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Approaches to Price Formation in Financialised Commodity Markets

Sophie van Huellen*

Abstract

A recent debate over the financialisation of commodity markets has stimulated the development of approaches to price formation which incorporate index traders as a new trader category in commodity futures markets. I survey these new approaches by retracing their emergence to traditional price formation models and show that these new models arise from a synthesis between commodity arbitrage pricing and asset pricing theories in the tradition of Keynesian inspired hedging pressure models. Based on these insights, I derive testable hypotheses to provide guidance for a growing literature that seeks to empirically evaluate the effects of index traders on price discovery and risk management in commodity futures markets.

Keywords: Commodity prices; commodity futures; financialisation; index investment; speculation.

JEL classification: D84, G13, Q02.

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1. Introduction

Since the early 2000s, commodity futures markets have attracted a large influx of liquidity due to their favourable diversification properties (Erb and Harvey, 2006; Gorton and Rouwenhorst, 2006) and their satisfactory performance as an alternative asset class in a low interest environment (Mayer, 2012; Basu and Gavin, 2011). Investors can achieve exposure through passive instruments such as commodity indices, whereby investments are allocated to commodity futures markets in accordance with the composition of the index investors seek to replicate. Index traders are long-only, do not attempt to arbitrage the market, their trading behaviour is largely detached from the respective market's fundamentals and positions are correlated with global liquidity cycles (Nissanke, 2012; Mayer, 2012; Brunetti and Reiffen, 2014). Due to their unique investment behaviour, index traders were suspected to cause price levels, volatilities and co-movements beyond what could be explained by market fundamentals (Masters, 2008).

This so called 'financialisation of commodity markets', e.g. see Irwin and Sanders (2012) and Henderson et al. (2015), has stimulated the development of new approaches to price formation in commodity futures markets which incorporate the presence of index traders. Historically, price formation models for commodity futures markets emerged from two interlinked traditions: arbitrage pricing and asset pricing models. Arbitrage pricing models derive intertemporal price relations between spot and futures markets (or between futures with different maturity dates) under to the law of one price. Asset pricing models derive prices from agents' expectations under market clearing conditions. Both traditions consider heterogenous agents by distinguishing between hedgers and speculators in the arbitrage pricing literature and informed and uninformed speculators in the asset pricing literature. With the arrival of index traders, a new generation of price formation models emerged which provides crucial insights into the implications of index trading for price discovery and risk management.

The prime objective of this paper is to provide guidance for a growing empirical literature that investigates financialisation effects, e.g. see Irwin and Sanders (2011), Irwin (2013), Fattouh et al. (2013), Cheng and Xiong (2014) and Boyd et al. (2018), by reviewing recently developed models of price formation in financialised commodity markets. I focus on storable primary commodities and their futures markets. I hence largely exclude an important set of literature that investigates price formation in commodity spot and storage markets – see Gouel (2012) for a comprehensive review –, unless this literature makes direct reference to implications of speculative trading in futures for spot and storage markets. Specifically, I retrace the emergence of new approaches to price formation in financialised commodity markets to arbitrage and asset pricing models which are reviewed in sections two and three, before reviewing these new approaches to price formation in section four. I show that the new approaches emerge from a synthesis between arbitrage and asset pricing theories, following closely Keynesian inspired hedging pressure theories. In section five, I derive testable hypotheses as guidance for a growing

empirical literature on the financialisation of commodity markets. The sixth section concludes with suggestions for future research.

2. Arbitrage Pricing Models

A no-arbitrage condition between commodity futures and their underlying spot prices builds the foundation for different theories of price formation in commodity markets. Prices are assumed to be driven by supply and demand conditions in the spot markets, while the possibility of arbitrage ensures alignment of the futures price to its underlying physical market. The no-arbitrage condition can be summarised as in Eq. (1). $F_{t,T}$ is the futures price at time t that matures at time T , S_t is the cash price, r_t and w_t are cost of capital and cost of storage and $\tau = T - t$ is the time to maturity:

$$F_{t,T} = S_t e^{(r_t + w_t)\tau} \quad (1)$$

At maturity $\tau \rightarrow 0$ so that $F_{t,t} = S_t$ and the market basis $B_t \equiv S_t - F_{t,t} = 0$. However, futures and spot prices do not necessarily comply with Eq. (1) empirically. Particularly, a situation in which the futures contract trades below the spot price (backwardation) has received attention since futures contracts are bound to trade above the spot price (contango), as $r_t, w_t \geq 0$ in Eq. (1). The theory of storage, ascribed to Kaldor (1939), Working (1949) and Brennan (1958), and the theory of risk premium, advanced by Keynes (1930) and Hicks (1939), offer two distinct, although complementary, explanations for backwardation.

