD	17 *commodities* (including agricultural and metals)	Currencies AUD CAD NZD ZAR	Significant predictability of currencies exchange rate using a factor drawn from a 17 *commodity* prices panel
Fasanya and Awodimila 2020	1980-2017 (Head. Infl.) 2002-2017 (Core infl. SouthA.), 1995-2017 (Core infl Nigeria)	FQGLS estimator forecasting model	Energy and nonenergy *commodities*	Headline and Core Inflation	*Commodity* prices drive inflation in these two countries. Some of them, as energy, drives more Nigeria inflation than others.
Mandaci et al., 2020	1992-2019	TVP-VAR connectedness approach	WTI, NGF, HOF, GLD, SLV, PAL, PLT, COP	USB, DJD, DJE, DXY	Moderate interdependence among the volatilities of the assets

Study	Data	Method	*Commodities*	Other variables	Key findings
Bouri et al., 2021	2011-2020	TVP-VAR connectedness approach	S&P GSCI gold, crude oil, MSCI World	Effect of *COVID-19* outbreak, USD index, PIMCO Investment Grade Corporate bond index	Clear evidence for strong spillover effects in financial markets
Ji et al., 2018	2011-2016	Granger causality and DCC model	Oil and gold	US and BRICS equities	Integration structure among markets volatility is limited

Notes: DCC GARCH: Dynamic conditional correlation GARCH model; FAVG: Factor average; RWWD: Random walk with drift; FQGLS: Feasible Quasi Generalized Least Square; TVP-VAR: Time-Varying Parameter Vector Autoregressions

Table 3.1. Linkage between microeconomic and macroeconomic variables and trends in *commodities* literature.

3.4.2. Primary base metals references.

On the supply-demand spectrum, the influence of economic cycles in metals has been investigated by Maranon and Kumral (2020). However, the entire metal environment is facing different challenges depending on the metal in the hard *commodities* (base metals) system selected. One of the exercises explored in this study is to check if there is a higher correlation between prices and structure of prices in metals that are more financialized than others. This exercise explores the data obtained on the LME's Commitment of Traders Report[17], with the number of lots traded of each *commodity* in the same period. There are several ways to study metal financialization: the number of lots traded (e.g., this study), the multiple of price per lot traded, or using only those lots that are out from the normal course of physical business. The first approach (Figure 3.1) shows that *aluminum* and copper are the most financialized metals, followed by zinc and nickel, with tin and lead being the less financialized metals. In Figure 3.2, a similar approach is used but nickel is the most financialized due to its high price reference. We will discuss in the Results and Conclusions sections how related these financialization levels and the high price-*backwardation* pair are.

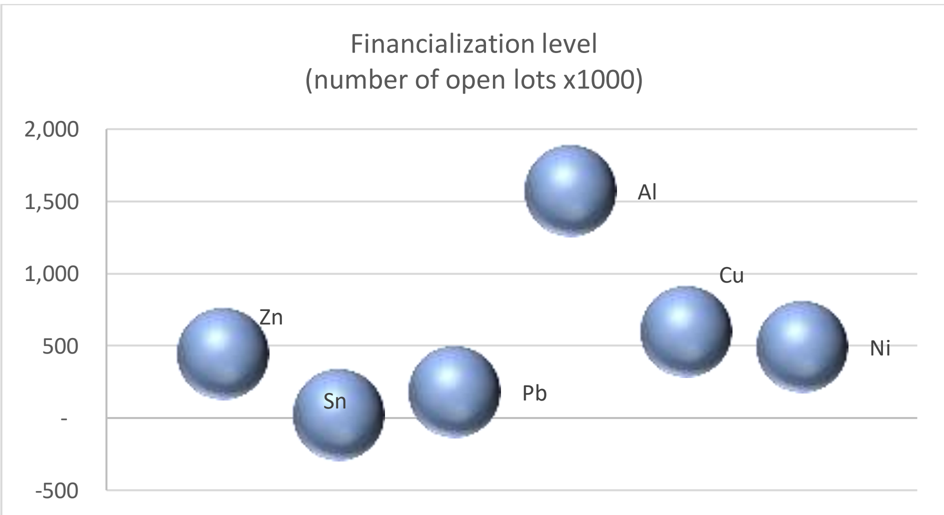


Figure 3.1. Financial institution holdings in LME, lots based, formatted from authors' data.

[17] https://www.lme. com/Market-Data/Reports-and-data/Commitments-of-traders#tabIndex=0.

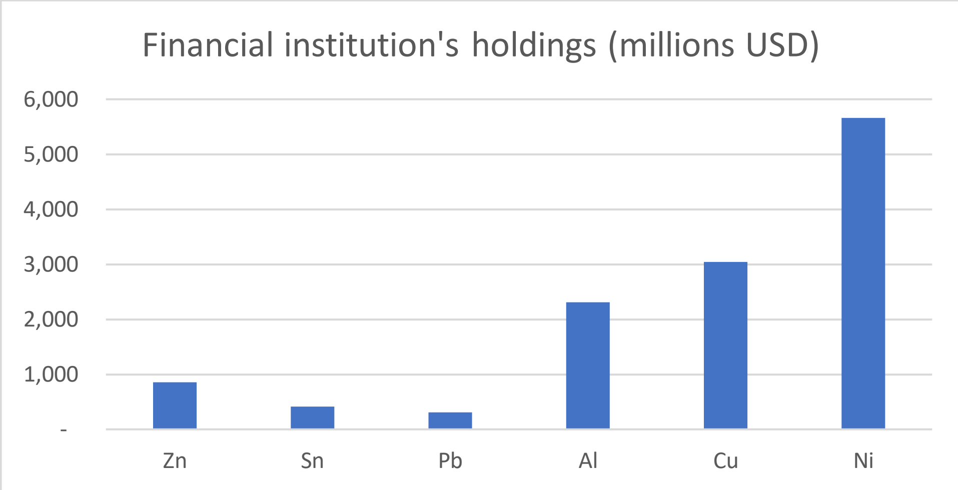


Figure 3.2. Financial institutions' holdings in LME, lots per price base.

Reviewing the specific situation of each base metal studied in this paper:

Copper: The International Copper Association (ICA)[18] continuously providing advice about the rising demand for copper, not only in 2019, sharing this view with other international associations such as AMM[19] (America Metals Market 2019 or Metals Market Magazine 2019). They cite the growth of the global middle class and the equivalence between GDP and copper consumption. Also, once immersed in the *COVID-19* health crisis, they identify copper as one of the metals with the greatest potential for intensive consumption due to offsite units for social distance practices, thermal heating in buildings to reduce GHG (greenhouse gases) including sunlamps, electricity generation, renewable energy bumps, electricity supply networks, urban mining for sustainability and economic global stimulus schemes. They also cite an increase in copper use in electric vehicles globally (Jones et al., 2020).

Considering only classical mining and discovered resources, 2400 looks like the year when the world will run out of copper (Sverdrup et al., 2014), which is why recycling with the slogan of "Urban mining" is playing a key role in the short- and long-term outlooks of copper (Wallsten et al., 2013). Looking at these *commodity* warehouses' global stocks, we can also envision a tense situation that considers

[18] https://copperalliance.org/about-ica/
[19] https://www.amm.com/

availability minus demand based on recently dropping copper prices at their highest level ever[20].

Aluminum is the most financialized metal, followed by copper, zinc and nickel. This conclusion implies that demand for *aluminum* is sometimes not linked to a real fundamental metal; however, the primary metal institutions also see *aluminum* as a key metal for future applications and its supercycle.

Li et al. (2021) described the increase in consumption of *aluminum* in recent years with the target to reduce the GHG emissions in certain regions, making this metal one with a higher ratio of increase (32 times higher than a decade ago) and in line to continue the same trend for the next 10 years.

The reports of the International *Aluminum* Association[21] (IAA) state that in *Aluminum* Sector Greenhouse Gas Pathways to 2050, the role of recycling and the reduction of emissions in general makes *aluminum* one of the more interesting metals that is used in most industries, including automotive and transport; building and construction; and packaging and consumer goods.

Even if stocks on the LME appear sufficient for sourcing real demand in industry, the role of traders in moving the metal price forces a queue to extract these units from the LME's warehouses, a problem that has been described but still threatens every market player, as stated by Kim et al. (2021).

Nickel: Even if nickel consumption has reached 70% for stainless steel and 5% for batteries, according to the Nickel Institute[22], the recent increase in battery production due to electric vehicles has increased this value (Olafsdottir and Sverdrup, 2021). A difference from other *commodities* is that zinc will likely always fulfil global need for the next century, according to the International Nickel Study Group[23]. This fact makes nickel a high price metal, primarily due to its costs

[20] https://www.mining.com/copper-price-hits-10000-again-as-chinese-investors-unleash-demand/#:~:text=Copper%20price%20hit%20a%20record, high%20reached%20in%20February%202011.
[21] https://www.world-aluminum.org/statistics/primary-aluminum-production/
[22] https://nickelinstitute.org/about-nickel/#04-first-use-nickel
[23] https://insg.org/index.php/about-nickel/production-usage/

of extraction, but not a real *commodity* role player in the exchanges. thus, nickel should not be a backwardated metal, but it is used as a case study in this paper.

Lead: Lead is currently one of the more discussed metals due to the recycling of batteries coming from electric vehicles (Baars et al., 2021). Lead's low price, compared with the other LME metal prices, also makes it one of the less used metals for speculators and traders to either force price changes or be involved in *backwardation* time frame scenarios. Per Figuerola-Ferretti and Gonzalo (2010), lead is one of the least liquid LME contracts, and therefore, an analysis of *backwardation* makes more sense than other LME contracts, such as *aluminum*, copper, nickel and zinc.

Zinc: In their 2020 annual report, the International Zinc Association[24] highlighted the growing role of zinc with lightening automotive structures' galvanized high-strength steel. Sverdrup et al. (2019) projected an increase in zinc world consumption up to the year 2100, also modeling a soft scarcity in this century for zinc, defining scarcity as "when demand is reduced due to a high price"; this information was also presented by Tokimatsu et al. (2017) using a mineral balance model. Regarding the future structure of this metal, zinc is facing normal *backwardation* sporadically, with the future price being a predictor of a price increase (Peterson, 2015), even at a lower significance value than other metals such as *aluminum*.

Tin is one of the more backwardated metals compared in total value with the other base metals, and its physical premiums and price have been reaching their highest values ever currently. When comparing the relative percentages between the futures price structure and price of each *commodity*, tin has more price structure volatility, as shown in Figure 3.3.

[24] http://www.zinc.org

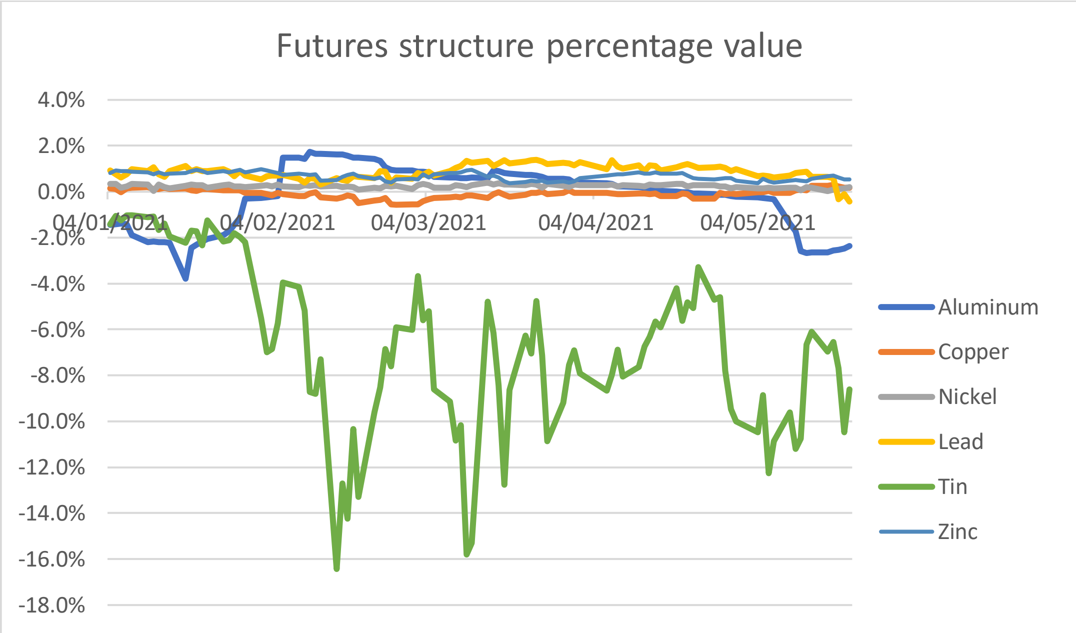


Figure 3.3. Futures structure in percentage to the price. LME data.

The primary reason for this structure comes from a lack of availability in the market (e.g., entire global stocks in official LME warehouses of no more than 2,000 MTs, covering only approximately 0.5% of worldwide consumption, based on up to 400,000 MTs per year; Li et al., 2021) also from the disappearing liquid positions in the respective exchanges, which primarily occur due to a concentrated production reported in the same study. When tin is not considered, we see that even if not achieving the same levels, *aluminum* is also in percentage (i.e., in reference to its value) eventually volatile in terms of its future price structure; this result was also previously described in the individualized analysis of metals.

3.5. Data and Methodology

3.5.1. Data

The data used for this study were LME cash values at the second ring close and the 3-months official prices (the most liquid, according to Otto, 2011) between 01/01/2016 and 31/12/2020 with the base metals in mining and economics, and traded under the non-ferrous indices on the London Metal Exchange: *aluminum* (AA), nickel (NI), lead (PB), tin (SN), zinc (ZI) and copper (CU).

