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# LIQUIDITY COGNITION AND LIMITS OF ARBITRAGE

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# Liquidity cognition and limits of arbitrage

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Abstract. *The great financial crisis has stimulated a rethinking of the multifaceted problem of liquidity as a cognitive problem. It is the aim of this paper to argue about the connection between liquidity cognition and the nature and limits of arbitrage, and thereby shed further light on the monetary relevance of market microstructures and balance sheet compositions in pivoting market imbalances and liquidity provision. We distinguish between cognition about the incentives driving liquidity management and transformation, and cognition about related potentially emerging constraints, and argue that the interactions between such types of cognition represent fundamental aspects of the "monetary" nature of arbitrage activity. The CDS-bond basis phenomenon is shown to provide a natural playfield for our monetary vision on the liquidity-arbitrage connection. The current debate on the scarcity of safe assets enables us to sharpen the monetary stance of our approach, which builds on the principle that frictions give rise to the value of money.*

Keywords: Market Liquidity; Funding liquidity; Liquidity Constraints; Incentives; Limits of Arbitrage; Safe Assets.

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Liquidity is an illusion; here one day, gone the next.
*Mervyn King*

## 1 Introduction

The great financial crisis of 2007-2009 has dramatically re-established the multifaceted problem of liquidity as a major challenge for academics, policymakers and regulators (e.g. BdF, 2008; Brunnermeier and Pedersen, 2009; Krishnamurthy, 2010; Tirole, 2011; Mehrling et al., 2013; Pozsar, 2014; Acharya and Mora, 2015; Daley and Green, 2016; Singh, 2017; Adrian et al., 2017; Kurlat, 2018). "We need to better understand the degree to which any changes in the nature of liquidity reflect the evolving structure of financial markets, changes in regulatory power or other factors" (Dudley, 2015). In fact, the "elusive" problem of liquidity has been interpreted as a *cognitive* problem (see for instance Bervas, in BdF, 2008, "Bervas" henceforth) which we aim to connect with the concrete aspects of arbitrage activity.

Much of financial theory and asset pricing have been developed under the "efficient market hypothesis", which posits, among other things, the existence of powerful arbitrageurs that can profit from temporary mispricing, and promptly restore market equilibrium and efficiency (and, thereby, liquidity) irrespective of the specific market microstructure. The limits of such an ideal picture have been thoroughly discussed (e.g. Shleifer and Vishny, 1997; Gromb and Vayanos, 2010). In the wake of the crisis, unsurprisingly, such a theme has been receiving increasing consideration, and a growing literature is currently engaged in the explicit representation of the market microstructures and balance sheet management strategies that shape our understanding – cognition – of market imbalances, liquidity provision and limits of arbitrage (e.g. Anderson et al., 2017; Dow and Han, 2018; Gromb and Vayanos, 2018; Du et al., 2018, Kondor and Vayanos, 2018). It is the aim of this paper to tailor a cognitive perspective on such research advances, building on the principle that financial frictions give rise to the value of money.[1] Write $P_0$ for such principle.

In the years preceding the great financial crisis, both policymakers and market participants seem to have been underappreciating the potential emergence of instabilities in both market and funding

[1] For recent applications of such a principle see the contribution by Brunnermeier and Sannikov ("Macro, Money and Finance: A Continuous Time Approach") to the last edition of the Handbook of Macroeconomics.

liquidity supply.[2] The *evolution* of liquidity management in the last few decades has been pointed out among the reasons of its elusiveness; a genuine cognitive problem seems to raise concerning the assessment of market liquidity in such evolving scenarios. "New business practices, technological innovation, and changes in regulation [...] can alter the meaning and the relevance of traditional metrics and methods that many use to gauge fixed income market liquidity conditions" (FSOC, 2016, p. 124). Such evolution has been paralleled by increasing diversification of funding liquidity supply and the emergence of the shadow banking system. "Financial innovation, to an extent, may have let market participants believe that they could, on an enduring basis, escape from the monetary constraint (the need for genuine cash) and that they could make do with the liabilities issued by other institutions to meet their liquidity needs" (Bervas, p. 123).

True, the history of money markets witnesses that liquidity cognition represents a perpetual challenge. For instance, the celebrated Bagehot's description of the XIXth century London money market provides a lively account of the cognitive challenges facing the directors of the BoE themselves concerning the role the Bank reserve.[3] Nowadays, liquidity is at the core of the macroeconomic debate, concerning for instance the desirable pace at which to unwind unconventional monetary policies, and the critical role of dealers of absorbing market imbalances and supplying market liquidity, whose empirical investigation is currently subject to methodological improvements (e.g. Adrian et al., 2017).

Interestingly, in the model set forth by Kurlat (2018), market liquidity is a property of the system, not of single securities subject to trade. One is immediately reminded of the systemic problem of the acceptability of money, which is not a matter of bilateral agreements, and rather a problem of trust in the multilateral consistency and fluidity of trade mechanisms. As is well known, money plays no role in the theoretical grand auction at the foundations of general equilibrium theory, in which trade is mediated by the "auctioneer"; quite on the contrary, money plays a key role in concrete markets in which the liquidity/acceptability of money is pivotal for the occurrence of trade. Kiyotaki and Moore (2001) provide a truly engaging account of the multilateral problem of the acceptability of money, which, in our view, conveys genuine insights on the role of market liquidity in the OTC markets in which the vast majority of bonds, derivatives and FX are traded. As pointed out by Bervas, "Ultimately, the liquidity of financial assets depends on the trust that they can be redeemed on demand." Building on such insights, we shall tailor a "monetary" approach to the nature, and limits, of arbitrage. Such a statement may sound somewhat heterodox; still, the recent literature seems to focus with increasing sharpness the inherent monetary aspects of arbitrage activity.

There is a somewhat intuitive sense in which arbitrage is, partly, a monetary phenomenon. After all, in order to establish their positions, arbitrageurs need to raise "money" (funding liquidity). True, we

[2] In such respect it is interesting to notice the enormous cash reserves held by nonfinancial large US corporations in recent years (Dittmar, 2008; Pozsar, 2014).

[3] One of the directors explicitly stated that "the most mischievous doctrine ever broached in the monetary or banking world" is having the Bank "keep money available at all times to supply the demand of bankers who have rendered their own assets unavailable" (Bagehot, 1896, p. 171).

seem to envision a more profound sense in which arbitrage has inherently monetary features. Wholesale money markets[4] represent a systemic monetary phenomenon that has not been given as yet adequate theoretical status (at least, according to Pozsar, 2014, and Singh, 2017). Such a theoretical void is where our approach aims at fixing a few logical elements of the connection between contemporary money markets and capital markets. Arbitrageurs are part of the connection; their activity impinges on the dynamics of market liquidity and funding liquidity, whose nexus is the frontier of monetary research. According to Kiyotaki and Moore (2001), Monetary Economics should be displaced by "Liquidity Economics". Such a strong claim, admittedly, has represented a major inspiration for our inquiry. Mantovi (2018) provides a sharp account of the macroeconomic relevance of the monetary dimension of arbitrage; the microeconomic aspects of such dimension are the subject of the present contribution. Roughly speaking, we shall try to fix the cognitive problems associated with the way liquidity dynamics "is endogenous to balance sheet choices and to information acquisition" (Tirole, 2011).

No explicit analytical model, we all know, can account for all of the consequences of potentially emerging constraints on balance sheet management (look at the sheer size of the analytical model set forth by Gromb and Vayanos, 2018). In recent years a key problem has been emphasized, namely, the fact that the total margin on all positions is limited by the dealer's capital (e.g. Brunnermeier and Pedersen, 2009). This constraint has been extensively discussed in recent years, and its 'cognitive status' seems therefore quite established. Our research focus is on less established criticalities of arbitrage activity, which pertain to the environment in which such activity takes place. Mehrling (2012) provides an insightful monetary framework for appreciating the relevance of the market-making function of dealers of transporting liquidity from one market to another, having limited capital and limited capacity (possibly, willingness) of expanding the balance sheet. Definitely, such a picture lies at the foundations of our intuitions.

The great financial crisis, needless to say, is the major inspiration for the present contribution. The collapse of the shadow banking system built around top tranches of residential mortgage backed securities (Brunnermeier, 2009) provides a concrete example of the pivotal role of collateral in the stability of "money market funding of capital market lending" practices (Mehrling et al., 2013). Flows of risks and collateral are not simply there for all to see, witness the very expression "shadow banking". Cognition about market imbalances and potential instabilities are nontrivial issues; for instance, in the phenomenology discussed by Mitchell and Pulvino (2012), "from an arbitrageur's perspective, seemingly long-term capital became truly short-term overnight" (ivi, p. 490). The "seemingly" adverb in the quote points at a cognitive assessment that has been dismantled by the events.

[4] According to Tirole (2011), "overreliance" on wholesale funding is one of the causes of the great financial crisis.