2.1 Theory of Storage

The theory of storage explains backwardation with the distinct economic properties of the physical good compared to its derivative. Kaldor (1939) introduced a convenience yield, φ_t , which is acquired from owning a commodity and is inversely related to speculative stocks, that is, stocks beyond what is required for normal business, I_t .

$$F_{t,t+1} = S_t e^{(r_t + w_t - \varphi_t(I_t))\tau} \quad (2)$$

As evident from Eq. (2), the extent of backwardation does not have a limit, but a contango has its maximum in the carry cost. A negative basis, in theory, cannot exceed $r_t + w_t$ (with $\varphi_t = 0$), while a positive basis depends on the 'size' of the convenience yield (Lautier, 2005).

The convenience yield found multiple interpretations in the literature. Kaldor (1939) originally introduced the yield as the inverse of Keynes's own rate of interest. Later authors, such as Brennan (1958), Pindyck (2001), Bozic and Fortenbery (2011) and Pirrong (2011) proposed a utility-based explanation of the convenience yield. The convenience yield accrues to the owner of inventory due to the opportunity gained from taking advantage of an unexpected increase in demand. Despite the different opinions on what constitutes the convenience yield, authors agree on an inverse relationship between the yield and storage. Pindyck (2001) formalises this relationship and shows that if a commodity is storable, the equilibrium in the physical

market is not only governed by production and consumption, but also by changes in inventories, which in turn enters the futures price through the convenience yield.

The triangular relationship between spot, inventory and futures markets unfolds complex feedback mechanisms. Positive price trends in volatile markets can be intensified through inventory hoarding, either because inventories serve as physical options (Deaton and Laroque 1992; Singleton 2014), or because they are accumulated for precautionary reasons (Pindyck 2001; Bozic and Fortenbery 2011). While various models take these complex feedback mechanisms into consideration – see Gouel (2012) for a comprehensive overview – many of these models remain incomplete because futures markets are modelled as a reflection of dynamics in spot and inventory markets; e.g. Pindyck (2001). Conceptualised this way, futures markets serve an information function by revealing storage availability and agents' preferences through the convenience yield, but do not serve a price discovery function.

2.2 Theory of risk premium

A second, arbitrage-based approach, assumes that prices should be subject to a risk premium since non-commercial speculators demand a premium for taking on hedgers' risk (Keynes, 1930; Hicks, 1939, p. 147-8). As the number of short hedgers does not match the number of long hedgers at any point in time, speculators¹ are invaluable in providing liquidity (Working, 1960). Hedgers are not exposed to any price risk after entering the hedging position, while speculators take on risk exposure and therefore provide an insurance service to hedgers. Depending on the relative weight of short and long hedgers in the market, futures markets are in contango or in backwardation.

The original risk premium theory is based on an excess demand framework and was critiqued by Fama and French (1987) and others for being incompatible with general equilibrium theory (Cootner, 1960). Two strands of theories, which seek to make Keynes's risk premium approach coherent within a neoclassical framework, have evolved: (1) theories of asset-pricing, which assign a risk premium to (systematic) risk; and (2) theories of hedging pressure, which incorporate market imperfections, like transaction costs, into multiple-period pricing models.

Kaldor (1939) links the risk premium to the uncertain expectations of future prices and lays the foundation for an asset-pricing interpretation of the premium. The degree of uncertainty is proportional to the own price variance, σ_f^2 and the difference between the expected spot price and current spot price is determined by net-carry cost and a risk premium, π_t , times the original cash outlay. With small letters for the natural logarithm:

$$E_t[s_T] - s_t = r_t + w_t - \varphi_t + \pi_t(\sigma_f^2)s_t \quad (3)$$

¹ Following Working (1960), the term speculator is here used for any trader whose primary business does not involve trading the physical commodity.

By taking logs and substituting Eq. (2) into Eq. (3), it is shown that the forward price, $f_{t,T}$, falls short of the expected spot price by the risk premium and the forward price becomes a biased estimator of the expected future spot price.

$$f_{t,T} = E_t[s_T] - s_t \pi_t (\sigma_f^2) \quad (4)$$

Departing from Kaldor (1939), Dusak (1973) links the risk premium to systematic risk instead of idiosyncratic risk. She is the first to apply a capital asset-pricing model (CAPM) to the commodity futures market and to show that the expected excess return, $E_t[R_{c,T}] - r_t$, which accrues to the holder of a commodity futures contract is equal to the excess market return, $E_t[R_{m,T}] - r_t$, multiplied by the market beta defined as $\beta_c = Cov(R_m, R_c) / \sigma^2(R_m)$.

$$E_t[R_{c,T}] - r_t = (E_t[R_{m,T}] - r_t) \beta_c \quad (5)$$

After substituting for $E_t[R_{c,T}] - r_t = \{E_t[P_T] - P_t(1 + r_t)\} / P_t$ and rearranging, Eq. (5) yields $P_t(1 + r_{ft}) = E_t[P_T] - P_t \beta_c (E_t[R_{m,T}] - r_t)$, with P_t being the current commodity price. Following Dusak (1973), one can interpret $P_t(1 + r_t)$ as the current futures price for delivery and payment in period T and $E_t[P_T]$ as the spot price expected at T , which leads to Eq. (4), with $\pi_t = \beta_c (E_t[R_{m,T}] - r_t)$.