The total data set contained 1,264 samples per metal, defining a 7,584 references matrix panel data, grouping by cash metal prices series (official price at the second ring close) and futures metals structure price series (defined as the difference of the 3-months basis price and the aforementioned cash priced):

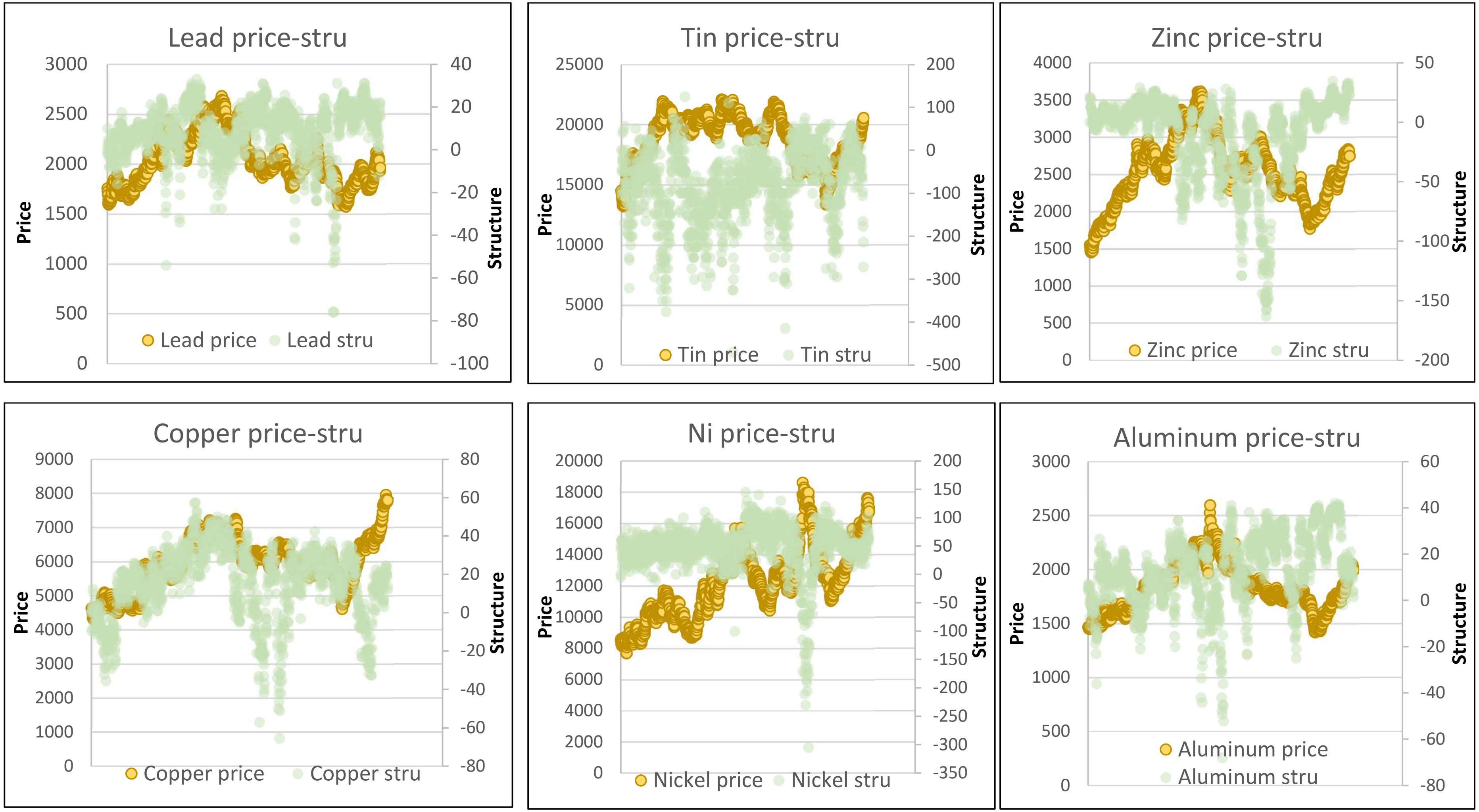


Figure 3.4. Price data and futures price structure for every metal. LME data and authors’ graphic.

3.5.2. Methodology

Cointegration and causality can be considered good tools to determine if two data series, such as price and the structure of future prices, are linked somehow. Thus, we analyzed the constructed data matrix in two ways:

- Using time data series causality
    - Across the entire data timeframe and metal by metal
    - Using intervals of study coming from structural breaks, metal by metal
- Using panel data structures causality

There are many previous studies of time series causality, including Engle and Granger (1987), who used the Johansen approximation (Johansen 2008): Eross et al. (2019), who applied the methodology to study bitcoins; Qadan (2019) and Rutledge et al. (2013), whose analyses of the same market environment explored in this study or other topical studies; and Hossain and Mitra (2017), Alam (2017), Hadi et al. (2019), Dong (2017), Chalmers et al. (2019) and Samsi et al. (2019) and more recently by Galán-Gutiérrez and Martín-García (2021). Unlike these time series approaches, there is also the chance to perform a global study using data panel analyses, increasing the number of data points and the interaction between the different time series, as in Banerjee and Carrion-i-Silvestre (2015) and Villca et al. (2020) and specifically in the world of *commodities*, Sharma (2020), Agnello et al. (2020) and finally Karabiyik et al. (2021) in the relationship between price metals and fundamentals. The usage of panel data series has different advantages compared to time series studies, such as those described in Hsiao (2007) and its different comments, Arellano (2007), Baltagi (2007), Mairesse (2007), Nerlove (2007), Park and Song (2007), Shin (2007), Sickles (2007) and Wansbeek et al. (2007). These advantages include more accurate inference of model parameters, greater capacity for constructing more realistic behavioral hypotheses, uncovering dynamic relationships, controlling the impact of omitted variables, generating more accurate predictions for individual outcomes, providing microfoundations for aggregate data analysis, and simplifying computation and statistical inference (Hsiao, 2014).

With time series causality tests, performing the Johansen approximation under Engle and Granger, we study the following series:

Structure of copper futures prices, $(y_t)_{t=1}^{N}$: $(stru_t)_{t=01-01-2016}^{31-12-2020}$ (Equation 3.1a)

Price of metals, $(z_t)_{t=1}^{N}$: $(PRICE_t)_{t=01-01-2016}^{31-12-2020}$ (Equation 3.1b)

Using the different metals (tin, lead, copper, *aluminum*, nickel and zinc), we have 12 time series, 6 price series and 6 structure series. This study will be done in 2-by-2 series packs for each metal.

These causality tests require stationary time series or nonstationary transformed series of the same order. Thus, several tests are performed to verify stationarity:

- Those where the stationarity of the series is the null Hypothesis H0, such as KPSS (Kwiatkowski et al., 1992) and as the Leybourne tests and McCabe tests (Leybourne and McCabe, 1994). These tests have recently been used by Su et al. (2020) and by Cui et al. (2021), linking bitcoin and oil prices.

- Others where the null hypothesis assumes nonstationarity, such as the Dickey-Fuller test as well as the augmented Dickey Fuller test. This set of tests was initially introduced by Dickey and Fuller (1979) and extensively used over the years but more recently in Syed et al. (2021) or Li et al. (2021), the Phillips-Perron test (Phillips and Perron, 1988) and the DF-generalized least squares tests (Elliot et al., 1996). The number of lags complies with the Bayesian information criterion (BIC), as suggested by Yao (1988), and the Akaike information criterion (AIC), Akaike (1974) and extended in Bai and Perron (2003). This set of tests is broadly referenced in real topics as oil and stock markets (Sarwar et al., 2020) or cryptocurrencies (Gil-Alana et al., 2020).

Based on Engle and Granger's causality cointegration, autoregressive vectors (VARs) were calculated. Johansen's approximation is used to look for the cointegration between the two series, as in Ivascu et al. (2021) and Mat et al.

(2020). This method is valid when the tentative cointegrated series have a low stationarity value like I(1), even if it is also a tool with strength for other values (Hjalmarsson and Österholm, 2010). The trace test and λ_{max} one are the two variables used to execute the Johansen approximation.

- Engle and Granger's cointegration tests were used to estimate the two equations shown below from the two series of OLS transformed data:

$$stru_t = \alpha_0 + \alpha_1\, stru_{t-1} + .. + \alpha_1\, stru_{t-l} + \beta_1\, stru_{t-1} + \cdots + \beta_1\, PRICE_{t-l} + \varepsilon_t, \quad \text{(Equation 3.1c)}$$

$$PRICE_t = \alpha_0 + \alpha_1\, PRICE_{t-1} + .. + \alpha_1\, PRICE_{t-l} + \beta_1\, PRICE_{t-1} + .. + \beta_1\, stru_{t-l} + u_t \quad \text{(Equation 3.1d)}$$

where l is the number of delays used; α and β are the parameters to be studied; and ε_t and u_t are the errors or random disturbances, respectively, which are normally uncorrelated.

If $\beta l = \beta_1 = 0$, there is no inter-series causation, while if $\beta l \neq \beta_1 \neq 0$, the two are cointegrated, as defined by Granger.

The Johansen approximation yields α and β as the vectors:

$$\alpha = |p,r| \quad \text{and} \quad \beta = |m,r|$$

where r is the number of cointegrating vectors, and p and m are the series vector components.

To understand if there are structural breaks and intervals of study to be investigated in detail, we use the references used by Gil-Alana (2002), Bai and Perron (2003), Gil-Alana (2008) and Caporale et al. (2020). Gil-Alana also used fractional unit root tests, which could be a base for a more accurate exercise in this study or in others of the same nature.

This theory is used when working with fractional integration as a generalization of the ARMA-ARIMA specifications, these I(d) models could use d integer or fractional values.

These studies use the test described by Chow (1960) for a classical linear model, and the null hypothesis of no structural break is constructed using a Wald statistic, whose properties are surveyed in Perron (2006).

Once a structural break is identified, we use descriptive analysis to find other possible structural breaks that will be checked in the way that the coefficients do not vary over the subsamples used. Structural breaks allow coefficients to change after a break date. If b is the break-date, the model is:

$$y_{it} = \begin{cases} \beta_i \, x_{it} + \gamma_i \, z_{it} + \varepsilon_{it} & if\ t \leq b \\ (\beta_i + \partial) \, x_{it} + \gamma_i \, z_{it} + \varepsilon_{it} & if\ t > b \end{cases} \qquad \text{(Equation 3.1e)}$$

The null and alternative hypotheses are H0= $\partial = 0$ and H1 = $\partial \neq 0$, respectively.

With the panel-data cointegration tests, we analyze cointegration individually inside each time series and the common trends of every of each metal together with a larger database (every metal instead of one by one), thus obtaining the same cointegration. In short, this test analyses the full series set (12 series).

Kao (1999), Pedroni (2001) and Westerlund and Edgerton (2008) used cointegration tests that relied on the common approach with a null hypothesis of no cointegration. Kao and Pedroni's tests demonstrate in their different theories that the studied variables are cointegrated throughout the range of data on the panel. Similarly, Westerlund's tests only show cointegration in certain metals.

These tests are based on the panel-data model for the dependent variable y_{it} :

$$y_{it} = \beta_i \, x_{it} + \gamma_i \, z_{it} + \varepsilon_{it} \qquad \text{(Equation 3.1f)}$$

where i = 1,…,N denotes the individual panel, t = 1,….,T_i denotes time, x_{it} is the independent variable, β_i is the cointegration vector, and γ_i is the vector of coefficients on z_{it}.

The basis of these three package tests (Kao, Pedroni and Westerlund) is founded in the previously referred ADF, PP and KPSS tests using vectors and matrices instead of linear series under Equation 3.1f.

To summarize the methodology and steps performed in this paper, the primary target of this study is to investigate whether there should be some link between an increase in the price of a hard *commodity* (e.g., a base metal) and a negative futures price structure (*backwardation*).

We have investigated different metals, some of which are more financialized, and others are more dependent on their fundamental drivers.

In the first stage, we do have two different groups of studies:

- All of the data
- Data intervals as defined by structural breaks:

<u>All data</u>: Augmented Dickey Fuller and Phillips Perron tests have only shown a strong value to determine the same order between the price data and the futures price structure for some metals, even if other tests such as KPSS have shown the same for a wider range of them.

<u>Data intervals</u>: First, intervals are obtained via structural breaks with a given accuracy value and later through descriptive analysis, thus determining which values are more doable to be used as possible breaks and after. We also check if previous breaks can be used to reject the null hypothesis of no structural break.

In the second stage, we run the test throughout the panel data series for the entire data range, finding a global cointegration of all metals.

3.6. Results

In this section, we document the results of the double analysis described above: a two-in-two-variable analysis and the matrix defined by the full dataset with panel structure

3.6.1. Metal by metal results

Results show that *aluminum*, tin, zinc and copper are the only possible stationary series (under the KPSS tests, as ADF/PP only describes tin) and the only possible cointegrated metals. Time series stationarity tests, metal by metal and using the entire-time range are shown in Table 3.2:

p value	*ADF*	*PP*	*KPSS*	*Stat.*	*Same order ADF/PP*	*Same order KPSS*	*Average price*
Al price	< 0,0001***	< 0,0001***	< 0,0001***	Yes/No	No	Yes	$ 1.835
Al-stru.	0,646	0,801	< 0,0001***	No/No			
Ni price	0,042**	< 0,0001***	0,104	Yes/Yes	No	No	$12.167
Ni-stru.	0,316	0,884	< 0,0001***	No/No			
Pb price	< 0,0001***	< 0,0001***	0,082	Yes/Yes	No	No	$2.050
Pb-stru.	0,275	0,662	<0,0001***	No/No			
Sn Pric	0,001***	< 0,0001***	0***	Yes/No	Yes	Yes	$18.793
Sn-stru.	*0,073**	0,833	< 0,0001***	Yes/No			
Zn price	*0,097**	0,001***	0***	Yes/No	No	Yes	$2.544
Zn-stru.	0,341	0,822	< 0,0001***	No/No			
Cu price	0,014**	0***	0,006	Yes/No	No	Yes	$5.944
Cu-stru.	0,685	0,932	< 0,0001***	No/No			

Notes: *** 1% significance, ** 5% significance, * 10% significance

Table 3.2, stationary tests data

The application of the Johansen approximation of Engle and Granger's theory for metals whose series have the same level of stationarity shows that the time series (price and future price structure) are cointegrated (Table 3.3).

(Signif. value 5%) p value	VAR order	Lambda max test	Trace test	Adjustment coefficient alfa		Adjustment coefficient beta	
Al price	4	At least one Cointegration relation		1,300	0,266	0,000	0,001
Al-structure				-0,706	0,003	0,067	0,000
Sn price	4	At least one Cointegration relation		-1,305	3,289	0,000	0,000
Sn-structure				9,166	-0,197	-0,014	0,000
Zn price	3	At least one Cointegration relation		3,519	0,252	0,000	0,000
Zn-structure				-0,792	0,050	0,029	-0,002
Cu price	5	At least one Cointegration relation		3,436	-2,276	0,000	0,000
Cu-structure				-0,711	-0,049	0,057	0,001

Table 3.3, cointegration data

Lambda max and trace tests show that the four pairs of series are cointegrated with different VAR orders, with *aluminum* and tin of the same order (4), zinc with VAR order (3) and copper with order (5).

Finally, the results from the analysis of the entire data series show that on *aluminum*, tin, zinc and copper, the price data series are cointegrated with the futures price structure data series ($p < 0,05$). In connection with the hypothesis that financialization could be a driver for this connection of *"normal backwardation"* with high prices, we can initially say that this hypothesis is true with copper and *aluminum* (the two more financialized metals) but not with nickel. Conversely, we find that some less financialized metals, such as tin, exhibit this type of cointegration.

Once we have determined that the entire-time data series are cointegrated for some metals, we find structural breaks in the time series and perform stationarity and cointegration tests for the intervals obtained. Applying Chow tests for structural breaks in time-series data, we obtained the breaks shown in Table 3.4 ($p < 0.01$). To study their stationarity, we used the augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP) test, and finally the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test.