Soros (2013) envisions the cognitive problems faced by market participants as pivotal for the understanding of the concrete patterns of behavior that emerge in times of stress. Our approach to liquidity cognition aligns with such a view. Thus, the research problem we aim to address is the following. Can one find a representation of the cognitive problems discussed by Bervas that does not reduce to the technical apparatus of information economics, and rather impinges on fundamental notions of economic analysis, namely, incentives and constraints? In order to pursue such a program, we shall define *i*) cognition about the incentives which drive liquidity management and transformation, and *ii*) cognition about the potentially emerging constraints that may affect such activities. A number of specific examples (see subsection 2.1) witness that such notions are not a rephrasing of well established concepts. Building on such notions, we shall tailor a "mechanism" representing arbitrage as an activity that explores the boundaries of markets, the potential for supplying market liquidity, and the feedback between the implementation of strategies and liquidity cognition (see Figure 2 below). Furthermore, the theoretical – monetary – relevance of our approach shall be given a somewhat sharp description (section 5).

The rest of the paper unfolds such logic. In the following subsection we connect our approach to the relevant literature. In section 2 we introduce our cognitive perspective on liquidity, upon which we build, in section 3, our vision an arbitrage. Section 4 provides empirical backing for such an approach. Section 5 addresses the monetary relevance of our approach. Conclusions follow.

### *1.1 Related literature*

A major inspiration for the present contribution is the article by Arnaud Bervas (BdF, 2008), in which, in the wake of the 2007 credit crunch, the Author provides a clear account of the evolution of the "elusive" problem of liquidity over the last decades, in particular concerning the cognitive implications of financial innovation and liquidity management. The contribution by Caruana and Kodres in the same Issue provides further elements for our research question, in first instance concerning the relevance of "the degree to which information about the risks underlying the financial instrument are well understood by both buyers and sellers." The relevance of market liquidity for the functioning of the shadow banking system is given a profound characterization by Mehrling et al. (2013).

The beautiful 2001 Clarendon Lecture by Kiyotaki and Moore provides sophisticated insights on the economic drive to create liquidity. Such a contribution is truly remarkable in many respects; among other things, the Authors remark that the debate on the macroeconomic relevance of money was, at the time, "suspiciously quiet." The current rethinking of the macroeconomic representation of money and finance has been prefigured by Kiyotaki and Moore well before the great financial crisis.

Tirole (2011) offers a comprehensive review of the various strands of literature confronting the problem of illiquidity. Krishnamurthy (2010) fixes a sharp analytical setting for envisioning the reach of our cognitive notions. The Author tailors a twofold picture for the onset of liquidity spirals, which encompasses "balance sheet mechanisms" and "information mechanisms"; our cognitive notions are

meant to align with such a fundamental dichotomy. Daley and Green (2016) and Kurlat (2018) provide sophisticated models of "information mechanisms"; in particular, Kurlat's (2018) model embodies a fundamental property that our approach is meant to emphasize, namely, the fact that liquidity is a property of the system, not of single securities. The recent literature on the relevance (and scarcity) of safe assets (e.g. Andolfatto and Williamson, 2015, Gorton, 2017; Caballero et al., 2017) enables us to compare, in section 5, the (cognitively complex) role of market-makers in the supply of market liquidity with the (in principle, cognitively trivial) supply of inherently liquid (safe) assets. The relevance of collateral flows for the theoretical and empirical investigation of current monetary phenomena is discussed by Singh (2017).

Evidently, our approach is meant to contribute to the literature on the limits of arbitrage (Shleifer and Vishny, 1997; Gromb and Vayanos, 2010, and references therein), that is currently experiencing an expansionary phase on both theoretical (e.g. Gromb and Vayanos, 2018; Kondor and Vayanos, 2018) and empirical (e.g. Sushko et al., 2016; Du et al., 2018) grounds. In particular, the empirical literature on the CDS-bond basis (e.g. Stulz, 2010; Nashikkar et al., 2011; Subrahmanyam et al., 2014; Augustin et al., 2014) provides a robust backing for our conceptual approach (see section 4). The literature on slow-moving capital (e.g. Duffie, 2010; Mitchell and Pulvino, 2012; references therein) can be considered part of the stream.

To conclude, the insightful monograph by Mervyn King (2016) provides a number of conceptual building blocks for our approach (see section 3). Such a monograph advocates a radical approach to the reform of the financial system. It is not our aim to argue in favour (or to the contrary) of such proposals; it is the conceptual elements employed by King (2016) that we are interested in.

## 2 Liquidity and cognition

The analysis of *liquidity constraints* represents a time honored inquiry for which Minsky (1986) provided a landmark contribution, and which the great financial crisis has brought back under the spotlight (The Economist, 2016) in connection with the network of constraints which regiment flows of funds and risks in contemporary markets (Brunnermeier, 2009; Pozsar, 2014). True, the interpretations of the run-up to the crisis seems to revolve around (what we may call) the *liquidity incentives* that have been driving the evolution of markets over the last decades.

Arguably, the incentives to perform liquidity transformation have been at play throughout the entire history of banking. In the words of Kiyotaky and Moore (2001), the economic drive to crate liquidity is hard to stop.[5] Somewhat recently, though, financial innovation has been opening new avenues for such incentives to unfold, by engineering new ways of transforming illiquid assets into more liquid ones, and then to slice, price and sell specific risks, thereby (seemingly) gauging the risk and liquidity profile

[5] According to the Authors the introduction of the bill of exchange can be traced to the desire to circumvent legal restrictions to the transfer of debt in the Middle Ages.

of asset classes. The emergence of the shadow banking system is part and parcel of such a secular process. Somewhat unavoidably, then, our approach to liquidity cognition builds on the recognition of the *pivotal* role of market liquidity in the current market-based credit system.

Mehrling et al. (2013) envision an enlightening parallel between the XIXth century London money market – Bagehot's world – and the current system. "Bagehot's world was organized as a network of promises to pay in the event that someone else doesn't pay, whereas our own world is organized as a network of promises to buy in the event that someone else doesn't buy" (ivi, p. 7). The Authors thereby provide a profound perspective on the pivotal role of market liquidity in current market arrangements, that rely to a significant extent on sort of 'parallel payment system' in which collateral is the flip side of funding liquidity (see Singh, 2017). In our view, the contemporary cognitive problem of liquidity revolves around the complex implications of such a role of market liquidity, which is increasingly difficult to disentangle from solvency problems, if only for the procyclical effects of fair value accounting (Tirole, 2011).

Liquidity incentives and liquidity constraints are the target of our cognitive perspective, for which a preliminary insight goes as follows. The incentives to borrow short and lend long in order to capitalize on the corresponding spread – a sort of arbitrage – are not difficult to understand, and therefore seem not to represent a real cognitive challenge. Still, the great financial crisis has spelled the truly challenging cognitive problem of appreciating the systemic consequences of a widespread adoption of such liquidity transformation practices. The *actual* emergence of the *potential* liquidity (cum solvency) constraints inherent to such practices has triggered the worst financial crisis ever. Thus, our cognitive perspective is meant to focus in first instance the *sequential* nature of the cognitive problems connected with liquidity management, from emerging (cognition about) profit opportunities to the riskiness and stability of the positions meant to exploit such opportunities, and then to new opportunities and so forth.

To begin with, information plays a role in the cognitive problem of financial market participants, that are constantly engaged in information processing (see Vives, 2008), for which market prices, undoubtedly, represent key entries. Unfortunately, the dynamics of liquidity is a complex phenomenon – or set of phenomena – for which market prices seem to represent neither a complete set of state variables, nor a revelation/allocation mechanism like the one notoriously discussed by Hayek (1945).[6] The allocative function of prices in (typically primary) real markets is somewhat clearly established (witness standard introductory microeconomic textbooks). On the other hand, the allocative function of prices in (typically secondary) financial markets is much more nuanced, and the concrete activity arbitrageurs in concrete financial markets can hardly fit the standard textbook definition – as noticed by Mitchell and Pulvino (2012), it is often the case that the securities underlying the trades of hedge

[6] We thank W. De Bondt for a profound discussion of this point.

funds are "merely related, not identical" (ivi, p. 470). We begin to envision the preliminaries of our reconsideration of the liquidity-arbitrage nexus.

Given that prices *per se* do not embody all of the relevant information, significant theoretical progresses are under way of our understanding – cognition – of the sensitivity of market liquidity to information dynamics. For instance, Daley and Green (2016) represent a mechanism in which future market liquidity depends on the realization of news correlated with assets' quality. Needless to say, the opacity of structured securities and the onset of the subprime crisis (see Brunnermeier, 2009) has represented a major stimulus for such lines of research. Thus, let us introduce a notion of *cognition about liquidity incentives* (CLI), meant to embody the ability of agents – including commentators and regulators – to recognize incentives (profit opportunities) connected with liquidity management or transformation, in a somewhat generalized sense.

A simple example of CLI concerns cognition about the profitability of taking positions in instruments whose liquidity properties have been reassessed, perhaps due to increase in demand; dealers are constantly engaged in such information processing, that does not reduce to a plain check of market prices, and is fundamentally connected with the implications of imbalances in order flows and estimates of the riskiness of marginal positions. A somewhat more elaborate example is given by the emergence of CLI about the profitability of "originate to distribute" practices some three decades ago or so. In general, incentives do not spring out of simple information gathering; typically, it takes a business model to spot the incentives emerging out of new information. Still, in extreme cases, the emergence of incentives to liquidate positions may be quite straightforward (see the subsection below).