Alongside theories which link the risk premium to own and cross-price variation, hedging pressure theories developed, which are, arguably, closer to Keynes's original idea. Hedging pressure models derive the premium as a function of demand for hedging positions under the assumption that the supply of contrarians to hedging positions is not perfectly elastic due to market frictions (Hirshleifer, 1988; 1990; Chang, 1985; Bessembinder, 1992).

Hirshleifer (1988) distinguishes between two trader types – producers (hedgers) and outside investors (speculators) – and assumes that the latter trader type incurs transaction costs, due to fixed set-up costs or effective informational barriers. In a later model, he adds fixed set-up costs for long hedgers and assumes risk-averse speculators instead (Hirshleifer, 1990). Under these assumptions, a trader's optimal choice of positions depends on the size of the transaction cost and the trader's risk perception. Hirshleifer (1988; 1990) shows that under these assumptions, the risk premium entails a systematic risk component as in Dusak (1973), which depends on the market beta – the first component of Eq. (6) – and a residual risk component, which rises with transaction costs k and hence, the number hedgers relative to the number of speculators – the second component of Eq. (6).

$$\pi_t = \beta_c (E_t[R_{m,T}] - r_t) \pm \sigma_c \sqrt{2\alpha k(1 - \rho^2)} \quad (6)$$

The second component can be positive and negative, depending on whether there are more short or long hedgers in the market. σ_c is the standard deviation of R_c , α is the coefficient of absolute risk aversion, and $\rho = Cov(R_m, R_c) / \sigma(R_m)\sigma(R_c)$. Hedging pressure theories are related to more general price pressure theories which are based on the assumptions of risk aversion and transaction costs; e.g. see Harris and Gurel (1986) and Shleifer (1986). Since these models combine arbitrage pricing with

a microstructure for trader behaviour, they are a synthesis of arbitrage and asset pricing models. Table 1 summarises the different theories derived from the simple no-arbitrage condition in their final forms of which the latest form combines storage costs, convenience yield, systematic risk and hedging pressure in a single model.

Table 1. Summary Table arbitrage Pricing Models

No-arbitrage	Convenience yield	Risk premium	
$f_{t,T}$ $= s_t(1 + r_t) + w_t$	$f_{t,T}$ $= s_t(1 + r_t) + w_t - \varphi_t$	$f_{t,T}$ $= E_t[S_T] - s_t\pi_t$	Idiosyncratic $\pi_t = \pi_t(\sigma^2)$
	→	→	Systematic $\pi_t = \beta_C(E_t[R_{m,T}] - r_t)$
			→ Hedging pressure $\pi_t = \pi_{t,m} \pm \pi_{t,k}$
			$\pi_{t,m} = \beta_C(E_t[R_{m,T}] - r_t)$
			$\pi_{t,k} = \pm \sigma_c \sqrt{2\alpha k(1 - \rho^2)}$

Notes: Summary based on Eq. (1) – (6). Futures and spot prices are in logarithms and for ease of presentation $\tau = 1$.

3. Asset Pricing Models

Asset pricing models are based on a different kind of arbitrage relation than the previously reviewed storage models and are more general in that they apply to all asset classes and not only commodities.² The asset pricing literature relies on *fundamental arbitrage* where arbitrage opportunities arise if prices deviate from their fundamental value, while previously reviewed models rely on *spatial arbitrage* where arbitrage opportunities arise if spot³ and futures prices deviate. By implication, spatial arbitrage enforces a close relationship between two related markets but does not necessarily link an asset to its fundamental value. Fundamental arbitrage corrects for an over- or under-valuation of an asset, but not for a misspecification in relative prices.

The concept of fundamental arbitrage is related to the efficient market hypothesis (EMH), first formulated by Fama (1965) in its weak form. In accordance with the hypothesis, commodity futures prices are determined by trader' consensus expectations regarding the market's future fundamental value. Each trader is assumed to base her trading decision on a subset $[\Omega_{i,t}]$ of the total information set of market fundamentals $[\bar{\Omega}]$. Consequently, each position taken by a trader will add to the market information density. With perfect foresight, the probability of the future price of the commodity would be certain, so that: $P(S_{t+1}|\bar{\Omega}) = 1$, and hence: $F_{t,T} = E_t[S_T|\bar{\Omega}] = S_T$.

The proposed alignment of a market with its fundamentals relies on a row of conditions. Key market participants must evaluate assets regarding fundamentals only, base their actions on publicly available information or their own private sources

² As discussed previously, arbitrage pricing or storage models intersect with the asset pricing literature in the risk premium approaches.