El.	Break	Intervals per the first test		ADF	PP	KPSS	Johansen
Al	**19/07/18**	04/01/2016	20/07/2018	**1st(0,013/0,001)**	1st(<0,0001/0,855)	1st(0,033/<0,0001)	N/A
	***	19/07/2018	30/12/2020	2nd(0,040/0,986)	2nd(0,006/0,568)	**2nd(0,009/<0,0001)**	
Ni	**15/07/19**	04/01/2016	16/07/2019	1st(0,001/0,407)	1st(<0,0001/0,837)	**1st(<0,0001/<0,0001)**	(1) AIC 5 p 1%
	***	15/07/2019	30/12/2020	**2nd(0,649/0,937)**	2nd(0/0,810)	**2nd(<0,001/<0,0001)**	(2) AIC 5 p >10%
Pb	**12/03/20**	04/01/2016	12/03/2020	1st(0,001/0,586)	1st(<0,0001/0,601)	1st(0,018/<0,0001)	N/A
	***	12/03/2020	30/12/2020	2nd(0,075/0,583)	**2nd(0,247/0,817)**	2nd(0,038/<0,0001)	
Sn	**18/06/20**	04/01/2016	19/06/2020	1st(0,002/0,080)	1st(<0,0001/0,820)	1st(0,102/<0,0001)	N/A
	***	18/06/2020	30/12/2020	**2nd(0,669/0,598)**	2nd(<0,0001/0,759)	**2nd(0,001/<0,0001)**	
Zn	**14/09/20**	04/01/2016	15/09/2020	1st(0,003/0,293)	1st(<0,0001/0,983)	**1st(0,001/<0,0001)**	(1) AIC 2 p 1%
	***	14/09/2020	30/12/2020	**2nd(0,130/0,904)**	2nd(0,009/0,522)	**2nd(<0,0001/<0,0001)**	(2) AIC 3 p 4%
Cu	**29/09/16**	04/01/2016	30/09/2016	**1st(0,296/0,310)**	1st(0,013/0,726)	1st(<0,0001/0,017)	N/A
	***	29/09/2016	30/12/2020	2nd(0,008/0,614)	2nd(0,001/0,932)	**2nd(0/0,002)**	

Notes: *** 1% significance, ** 5% significance, * 10% significance.
Bold on ADF/PP and KPSS indicate the same level of either stationarity/non stationarity.

Table 3.4, Stationarity and cointegration for intervals defined through the structural break obtained

There is not the same stationarity I(x) with the ADF and PP tests for the time series of price structure and price of the different metals studied, even though the KPSS analysis shows that it can be present with nickel and zinc. We have considered that the two-time series (price and price structure) in every interval have different stationarity levels; therefore, it is nonsensical to transform them using the Box–Cox method.

Using the Johansen approximation with nickel and zinc, we do not find that the two-time series under the two intervals defined by the structural breaks are cointegrated in the same value. Only with zinc do we find a certain level of cointegration between the two-time series in the two intervals in the first time series defined in the interval ($p < 0.01$) and in the second ($p < 0.04$). Therefore, in general, the analysis with two breaks does not show cointegration, which is why this analysis must be improved looking for more breaks for the full time series. These results thus could be considered in comparison to the linkage between financialization and the cointegration studied in this paper.

Searching for additional breaks that can better describe each metal price behavior, we performed a descriptive analysis of the time series per metal, finding additional breaks: three on *aluminum*, one in nickel, two in lead, four in tin, four in zinc and four in copper. These intervals make up for the shortcomings shown by the initial breaks. Through the Wald and likelihood-test ratio, different significance values were obtained (Table 3.5). The final intervals obtained are plotted in Annex 3.1, Figures 3.5-3.10.

Metal	Other tentative breaks obtained Descriptive+Wald	Initial break obtained
Aluminum	07/01/18*** 22/07/18*** 28/11/19	22/07/18***
Nickel	10/10/19	16/07/19***
Lead	18/08/17 01/02/18**	13/03/20***
Tin	03/07/17** 19/11/18*** 15/06/20*** 13/10/20***	20/06/19***
Zinc	14/09/18*** 30/11/18*** 24/05/19*** 06/11/19***	15/09/17***
Copper	03/10/16*** 17/05/18** 11/05/20***	03/10/16***

Notes: *** 1% significance, ** 5% significance, * 10% significance.

Table 3.5. Structural breaks obtained

In the periods obtained through analysis, a stationary test and a cointegration test were performed with those series that had the same level of stationarity, except for nickel and lead, in which the structural break used previously was sufficient (i.e., no more highly significant breaks were found).

The new intervals obtained are shown in Table 3.6:

Metal	Intervals					
Al	04/01/2016 07/01/2018	08/01/2018 22/07/2018	23/07/2018 27/11/2019	28/11/2019 30/12/2020		
Sn	04/01/2016 19/11/2018	20/11/2018 20/06/2019	21/06/2019 15/06/2020	16/06/2020 13/10/2020	14/10/2020 30/12/2020	
Zn	04/01/2016 15/09/2017	16/09/2017 14/09/2018	15/09/2018 30/11/2018	01/12/2019 24/05/2019	25/05/2019 06/11/2019	07/11/2019 30/12/2020
Cu	04/01/2016 03/10/2016	04/10/2016 17/05/2018	18/05/2018 11/05/2020	12/05/2020 30/12/2020		

Table 3.6. Intervals per metal (Al, Sn, Zn, Cu)

Stationarity tests and cointegration tests in those with the same level of stationarity/non stationarity are shown in Table 3.7.

	Stationarity			Causality
	ADF	PP	KPSS	Johansen
Al	**1st(0,002/0,003)**	1st(0,002/0,975)	**1st(0/<0,0001)**	**(1) var 5, 1%*** **
	2nd(0,698/0,358)	2nd(0,031/0,573)	**2nd(0/0,066)**	(2) var 1, No cointegrated
	3rd(0,356/0,142)	3rd(0,002/0,210)	**3rd(0,049/<0,0001)**	(3) var 1, No cointegrated
	4th(0,006/0,904)	**4th(0,264/0,884)**	**4th(0,003/<0,0001)**	**(4) var 1, 10%***
Sn	1st(0,013/0,115)	1st(<0,0001/0,856)	1st(0,056/<0,0001)	(1) N/A **(2)**
	2nd(0,314/0,806)	2nd(0,021/0,630)	**2nd(<0,0001/0,001)**	**var 3, 10%*** (3)
	3rd(0,671/0,122)	3rd(<0,0001/0,393)	**3rd(<0,0001/<0,0001)**	var 5, No cointegrated **(4)**
	4th(0,545/0,141)	4th(<0,0001/0,853)	**4th(<0,0001/<0,0001)**	**var 4, 10%***
	5th (0,998/0,599)	**5th (0,987/0,978)**	**5th (<0,0001/<0,0001)**	(5) var 1, No cointegrated
Zn	1st(0,027/0,291)	1st(0,000/0,987)	**1st(0,002/<0,0001)**	**(1) var 3, 1%*** **
	2nd(0,337/0,753)	2nd(0,036/0,250)	**2nd(0,000/<0,0001)**	(2) var 1, No cointegrated
	3rd(0,036/0,175)	**3rd(0,935/0,900)**	3rd(<0,0001/0,028)	(3) var 1, No cointegrated
	4th(0,591/0,799)	**4th(0,701/0,682)** 5th	**4th(<0,0001/<0,0001)**	**(4) var 4, 5%****
	5th (0,834/0,948)	(0,004/0,394)	**5th (<0,0001/<0,0001)**	(5) var 2, No cointegrated
	6th(0,014/0,693)	6th(0,003/0,779)	**6th(<0,0001/<0,0001)**	**(6) var 2, 5%****
Cu	**1st(0,290/0,304)**	1st(0,020/0,726)	1st(<0,0001/0,015)	(1) var 3, No cointegrated
	2nd(0,013/0,238)	**2nd(0,228/0,938)**	**2nd(<0,0001/<0,0001)**	**(2) var 5, 10%* (3)**
	3rd(0,065/0,111)	3rd(0,001/0,229)	**3rd(<0,0001/<0,0001)**	**var 3, 10%* (4)**
	4th(0,620/0,646)	4th(0,036/0,999)	4th(0,002/0,1)	**var 2, 5%****

Notes: *** 1% significance, ** 5% significance, * 10% significance. Bold levels on ADF/PP and Bold levels on ADF/PP and KPSS indicate the same level of either stationarity/non stationarity.

Table 3.7. Stationarity tests and cointegration per metal and interval

There are several intervals (Table 3.7) where cointegration between the metal price and the future price structure exists for every metal studied. Copper and *aluminum*, the two more financialized metals, are again shown to confirm part of this theory.

Summarizing the first block of the results, we find the following:

- Across the entire data range, we identified cointegration between the price data series and the futures price structure with tin, *aluminum*, zinc and copper.
- The intervals obtained through the structural breaks analysis are shown:
  - Only zinc is cointegrated with some significance level for every two intervals obtained through the structural break of each data series.
  - Using a descriptive analysis and corroborating the structural breaks, two intervals were identified to exhibit cointegration between both series with *aluminum* and tin, and three intervals with zinc and copper.

3.6.2. Robustness test: Panel data results

On the second block of the analysis, in order to test the strength of the methodology and the cointegration of the data, rather than only to test the time series through the Johansen approximation, we have also run a data panel test. Rather than only test the time series using the Johansen approximation, we also run a data panel test that considers the matrix of every metal and the entire data range, thereby yielding a strongly balanced panel variable. Thus, the Kao, Pedroni and Westerlund tests were used for cointegration and yielded the following results.

Kao test for cointegration	
Ho: No cointegration Number of periods = 1,262	Ha: All panels are cointegrated Number of panels = 6
Cointegrating vector: Same	
Panel means: Included Time trend: Not included AR parameter: Same	Kernel: Bartlett Lags: 5.17 (Newey-West) Augmented lags: 1
	Statistic
Modified Dickey-Fuller t	-1.6e+02***
Dickey-Fuller t	-31.4654***
Augmented Dickey-Fuller t	-18.0906***
Unadjusted modified Dickey-Fuller t	-2.3e+02***
Unadjusted Dickey-Fuller t	-32.2141***

Notes: *** 1% significance
** 5% significance
* 10% significance.

Table 3.8. Kao test for cointegration on the panel data for the entire database.

Pedroni test for cointegration	
Ho: No cointegration	Ha: All panels are cointegrated
Number of periods = 1,263	Number of panels = 6
Cointegrating vector: Panel specific	
Panel means: Included	Kernel: Bartlett
Time trend: Included	Lags: 7 (Newey-West)
AR parameter: Panel specific	Augmented lags: 1
	Statistic
Modified Phillips-Perron t	-63.8807***
Phillips-Perron t	-22.9082***
Augmented Dickey-Fuller t	-25.0929***

Notes: *** 1% significance
** 5% significance
* 10% significance

Table 3.9. Pedroni test for cointegration on the panel data for the entire database.

Westerlund test for cointegration	
Ho: No cointegration	Ha: Some panels are cointegrated
Number of periods = 1,263	Number of panels = 6
Cointegrating vector: Panel specific	
Panel means: Included	
Time trend: Included	
AR parameter: Panel specific	
	Statistic
Variance ratio	-2.4165***

Notes: *** 1% significance
** 5% significance
* 10% significance

Table 3.10. Westerlund test. Cointegration on the panel data for the entire database.

Tables 3.8-3.10 show that that there is cointegration on the entire panel data ($p < 0.01$). From the Kao analysis, we find that the panel data are cointegrated ($p < 0.01$) based on the different versions of Dickey Fuller theories, the Pedroni tests with Phillips-Perron, Modified Phillips-Perron and finally with the Augmented Dickey-Fuller tests, thus confirming cointegration in every interval. Westerlund tests certify that cointegration exists in at least some intervals, as described in the methodology.

We also obtained the same results as those with the first block of data, finding cointegration for the different metals between their prices and their future price structure as a global data matrix. These results are also consistent with Yu et al.'s (2021) results for copper in specific time intervals.

Therefore, a relationship between the price and futures price structure of each metal is characterized as follows:

- Cointegration between *aluminum*, tin, zinc and copper using the full time series.
- Cointegration only with zinc at a low level using two intervals defined per structural breaks.
- Cointegration in two intervals with *aluminum* and tin, and in three intervals on copper and zinc using intervals defined by several structural breaks
- Cointegration between every metal series using panel data research.

3.7. Conclusions and policies

In this period of strong demand for raw materials that also includes the *COVID-19* pandemic, and from which the recovery has been strong and consistent, there is a widespread belief in the industry that we are entering a new *commodity* supercycle, which could last for years or even decades. There are many factors that point to this conclusion. First, some factors that show common patterns between the early 2000s and the 2020s, such as China's economic performance and the investment cutback in metal companies during the 2012-2020 period due to a fall in prices, will likely lead to lower future supply and high prices. Second, new structural factors, such as the energetic transition and the development of electric vehicles, plus the electrification of the remaining parts of the world, are likely to lead to this supercycle. Third, financial issues currently exist, including *commodities* being used as haven securities for investors. Compared to other alternative assets (such as equities), *commodities* are cheap and have revaluation potential, particularly those more financialized, which is attractive to investors. Public stimulus is also an important factor. The end of the quantitative easing (QE) implemented after the 2007 crisis, which had such a negative impact on the price of *commodities*, and the entry of governments worldwide fiscal and monetary stimuli to boost the recovery of economic growth are also two factors that will favor these markets in the near future.

Thus, metals could be in a position to increase in price, thereby being in a position of *"normal backwardation*". In this context, this study searches for patterns and relationships to understand the joint behavior of price structure and level of price (high, low, increasing or decreasing) to assess market agents to optimize their positions. Causality tests using Engle and Granger's theory and Johansen´s approximation for the same stationarity series using ADF, PP and KPSS methodology were performed with the time series of metal prices.

Results show a clear linkage between increases in metal price and an increase in the short-term price compared with the long-term price (futures price structure). This effect is stronger for tin, copper, *aluminum* and zinc via independent data series analysis and on intervals defined by structural breaks. Robustness tests with data panel and a full data matrix confirm these results. Additionally, the linkage of financialization and this theory for the two most financialized metals (*aluminum* and copper) is demonstrated. This link has not been found for metals with low financialization.

Considering only the price and not the futures price structure, when the market is high and fundamentals propose an even tenser scenario, everyone thinks about buying the *commodity* today to be sold tomorrow. This strategy is commonly used by price speculators and, in general, high-risk investors. Instead, when the focus is set on price structure, agents who are in high-price tensioned markets and already have physically hedged positions could take advantage of *backwardation*, positioning short in the long term to achieve value from the carries (i.e., lending instead of borrowing) and staying long in the short term. This strategy would let them not speculate on price but on the price difference over time (price structure), which could be more stable than intraday or interday price changes.

This study provides a more reliable and econometric-based pattern to confirm that when prices are generally high, markets tend to backwardate (*commodity* spot prices are higher than future prices). The results of this study have important implications for players that hedge their exposure, using this theory to position profit taken and stop loss orders as *hedging* tools in scenarios where the metal price is high to ensure good results. For the variety of metals that price on the base metal LME structure, *aluminum* and copper (the most financialized metals) behave with the cointegration described in this paper, showing a linkage between financialization and normal *backwardation* in high price scenarios. The refuge of some investors on base metals depending on the global market situation is a fact; therefore, another justification to consider this theory to be a key factor to move the liquidation of positions between different stock values. Policy-makers can thus structure this cointegration as a reference to reduce volatility and instability that, in a specific period of time with high prices, could occur. Thus, countries' metal reserves can always be a strong tool to leverage the market.