Correspondingly, let us introduce a notion of *cognition about liquidity constraints* (CLC) concerning the appreciation of potential constraints or frictions (in a generalized sense) that may hinder liquidity management, and thereby limit the self-stabilizing character of a market. Every agent manages a *local* environment, and such management, in particular circumstances, may be driven critically by emerging constraints, among which liquidity constraints are those requiring immediate responses.[7] A simple example of CLC is given by the recognition of the potential emergence of a liquidity constraint resulting from default of a counterparty. A more elaborate example concerns anticipating potential instability mechanisms like the one discussed by Brunnermeier and Pedersen (2009). A systemic failure of CLC is recorded by The Economist (2008): "In January 2007 the world looked almost riskless […] Where is the liquidity crisis supposed to come from? […] No one could give a good answer" (ivi).

Definitely, our differentiation between CLI and CLC closely parallels the differentiation between amplifier mechanisms for liquidity crises discussed by Krishnamurthy (2010). The Author discusses the "balance sheet mechanism" – from price shocks to financial constraints and then to fire sales that put further downward pressure on asset prices – as well as the "information mechanism", in which,

[7] We thank P. Mehrling for helping us sharpen such an insight.

roughly speaking, a shock in the confidence over opaque assets leads to a flight to liquidity resulting in a liquidity dry-up. To a large extent, CLC can be associated with the former mechanism, and CLI with the latter; still, our cognitive notions are meant to apply to general liquidity dynamics, and not only to the amplification mechanisms discussed by Krishnamurthy (2010).

One may argue that cognitive problems are pervasive in economic and financial activity, and that we are simply rephrasing standard issues in information economics. That is not the case. Our perspective on liquidity and arbitrage (Claim 1 below) cannot be reduced to an information problem, and our cognitive notions *do not* reduce to beliefs or information sets, and rather pertain to *emerging properties* like the conditions for the onset of liquidity spirals, as discussed for instance by Krishnamurthy (2010). The empirical relevance of our approach seems to be reflected in the monitoring and regulation approaches to the problem of "shadow" banking (e.g. FSB, 2018).

How about moral hazard? It has been extensively pointed out that misconduct must find a place in a sound representation of the instabilities at the roots of the crisis. Needless to say, our approach is in no way meant to justify or absolve hazardous practices on the altar of limited cognition. Quite on the contrary, our approach may help sharpen the potential onset of conditions (incentives) for misconduct.

A few examples may help clarify our cognitive approach, and differentiate it from both standard and "new" behavioral approaches to cognition about financial instability (see Dow, 2010, and references therein).

*2.1 Examples*

Specific decisions concerning liquidity management and regulation are based (evidently) on the extant cognition of decisionmakers. The following examples are meant to sample the varying degrees with which our cognitive notions may be at play in various (theoretical and empirical) settings, thereby clarifying the notions themselves. We seem to succeed in showing that our cognitive notions can be sharply disentangled in specific contexts.

*Example 1*. Kurlat (2018) provides an insightful display of CLI. The Author, much in the spirit of Akerlof (1970), depicts a market for assets with differentiated (constant) quality, good ("capital") or bad ("lemon"). The owner of an asset is the only agent knowing exactly its quality. The model posits exogenous gains from trade that are counterbalanced by the worthlessness of lemons; equilibrium prices of (alleged) capital and lemons gauge such a tradeoff. Trade generates signals about the quality of assets.

In fact, two kinds of signals are at play in Kurlat's model. Signals of the first kind (ex-ante "s" signals) typifying the quality of each asset (this asset seems to be "capital", that asset seems to be a "lemon") are generated with random informativeness. Signals of the second kind (ex-post "z" signals) are, at times, generated after trade takes place, and confirm or not the corresponding s-signals. Then, a

sequence of pairs {s, z} is stored over time, by means of which the economy 'learns by trading', and develops a "social expertise" in addressing the informativeness of signals. Still, initial scarce informativeness may hinder the learning process, and eventually lead to an "illiquidity trap"; a sound instance of path dependence is thereby represented. In our view, a major merit of the model is to envision liquidity as a property of the system, and not of individual assets.

For sure, there is more to market liquidity than Kurlat's model; for instance, the model does not encompass dealers quoting bid-ask spreads, and sellers are not allowed to buy back assets – sellers live one period. Furthermore, funding liquidity is nowhere to be seen. Still, the model displays a rich phenomenology, and a convincing representation of the implications of the contingent informativeness of signals, among which the fact that liquidity is more stable in more "mature" markets. Our interest in Kurlat's (2018) model is thus fixed: the model provides a paradigmatic example of the *disentanglement* of our cognitive notions. Kurlat's illiquidity results from asymmetric information and the resulting incentive not to trade, i.e. an instance of CLI. The sustainability of positions is not at stake, and in fact agents are not engaged in balance sheet management within a network of counterparties. No instance of CLC displays in the model.

*Example 2*. Vayanos and Wang (2007) provide another insightful display of CLI. The Authors set forth a theory of market liquidity meant to enlighten the different concentration of liquidity in essentially similar markets. Agents of different horizons aim at investing in one of two identical assets, whose differentiation comes from the market in which they are traded, market 1 and market 2. A behavioral assumption makes buyers choose which of the markets to explore, and prevents them from switching to the other. Search takes time, and buyers are driven by the incentive to minimize the cost of searching. The model displays CLI, i.e. incentives driving the behavior of agents which gauge the liquidity of markets; the Authors in particular discuss the differences of liquidity of substantially similar assets like "on-the-run" and "off-the-run" Treasury bonds. The only constraint in the model is the fact that buyers perform their search in one market only; no instance of CLC displays in the model set forth by Vayanos and Wang (2007).

*Example 3*. A bank run is an example of a phenomenon that may be driven (and interpreted) solely in terms of CLI. It does not take a sophisticated model of information processing to establish that, for any single depositor, running to the bank is the best response to others running (King, 2016, elaborates at length on the consequences of such a basic fact). A hypothetical bank run may, in principle, be generated just by *unjustified* panic. The run on money market mutual funds (MMMFs) of summer 2007 (generated by the downgrading of structured securities) for sure does not fit exactly such a stylized example; still, irrespective of the soundness of a fund's balance sheets, the collective incentives (first mover advantage) to run once the run had begun can be interpreted solely in terms of CLI. Among

other things, Bengtsson (2013) notices that not all MMMFs had significant exposure to structured securities, but investors were hardly in a position to *readily* discriminate.

Before the crisis, MMMFs were ascribed a stabilizing role for money markets (Bengtsson, 2013), and were thought of as immune to runs (and, after all, no such run had occurred before 2007). In addition, the mechanism of liquidity supply employed by MMMFs seemed to provide a sound backing for their alleged stabilizing role, thereby building CLC about the stability of the fund. The crisis has unfolded instability channels that had not been appreciated, thereby improving our CLC about the functioning of MMMFs. Recent regulation of MMMFs is meant not only to strengthen the solidity of such business, but in fact to strengthen CLC thereof.

*Example 4*. According to M. Singh (2017), the flows of collateral "lie at the heart of any proper understanding of market liquidity, and hence of financial stability [...] Viewed together, both money and collateral provide a more comprehensive picture of how global liquidity should be considered." Not only do we align with such a view, but hope to provide further motivation for such claims.

The Author addresses the properties of collateral flows related to securities lending and derivatives markets, and in fact stresses the relevance of collateral in daily operations: "the financial system requires collateral or money for intraday debits and credits". With respect to the standard banking architecture of the payment system, flows of collateral represent sort of 'parallel' payment system in which market liquidity and finding liquidity interact in the absence of clearinghouses comparable to those arranged by central banks.

The *cognitive role* of the traditional clearinghouse may not have been adequately represented in standard monetary textbooks. The clearinghouse is not only meant to perform the netting of payments; the clearinghouse *does gain cognition* – CLC – about imbalances in payments, and supports the fluidity of the system by extending temporary credit. It is not a technical detail for agents to have *common knowledge* about the function of the clearinghouse; it has consequences on the stability of the system (which is, after all, one of the reasons why clearinghouses 'evolved' into central banks). With respect to the benchmark of perfect cognition about payments and imbalances which is embodied by a well functioning clearinghouse, building CLC about imbalance and shortages in collateral flows entails more difficult steps for both policymakers and market participants: the system is not centralized, and its exact state is therefore not observable. Both Singh (2017) and Pozsar (2014) advocate improvements in official statistical accounts of flows of collateral, which should complement the ordinary flows of funds accounts. For sure our cognition of the potential instabilities of collateralized financing has been significantly improved in recent years (see for instance Gârleanu and Pedersen, 2011).

*Example 5*. Mitchell and Pulvino (2012) provide a sharp account of a breakdown of CLC concerning the stability of the connection between prime brokers and hedge funds in the wake of the Lehman crack

(September 2008). Recall, prime brokers – typically arms of global banks – provide a number of services to hedge funds, among which securities lending, trading services and debt financing. The prime broker employs part of the collateral pledged by the hedge fund to collateralize the loans obtained by rehypothecation lenders. A two-steps credit chain therefore represents a significant part of the financing of the hedge fund. The efficiency of the lending chain (CLI thereof) is gauged by favourable rates; still, its stability has been severely challenged by the crisis.