³ Or any other close substitute to futures.

and do so independently of each other. If these conditions are met, traders' price expectations are identically and independently distributed around the fundamental value of the commodity and the more traders enter the market, the closer the futures price approaches its fundamental value (Carter, 1991). Further, sophisticated arbitrageurs immediately identify and take advantage of any price deviation induced by misguided 'noise' traders if unconstrained in their resources. These assumptions have been challenged on epistemological grounds by the behavioural finance and market microstructure literature and on ontological grounds by the Post-Keynesian literature.

3.1 Bounded Rationality and Rational Herding

Bounded rationality theories question the capabilities of individuals to act fully rational, while rational herding theories acknowledge that if the degree of uncertainty is measurable but information gathering is costly, traders are incentivised to follow other traders instead of their own information; see Shleifer (2000) for an overview. Both theories comprehend a row of different trader behaviours, including arbitrage as well as trend following, chartism and other technical trading strategies. Under the assumption of heterogeneity in trading motives and strategies, not every investor's position necessarily adds to the overall information set regarding market fundamentals (Hayes, 2006; Adam and Marcet, 2010a, 2010b).

The bounded rationality perspective is closely linked to behavioural finance, which moves away from the assumption of fully rational agents and takes a more eclectic approach to understanding agents' behaviour. Theories are informed by cognitive science, human psychology, evolutionary biology and sociology (Baddeley, 2010). The term bounded rationality was originally coined by Simon (1955), who argues that individuals are unable to act as assumed in the neoclassical optimisation process. Earlier studies in the field understand noise traders as non-rational insofar as their demand for risky assets is affected by beliefs and sentiments. Traders tend to become overly optimistic or pessimistic (Shleifer and Summers, 1990) and tend to employ common heuristics to assess complex probabilities (De Long et al., 1990; Hirschleifer, 2001). Consequently, markets frequently overreact or underreact to information as optimising agents employ trial-and-error strategies in an evolutionary manner (De Grauwe and Grimaldi, 2006; Adam and Marcet, 2010a, 2010b; Lo, 2012). With increasing uncertainty, even rational traders switch to trial-and-error strategies. Such behaviour of market participants results in multiple equilibria and low-frequency boom and bust cycles as investment strategies undergo cycles of profit and loss.

The rational herding perspective introduces market frictions and is closely associated with market microstructure theories, which take the institutional environment and its links to the price formation process into consideration (O'Hara, 1997). Rational herding can occur in the presence of market friction such as payoff externalities, principal-agent problems, and informational learning (Devenow and Welch, 1996). The literature around payoff externalities focuses on second- and third-generation

currency crisis models and the occurrence of bank runs (Krugman, 1979; Obstfeld, 1986; Jeanne, 2000). Principal-agent problems arise over perverse incentives so that, for instance, asset managers prefer to 'hide in the herd' (Devenow and Welch, 1996; Scharfstein and Stein, 1990). The third friction arises when partially informed agents discard their own information in the light of information inferred from the observed actions of other agents due to known information asymmetries and costs to information gathering (Welch, 1992; Banerjee, 1992; Bikhchandani et al., 1992; McAleer and Radalj, 2013).

Both strands of literature, bounded rationality and rational herding theories, divide financial market participants into two categories: informed fundamental arbitrage traders and uninformed systematic noise traders. Both theories conclude that noise trader positions can be strongly correlated and lead to aggregate demand shifts, which impact prices if the noise traders' momentum in the market is large enough. Combining these insights with the arbitrage pricing theories, the alignment of consensus expectation across spot and futures markets, then depends on the efficiency of fundamental arbitrage. If limits to fundamental arbitrage exists due to the presence of 'noise trader risk' (De Long et al., 1990), transaction costs such as margin calls (Shleifer and Summers, 1990) or agency problems if arbitrage traders trade on behalf of clients (Shleifer und Vishny, 1997), fundamental arbitrage might fail to align spot and futures prices.

3.2 Post-Keynesian Fundamental Uncertainty

Post-Keynesian authors reject the assumption of ergodicity, so that 'true' uncertainty arises. An uncertain future is unknowable and cannot be predicted based on past and present observations (Lawson, 1985). Ergodicity is rejected because of the transmutable nature of the future resulting in fundamental uncertainty (Dunn, 2001). If the system is permanently changed, the past is not representative of the future (Davidson, 2002, p. 47). Therefore, a commodity's expected fundamental value cannot be quantified by market practitioners (Bernstein, 1999). If market practitioners are aware of the unknowability of the future, portfolio protection through diversification against changes in financial markets is an important activity (Davidson, 2002, p. 188). So, too, is speculation over the psychological state of other market practitioners (Carabelli, 2002).