Economic crisis and, more generally, unstable situations when markets were disturbed in some way should be investigated in future research, including subsamples studied with fractional integration trying not to lose any of the soft tentative cointegrations.

3.8. Annex

Annex 3.1:

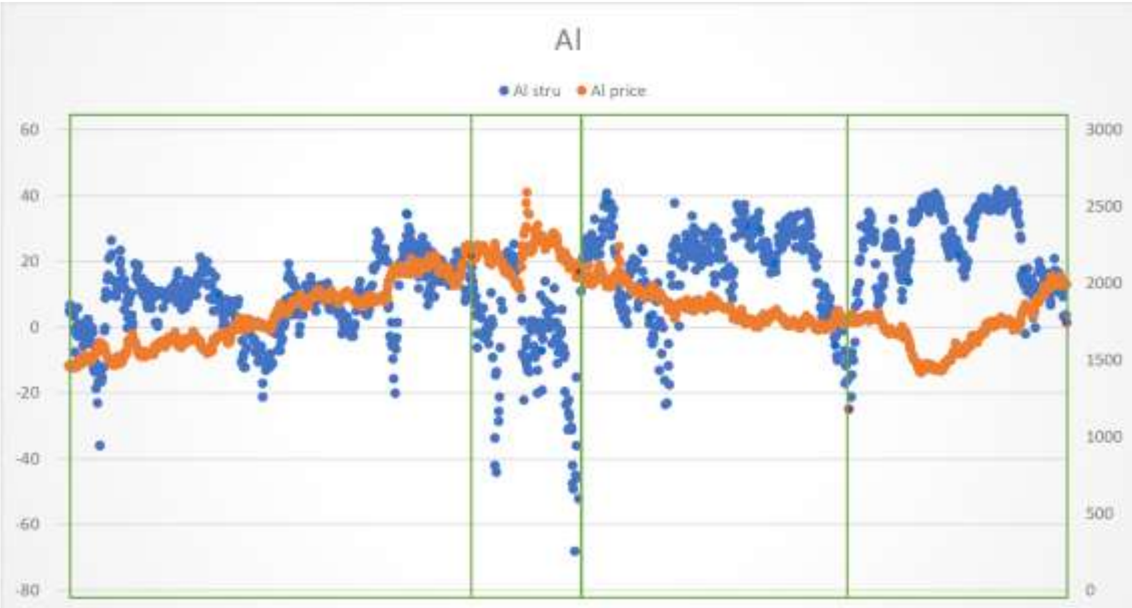


Figure 3.5 *Aluminum* price and futures price structure divided into the intervals obtained.

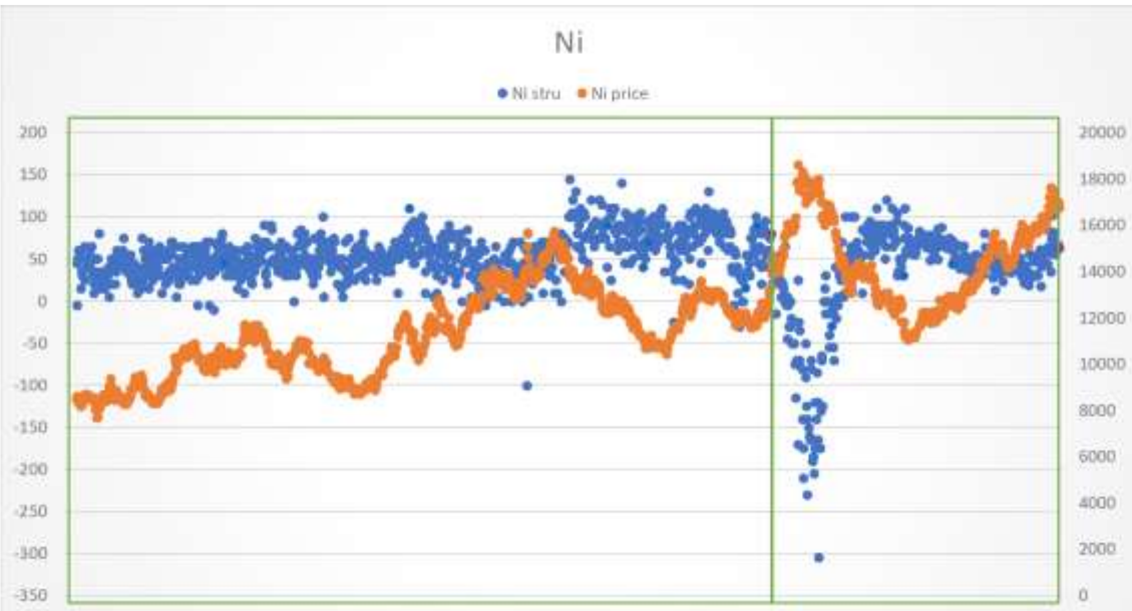


Figure 3.6 Nickel price and futures price structure divided into the intervals obtained.

Figure 3.7 Lead price and futures price structure divided into the intervals obtained.

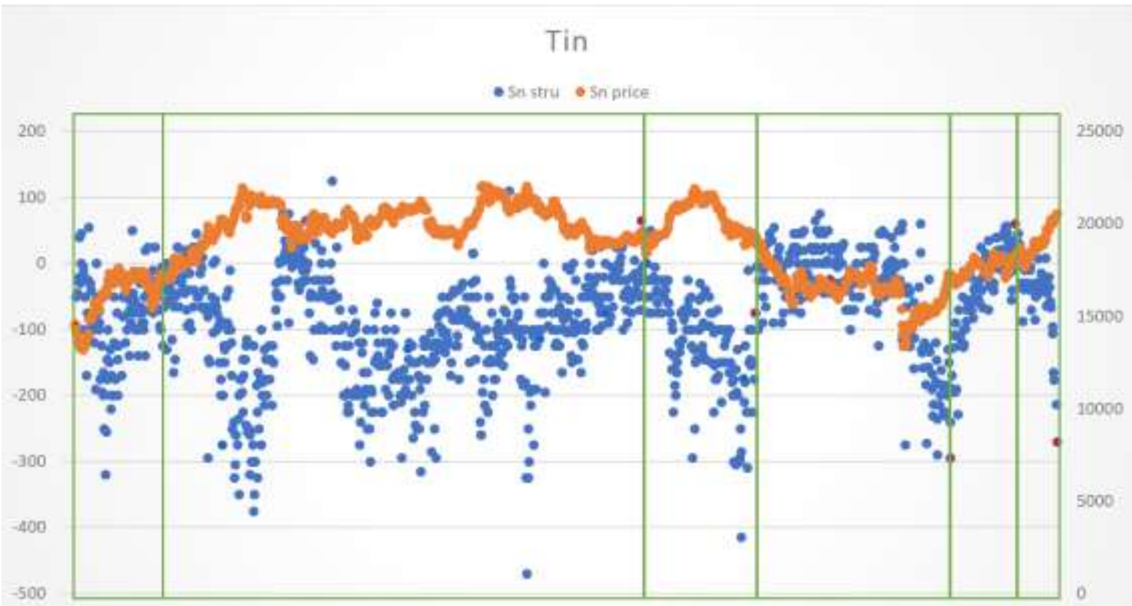


Figure 3.8 Tin price and futures price structure divided into the intervals obtained.

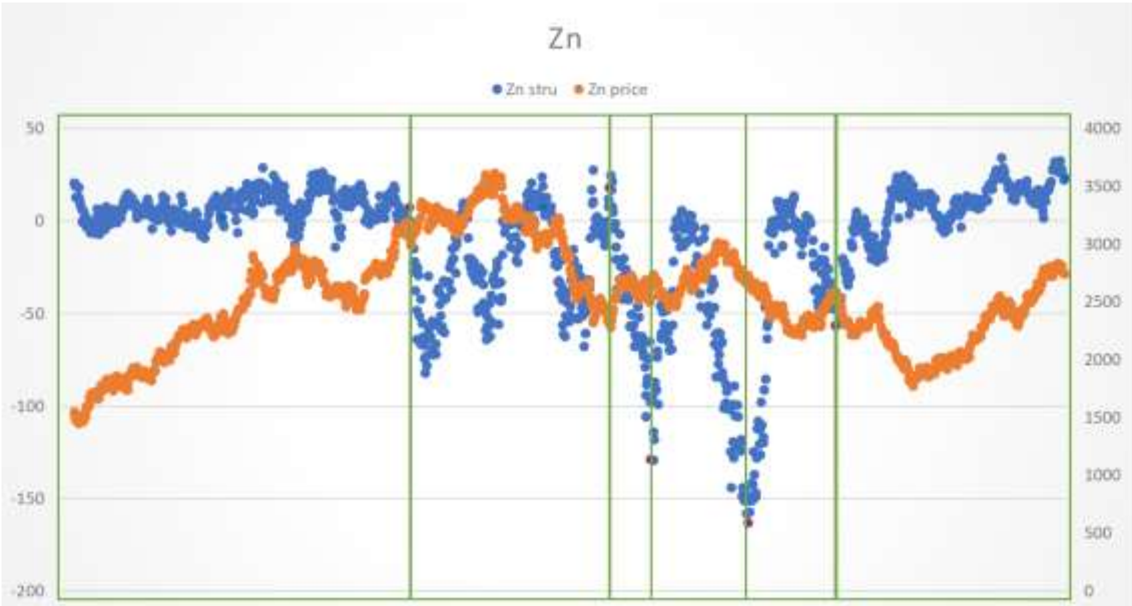


Figure 3.9 Zn price and futures price structure divided into the intervals obtained.

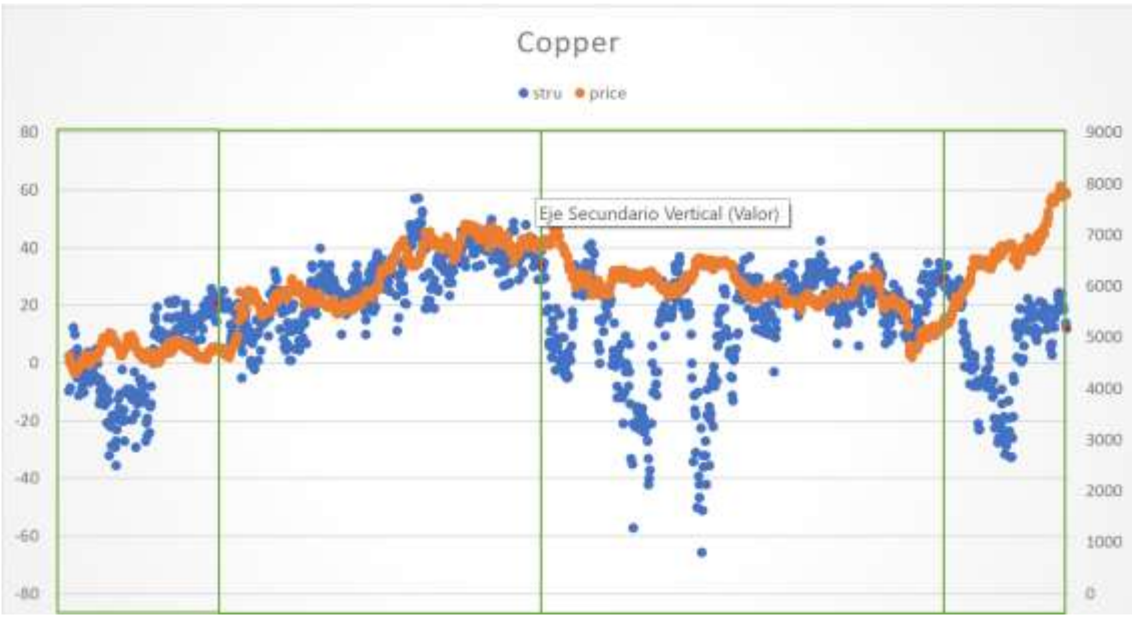


Figure 3.10 Copper price and futures price structure divided into the intervals obtained.

4. Fundamentals vs. financialization during extreme events: from *backwardation* to *contango*. A copper market analysis during *COVID-19* pandemic[25]

4.1. Abstract

The *COVID-19* pandemic has shocked *commodities* markets in general, and base metals markets in particular. The market turmoil made really difficult to act in the physical market, given the impossibility of establishing or maintaining physical and/or financial positions in a context of high uncertainty. This has happened both in different moments of the development of the pandemic and in geographically different frames. That is why this contribution tries to explain the evolution of warehouses and copper price structure and its utility for *hedging* in the context of an extreme event. To that end, Granger causality has been used to test if during the *COVID-19* first wave the pandemic evolution is cointegrated on one hand, with copper futures price structure and, on the other, with the incremental levels of copper stocks. Using 102 copper official prices on LME (London Metal Exchange) trading days, between 13/01/2020 and 05/06/2020 (once the most severe effects of the first wave have been overcome), it has been demonstrated that, during the first *COVID-19* wave in Europe, the weekly death index variation was cointegrated with the copper future price structure. It has been proven that, in this timelapse, *contango* in futures price structure has increased its value and the incremental levels of stock in copper LME warehouses are linked with a stable *contango* structure. In short, we find that fundamental market effects predominate, in a context in which *commodities* used to be more financialized. This leads market players, such as traders, miners and transformers, to move exposures in their *hedging* structures, under such extreme event situations, in favor of or against either *contango* or *backwardation*, so as to derive value from them.

[25] *Artículo publicado en la revista Mathematics, volumen 10, accesible en el enlace: https://www.mdpi.com/2227-7390/10/4/559.*

4.2. Keywords

COVID-19; *commodities*; structure of copper futures prices; cointegration; *contango*; *backwardation*; extreme event contexts

4.3. Introduction

The *COVID-19* pandemic started as an epidemic, with China being the first country reporting the disease. It was only 100 days until the declaration of the pandemic. After that, governments in every country implemented different measures to control the crisis, with a common structure: social distancing, lockdowns, stay-at-home orders and travel restrictions, all of which had economic impacts. The whole world experienced a period in which the economy was not running efficiently, causing some businesses to collapse.

The recovery after the emergence of the pandemic evolved differently depending on the country and the sanitary situation, causing a global disruption in the commerce interchange, and affecting the full value-added chain.