The Authors review the prime brokering activity of Lehman Brothers International Europe (LBIE). The filing of Lehman Brothers in September 2008 implied that rehypothecation lenders upstream LBIE were forced to sell the securities pledged as collateral; LBIE clients became in fact unsecured creditors of LBIE. The consequence on the hedge funds downstream was a sudden change in the duration of loans relative to the expected time to convergence of the arbitrage opportunities on the asset side of the balance sheet; in the words of Mitchell and Pulvino (2012), "from an arbitrageur's perspective, seemingly long-term capital became truly short-term overnight" (ivi, p. 490). The adverb "seemingly" points at a breakdown of CLC built in normal times, which did not stand the test of the financial turmoil. Such matters do not seem to have been fixed as yet: as pointed out by the Financial Stability Oversight Council (2016), "The potential for fire sales of collateral by creditors of a defaulted broker-dealer also remains an important risk" (ivi, p. 14).

*Example 6*. According to King (2016), effective advances in the stabilization of the financial system call for a profound transformation of banking business models and a reconsideration of the way central banks should approach the problem of lending of last resort. Building on a tradition dating back to Irving Fisher and Frank Knight, the former governor of BoE advocates a design of emergency lending rules based on a definite structure of the banks' balance sheets, so as to provide "incentives to prepare in normal times for access to liquidity in bad times" (ivi, p. 270). Roughly speaking (we refer to the original monograph for a proper account of the mechanism), central banks should establish ex-ante which collateral may be eligible, and at which margins, for emergency lending. One such transparent picture would enable banks to structure their balance sheets so as to be *immune* to the illiquidity problems generated by a systemic crisis. Admittedly, it is not our aim to argue in favor of such a proposal; for our purposes, it matters to notice that King's (2016) plan revolves around the relevance of the cognition of market participants about the (central bank) liquidity backstop for banks.

King's (2016) proposal targets *perfect cognition* of the amount of liquidity that a bank may be in a position to raise during a systemic crisis. One thereby achieves the solution of a sharp CLC problem. In turn, such a certainty element induces a discipline element; King's (2016) proposal tailors a causal effect from the solution of a definite CLC problem to the incentives (CLI) which shape banks' liquidity management.

*Example 7*. Money markets represent a major transmission channel of monetary policy, and, no wonder, in recent years their functioning has been subject to deep scrutiny. In particular, the very significance of the "IBORs" has been debated in connection with their pervasive role in financial valuation and contracting, and evidences about their manipulation (see Duffie and Stein, 2015, and references therein).

Hull and White (2014) provide an insightful account of the "dilemma" of the empirical benchmark risk-free rate. Among the candidates, IBORs and "OISs" are largely considered the most significant; arguments are typically employed according to which IBORs are natural candidates once unsecured borrowing is at stake, and OISs for collateralized borrowing. However, the Authors challenge such arguments: "the evaluation of an investment should depend on the risk of the investment and not on the way it is funded" (ivi). Hull and White seem to envision a cognitive bias (or perhaps a number of biases) at the roots of the dilemma. How about enlightening the dilemma in terms of our cognitive notions? Not an easy task.

Both secured and unsecured borrowing rates realize in money markets under the interaction of demand, supply and monetary policy – which pegs the policy rate. Such rates can be considered as the 'prices' of funding liquidity, and to reflect the cognition of policymakers and market participants about the incentives driving liquidity management and potentially emerging constraints. Being emergent phenomena, such prices of liquidity can hardly be decomposed into a component reflecting the incentives at play (e.g. profit seeking, policy corrections) and a component reflecting the constraints (e.g. cash flow commitments) that should be reflected in such prices. Far from being a flight into abstruse academic speculation, such considerations reflect concrete concerns on the nature of the IBORs. The "judgmental" nature of the IBORs has been widely criticized; such rates are *quoted* by a panel of large banks as the rates at which they *believe* they can borrow unsecured. The incentives at quoting low rates that in principle are involved in such a mechanism have been thoroughly discussed in recent years, as well as the fact that amid a credit crunch such rates have scarcely any significance. In fact, the need for a transition towards *transaction based* EURIBORs has been firmly established.[8] One can rephrase such considerations as witnessing the inherent inconsistency of IBORs reflecting (mostly) CLI and (possibly) not CLC.

### *2.2 Interaction*

The previous examples were meant to sharpen the content of our cognitive notions. Examples 1 to 6 seem to witness the consistency of our differentiation between the cognitive aspects related to the incentives driving liquidity management (the subject of CLI) and the aspects related to the effects of the potential emergence of liquidity constraint (CLC). In such respects, example 7 is somewhat problematic, in that it points at a seemingly physiological entanglement of CLI and CLC. Should we

[8] https://www.emmi-benchmarks.eu/euribor-org/euribor-reform.html

consider example 7 as undermining the consistency of our approach? Not at all. On the contrary, example 7 enlightens a crucial element of our cognitive approach. The point is (it is our aim to argue) that CLI and CLC *do interact*.

This is a crucial point, which should be addressed on explicit analytical grounds. Still, due to the preliminary nature of the present contribution, we shall content ourselves with a few qualitative remarks. We do not need the full machinery of partial differential equations to tell "superposition" from "interaction". For instance, sounds superpose (think of an orchestra) and still maintain their recognizability (one recognizes each instrument since it 'sounds the same') – sounds satisfy linear partial differential equations. On the other hand, clouds interact (they satisfy nonlinear equations) and do not maintain their characteristics on their way. In our view, CLC and CLI may not only superpose, adding new information to consolidated expertise. They may interact, with CLC influencing CLI and viceversa.

We can consider example 7 as a paradigmatic representation of the interaction between CLI and CLC, and of the fact that, with limited arbitrage, the price of liquidity is 'ambiguous'. Our perspective on the limits of arbitrage is meant, among other things, to deepen such considerations.

## 3 Arbitrage

Arbitrage does matter. "Modern finance theory rests on the ability of arbitrageurs to ensure that substantially similar assets trade at substantially similar prices" (Mitchell and Pulvino, 2012). In fact, "no-arbitrage" conditions play a fundamental role in standard asset pricing models; still, the effectiveness of the specific arbitrage strategies meant to support such conditions, and the frictions that might stand in the way, seem to have raised to a fundamental status only with the landmark contribution by Shleifer and Vishny (1997).

Recall, 'ideal' arbitrage can be defined as *the simultaneous purchase and sale of the same, or essentially similar, security in two different markets for advantageously different prices* (Sharpe and Alexander, *Investments, 4th edition*; Prentice Hall, 1990) and considered neither to entail risk nor to require capital. The figure below sketches the 'classical' steps towards the re-establishment of the law of one price, and therefore "perfect market liquidity". With respect to such an ideal picture, limits of arbitrage and other market imperfections have been referred to as "anomalies"; still, a growing literature has succeeded in displaying the physiological character of such anomalies. Game theorists have long established that Pareto inefficient outcomes can occur as perfectly rational Nash equilibria; along similar lines, a number of scholars have succeeded in showing that inefficient allocations and limited arbitrage may at times be perfectly rational market outcomes, as a result of best responses of agents to the emergence of financial constraints.

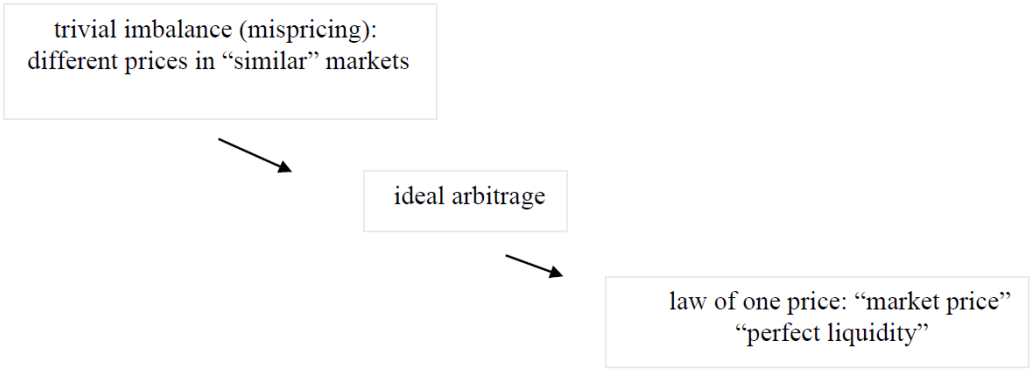


**Figure 1**. Ideal arbitrage.

Shleifer and Vishny (1997) deepen the agency problem faced by professional arbitrageurs who manage other people's money (like pension funds and hedge funds) and whose compensation is contingent on performance. The Authors employ an agency model to establish that performance based arbitrage (PBA) can become most constrained precisely when the best opportunities arise (see also Shleifer, 2000). Such a theoretical argument reflects relevant empirical phenomenology; in fact, both the use of redemption gates by a number of hedge funds and the grant of favorable redemption terms by others (Teo, 2011) witness that redemption conditions represent a significant strategic variable for applied PBA. True, a growing literature has been addressing the range of frictions that impinge on arbitrage activities. For instance, holding costs and borrowing constraints have been extensively discussed as relevant frictions impinging on the ability of arbitrageurs to establish further positions (see Gromb and Vayanos, 2010, and references therein).