Keynes's own writing about uncertainty has found slightly different interpretations among Post-Keynesian scholars (Rosser Jr., 2001). For instance, Lawson (1985) stresses that Keynes does not reject the existence of knowledge per se. He distinguishes between three cases, which are knowledge of, knowledge about, and the unknowable. 'Knowledge about' is knowledge about the probability proposition of something (secondary proposition), but not the 'knowledge of' something (primary proposition). Knowledge of a secondary proposition then leads to a 'rational belief of the appropriate degree' in the primary proposition. He distinguishes between cases where the probability is unknown due to lack of skills — close to the bounded rationality literature — and cases where the probability is immeasurable or

indeterminate. Only in the latter case does true uncertainty exist, under which people fall back on conventions.

For Lawson (1985), traders are heterogeneous in their trading strategies, since trading motives are conditioned on knowledge and the interpretation of knowledge that is obtained by each individual trader through practice. Different societies will bring about different trading motives, and hence, behaviour. Similarly, Bibow et al. (2005) refer to Beckert (1996) and argue that reliance on peoples' 'social devices' makes action more predictable. Mimicking then arises from the attempt to conform to the majority.

For bounded rationality, rational herding and fundamental uncertainty, the past only offers limited guidance for predicting future events, because the past cannot be fully comprehended, the comprehension of the past is costly, or the past is substantially different from the future. In all three settings, optimisation is impossible or greatly limited so that agents return to conventions violating rationality assumptions of the EMH.

4. Price Formation in Financialised Commodity Markets

With the arrival of index traders in commodity futures markets the traditional binary divisions between hedgers and liquidity providing speculators or informed and uninformed speculators become insufficient as index traders appear to be of an altogether different kind. With reference to the previously reviewed literature, studies discussing potential implications of index traders for price discovery and hedging effectiveness in commodity futures markets suggest a fourfold division of trader types: hedgers, informed speculators, uninformed speculators and index traders; e.g. see Nissanke (2012) and Mayer (2012).

The four trader types arise from different combinations of the contrasting categories informed and uninformed traders and active and passive traders as summarised in Table 2. Active traders are those who trade based on commodity specific information signals, either information signals about market fundamentals or information extracted from price signals by use of statistical patterns. The latter being referred to as uninformed traders as they attempt to infer information from price signals and do not bring new information into the price discovery process. Passive traders are those who do not take commodity specific information into consideration when making trading decisions but rather base their trading strategies on global liquidity cycles.

Table 2. Trader Categories under Different Theories

			Arbitrage Pricing Theories	Asset Pricing Theories	Financialisation Theories
Active	Informed	Hedgers/Arbitrage	X	(X)	X
		Speculators/Arbitrage	X	X	X
	Uninformed	Speculators/Chartists		X	(X)
Passive	Uninformed	Index investors			X

Indices are relatively novel investment instruments for commodities but have a long history in stock markets where index investments were empirically linked to substantial and relatively permanent increases on stock returns (Harris and Gurel, 1986; Shleifer, 1986), a reduction in the information content of stock markets resulting in an increase in price volatility (Grossman, 1988; Brennan and Schwartz, 1989), and an increase in co-movement across indexed stocks (Greenwood, 2005; Barberis et al., 2005; Basak and Pavlova, 2013).

In the following, I will focus on approaches to price formation that explicitly account for the presence of index traders as passive investors in commodity futures markets. To the best of my knowledge, only three pricing models, compared in Table 3, fall into this category: Basak and Pavlova (2016), Brunetti and Reiffen (2014) and Hamilton and Wu (2014; 2015). All three models build on a synthesis of arbitrage pricing and asset pricing models, with reference to hedging and price pressure theories; although the synthesis remains incomplete in some important ways as I will discuss in the following.

Table 3. Summary of Price Formation Models that Account for Index Investment

	Basak and Pavlova (2016)	Brunetti and Reiffen (2014)	Hamilton and Wu (2014)
Hedgers	NA	Utility function: $u_H(W_{HT}) = A - \exp(-\alpha W_T)$.	Exogenous: NA
Informed speculators	Utility function: $u_S(W_{ST}) = \log(W_{ST})$.	Utility function: $u_S(W_{ST}) = A - \exp(-\alpha W_T)$.	Utility function: $u_S(W_{ST}) = E_t[W_T] - \alpha Var_t(W_T)$.
Index investors	Utility function: $u_I(W_{IT}) = (a + b\psi_T)\log(W_{IT})$, $a, b > 0$ $\psi_T = \prod_{i=1}^L F_{IT}^{1/L}$, $L \leq K$.	Exogenous: I_i . (positions in contract i) $N_H X_H^i + N_S X_S^i = -I_i$.	Exogenous: I_i . (positions in contract i)
Investment choices	Stock market, bond market, commodity market. $W_{nT} = \sum r_t Q_n + \sum f_t X_n$, $n \in \{S, I\}$.	Two consecutive futures contracts traded at the same market. $W_{nT} = W_0 + \sum f_t X_n + f_T C_n$, $n \in \{S, H\}, C_S = 0, C_H = C$	Stock market, bond market, commodity market. $W_{ST} = \sum r_t Q_S + \sum f_t X_S$.
Implications	Excess co-movement, volatility, price level.	Excess spread, co-movement, price level.	Excess spread, price level.
Extension spot prices	Extension of Deaton and Laroque (1992). Inventory hoarding resulting in higher spot prices.	NA	NA