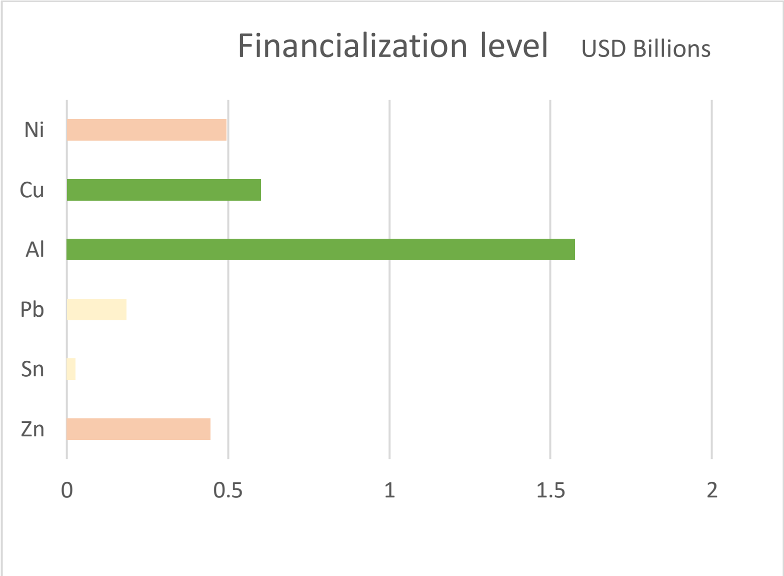
Commodities market prices reached their lowest level in decades, such as for example the crude oil and natural gas markets (Adekoya & Oliyide, 2021). Other *commodities* traded in futures exchanges, such as soft *commodities* and metals, also reacted sharply to this global crisis, with a vast shift in prices (Ahmed & Sarkodie, 2021) and the historical refuges of these stock markets also being affected (Lahiani et al., 2021). Copper, in particular, underwent a price decrease of almost 25%, from EUR 6,200 at the beginning of 2020 to EUR 4,627 per metric ton only 3 months after, with a lack of interest in the buying market and with most of the players trying to liquidate their long-held positions in official warehouses.

This *COVID-19* pandemic has had by far the biggest influence on every market in recent times, when base metals prices on *commodities* exchanges have been influenced by macroeconomic and microeconomic events. Each of these base metals shows different behaviors depending on its supply–demand situation, and how financialized each is.

Microeconomic and macroeconomic events have influenced *commodities*' behaviors in different exchanges. Some of these macroeconomics variables, such as GDP (Gross Domestic Product), have been used to determine the effects on the 27 *commodity* futures traded on the *Commodity* Research Bureau (CRB) as per Ge & Tang (2020), and the effect on the S&P 500 index has been tested using *commodity* price indexes (Creti et al., 2013). It is also informative to study currency volatility, and the link between currency rates for 17 soft and hard *commodities* (Liu et al., 2020). Crude oil prices have also been analyzed by some authors, who found a vast range of variables affecting prices, such as the *COVID-19* outbreak, the USD index and PIMCO (Pacific Investment Management Company, LLC) Investment Grade Corporate bond index (Bouri et al., 2020), and US and BRICS (Brazil, Russia, India, China and South Africa) equities (Ji et al., 2018). Globally, it has been demonstrated that price cycles are affected by macroeconomic variables (Agnello et al., 2020).

The increase in financialization on the *commodity* market has been observable for a while (Batten et al., 2010, Chen, 2010), with *commodities* in general and base metals in particular being a refuge for investors trying to hedge their global exposure. In this regard, 2004 has been pinpointed by some authors (Adams et al., 2020) as the year in which financialization became more present, ultimately achieving inflows of up to USD 450 billion seven years later in 2011 (Bicchetti & Maystre, 2013).

Specifically, we find that copper and *aluminum* are the two most highly financialized base metals, following the LME's (London Metal Exchange) Commitment of Traders Report (see Figure 4.1).



NOTE: Ni (nickel), Cu (copper), Al (*aluminum*), Pb (lead), Sn (tin), Zn (zinc).

Figure 4.1. Financialization level per metal, financial institutions holdings on LME.

The so-called *"normal backwardation*" theory links the fundamental scarcity level of a *commodity* (physical supply and demand) with the appearance of a higher price in the short term than in the long term. This was first studied by Keynes (1930), looking generally at *commodities* (Anderson & Danthine, 1983) and specifically at certain metals such as zinc (Peterson, 2021), and some have recently assessed financialization factors (Güntner & Karner, 2020). Several trends in the data also reflect the disappearance of *"normal backwardation*" in specific periods of study, and in different *commodities* (Rouwenhorst & Tang, 2012; Mishra, 2016).

The theory of normal b*ackwardation* is also established through the theory of storage and is related to the Cost of Carry (COC) model, as shown in Watkins & McAleer (2002), where it was shown that risk premium could be used to determine a long-term pricing model. This theory of storage was used to study the levels of stocks in warehouses in different exchanges, which has always been one of the main factors of the fundamentals-based movements of *contango* and *backwardation*. The literature addressing this theory is broad (Arseneau & Leduc, 2013; ap Gwilym & Ebrahim, 2013 and Socking & Xiong, 2015), and a model combining *backwardation* and storage has even been considered (Ekeland et al., 2019). We can also find evidence of normal *backwardation* in oil price curves (Lembarki, 2018; Ames et al., 2020; and Socking & Xiong, 2015).

"Normal backwardation" is a theoretical framework that studies the futures price structure, whether it be *backwardation* or *contango*, wherein the fundamentals are the main drivers of prices in the short term. Said structure is also linked to several factors, such as the combination of lack of demand and excess of offer, indicating *contango*, and an absence of offer with a surplus of demand, indicating *backwardation*.

In this paper, the purpose is to follow and to check the link in between the increase of LME warehouses' stock and a high *contango* value on copper prices, which is evidence of the normal b*ackwardation* theory, related to an extreme event, such as *COVID-19*. This recent crisis has shocked the metals market, causing the whole value-added chain to slow down in the period immediately after the declaration of the pandemic. This slowing forced some market participants to increase their efforts to finance their sales to official warehouses. In the case of *commodity* sellers, the goods were directly moved to LME warehouses. Therefore, an increase in the stocks in warehouses was achieved at the same time as the pause in commerce, and the copper market futures prices developed into *contango* structure. Thus, we have analyzed prices and stocks data obtained from LME, and the number of deaths due to *COVID-19* by geographical area, obtained from the World Health Organization (WHO), building data series to assess stationarity. Stationary tests have demonstrated stationarity or same level of non-stationarity, performing ADF (augmented Dickey–Fuller) as per Dickey & Fuller (1979), PP (Phillips Perron), Phillips & Perron (1988) and KPSS (Kwiatkowski Phillips Schmidt Shin) tests (Kwiatkowski et al., 1992). Then, the cointegration between prices and deaths on the one hand, and *contango* structure and level of stocks in warehouses on the other hand, can be obtained by the Johansen approximation (Johansen, 2008) of the Engle and Granger causality theory.

The aim of this work is to clearly show that copper is a market linked to fundamentals, and is not only a refuge of investors, traders and speculators, it is, for instance, a financialized market. The importance of copper to our daily lives makes the influences on offer and demand extremely important, and the situation during the first waves of *COVID-19* in Europe offers evidence of this.

The contributions of this research include the findings of co-movements between the *COVID-19* index of weekly deaths and the copper futures price structure during the first wave of contagions in Europe, and of evidence of normal *backwardation* with the development of such a futures price structure and the increase in stocks in official LME warehouses.

More specifically, we have completed an analysis of the development of *contango* in crisis situations, and not only of the effects on prices (as in Baek et al., 2020), which opposes the findings of some other authors (such as Sifat et al., 2021 and Farid et al., 2021), which continued to see financialization throughout the *COVID-19* crisis and other references as Güntner & Karner (2020) that really focus on the paper of Financialization against normal *backwardation*.

A better illustration of how *COVID-19* has shocked the copper market in particular is offered by the descriptive change in tendence in the first half of 2020 (during the first wave of *COVID-19* contagions in Europe) (see Figure 4.2). The figure shows LME copper market evolution, in reference to its official historical price structure, and it can be seen, too, how the market had been in a negative (-0,0102) trend, to a positive one (+0,0362), in both cases, using a linear regression approach.

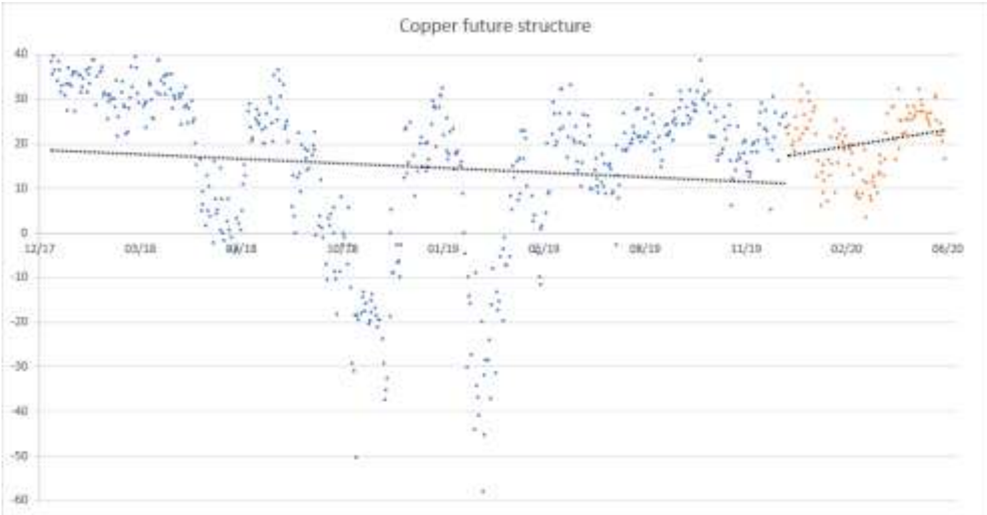


Figure 4.2. Copper future structure from January 2018 to June 2020.

An additional illustration of the influence of the situation on stocks in the first half of 2020 is given by Figure 4.3, representing the average levels of stocks in warehouses.

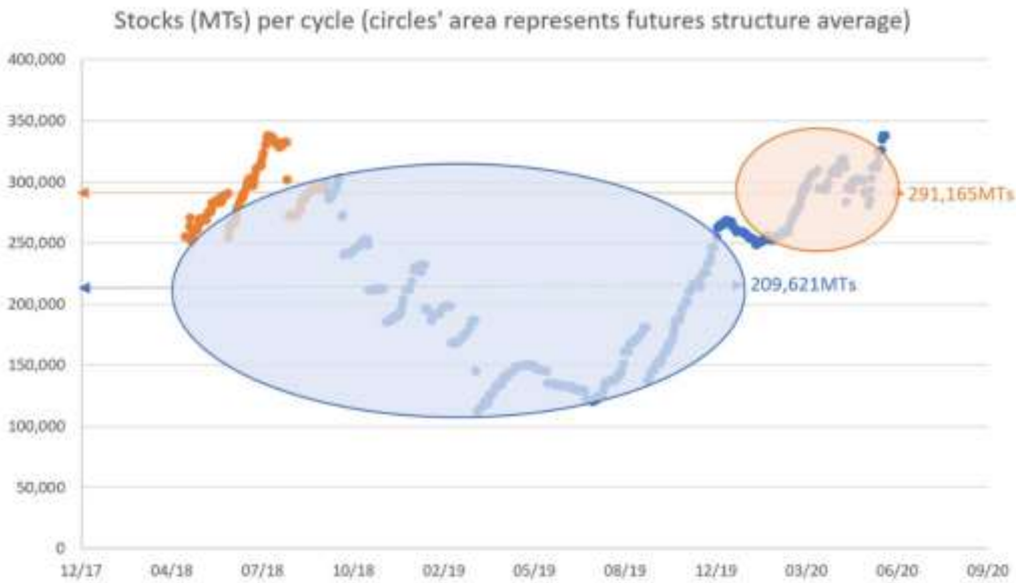


Figure 4.3. Average value of stocks in warehouses in different frames.

Copper stocks significantly changed, as volume went from 209,621MTs, on average, during 2018-2019, to 291,165MTs, on average, during the first half of 2020, what represents a 39 % increase.

The remainder of this paper is organized as follows. Section 4.4 reviews the relevant literature on cointegration, co-movements, copper and the *COVID-19* crisis. The data and methodology are reviewed in Section 4.5. A description of the results and an analytical review are presented in Section 4.6. Finally, conclusions and recommendations are discussed in Section 4.7.

4.4. Literature review

The main aim of this study is to prove the appearance of *“normal backwardation*” under the conditions of a critical event, such as the *COVID-19* pandemic. For this purpose, we have assessed the literature on co-movements and the *COVID-19* pandemic.

4.4.1. Cointegration and co-movements: copper

The influence of different variables on time series fluctuations has been a matter of global study within several economic environments and, specifically, in *commodity* markets, as has been assessed by Engle & Granger (1987) and Golosnov & Rossen (2018) and more recently, Lim et al. (2019), Fasanya & Awodimila (2020), Mandacı et al. (2020) and Ding & Zhang (2020).

Some *commodities*’ prices move together, which is referred to as co-movement, such as in the energy markets (Boako et al., 2020 and Ma et al., 2021) and oil markets (Mensi et al., 2020), and between different metals (Madaleno & Pino, 2014, Qadan, 2019, Al-Yahyaee et al., 2020 and Sharma, 2019) and in metal exchanges (Karabiyik et al., 2021).

Interest in cointegration and causality has also been present in topics such as cryptocurrencies (Rutledge, 2013) and *Brexit* (Eross et al., 2019).

Copper has been chosen for this study for many reasons. Firstly, it is one of the most financialized base metals priced on the Shanghai Futures Exchange (SHFE), the London Metal Exchange (LME), and the New York *Commodity* Exchange (COMEX), which are commonly used for speculative strategies

(Galán-Gutiérrez & Martín-García, 2021). Secondly, it has a large influence at different economic levels, for example in rich economies, such as Chile's, and in the development of many others (Shao et al., 2013). Thirdly, it is one of the metals that are taking over the incipient metal super-cycle, due to the increase in needs and consumption related to the appearance of electric vehicles (Pedersen, 2019), the increase in renewable energies, and the use of electric applications in general. Given all these factors, authors such as Jones et al. (2020), have identified a high probability of a lack of copper in the short term. This battle between the influence of fundamentals and financialization on copper markets has also been studied by Sverdrup et al. (2014). In addition, cointegration and co-movements in the copper market have been a matter of study for authors such as Guzmán & Silva (2018), assessing not only copper but also another 43 *commodities*; Cashin et al. (2004), assessing efficiency in the structure of prices; Park & Lim (2018), studying the cointegration of copper prices with China's activity and stock returns, and finally Guo (2018), looking at cointegration in certain time periods between future prices and cash prices.

4.4.2. *COVID-19* influence on markets

COVID-19 has been the biggest macroeconomic influence in recent history, affecting the global economy, the flow of trade, and human beings in general. Even though this is a relatively recent matter, the numbers of studies and authors that have concentrated their efforts on investigating and rationalizing each step of this process has been extremely important. The economic effect of *COVID-19* is obvious, as Annex 4.2 shows. Below is a compendium of articles showing *COVID-19*'s influences on the *commodities* market (Table 4.1).