Until recently, limits to arbitrage seemed to represent sort of exception to the rule of unconstrained arbitrage. Well, recent research efforts seem to turn things around, and envision perfect arbitrage as the exception to the rule of limits. For instance, Gromb and Vayanos (2018) represent a number of problems connected with the expansion of the balance sheet that limit the activity of arbitrageurs. The Authors depict a stylized financial system with a single risk-free security and infinite pairs of risky securities traded in segmented markets that define the arbitrage opportunities that arbitrageurs, in principle, may attempt to exploit. In practice, though, arbitrageurs are constrained in their access to external capital. "The need for collateral limits the positions that an arbitrageur can establish, and that constraint is a function of his wealth" (ivi). Admittedly, our approach to the effectiveness of arbitrage is meant to align with such research advances, and in particular to tailor a sharp connection with the cognitive problem of liquidity in terms of our cognitive notions – CLI and CLC.

In subsection 2.1 we have been discussing an empirical setting in which to envision a 'physiology' for the interaction of CLI and CLC in the formation of a 'price' for funding liquidity (example 7). In a sense, our perspective on arbitrage is meant to envision the generality of such physiology. In such respects,

Stulz (2010) provides a truly significant insight concerning the CDS market: "If the credit default swap market is reduced to having only hedgers, with speculators banned, hedgers will not find counterparties because the market will have no liquidity [...] Prices cannot be efficient if investors who see profit opportunities cannot exploit them" (ivi, p. 85). Such a fundamental insight is reflected in our perspective on arbitrage, which is fixed in the following "claim" – and sketched in Figure 2.

**Claim 1**. *Arbitrage activity mediates the interaction between CLI and CLI: arbitrageurs explore such interaction in experimenting the feasibility and effectiveness of definite arbitrage strategies. Three stages can be identified*:

**Detection Stage 1**. *Market imbalances show up as nontrivial instances of imperfect market illiquidity. Such instances are spotted and analyzed in order to build CLC – cognition about the constraints to liquidity dynamics that prevent the imbalance from being removed*.

**Engineering Stage 2**. *Building on the cognitive elements established in the previous phase, the arbitrageur engineers ways – CLI about strategies and positions – to exploit the imbalances*.

**Implementation/feedback Stage 3**. *The strategies are implemented and the impact on market imbalances and liquidity conditions is observed; the state of imbalances is reassessed – back to the detection stage – and the loop, possibly, is iterated*.

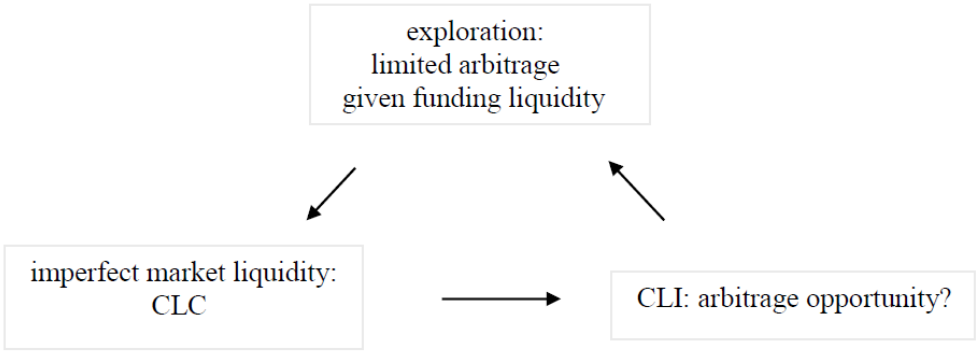


**Figure 2**. The liquidity-arbitrage connection according to C1.

One may conceive of ideal arbitrage (Figure 1) as the *limit* of C1 in which market imbalances reduce to explicit departures from the law of one price (implying a trivial stage 1), and the specific composition

of the arbitrageur's balance sheet is irrelevant for the feasibility and profitability of the arbitrage strategy (implying a trivial stage 2).

The first stage represented in C1 generalizes the somewhat straightforward problem of spotting mispricing in well developed markets (as for twin stocks). In general, market imbalances do not reduce to explicit departures from the law of one price, and rather represent more nuanced situations in which the prices of different instruments are expected to satisfy definite 'equilibrium' relations. Covered interest parity (CIP) is perhaps the clearest setting in which the detection stage reduces to checking a simple equilibrium condition.[9] In general, equilibrium conditions entail definite estimates and assumptions about the state and the dynamics of markets (think of convertible bond arbitrage). It may even be the case that prices may not be well defined for instruments traded in poorly developed markets. That being the case, spotting market imbalance amounts, to some extent, to envisioning potential 'completions' of the market under consideration. Thus, stage 1 represents the process of building CLC about the nature of the imbalances in place, for which we can employ the expression "imperfect market liquidity" – after all, with no imbalance in well developed markets, market efficiency should lead to (approximately) "perfect liquidity".

The second stage involves assessing the expected profitability of (building CLI about) potential strategies and positions meant to exploit the aforementioned imbalances. For standard arbitrage opportunities such problems have been extensively addressed in the literature; for instance, engaging in CIP means assuming definite positions in FX swaps and money – or securities. Still, the key problem that researchers seem to be currently spotting is the 'consistency' of balance sheet management. One can think for instance of convergence arbitrage, in which positions are expected to generate profits in a somewhat undetermined horizon, and their compatibility with the rest of the arbitrageur's balance sheet is at stake in the sustainability of the risks involved (in first instance, liquidity risks, price risks, counterparty risks). The repeated violations of CIP since 2007 (initially for short-term, and then for longer term; see Sushko et al., 2016, and references therein) have stimulated, among other things, a reconsideration of the models of balance sheet dynamics, in connection with the bite of new regulation (e.g. Anderson et al., 2017).

The third stage represents the implementation phase, in which capital is allocated and risks are assumed. The strategy may succeed and imbalances may reduce to some extent; the arbitrageur is (and other market participants may be) in a position to update CLC about the imbalances under considerations. The current debate on CIP seems to be focused on such stage: imbalances in FX US$ hedges seem to represent a persisting force that arbitrageurs are not in a position to overcome (see the proceedings of the Symposium on CIP held at the BIS in 2017).

[9] According to Borio et al. (BIS Quarterly Review, September 2016), CIP is "the closest thing to a physical law in international finance."

*3.1 Motivation*

Evidently, the three stages depicted in Claim 1 (C1) do not represent straightforward 'execution rules' of arbitrage activity. The most uncontroversial fact about concrete arbitrage activity is that it is far from straightforward (witness the spectacular collapse of LTCM in 1998). Therefore, *not all* of the stages depicted in C1 can be straightforward; in our vision, such stages are meant to frame the complexity that arbitrageurs face in their activity. True, we seem to envision a significant consistency between C1 and standard visions on the nature of arbitrage. Goetzmann's interpretation of hedge funds as explorers of the frontiers of markets clearly reverberates in C1, along with the well established role of arbitrageurs of supporting secondary market liquidity and price discovery (e.g. Kenny and Mallaburn, 2017).

In fact, the role of dealers of transporting liquidity from one market to another is the basic intuition that C1 is meant to embody, in connection with the incentives and (potential) constraints which arbitrageurs experiment in their exploration activity. In essence, C1 represents sort of 'learning by doing' which, in the spirit of Soros (2013), we can consider a feedback loop between liquidity cognition and arbitrage activity. In our view, such a loop provides a sound instance of the "coping strategy" approach discussed by Mervyn King (2016).

According to the former BoE governor, both optimizing models and behavioral descriptions provide unsatisfactory representations of empirical economic patterns, on which coping strategies seem to provide a better grip. A coping strategy is one that pursues definite goals with a continuous updating of information and re-modulation of the strategy. The approach economizes on rationality assumptions and computational resources, and its flexibility is meant to enhance its ability to cope with the emergence of unexpected or unpredictable shocks.[10] Such an approach does fit nicely our perspective in which agents build and update cognition about market imbalances and liquidity patterns. It has been argued that liquidity is not an observable variable (Acharya and Pedersen, 2005); true, despite the availability of bid-ask spreads *today* for some type of assets, one can hardly plan a course of action in which future liquidity conditions are estimated at the outset. The relevance of coping strategies in liquidity management seems to emerge quite naturally. With that said, in our view, thinking in terms of coping strategies does not imply disregarding well developed analytical and conceptual building blocks of analysis.

Boyson et al. (2010) provide empirical evidence of the sensitivity of hedge fund performance to large liquidity shocks, and argue that standard models addressing hedge fund returns are not well suited to represent such effects; our approach aims, among other things, to provide conceptual elements for such an inquiry. Needless to say, C1 is not meant to supersede well established visions on the nature and role of arbitrage; rather, it is meant to open a cognitive perspective on such investigations.