Notes: T is the date of consumption, t is the current date, u is utility, W_n is the n^{th} investors wealth, N is the total number of investors in the market, X_n is the total number of futures positions held by the n^{th} investor, C_n the total number of physical positions held by the n^{th} investor, Q_n is the total number of other asset positions (stocks) held by the n^{th} investor, F_i is the futures price of the i^{th} contract, f_i is the return on the i^{th} futures contract, r is the return on other assets (stocks), K is the total number of commodities available, ψ is he value of a commodity index, and α is a measure of risk aversion.

Basak and Pavlova (2016) suggest a dual trader division in which they contrast informed speculators and institutional investors that hold commodity indices as part of their portfolio. They do not make explicit reference to the hedging pressure literature, but to price pressure models in general and the literature on index trading in stock markets (Basak and Pavlova 2013). They show that index investment leads

to co-movement between commodities included in the same index, increased price volatilities and increased price levels. Based on the competitive storage model by Deaton and Laroque (1992), Basak and Pavlova (2016) show that if institutional investors are also shareholders of storage firms, inventories are withheld, which, in turn, leads to higher spot prices.

Brunetti and Reiffen (2014) consider index traders, informed speculators and short hedgers, with index positions being modelled as exogenous. Traders diversify into different futures contracts of the same commodity. They show that the calendar spread is enlarged and thereby costs for short hedgers diminished by index traders rolling over their positions. Hamilton and Wu (2014; 2015) also consider index traders, informed speculators and short hedgers and show that index investment has the inverse effect of hedging pressure. Reminiscent of the argument made by Kaldor (1939) and Hicks (1939, pp. 146), long index traders ease hedging pressure by short hedgers as long as short hedging positions exceed long index positions. However, index traders have to pay the premium, if their long positions exceed short hedging needs. Hence, index pressure and hedging pressure alternate with the composition of traders in the market.

Akin to the hedging pressure literature, the three models assume either credit constrained or risk averse speculators so that both hedgers and index traders must pay a premium to liquidity providing speculators. While these models successfully incorporate index traders, only Basak and Pavlova (2016) endogenously model index traders' behaviour. They draw from a market microstructure model they develop in an earlier paper for stock markets (Basak and Pavlova 2013). Their model is hence a synthesis of hedging pressure and market microstructure models, while Brunetti and Reiffen (2014) and Hamilton and Wu (2014) draw on the hedging pressure literature alone.

However, the synthesis remains incomplete as one trader category referenced by the financialisation and asset pricing literature is omitted from all three models, uninformed and potentially trend following speculators; see Table 2. Trend following behaviour is likely in commodity markets, where information asymmetry is an inherent feature; see Cheng and Xiong (2014), Sockin and Xiong (2015), Goldstein and Yang (2016). Hedgers have a known information advantage on inventory levels, as well as future production and consumption. Since the identity of a trader is not disclosed, a large inflow of index traders could be confused with a trade placed by an informed hedger. The prevalence of extrapolative traders may prompt arbitrageurs to close their short positions by going long, as margin calls pose increasing costs and trend-following behaviour becomes profitable.

Another limitation of the pricing models summarised in Table 3, except for Basak and Pavlova (2016), is the neglect of the linkages between futures, spot and inventory markets. Several recent contributions by Knittel and Pindyck (2016), Kilian and Murphy (2014), Acharya et al. (2013), Ekeland et al. (2015), Sockin and Xiong (2015) and Goldstein and Yang (2016) could potential complement the reviewed

models in Table 3. These contributions, summarised in Table 4, incorporate speculative effects in commodity futures (and spot) markets and derive implications for spot and storage markets. Although none of these studies consider index traders as a separate trader category but only uninformed or partially informed speculators, they provide important insights into the interplay between futures, spot and inventory markets.

Table 4. Summary of Storage Models that Account for Speculation

	Knittel and Pindyck (2016) & Kilian and Murphy (2014)	Acharya et al. (2013) & Ekeland et al. (2015)	Sockin and Xiong (2015) & Goldstein and Yang (2016)
Assumptions	Traders in spot and inventory markets are rational and have perfect foresight (~EMH).	Risk averse producers and capital constraint speculators (~Hedging pressure models)	Information friction, asymmetric information. Risk averse producer (~Rational herding models; {Hedging pressure models})
Trader types	NA, no microstructure provided.	Consumer, Producer {Storer, Processor}, Speculator	Consumer, Storer, Processor, {Speculator}.
Implications	Speculative effects through storage hoarding, otherwise short lived.	Costs of hedging affects cost of storage through market basis, affects storage decisions.	Futures markets provide an information signal resulting in feedback effects from futures to spot markets.