Table 4.1. Articles concerning *COVID-19*´s influence on the *commodities* market

Doc.	Topic/Theme	Context	Purpose	Key findings
Yu et al. (2021)	Co-movements in energy counterparties' parameters under extreme conditions	*COVID-19* crisis and West Texas Intermediate (WTI) oil future prices showing negative prices	To study transmissions and contagion in the energy sector	Existence of spillovers and co-movements among these energy-focused corporations
Corbet et al. (2020)	Connectedness in energy *commodities* after *COVID-19* pandemic beginning	First two months of the *COVID-19* outbreak	To look into the financial impact on *COVID-19*, concentrated on the energy sector	Dependence among energy *commodities* increases
Adekoya & Oliyide (2021)	Effect of the pandemic on the connectedness amongst the *commodities* market	US and worldwide *COVID-19* pandemic effect	To explore the risk transmission in *commodity* and financial markets during the *COVID-19* pandemic	Volatility connectedness between *commodities* and financial markets
Lin & Su (2020)	*Commodity* price returns during the pandemic	*COVID-19* Global Fear Index (GFI) rising	To examine how GFI is linked to *commodity* price returns	*Commodity* prices' linkage with global *COVID-19* fear index
Salisu et al. (2020)	Alternative markets study	*COVID-19* beginning up to March 2020 and the safe haven assets	To study the effectiveness of safe haven markets under the *COVID-19* crisis	The safe havens of gold and soybean
Ji et al. (2020)	Study of some *commodities*' market volatilities	Price prediction model changes during the *COVID-19* crisis	To readapt the existing price prediction models to the variations caused by *COVID-19*	Volatility of *commodity* prices
Sifat et al. (2021)	Speculation on *commodities*	No speculation increase caused by other critical financial effects	To evidence the increase in the speculation of *commodities* (energy, soft and precious metals) in the presence of *COVID-19*'s effects	Different influences on soft and hard *commodities*

Doc.	Topic/Theme	Context	Purpose	Key findings
Kamdem et al. (2020)	Overreactions in *commodities* prices	Intraday price changes (changes of prices followed by proportional price reversals)	To identify how 20 different *commodities* react to *COVID-19*'s effect on intraday prices	*Commodity* price overreactions in this period
Borgards et al. (2021)	Volatility connectedness among assets peaked during the outbreak	US ETFs, before *COVID-19* and during the first wave (up to May 29th, 2020)	Changes in the structure and time-varying patterns of volatility connectivity between stocks and major *commodities* (oil, gold, silver, and natural gas)	Volatility connectedness peaked during the *COVID-19* pandemic
Ezeaku et al. (2021)	The influence of the *COVID-19* pandemic on *commodity* prices	International *commodity* (metal and agricultural) prices (December 2nd, 2019–October 1st, 2020)	To show, in the context of the *COVID-19* pandemic, the impacts of oil supply and global demand shocks on metal and agricultural *commodity* prices	The pandemic represents a mix of supply, demand and uncertainty shocks, and the result is that price indices have significantly declined as it continues to disrupt global supply and demand chains
Rajput et al. (2020)	Comparative *commodity* (oil and metals) prices	The *COVID-19* outbreak generated price declines in precious and industrial metals, although drops were lower than in oil prices	To comprehensively address the potential impacts of the *COVID-19* outbreak on *commodity* markets	Drop in oil market prices and metal prices, particularly in copper
Güntner & Karner (2020)	Since the correlations between stocks, bonds, and *commodity* futures returns are likely to change over time, optimal portfolios' *commodity* futures' weight could also be time-varying	*Commodity* futures have traditionally shown low correlations with stocks and bonds	Normal b*ackwardation* in *commodity* markets no longer works	End of normal b*ackwardation* in recent times and the difficulty of *hedging* in the present scenario
Baek et al. (2020)	Trend-following strategies create significant abnormal returns in futures markets	A paired trading market–neutral strategy is used (through machine learning algorithms), involving long and short positions in two different future contracts with similar time series price trends	To show that normal *backwardation* and *contango* do not consistently characterize futures markets, but each futures market exhibits unique prevailing price trends	Algorithm of trading pairs in futures price structures and the effect on *hedging* strategies during the *COVID-19* crisis

Therefore, the effects of co-movements on *commodities* in general and on copper in particular have been studied in depth in the literature, finding that, in general, there is a dependence between the behaviors of the prices of these *commodities* and different factors, such as microeconomic and macroeconomic events. In this regard, *COVID-19* is the recent event that has most strongly affected the whole structure of exchange markets, shaking the entire market's structure in different sectors.

4.5. Data and Methodology

4.5.1. Data

The copper price data were obtained from the London Metal Exchange and have been used to establish the price structure upon official daily close of the market. The database includes 102 official LME calendar trading days, stretching between 13/01/2020 (day 44 of the pandemic, following Allam (2020), with the first case identified in China) and 05/06/2020 (day 188, when the first wave in Europe was considered under control), as used for a descriptive analysis of the first wave of contagions in Europe as the growth rate moved to zero (this interval has also been used by some other authors like Drożdż et al. (2020). The *COVID-19* data index we used was composed of the accumulated deaths collected each week in different regions of the world, according to the data published by the WHO (World Health Organization), evaluating the number of cumulative deaths (weekly summarized) per population (10000 habitants' ratio) as per the United Nations World Populations Prospects 2019. These *COVID-19* data were segmented by:

Date/Country/WHO_region/New_cases/Cumulative_cases/New_deaths/Cumulative deaths, and the different regions are shown below.

Table 4.2. Regions as per WHO

European Region	EURO
Eastern Mediterranean Region	EMRO
Western Pacific Region	WPRO
African Region	AFRO
Region of the Americas	PAHO
South-East Asia Region	SEARO

4.5.1.1. WHO Weekly mortality index

We have used the percentage of increase in cumulative deaths, measured weekly as a percentage per 100,000 habitants, as cases detected during the first wave were not measured in the same diametric manner by every country (due to the different capacities to do so) and weekend data were usually not published on time by every country. The availability of tests and the differences in how countries report their figures have been amongst the biggest limitations to our data.

The figures show the data on the biggest countries in each WHO region to perform a descriptive analysis of the information available.

The COVID-19 weekly mortality index (represented by the time series COVIDt) was obtained through arithmetic assessments of the data given every Monday by WHO, focusing on the difference in cumulative deaths between one reference and that from the previous week. The percentage of growth shown by one reference over this period is the focus of our study. These data have been assessed for the number of inhabitants in every region. As such, we can establish:

Day 1	Cumulative deaths 1	Mortality assessed 1
Day 8	Cumulative deaths 2	Mortality assessed 2

$$INDEX = \frac{(\text{Cumulative deaths 2} - \text{Cumulative deaths 1}) * 100}{\text{Number of inhabitants}} \qquad \text{(Equation 4.1)}$$

Cumulative Deaths Data from Monday to Sunday were calculated through the sum of daily deaths that were published. Even though Europe alone is the subject of our investigation, we display the results for the 6 areas (see Figures 4.4-4.9).

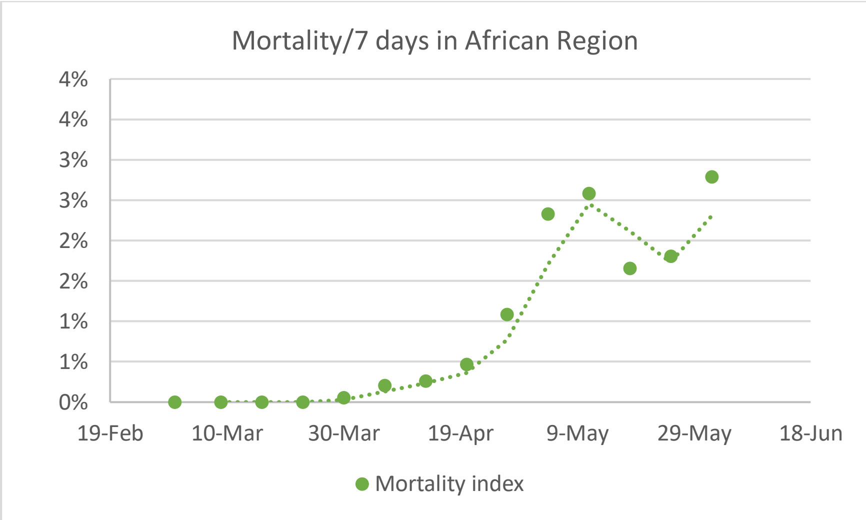


Figure 4.4. *COVID-19* weekly mortality index in Africa.

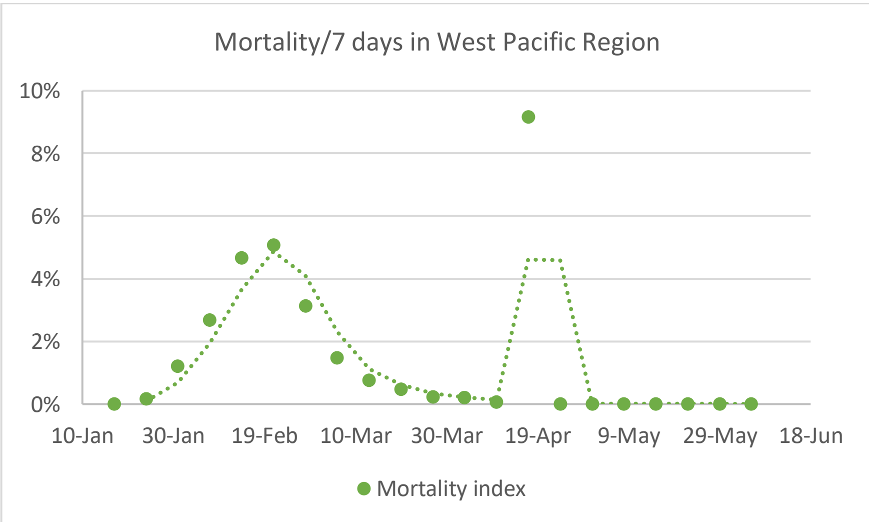


Figure 4.5. *COVID-19* weekly mortality index in the West Pacific.

Low values were found in these two regions during the first wave of contagions in Europe, and these are mainly related to the low ages of the populations in the main countries in the African area, and to the heavy measures taken to control the pandemic in the West Pacific region.

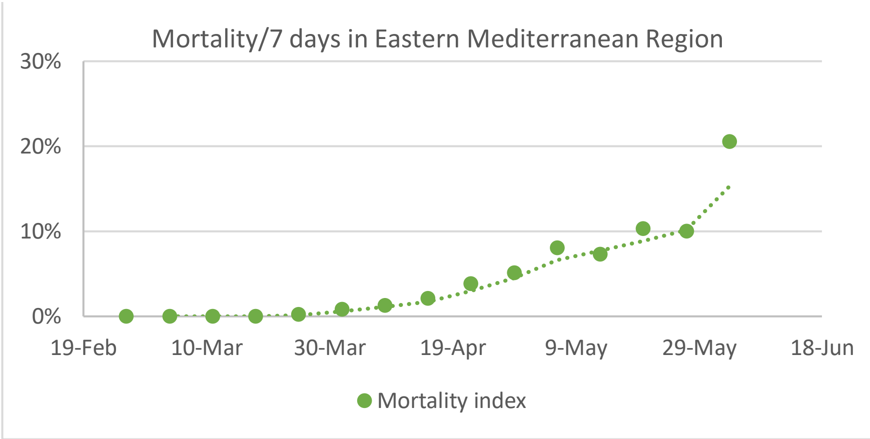


Figure 4.6. *COVID-19* weekly mortality index in the East Mediterranean region.

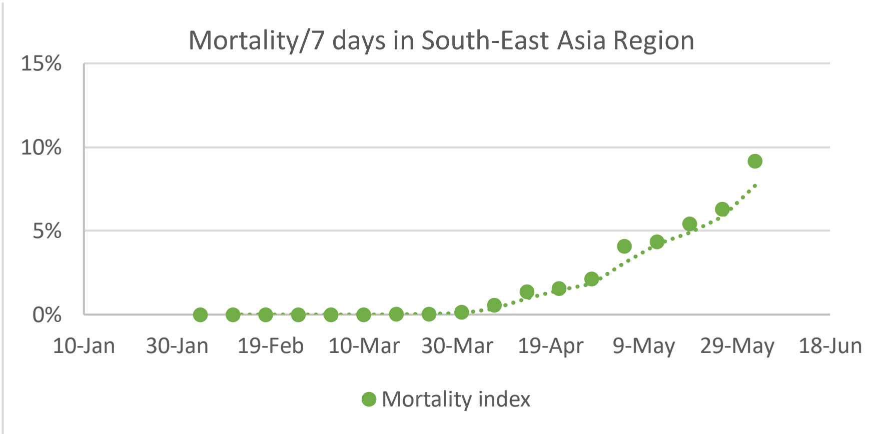


Figure 4.7. *COVID-19* weekly mortality index in the East Asia region.

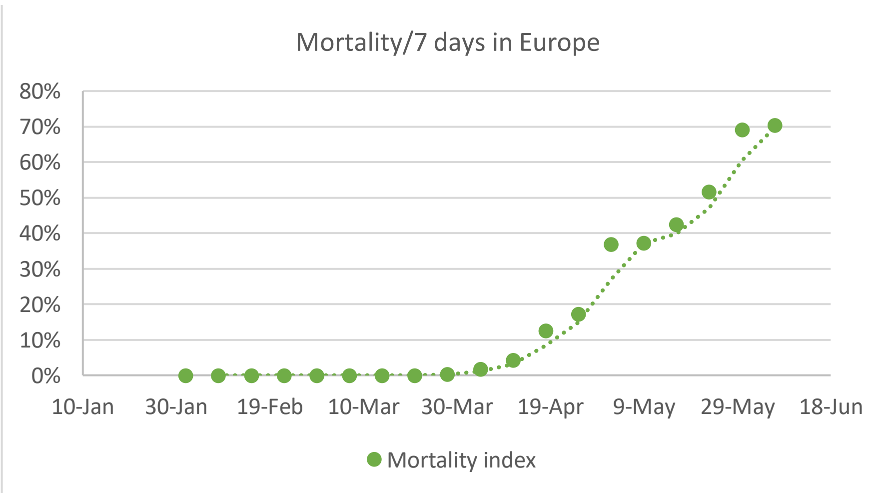


Figure 4.8. *COVID-19* weekly mortality index in Europe.

The three regions have shown constant increases, but Europe has shown a very significant constant increase in the seven days mortality index.