[10] The game of Chess represents a clear example of the *necessity* of coping strategies in competitive settings in which no game-theoretic solution concept seems to provide comprehensive guiding lines. True, King (2016) advances the metaphor of the fielder looking at the ball and running in a curve that enables him to catch the ball while still running (ivi, p. 131). One of the authors enjoys playing baseball; we both agree about the soundness of the metaphor.

*3.2 Comprehensiveness*

C1 fixes *a point of view* on arbitrage, which is not meant to be comprehensive. In our view, this is not a weakness of our approach. After all, once we abandon the ideal *sharp* definition of arbitrage, there is an inherently conventional aspect in the definition of *what* arbitrage is. For instance, Mitchell and Pulvino (2012) notice that many arbitrage strategies commonly employed by hedge funds, like convertible debenture arbitrage or merger arbitrage, are not "truly" arbitrage strategies (ivi, p. 470). A similar problem raises in the definition of hedge funds; "you cannot define us, we all do such different things", the saying goes in the industry. This paper is simply meant to argue about the relevance of the point of view expressed in C1.

In particular, C1 is not meant to encompass the arbitrage opportunities connected with different prices for funding liquidity in different unsecured money markets (e.g. Fed Funds and Eurodollars). In fact, in our vision, such an arbitrage opportunity is better represented in the ideal setting depicted in Figure 1.

*3.3 A case study*

The apparent soundness of the above motivations for C1, evidently, does not exhaust our task. The true challenge for C1 is to yield relevant empirical insights concerning arbitrage opportunities in which all the stages represented in C1 happen to display genuine intricacies. The CDS-bond basis trade (largely employed by hedge funds: Mitchell and Pulvino, 2012; Augustin et al., 2014) provides one such phenomenon.

Recall, a CDS is an instrument which protects – hedges – against credit default (typically, of corporate or sovereign bonds). Thus, in first instance, CDSs are meant to enhance the efficiency of credit risk allocations, and, in turn, the beneficial welfare effects of market-based credit. Still, the extant literature has uncovered a number of *incentives* generated by CDS trading that transcend the primitive role of hedging instruments; a number of scholars have been arguing about *interactions* between CDS trading and bond riskiness, nonlinear effects that witnesses the "ambivalence" of the nature of the CDS (Stulz, 2010; Subrahmanyam et al., 2014, and references therein). The role of CDSs in the financial crisis has been investigated (bans have been advocated for CDS trading), as well as the impact of recent regulations (e.g. Dodd-Frank) mandating central counterparties for CDS positions. True, our methodological interest in the CDS-bond basis arbitrage is clearly motivated by the aforementioned quote from Stulz (2010), that emphasizes the role of market liquidity in the CDS market in the efficient pricing of credit risk.

## 4 CDS-bond basis

Evidences about arbitrage opportunities generated by a CDS-bond basis have been the subject of substantial interest over the last decade (e.g. Duffie, 2010; Mitchell and Pulvino, 2012; Augustin et al.,

2014), meant to motivate the widening of the basis into negative territory since the 2007 crunch, with the trough at the turn of 2008 (Figure 3).

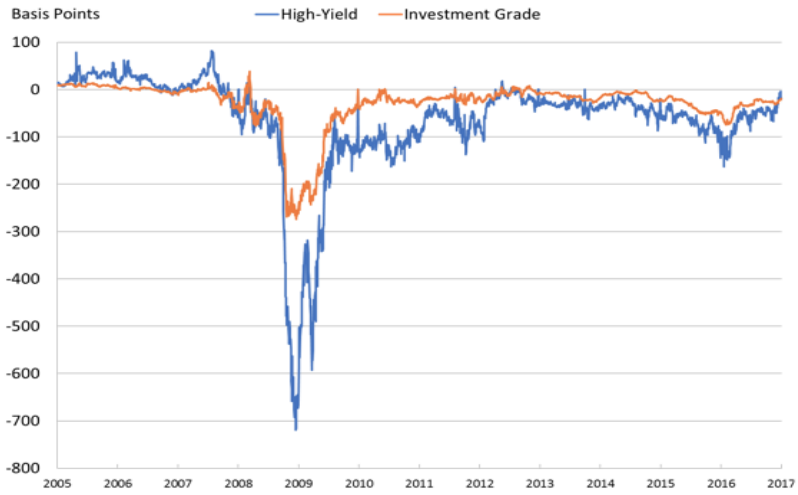


**Figure 3**. The CDS-bond basis for high yield and investment grade corporate bonds, as reported by Adrian et al., "Market liquidity after the financial crisis." VOX. CEPR's Policy Portal. September 14, 2017.

Early investigations of the phenomenon have been emphasizing the various stresses to which market participants have been subject after the credit crunch. More recently, the bite of new regulations have been discussed. Deleveraging activity has been conjectured to influence the widening of the basis, but such interpretations have been challenged (see Augustin et al., 2014, and reference therein). Anecdotal evidence witnesses that a slightly positive basis is typical of normal times, whereas a negative basis is generated in times of stress; true, the short history of the phenomenon[11] is an issue: the maturation of markets and cognition thereof, arguably, should be reflected in time series. It has been conjectured that debt financing risk has a role in both driving the base towards negative territory, and limiting the ability to arbitrage it (Mitchell and Pulvino, 2012; Augustin et al., 2014).

In fact, a CDS-bond basis is conventionally interpreted as a signal of arbitrage opportunities, somehow on the same footing as the existence of a CIP basis. Still, the two phenomena display significant differences. On the one hand, the CIP condition reflects the somewhat intuitive requirement of equal returns on securities that differ *only* in their denomination; as such, CIP represents an equilibrium condition for 'explicit' market prices (interest rates and exchange rates). Notice, conceptually, CIP admits a deterministic limit (perhaps, a dynamic general equilibrium benchmark) in

[11] The first CDS seems to have been negotiated between JP Morgan and the European Bank for Reconstruction and Development in 1994; see Augustin et al. (2014).

which the interest and exchange rates embed no risk component. On the other hand, no such deterministic limit can be found for the CDS-bond basis, since the vanishing of default risk makes the CDS collapse to worthlessness, leaving us with no equilibrium condition for the prices of the instruments under consideration. The requirement of consistent pricing of credit risk across cash and synthetic instruments for sure represents, in the words of Nashikkar et al. (2011), a "strong economic relationship"; still, such a relationship cannot be represented as a closed form formula for explicit market prices. This is the fundamental element of complexity of the CDS-bond basis phenomenon that our approach is meant to target.

As is well known, different ways to define the CDS-bond basis have been discussed, reflecting different points of view on the *interaction* between the price of the bond and the price of the CDS. A credit risk model can be used to price both instruments, but the specificity of the model may turn into a weakness of the results. In order to make the bond spread 'more comparable' with the CDS spread, a "par equivalent" CDS spread can be derived so as to account for the term structure of CDS default probabilities and recovery rates (see Augustin et al., 2014, and references therein), and thereby straighten the logic of consistent pricing of default risk by deriving an equilibrium condition for 'implicit' prices of the instruments involved. This is where the role of market liquidity comes to the fore: the 'explicit' market prices of the bond and CDS embody distinct 'implicit' valuations of the credit risk of the bond issuer; unfortunately, "imperfect" market liquidity can distort such valuations, as clearly stated in the aforementioned quote by Stulz (2010). Our interpretation (subsection 4.2 below) of the empirical analysis set forth by Nashikkar et al. (2011; "NSM" henceforth) is meant to argue about the effectiveness of our recipe C1 in representing such problems. Before that, let us resume some of the common wisdom about the phenomenon.

*4.1 Investigations*

The cost of shorting bonds represents a firm pillar of the inquiry about the CDS-bond basis. "Agents participating in the CDS market and the corporate bond market may have different valuations for the credit risk of the obligor. However, arbitrageurs who try to profit from this difference may find it difficult to sell corporate bonds short because of limited supply in the borrowing and lending markets for corporate bonds. Thus, illiquid corporate bonds of firms with greater uncertainty are more likely to be expensive relative to their CDS contracts" (NSM, p. 629). In fact, a CDS-bond basis is typically considered to embody a premium for liquidity, among other nondefault-related components of the yield spread. This is a pivotal point for our application of C1 to the CDS-bond basis arbitrage, in that the aforementioned liquidity premium, which is not represented directly by market prices, reflects the market imbalances ("imperfect market liquidity") that the arbitrageur is meant to detect in the first stage of our recipe.

In an ideal market, the spread on a CDS written on a single company should coincide with the risky bond yield spread of a par floating note in excess of the appropriate risk-free rate. Duffie (1999)

provides a landmark model of such a benchmark valuation in which market liquidity is "perfect". Subsequently, a blossoming literature has been addressing the pricing problem in terms of structural or reduced form models (for a review, see Augustin et al. 2014). Longstaff et al. (2005) set forth a landmark reduced form model in which illiquidity does *not* affect CDS prices. This crucial assumption connects with the insight by Stulz (2010) discussed at the end of the previous section, in that it represents, so to say, the "perfect CDS liquidity" benchmark.