Notes: Curly brackets indicate presence in the second but not the first paper listed in the first row.

Knittel and Pindyck (2016) and Kilian and Murphy (2014) derive a structural model in which speculative influences enter in form of a premium to the futures price without further elaboration of the origin of the premium. They argue that the premium could result in an increase in spot prices via spatial arbitrage, but the increase would be short-lived unless speculative hoarding in the inventory market occurs and the price elasticity of physical demand and supply is low; the latter being a realistic assumption in the short-run due to the financial planning timeframe of corporations which might be up to 12 months (Lagi et al. 2011). While insightful, the models by Knittel and Pindyck (2016) and Kilian and Murphy (2014) are limited in that they do not account for limits to arbitrage, information friction or different trading motives of heterogenous agents. They do not provide a microstructure for trader behaviour and appear to follow the EMH assumption of rationality and perfect foresight.

Acharya et al. (2013) synthesise Hirshleifer's (1988; 1990) hedging pressure model with Deaton and Laroque's (1992) optimal inventory management model. They distinguish between three different trader types in their two-period model: consumers who are only active in the spot market, risk averse producers who are active in the spot, storage and futures market and who use the futures market for hedging and speculation and capital constraint speculators who are active in the futures market. Ekeland et al. (2015) suggest a similar model but with a four-fold trader division, further distinguishing between storers and processors in the producer category to distinguish between short and long hedging demand. Both Acharya et al. (2013) and Ekeland et al. (2015) show that with increasing (short) hedging pressure, storage

becomes costlier due to a stronger risk premium, resulting in a reduction of inventory holdings and therefore a lower demand in the spot market.

The two models by Acharya et al. (2013) and Ekeland et al. (2015) assume speculators to act as liquidity providers and hence price pressure originates solely from hedging demand. However, implications can be adapted for the index pressure models summarised in Table 3. As index pressure, according to Hamilton and Wu (2014; 2015) and Brunetti and Reiffen (2014), contributes to a normal market, physical traders are incentivised to store inventories as storage becomes cheaper, resulting in a higher demand at the spot market and hence a higher spot price. These considerations do not require the assumption of institutional investors buying shares of inventory firms as in Basak and Pavlova (2016) or speculative inventory hoarding as in Knittel and Pindyck (2016) and Kilian and Murphy (2014).

Sockin and Xiong (2015) and Goldstein and Yang (2016) show, in contrast to previous models, that under information frictions, speculators' influence on futures prices and spot prices is not necessarily reflected in changes in inventory. Sockin and Xiong (2015) distinguish between consumers, producers and processors in their two-period model where processors hold private information about global demand and producers hold private information about supply shocks. Under these assumptions, higher prices can result in higher demand for the commodity as the information effect signalling increasing global demand outweighs the cost effect. Goldstein and Yang (2016) combine insights from Sockin and Xiong (2015) with hedging pressure models by adding financial speculators at futures markets and assuming risk averse producers and speculators. In their model, financial speculators and hedgers hold private information which enter as information signal into prices. Similar to Sockin and Xiong (2015), feedback effects between futures and spot markets can lead to pro-cyclical trading behaviour without implications for inventory holdings.

Sockin and Xiong (2015) conclude that the assumption that the 'futures price of the commodity simply tracks the spot price' must be abandoned (pp.2064). Since the two markets host different groups of market participants, the futures price is not simply a shadow of the spot price or vice versa, but dynamics in both markets and their feedback effects must be considered. Similarly, Goldstein and Yang (2016) insist that 'the futures market is not just a side show, and it has consequences for the real side' (p.11). These insights clearly distinguish these two models from the other four in Table 4.

Commodity pricing models which explicitly account for index traders as a separate trader category borrow heavily from Keynesian inspired hedging pressure models. Hedging pressure models are built on the assumptions of risk averse producers and consumers and capital constraint speculators. These assumptions are carried over into the new generation of models which incorporate index pressure alongside hedging pressure. A common shortcoming of these new models is the lack of consideration of spot and storage markets; a shortcoming which has been addressed by a separate set of storage models which account for the presence of

speculators but not index traders as a separate trader category. These models draw from both the hedging pressure literature and market microstructure models with the additional assumption of information friction. A combination of both model types is promising. Interestingly, despite their Keynesian roots, none of the models considers fundamental uncertainty, which could potentially be an interesting addition.

5. Implications for Empirical Testing

Drawing on the price formation models in Table 3 and the storage models in Table 4, implications for empirical studies that seek to explore implications of the financialisation of commodity markets for price formation and risk management can be derived. Price formation models which explicitly account for the passive investment behaviour of index traders predict excess in price levels, price volatilities, and calendar spreads and an increase in co-movement of commodities that are listed in the same index. If extending these predictions by insights from storage models, one can add an excess in market basis and a reduction in the costs for short hedgers to the list of testable predictions.