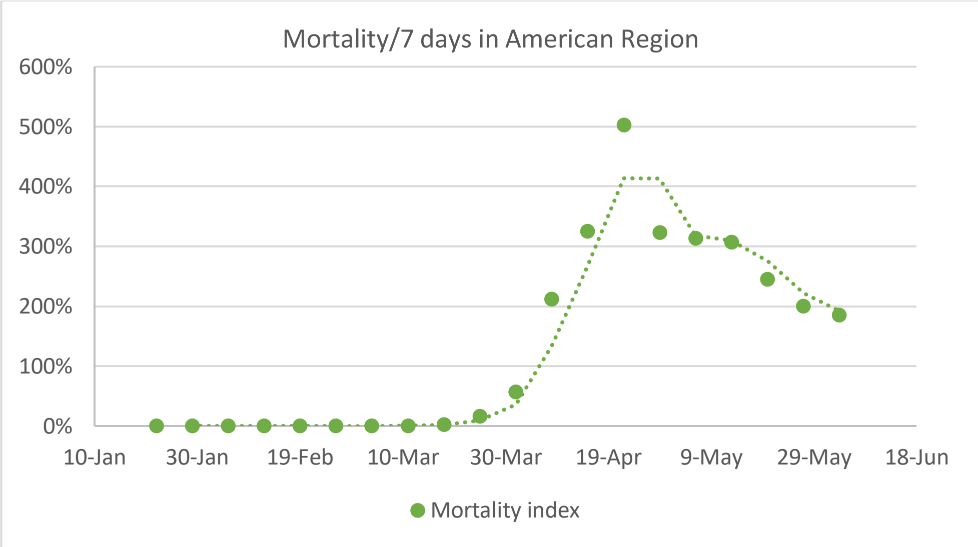


Fig 4.9. *COVID-19* weekly mortality index in the American region.

The American region has shown a constantly increasing, ratio indicating an uncontrolled pandemic situation followed by a period of apparent control, with a substantial drop in the percentage of increase in deaths due to *COVID-19*; the reality, though, is that the increase was so big (achieving values of more than 500%) that the decrease appears as 200%.

4.5.1.2. LME data: prices and warehouses' stocks

The allocation of the futures price structure is derived from the difference between the 3-month control reference and the cash or spot price. The 3-month basis is a liquid position (Otto, 2011), and is that to which the whole market refers a large part of its operations; therefore, this metal's structure refers to this difference, whereby a positive difference indicates *contango* and a negative one indicates *backwardation*.

The most common market structure should be *contango*, as the warehousing system is a regulator. *Backwardation* should only arise in a forced market, related to a lack of offer, an excess of demand, or a speculative global fund trading position. Nevertheless, this situation is becoming more and more frequent, with long periods of *backwardation* arising due to the developing super-cycle of metals (Wellenreuther, 2021 and Marañon & Kumral, 2021).

The copper futures price structure data have been taken from the LME and warehouses stock for the same period; the LME uses a worldwide warehouse system to normalize different levels of metal demand and offers. Producers and traders can place lots of metal into these warehouses if its brand and quality are assured by the LME's standards; this can be done through brokers, who also need to be listed under the LME's standards. As the premium for introducing a metal into an LME warehouse is null, producers prefer to sell directly to the market so as to achieve a premium; therefore, it is usually only when the direct consumer market is not active or is sparse that metals arrive at these warehouses. Traders can also perform this type of operation to manipulate the structure of the prices or the forward curve in favor of their short- or long-term global positions. The levels of copper in LME's warehouses and the structure of the copper futures prices are shown in Figure 4.10.

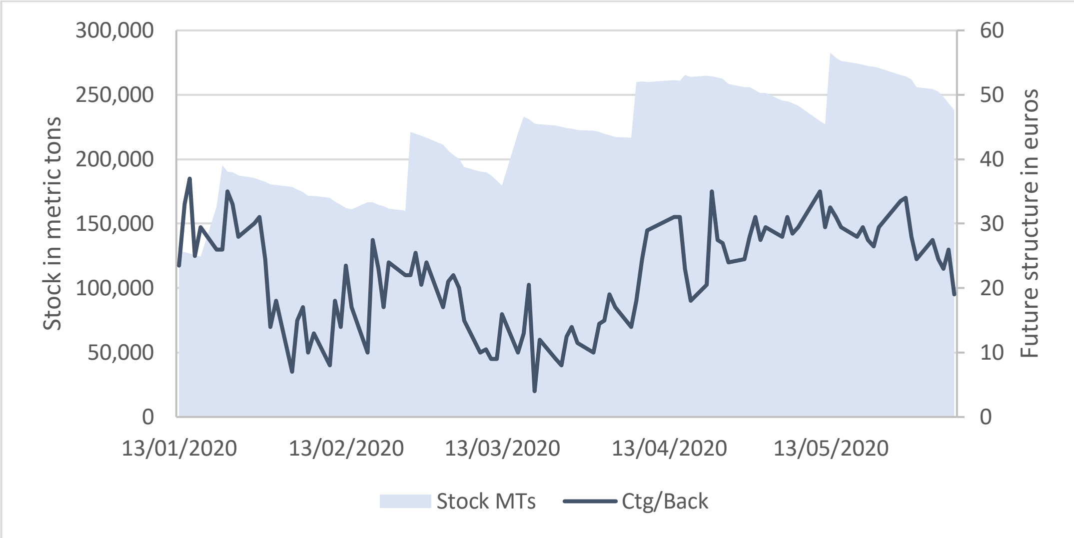


Figure 4.10. Stocks in LME warehouses ($STOCK_t$) and copper futures price ($stru_t$) over the period studied.

European data were chosen for this analysis for three reasons. Firstly, Europe is one of the major economies outside of China; secondly, it is where the LME warehouses have been established; thirdly, its markets are mostly based on fundamentals. Additionally, descriptive analysis also supports the strategy of using Europe as the basis of this study, as the same trends are shown in their *COVID-19* indexes as in the changes in LME warehouses.

Both data series -the COVID-19 index in Europe and the LME copper futures price structure- are represented in Figure 4.11

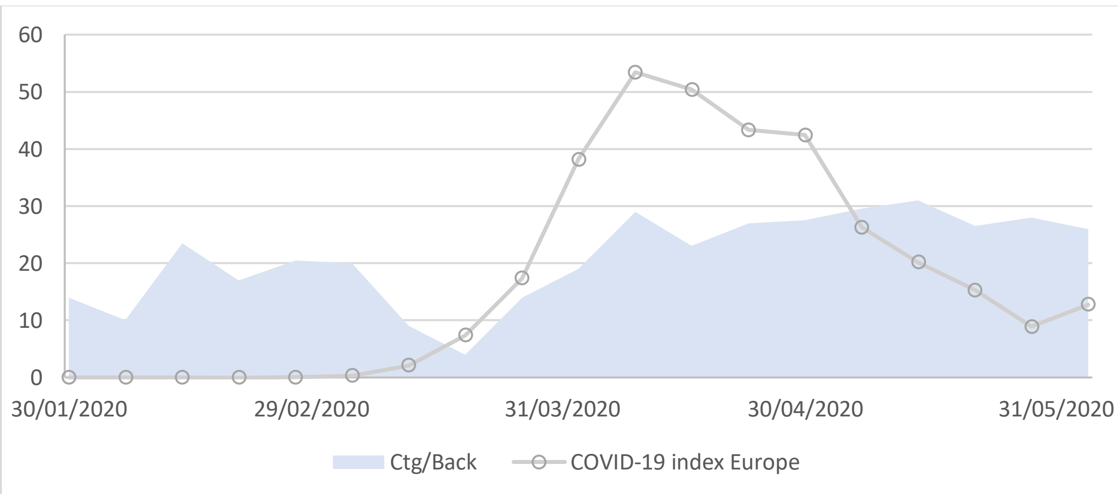


Figure 4.11 Copper futures price structure ($stru_t$) and *COVID-19*.

4.5.2. Methodology

Unit root tests have been performed to ensure that the time series do not follow a random walks structure, ensuring that they are stationary and that causality tests can be used. In this regard, our aim was to identify the situation wherein series bind together, with no deviation from equilibrium in the long run.

In these types of unit root tests, the null hypothesis can be linked with the stationarity of the time series, as in the ADF and PP tests, as well as in different ones, such as KPSS tests.

Since the time series addressed in this study were non-stationary and exhibited non-constant variance, they were analyzed with the augmented Dickey–Fuller (ADF), Dickey & Fuller (1979) unit root test, as recently deployed by de Souza et al. (2019) and Khalfaoui et al. (2019).

The three regression models for ADF are set out below:

$$\Delta y_t = \psi_{ADF} y_{t-1} + \sum_{i=1}^{p-1} \psi_i \, \Delta y_{t-1} + u_t; \;\; u_t \approx IID(0, \sigma^2); \quad t = 1, 2, \ldots, \qquad \text{(Equation 4.2)}$$

$$\Delta y_t = \psi_{ADF} y_{t-1} + \sum_{i=1}^{p-1} \psi_i \, \Delta y_{t-1} + \mu + u_t; \; u_t \approx IID(0, \sigma^2); \quad t = 1, 2, \ldots, \qquad \text{(Equation 4.3)}$$

$$\Delta y_t = \psi_{ADF} y_{t-1} + \sum_{i=1}^{p-1} \psi_i \, \Delta y_{t-1} + \mu + \gamma t + u_t; \;\; u_t \approx IID(0, \sigma^2); \quad t = 1, 2, \ldots, \qquad \text{(Equation 4.4)}$$

In these equations, the difference between two time values is a function of non-constant variance u_t, with or without constant drift, μ, and a trend term, γ_t.

The symbols in the above expressions are defined below.

Ψ_{ADF}, parameter determining the fulfilment or otherwise of the null hypothesis.

$\sum_{i=1}^{p-1} \psi_i \Delta y_{t-1}$, sum of differentials in the value series multiplied by Ψ in p-1 iterations.

p, maximum regression delay.

µ, constant.

γ_t, trend.

u_t, process error, a function of the variance series.

The ADF and Phillips–Perron test as a null hypothesis that there is a unit root for a times series. The existence of a unit root implies that the process is non-stationary. KPSS tests the null hypothesis that there is stationarity in the series (Michalak et al., 2018).

Engle and Granger causality-based cointegration tests (Farid et al., 2021) were performed on the transformed series. The latter yield the order of autoregressive vectors (VAR, Hatemi-j, 2003) and a basis for calculating λmax using Johansen's approximation, which is used to find at least one cointegration relationship between the two series.

The Granger causality theory (Johansen approximation, Johansen, 2008) was used to analyze the relationship between the series $(y_t)_{t=1}^{N}$.

Structure of copper futures prices, $(y_t)_{t=1}^{N}$: $(stru_t)_{t=05-06-2020}^{13-01-2020}$ (Equation 4.5)

Stocks in warehouses, $(z_t)_{t=1}^{N}$: $(STOCK_t)_{t=05-06-2020}^{13-01-2020}$ (Equation 4.6)

Structure of copper futures prices, $(y_t)_{t=1}^{N}$: $(stru_t)_{t=05-06-2020}^{13-01-2020}$ (Equation 4.7)

COVID-19 weekly deaths index, $(z_t)_{t=1}^{N}$: $(COVID_t)_{t=05-06-2020}^{13-01-2020}$ (Equation 4.8)

While on the other hand,

To resolve the equations shown below (4.9-4.10 and 4.11-4.12), Engle and Granger cointegration tests were conducted by applying OLS (Ordinary Least Squares) to the transformed data series:

On the one hand:

$$stru_t = \alpha_0 + \alpha_1\, stru_{t-1} + \cdots + \alpha_1\, stru_{t-d} + \beta_1\, stru_{t-1} + \cdots + \beta_1\, stock_{t-d} + \varepsilon_t \quad \text{(Equation 4.9)}$$

$$stock_t = \alpha_0 + \alpha_1\, stock_{t-1} + \cdots + \alpha_1\, stock_{t-d} + \beta_1\, stock_{t-1} + \cdots + \beta_1\, stru_{t-d} + u_t \quad \text{(Equation 4.10)}$$

where d is the number of delays used, $stru_t$ and $stock_t$ are the time series for which cointegration was to be determined, α and β are the parameters to be studied, and ε_t and u_t are the errors or random disturbance, which are normally uncorrelated. It is necessary to fit a VAR (Vector Autoregressive) model to obtain the optimum lag model (Hatemi-j, 2003).

On the other hand,

$$stru_t = \alpha_0 + \alpha_1\, stru_{t-1} + \cdots + \alpha_1\, stru_{t-d} + \beta_1\, stru_{t-1} + \cdots + \beta_1\, COVID_{t-d} + \varepsilon_t \quad \text{(Equation 4.11)}$$

$$COVID_t = \alpha_0 + \alpha_1\, COVID_{t-1} + \cdots + \alpha_1\, COVID_{t-d} + \beta_1\, COVID_{t-1} + \cdots + \beta_1\, stru_{t-d} + u_t \quad \text{(Equation 4.12)}$$

for the other pair of data series studied.

Finally, a robustness test has been done, studying cointegration between the independent variables of the above analysis: $COVID_t$ and $STOCK_t$.

From a methodological point of view, once the series are transformed enough times to obtain stationarity, these series can be represented as a set of p iterations with consecutive values, as follows:

$$y_t = c + A_1\, y_{t-1} + A_2\, y_{t-2} + \cdots + + A_p\, y_{t-p} + e_t, \quad \text{(Equation 4.13)}$$

in which the values are corrected by a series of constants, such as A_i, where i=1, …, n; the input constant is c, and the error vector is e_t.

The p value of the equation (4.13) defines the VAR order of the series (Scott Hacker & Hatemi-J, 2003). Here, it was found with the Schwarz or Bayesian (BIC) and Akaike information criteria (AIC), as defined by (Mauricio, 2006):

Akaike (AIC): $$AIC \equiv -\frac{2L^*}{n} + \frac{2m}{n}$$ (Equation 4.14)

Schwarz or Bayesian (BIC): $$BIC \equiv -\frac{2L^*}{n} + \frac{m\, ln(n)}{n}$$ (Equation 4.15)

where L* is the neperian logarithm of the likelihood function; n is the number of observations, and m is the number of estimated parameters.

The Johansen approximation yields α and β as the vectors:

α = |p,r| and β = |m,r| (Equation 4.16)

where r is the number of cointegrating vectors, and p and m are the series vector components.

The premise underlying the maximum lambda and trace tests was described by (MacKinnon et al.,1999), as follows: “The maximum likelihood theory of systems of potentially cointegrated stochastic variables presupposes that the variables are integrated of order 1, or I(1), and that the data-generating process is a Gaussian vector autoregressive model of finite order l, or VAR(l), possibly including some determinant components”. The trace test is defined in the following terms:

$$Trace = -T \sum_{i=r+1}^{p} \log\left(1-\lambda_i\right)$$ (Equation 4.17)

where λ_i are the eigenvalues in ascending order that deliver the solution to the “reduced rank regression problem”, and r and p form parts of values α and β, as above.

The test is run consecutively for r values of r = p-1, …, 0 or r = 0, …, p-1, up to the value at which the null hypothesis is first rejected, or to the end of the series if it is not rejected.

Instead of r, the validity of the null hypothesis may also be determined from r+1, which constitutes the λ_{max} test, which is the one used here:

$$\lambda_{max} = -T\log(1-\lambda_{r+1}) \qquad \text{(Equation 4.18)}$$

which is identical to the trace test when p-r=1.

Finally, it is necessary to determine whether one variable "Granger-causes" another. One variable causes the other if the past values of one are useful for predicting the other. See Annex 4.2 for an extensive explanation of the application of this methodology in different markets.