The liquidity of CDS markets, true, is not perfect. Augustin et al. (2014) review a number of contributions addressing the limited liquidity of CDS markets, some of which find evidences that liquidity is priced, and that higher illiquidity entails higher CDS spreads. Such evidences, evidently, do not undermine the relevance of the approach set forth by Longstaff et al. (2005), that posit, so to say, a 'top-down' approach in which an ideal arbitrage pricing benchmark (the 'top') frames the effects of definite distortions ('down' the road). In fact, a 'bottom-up' approach seems to be gaining momentum in recent accounts of the feasibility and effectiveness of definite positions in reaching for the arbitrage profit.

A 'bottom-up' approach can be envisioned in the optimization model advanced by Gârleanu and Pedersen (2011). The Authors model the contingent bite of margin constraints on the ability of dealers of assuming positions. The bond plus CDS positions meant profit from the corresponding basis suffered from the increase in margins that occurred since 2007, which provide convincing justification for the pattern represented in Figure 3. The Authors notice that the higher yield spread on the bond is justified by the lower capital required by a CDS position, so that the lower yield of CDS may represent a similar return per use of margin capital.

We do agree with the relevance of the effects depicted by Gârleanu and Pedersen (2011); still, as already pointed out, our focus is the ability of dealers to transport liquidity from one market to another, a problem which does not reduce to (albeit important) margin constraints. On top of that, our stylized arbitrageur is not meant to be an optimizer but an *explorer*. An optimizer has perfect cognition of the environment; concrete dealers have limited cognition of the system – and researchers as well, witness by the methodological improvements in empirical analysis advocated by Adrian et al. (2017). Despite the correctness of the incentives and constraints represented, optimization models may have less than firm a grip on the elusive problems connected with the evolution of liquidity (see Dudley, 2015). Interestingly, with respect to our coping strategy approach, the empirical analysis set forth by NSM seems to provide genuine insights on the cognitive problems embedded in the markets under inspection.

The Authors employ a dataset ranging from July 2002 to June 2006, prior to the crisis. One could argue that the phenomenology thereby represented may be scarcely interesting for the analysis of the market instabilities at the roots of the recent crisis and the time series represented in Figure 3. We feel somewhat immune to such criticism. The physiology of markets does not reduce to responses to dramatic shocks. In our monetary perspective, the physiology of markets – in particular OTC markets –

is triggered by the "dealer function" (in the sense of Treynor, 1987), which gauges the response of dealers to the price and liquidity risks generated by their positions. These effects represent ordinary problems that get exacerbated in a downturn, but whose proper assessment in ordinary activity seems to represent a hotspot of current research. In fact, our interest in the empirical analysis set forth by NSM is driven primarily by their methodological approach, which, in our view, leads the Authors to ask the right questions concerning the importance of market liquidity and its interaction with the price of risk. It is the aim of the following subsection to interpret the empirical analysis set forth by NSM in terms of our framework.

*4.2 The tree stages*

The first (detection) stage of our recipe C1 calls in first instance for an assessment of the basis, which is typically considered to gauge the very existence of arbitrage opportunities. NSM estimate the basis as the difference between the actual CDS spread (with respect to the US$Libor curve) and the hypothetical spread of a hypothetical CDS contract at par that has the same default risk and recovery rate. The basis, we already know, is slightly positive in the period 2002-2006 under consideration. True, beyond the basis, our step 1 is meant to enlighten the *nature* of (potential) market imbalance; interestingly NSM in fact engage in assessing the liquidity properties of both bond and CDS markets.

The market for corporate bonds is well known to be illiquid, and therefore somewhat challenging to characterize on statistical grounds. Still, differentiating bonds with respect to their (though, low) liquidity turns out to be instructive in the vision of NSM. The Authors adopt the "latent" measure of bond liquidity (introduced by Mahanti et al., 2008), which does not require large statistics – it does not reflect directly transaction volumes and costs – and rather embodies the weighted average turnover of the investors holding the bond. As such, latent liquidity reflects the vision of a typical sell-side dealer of liquidity as *accessibility* of a bond to market participants. Evidently, such a focus on concrete market allocations does fit nicely our approach to the cognitive problems faced by arbitrageurs in investigating under the surface of market prices. True, Mahanti et al. (2008) acknowledge the connection between the latent liquidity gauge and transaction costs; according to NSM, latent liquidity provides a direct measure of the search frictions which impinge on bond trade (see for instance Vayanos and Wang, 2007).

As concerning the liquidity of the CDS market, the Authors measure both standard and percentage bid-ask spreads (i.e. bid-ask normalized to CDS mid-price). Such measures reflect a different role for transaction costs; using both measures enables NSM to build a deeper cognition of CDS liquidity (the Authors notice for instance that the percentage bid-ask spread may fail to detect potentially important relationships between CDS spreads and liquidity). From our monetary perspective, the Treynor model (1987) provides sharp insights on the incentives which drive both mid-price and the bid-ask spread, thereby supporting the choice of addressing *both* standard and percentage bid-ask.

The aforementioned empirical assessment of bond and CDS liquidity represent key elements of the cognition – CLC – which stage 1 should convey to stage 2 of our recipe. The second stage, recall, is meant to address – build CLI about – the feasibility and profitability of definite arbitrage strategies. In such respects, a really challenging point is made by NSM, namely, the conjecture that "the liquidity premium of a bond is determined not only by *actual* trading activity in the bond […] but also by […] *potential* trading activity, as proxied by the latent liquidity measure" (ivi, p. 644). The empirical justification of such a conjecture is the main motivation of our interest in such paper. Our point is not to plea in favor of such a conjecture. Our point is to argue that NSM ask the data the right questions, among which the latent gauge of market liquidity, which reflects the accessibility of a bond to market participants. For instance, the Authors find evidence that older bonds have poorer latent liquidity. All in all, the interest in market allocations which informs NSM seems to fit nicely our perspective on the cognitive problems faced by concrete arbitrageurs.

Then, the cognition – CLC and CLI – built in the previous stages enables the Authors to investigate liquidity *spillovers* from the CDS market to the bond market. Such spillovers have been clearly emphasized in the recent literature (see also Augustin et al., 2014, p. 58), given that the CDS market is more liquid than the bond market, and that the pricing of credit risk is affected by such liquidity conditions (recall the aforementioned quote from Stulz, 2010). NSM find that bonds of issuers whose CDS contracts enjoy greater liquidity tend to have lower yields in the cross section compared with less liquid correspondents. Thus, overall, "the CDS market leads the corporate bond market" (ivi, p. 631).

This point is crucial on both the empirical grounds treaded by NSM and the conceptual stance which underlies our recipe C1, in which arbitrageurs are meant to transport liquidity from one market to another. "When the CDS contract is less liquid, the bonds themselves tend to be less liquid" (ivi, p. 642). This conclusion represent a crucial element for stage 3 of our recipe, in conjunction with the argument that the CDS-bond basis may reflect the liquidity of the corporate bond *relative* to the liquidity of the corresponding CDS (ivi, p. 638). The Authors conclude that the CDS spread does not account comprehensively for the riskiness of the bond; the limited arbitrage activity seems to represent a natural factor for such a distortion.

To sum up, our recipe C1 does fit substantially the conceptual stance employed by NSM. Needless to say, there is more to the CDS-bond basis than discussed by NSM. For instance, the role of funding liquidity has been pointed out among the elements in the analysis of the CDS-bond basis (see Adrian et al., 2017). Augustin et al. (2014) argue that among the reasons for the widening of the CDS-bond basis amid the crisis one should consider the instability of financing connected with rehypothecation lenders (see example 5 above, subsection 2.1). Still, our recipe seems to provide a cogent approach to the empirical investigation of the limits of arbitrage, in particular concerning the function of transporting liquidity from one market to another. The theoretical – monetary – stance of our approach is the subject of the following section.

## 5 Safe assets and cognition

A recent strand of literature addresses the relevance of safe assets for the current global scenario. Gorton (2017) tailors an historical perspective on the demand for safe assets and points out that, starting from the late 1970s, "the U.S. financial system underwent a significant transformation in which the role of demand deposits declined dramatically and short-term wholesale funding became very sizeable and important" (ivi). An evolution of financial phenomena has taken place in which the relevance of the information insensitiveness of (the value of) safe assets has been steadily increasing – the expression *no questions asked* ("NQA") has been recently introduced – resulting in the pre-crisis system built around market liquidity (BdF, 2008) and shadow banking (Mehrling et al., 2013). The interest in the characterization of such processes is connected with the apparent current *scarcity* of safe assets.