Further, a careful distinction between trading strategies is pivotal. This implies that Working's T index in its original form, used by some empirical studies, is not helpful in the current debate since it aggregates over passive investors, informed speculators and uninformed speculators; see Working (1960). As clearly demonstrated by the models reviewed, these trading strategies (or trader types) have profoundly different effects on price formation and risk management and hence must be clearly distinguished when modelling or testing their effect. In addition, the precise effect of index-based investments on price dynamics are based on assumptions of risk aversion, capital constraints and/or information asymmetry which needs careful investigation.

The claim of excessive price dynamics is made in relation to what can be justified by market fundamentals. Testing these hypotheses empirically is challenging since fundamental factors are partly latent or data is difficult to obtain. From an empirical point of view, index pressure effects on the calendar spread and market basis are potentially better suited to testing the financialisation hypothesis than effects on price levels and volatilities. This is because in the calendar spread and market basis, fundamental factors cancel out, which alleviates some of the data problems. Table 5 compares the empirical evidence gathered by four recent literature reviews by Irwin and Sanders (2011), Irwin (2013), Fattouh et al. (2013), Cheng and Xiong (2014) and Boyd et al. (2018). The studies summarised within each review are differentiated by their focus on testable hypothesis and evidence for or against the financialisation hypothesis.

Table 5 suggests an under-representation of studies that focus on calendar spread and market basis, while studies that focus on these areas tend to find evidence for a financialisation effect more often than studies that focuses on price levels and volatilities. Further, more recent studies appear to find evidence for the

financialisation hypothesis more often than earlier studies which is evident from the larger relative count of studies that find evidence in the two most recent literature reviews. The reasons behind these observations could be multiple. For instance, the development of index pressure models in recent years might have contributed to a better understanding of the implications of financialisation for price dynamics and thereby facilitated more apt empirical strategies. Alternatively, the fact that early empirical studies have predominantly reported no evidence of a financialisation effect, a publication bias against studies that report such evidence might have developed. Or different selection criteria for studies included in the review might have been chosen by different authors, with the last two literature reviews using similar criteria. It is impossible to draw any conclusions from Table 5 regarding the reasons for the patterns emerging and the table can be indicative of recent developments in the empirical literature at best.

Table 5. Summary of Empirical Evidence

	Irwin and Sanders (2011)		Irwin (2013)		Fattouh et al. (2013)		Cheng and Xiong (2014)		Boyd et al. (2018)		Σ
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	
Direct: price level & volatility	3	7	3	10	1	7	5	9	8	13	66
Indirect: prices level & volatility	2	1	0	0	3	4	9	2	5	2	28
Direct: basis & term structure	0	1	4	4	1	0	1	1	4	0	16
Σ	5	9	7	14	5	11	15	12	17	15	

Notes: Yes/No studies are those with some/without evidence for an effect of non-commercial traders on price dynamics; direct/indirect studies explicitly control/do not explicitly control for trader positions by use of CFTC position data; price level & volatility studies are concerned with price levels, returns, price volatilities and co-movements; basis & term structure studies are concerned with market basis and term structure effects of speculation. Where multiple testing methods and conflicting evidence are presented in one study, the study is double counted. Empirical studies summarised in the four papers overlap and hence should not be counted as separate evidence. Grey literature is excluded from the count. Literature considered here might include evidence from precious metal markets which are not the focus of this review.

6. Conclusion

This paper provides a review of recent approaches to price formation in financialised commodity markets. I show that these recent approaches draw heavily on the Keynesian inspired hedging pressure literature while also borrowing from market microstructure and rational herding models. Surprisingly, despite their Keynesian tradition, asset pricing models that incorporate true uncertainty in the Post-Keynesian sense are not considered. I further identify some shortcomings when extending these index pressure models to spot and storage markets. Three types of storage models which incorporate speculative effects by drawing from the EMH,

hedging pressure models and market microstructure models are reviewed as potential extension.

In a second step, I derive testable hypotheses from the reviewed models. Predictions by recently emerged index pressure models largely support the claims made early in the financialisation debate, e.g. Masters (2008), such as excessive price levels and volatilities, an increase in co-movement of commodities of the same index, and excessive calendar spreads and market basis. However, the derived hypotheses are formulated as excess price dynamics relative to what would could be explained by market fundamentals. Data constraints around market fundamentals hence pose challenges to the empirical testing of these hypotheses. A more operational approach to testing these hypotheses might be based on the difference between two commodity price series, as, for instance, the futures price and its underlying spot price, or price series of futures contracts with different maturity dates. Since these pairs of price series are driven by the same commodity-specific fundamentals, the difference in level and variability can be attributed to factors that are specific to the commodity price series, including the different composition of traders. A crude summary of the empirical literature reveals potential for future research in this area.

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