The residuals of the linear regressions built from the different data series are a matter of study in this paper, as assessed through the Durbin–Watson approach (Durbin & Watson, 1950, 1992, 1971).

Under this theory, the errors complete the definition of each time series, defined as εt, and taking in this formula, the definition of the statistic D can be given as

$$D = \frac{\sum_{t=2}^{n}(\varepsilon_t - \varepsilon_{t-1})^2}{\sum_{t=1}^{n}{\varepsilon_t}^2} \qquad \text{(Equation 4.19)}$$

where t refers to the different observations of the time series.

The null and alternative hypotheses of this test are H0, where the errors are not correlated, and H1, where they are. With a p-value below the significance level, we can certify that the residuals are sufficient to use in the following tests on the time series.

4.6. Results

In this section, we give the relations between the structure of copper futures, the LME copper warehouses' level, and the *COVID-19* weekly mortality index during the first wave of contagions in Europe. We have also seen, in general, how extreme events are linked with big effects on the future price in comparison with the cash price, ultimately developing a *contango* structure, evidencing the theoretical background of so-called *“normal backwardation*”.

4.6.1. Link between copper warehouses’ level and copper futures prices structure

Both series $STOCK_t$ and $stru_t$ have been shown to be non-stationary, even after Box–Cox (Box & Cox, 1964) transformations, and we also found non-stationarity at the following levels of both series. We confirmed this via ADF, PP and KPSS tests to check the non-stationary of the two series, $STOCK_t$ and $stru_t$, as can be seen in Table 4.3, finding that both series are non-stationary to the same degree. As regards the causality, Johansen’s approximation of the cointegration test of Engel and Granger was performed (see Table 4.4), obtaining cointegration between the $STOCK_t$ and $stru_t$ series in the time frame studied. This means that increases in contango and stocks are linked, giving evidence for the theory of normal backwardation.

Table 4.3. Stationary tests for $STOCK_t$ and $stru_t$.

		p-value		
Data		ADF	PP	KPSS
Stock MTs	I(0)	0.893	0.893	<0.0001
$stru_t$	I(0)	0.177	0.177	0.008
Stock MTs	I(1)	0.833	0.435	<0.0001
$stru_t$	I(1)	0.218	0.218	0.004

Table 4.4. Johansen’s approximation tests for causality $STOCK_t$ and $stru_t$.

	p-value		
Data series	Lambda max	Trace test	VAR estimation
Stock MTs $stru_t$	0.048**	0.072*	2 (21.988)

*** rejection of the null hypothesis at the 1% significance level
** rejection of the null hypothesis at the 5% significance level
* rejection of the null hypothesis at the 10% significance level

This means that, under strongly adverse conditions in the consumption market, because of economic crises, sanitary catastrophes, low demand or other extreme events, economic players, such as producers or traders, are forced to allocate their units to official warehouses, instead of to final consumption markets. From a practical point of view, this means that copper producers cannot easily alter their volumes to adapt to rapid decreases in market consumption. This is also a characteristic of the *commodity* market, wherein a complex global system of warehouses is established specifically “to regulate the inflows with the outflows”. The specific definition of *backwardation* based on fundamentals refers to the lack of availability of metal on the market, and in general, to the feeling of scarcity; therefore, *contango* means the opposite, that is, the excess of availability. Definitively, our findings support this fundamentals-based definition of *contango*, as under the conditions of a sanitary crisis, with a lack of consumption and the same production model, market inflows are higher than outflows, with a strongly positive offer–demand balance, excess being allocated to the official warehouses.

This theory can be used by market players when establishing their positions in favor of *contango* when such market disruptions are about to occur.

4.6.2. Link between COVID-19 mortality index and the structure of copper futures prices

As in the previous assessment of the series, we have also checked the stationarity of $stru_t$, this being the futures copper price structure data series, finding (see Table 4.5) that for both series (this one and the *COVID-19* mortality data index), non-stationary conditions were achieved. After Box–Cox transformations, we also found non-stationarity in the following levels of both series.

Table 4.5. Stationary tests for *COVID-19* index and $stru_t$.

p-value				
Data series		ADF	PP	KPSS
COVID-19 index	I(0)	0.459	0.459	0.048
$stru_t$	I(0)	0.177	0.177	0.008
COVID-19 index	I(1)	0.459	0.459	0.048
$stru_t$	I(1)	0.218	0.218	0.004

Both data series, before and after being transformed, showed the same levels of non-stationarity, making it appropriate to use Johansen's approximation of the Engel and Granger cointegration test to obtain co-movements between the *COVID-19* index and the future price structure of copper (see Table 4.6).

Table 4.6. Johansen's approximation tests for causality *COVID-19* index and $stru_t$.

p-value			
Data series	Lambda max	Trace test	VAR estimation (AIC)
COVID-19 index $stru_t$	0.003***	0.001***	5 (7.088)

*** rejection of the null hypothesis at the 1% significance level
** rejection of the null hypothesis at the 5% significance level
* rejection of the null hypothesis at the 10% significance level

These results show that an event with a strong impact on demand (such as the increase in *COVID-19* mortality rate) can cause market scarcity to disappear; in fact, it could generate a feeling of oversupply, thus developing a *contango* structure.

A producer that is starting to feel a lack of consumption interest from their customers due to a macro event, such as an incipient economic crisis or a sanitary emergency, could easily reassert their hedge position by selling their units using future due date prices, instead short-term prices. A good example of this has been the appearance of new variants of *COVID-19*, as a result of which the market could be preparing to restructure into a consistent *contango*. This approach, as others, is speculative by nature, so what is offered here is a better chance to prepare a strategy, as the market could have opposing drivers that would make the structures of copper futures prices fall into *backwardation*.

Relative to the joint evolution of $COVID_t$ and LME's warehouses stock series, as a robustness test, we have found that they are cointegrated. Please see Figure 4.12 and Table 4.7 below, showing p-values of Engle and Granger test:

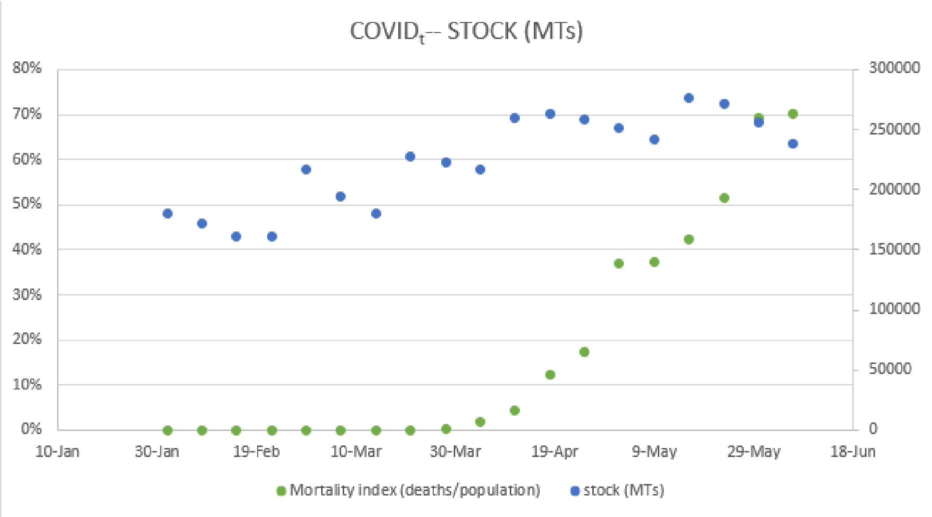


Figure 4.12. $COVID_t$ versus LME warehouses stock during the first wave of contagions of *COVID-19* in Europe

Table 4.7. Engle and Granger trough Johansen's approximation values on Cointegration

p-value

Data series	Lambda max	Trace test	VAR estimation (AIC)
$COVID_t$ stock	0.011**	0.006***	5 (13.645)

*** rejection of the null hypothesis at the 1% significance level
** rejection of the null hypothesis at the 5% significance level
* rejection of the null hypothesis at the 10% significance level

Finally, we tested the null hypothesis that residuals of the model are autocorrelated. Time series' residuals have been checked via the Durbin–Watson test, trying to certify that these residuals are autocorrelated and the tendence is consistent. The results show (see table 4.8) that, in the case of the series: Warehouse stocks, Structure of daily dataset and Futures price structure, the p-value is less than the 1% and, in the case of the *COVID-19* series, the p-value is lower than the 5%, so the null hypothesis can be rejected.

Table 4.8: p-value of Durbin–Watson tests performed on different time series.

Time series	Warehouse stocks	Structure of daily dataset	*COVID-19* index	Futures price structure on weekly dataset
p-value	<0.0001***	<0.0001***	0.029***	<0.0001***

*** rejection of the null hypothesis at the 1% significance level
** rejection of the null hypothesis at the 5% significance level
* rejection of the null hypothesis at the 10% significance level

4.7. Conclussions and Recomendations

The *COVID-19* pandemic has thrown the world economy into turmoil, and *commodity* markets have lived a tsunami since its beginning; its implications have proven a situation of strong normal *backwardation*.

This paper shows that the levels of stocks in warehouses are linked with the development of the *commodity* forward price (*contango* or *backwardation*). We prove that, in a multi-country lockdown scenario due to the first wave of *COVID-19* infections in Europe, in a long-term backwardated context, copper stocks rose, and a *contango* structure appeared, indicating a cointegration between the data series representing these stocks and the *contango* structure.

In the same context, under the influence of macroeconomic events affecting *commodity* prices, the present findings confirm the existence of a relationship between *COVID-19*’s impact and the structure of copper futures prices, measured on the grounds of *COVID-19* weekly mortality data.

In recent times, the financialization of *commodities*, and especially copper, has been a matter of close study and investigation, as explored in the Introduction section, and we are finding that fundamentals are also interfering in the forward price compared with spot prices. Times are approaching where analyses and statistics are suggesting there will be a lack of copper units (Pedersen, 2019 and Jones et al., 2020), so we can expect this *commodity* to be driven increasingly by fundamentals. The development of the EV (electric vehicle) and its higher level of copper usage for fabrication, the electrification of charging points, and the development of renewable energies are causing increases in optimism and a feeling that, again, fundamentals are playing an increasingly definitive role.

In this context, some highlights can be selected as policy recommendations, when market agents follow price structure strategies. Under normal b*ackwardation* theory, *backwardation* is the long-term trend; that implies that spot price is higher than 3-month price, so, depending on the position players have (short or long), they can try to move in favor of *backwardation*. However, an extreme event like *COVID-19*, that turned it into a *contango*, makes spot price lower. This way, as *contango* appears, players should, then, set long term positions, to optimize results.

Market players can benefit from changes in tendency and extreme events, such as the recent one studied here, related to the change from structural *backwardation* to *contango*. This fact can be used by volatility-based players to increase the weight of positions supported by extreme events, not only in terms of short-term *contango* or short-term *backwardation*, but also to set up a *contango*/*backwardation* structure change-based strategy. We have experienced, during the *COVID-19* pandemic, different scenarios within the *commodities* market, showing the strongest *contango*s ever during the first phase of worldwide lockdowns, followed by several ups and downs in the future structure of base metals in particular, as related to extreme events (in our recent context, *COVID-19*): the arrival of a vaccine, the acceleration of the vaccination process, the appearance of new variants, countries' herd immunity, new variants evading the protection of vaccines, new vaccines, new contagion waves, cross-relations between the variables under study, relations with other assets such as those in Otto (2011), etc. There is no doubt that the analysis of the *commodities* market's behavior in general, and that of copper's in particular, under all these scenarios opens up a new line of research and constitutes the basis of new papers. Additionally, the relation between data from the WHO regions and aggregated data from around the world could be a new research focus, even if it would be a huge challenge to measure the integrity of the data given the speed of communication between each country.

4.8. Annexes

Annex 4.1

Table 4.A1 shows some papers that evidence the effect on the economy of the *COVID-19* pandemic.

Table 4.A1. *COVID-19* effect on global economy.

Doc.	Influence	Geographic Frame
Zeshan (2021)	5% Global GDP decrease	140 regions
Guan et al. (2020)	Electronic trade decrease (13–53%) and automobiles (2–49%)	China, Europe, and USA, and global
Zhang (2020)	Readaptation of the supply chains to the lack of products	China based
Perasolo et al. (2020)	Different approaches of different economies to the economic pandemic effect	Australia, Brazil, China, Germany, Italy, South Africa, Sweden, and USA
Fernandes (2021)	Big effect on GDP of Spain, Greece, and Portugal	Spain, Greece, and Portugal
Sohrabi et al. (2020)	90% closure of export production units in China	China-based
Ozili et al. (2021)	Loss of investments and fluctuations in international trade	Global studies
Maghyereh & Abdoh (2020)	Investor sentiment change	Global trades
Glauber et al. (2020)	Concerns about food security	Vietnam and Kazakhstan on one hand and ex-China on the other
Schmidhuber (2020)	Possible hoardings, lack of pesticides	Worldwide
Belhadi et al. (2021)	Supply chain shocks	Global aerospace companies
Narayan et al. (2021)	Government economic stimulus and its influence	G-7 countries

Annex 4.2

The following are applications of Granger causality related the case study.

Table 4.A2. Granger causality in the literature.

Reference	Market Sector	Specific Methodology
Rutledge et al. (2013)	Bitcoin	GARCH regression and Granger causality
Madaleno et al. (2014)	Precious metals	GJR-GARCH and causality models
Hadi et al. (2019)	Exchange rates, short-interest rate and Bursa Malaysia	Johansen–Juselius cointegration test
Chalmers et al. (2019)	Liquid milk and powdered milk in Malawi	Johansen's cointegration procedure, TVAR, and TVCEM
Samsi et al. (2019)	Economic growth in the ASEAN-5 countries (Association of Southeast Asian Nations)	Johansen cointegration test, vector error correction model (VECM), and dynamic analysis
Su et al. (2020)	Bitcoin	VAR system and Granger causality
Sarwar et al. (2020)	Oil and stock markets returns	Bivariate BEKK-GARCH model
Gil-Alana et al. (2020)	Cryptocurrencies and stock market indices	Fractional integration and cointegration
Mat et al. (2020)	Animal production processes (Veal)	VECM model and Johansen cointegration test
Eross et al. (2019)	*Brexit* and base metals	Johansen cointegration test and Var model
Cui et al. (2021)	Oil and stock markets	Wavelet coherence and BK frequency connectedness method
Syed et al. (2021)	Climate variability	Mann–Kendell (MK) trend test, Sen's Slope (SS) test and Cox and Stuart (CS) test
Li et al. (2021)	Bitcoin	GSADF tests
Ivascu et al. (2021)	Work accidents	Johansen cointegration and Granger causality test

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6. Publicaciones

Esta tesis ha generado hasta la fecha de impresión las siguientes publicaciones:

Galán-Gutiérrez, J. A., & Martín-García, R. (2021). Cointegration between the structure of copper futures prices and *brexit*. *Resources Policy, 71*, 101998. doi:10.1016/j.resourpol.2021.101998

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