Caballero et al. (2017) notice that the production of safe assets has been historically confined to a small number of advanced economies, and that over the last decades the rate of such production has not kept pace with world growth. In addition, recent unconventional monetary policies have been reducing the amount of safe assets in circulation (see also Singh, 2017). The case for a theoretical reconsideration of the relevance of the scarcity of safe assets in the current rethinking of monetary economics and policy is advocated by Andolfatto and Williamson (2015). It has been argued that financial engineering may foster the supply of safe assets (see Caballero et al., 2017). Proposals to financial engineer safe bonds representing the overall fiscal potential of the Eurozone have been discussed by Brunnermeier et al. (2017) and Minenna and Aversa (2018). Evidently, it is not the aim of this section to provide a satisfactory account of the profound arguments set forth by such contributions. We shall simply try to argue that the (monetary relevance of the) scarcity of safe assets represents, so to say, the flip side of the (monetary relevance of the) cognitive role of arbitrageurs of exploring and extending – for profit – the liquidity of markets. On the one hand, with respect to our cognitive notions, safe assets are *trivial*, i.e., liquid by construction. On the other hand, in general, the liquidity of assets is contingent on the capacity of dealers, and arbitrageurs in particular, of making markets according to C1. It is our aim to argue that such a dichotomy represents a current (perhaps, not explicitly stated) line of progress of monetary economics.

As already pointed out, the cornerstone of our approach is a reconsideration of the principle $P_0$: financial frictions give rise to the value of money and arbitrage. It is somewhat natural to embrace safe assets in such a perspective, on account of their money-like nature; it is not that straightforward to appreciate the monetary relevance of the dichotomy between the supply of market liquidity that results from market-making activity and the supply of 'inherently' liquid (safe) assets. In Kurlat's (2018) model, market liquidity is a property of the system, not of single securities potentially subject to trade; quite on the contrary, the market liquidity of safe assets is meant to be independent of market conditions. Such a dichotomy tailors a sharp monetary stance for our recipe C1.

Mantovi (2018) addresses the macroeconomic relevance of the monetary dimension of arbitrage, in connection with the role of arbitrageurs of interacting with financial frictions. The present contribution is meant to focus the microeconomic aspects of such interaction, which pertain to the incentives and constraints that impinge on such an interaction. The point is that the precise features of the incentives to liquidity management and transformation, and the related potentially emerging liquidity constraints, are simply not there for all to see: it takes *cognition* about such problems to undertake arbitrage activity, as well as to provide a representation of such problems for academic or policy purposes. The current theoretical literature on the limits of arbitrage, in essence, is meant to sharpen such cognition. Our qualitative approach, which builds on the "coping strategy" recipe discussed by King (2016), is not meant to substitute current analytical approaches (e.g. Gromb and Vayanos, 2018; Kondor and Vayanos, 2018), but rather to complement them by a simple conceptual framework. The discussion in the previous section seems to witness the empirical soundness of our approach.

In the words of Gorton (2017), when there are not enough Treasuries, the private sector produces substitutes, making the economy more fragile. It is somewhat natural, then, to conjecture that a 'physiology' of the financial system should prescribe some sort of 'balance' between I) the supply of safe assets and II) the function of intermediaries of transforming (e.g. securitizing) and marketing (brokering and dealing) the liquidity of assets in general. It may be difficult to pin down the precise terms of such a conjecture; still, arguably, on purely methodological grounds, one should pin down the *objectives* with respect to which such functions (I and II) con be considered "substitutes" or "complements", a task for which our recipe C1 may provide clear insights. Krishnamurthy (2010) tailors a twofold analytical framework for representing the mechanisms thorough which liquidity spirals amplify in a market downturn; our approach posits that the twofold framework envisioned by Krishnamurthy (on the one hand, "balance sheet mechanisms", on the other hand, "information mechanisms") provides a sound basis for envisioning a twofold framework (CLC and CLI respectively) for addressing the cognitive problems raised by liquidity transformation and market-making.

According to Andolfatto and Williamson (2015), recent monetary phenomena, for instance, the disconnect between monetary aggregates and price levels, invite us to revise our views about the nature of money and the role of collateral. In such respect, our perspective on the monetary dimension of arbitrage is meant to provide a simple conceptual scheme. Financial frictions give rise to the value of money and safe assets, which are liquid by constitution, and then, (allegedly) cognitively trivial. Correspondingly, financial frictions give rise to the value of market-making arbitrage activity: arbitrageurs support market liquidity and gain cognition about (and in fact assume onto their balance sheets) the risks involved in such activities. The current debate on monetary theory and policy seems to revolve around a 'balance' for such dichotomy (for which the hierarchy of money-and-security dealers envisioned by Mehrling, 2012, seems to provide an insightful framework).

Some three decades ago, Amihud and Mendelson (1986) wrote that "the role of liquidity in capital markets is hardly reflected in academic research." This is no more the case. In particular, the relevance of dealers' (long and short) positions in money for the liquidity of capital markets is by now (after the great financial crisis!) well established. It has been long appreciated that the formation of prices and the dynamics of allocations in secondary financial markets can hardly be described in terms of a fictitious walrasian auctioneer that drives the market towards an "equilibrium" in which money does not matter. Positions in money and securities are, to a large extent, functional to trade capacity; in the words of Pozsar (2014), money dealing activities are about the provision of working capital for asset managers. It is quite undisputed by now that *money matters* in secondary financial markets; still, a comprehensive analytical representation of *the way* money matters seems not to have achieved as yet a satisfactory status; the current analytical approaches to the limits of arbitrage (e.g. Kondor and Vayanos, 2018) can be considered a major line of progress in such a direction, with substantial relevance for the analysis of the transmission mechanisms of monetary policy, which depend crucially on the way arbitrageurs (and dealers in general) transport liquidity from one market to another. It is well known that supplying market liquidity is both risky and costly. No questions asked for safe assets; asking *the right questions* – an essential function of arbitrageurs – is the aim of our recipe C1.

## 6 Conclusions

It was the aim of the previous sections to tailor a representation of arbitrage activity in connection with the cognitive aspects of liquidity problems that have been repeatedly pointed out over the last decade. Our theoretical stance builds on the role of dealers of transporting liquidity from one market to another. From such a standpoint, we have represented arbitrage as a "coping strategy" (in the sense of King, 2016) meant to detect market imbalances connected with 'imperfections' in market liquidity, envision the feasibility and potential profitability of definite strategies meant to exploit such imbalances, and finally get feedback from the implementation of such strategies. Our conceptual recipe should sharpen the sense in which, in the words of Caruana and Kodres, liquidity is created and maintained by market participants themselves (BdF, 2008, p. 65).

According to Dudley (2015), we need to "better understand the degree to which any changes in the nature of liquidity reflect the evolving structure of financial markets, changes in regulatory power or other factors." According to Adrian et al., (2017), the methodological aspects of the empirical analysis of bond liquidity provision is undergoing a transition phase, in which attention is shifting towards the link between the structure of the dealer's balance sheet and the capacity of liquidity provision. This is exactly the spirit of the current theoretical advances on the limits of arbitrage (e.g. Gromb and Vayanos, 2018, Kondor and Vayanos, 2018), whose aim is to provide analytical frameworks for the representation of the arbitrageur's incentives and constraints in intertemporal optimization settings. Our recipe aims at envisioning the role of incentives and constraints in settings in which the

arbitrageur is not an optimizer, but rather an agent that explores the environment in search of feedback. This is not, evidently, to dismiss optimization approaches; among other things, our approach aims at providing sort of 'preliminaries' for the definition of optimization models. Asking the right questions seems to be the aim of the empirical analysis on the liquidity of bond markets set forth by Nashikkar et al. (2011). Asking the right questions as well is the aim of our recipe.

Mehrling et al. (2013) envision a critical feature of contemporary market arrangements in the promises to buy in case someone else doesn't buy. Such a truly profound insight points at the systemic feature of market liquidity. Correspondingly, we seem to envision a critical feature of the inquiry on the limits of arbitrage in the three stages of liquidity cognition and experimentation depicted in Figure 2. The systemic procyclic character of liquidity dynamics reverberates in all such steps, and may provide sharp conceptual elements to the current investigation of the impact of new regulation on the capacity of dealers of supplying liquidity in bond markets (see Adrian et al., 2017).

As pointed out by Acharya and Pedersen (2005), liquidity is not an observable variable (ivi, p. 385). According to Kurlat (2018), market liquidity is a property of the system. In a sense, liquidity is an "illusion" (King, 2016, p. 253). For sure, liquidity is a *complex* problem. Our approach is meant to deepen the cognitive problems raised by such complexity, which critically affect the ability (and, in fact, the desire itself) of arbitrageurs, and dealers in general, of confronting market imbalances. Our differentiation between cognition about liquidity constraints and incentives seems to provide convincing insights on the methodology employed by current theoretical and empirical investigations about liquidity dynamics, at least according to the examples discussed in subsection 2.1.

A growing literature is addressing the explicit analytical representation of the specific balance sheet mechanisms involved in the generation of limits of arbitrage (e.g. Gromb and Vayanos, 2018; Kondor and Vayanos, 2018). Then, theoretical lines of progress for our approach may pertain to the explicit analytical representation of the insights be have been pursuing. Still, our approach is meant in first instance to define a *logic* for the investigation of the limits of arbitrage. As such, our recipe should be considered a preliminary level of analysis, meant to *inform* theoretical and empirical investigations concerning limits of arbitrage and the causal links between recent regulation and market liquidity (which, according to Adrian et al., 2017, rank high in the research agenda of applied economists) or the structural changes brought about by the crisis (e.g. Cagliesi et al., 2016). With that said, it is quite engaging to imagine that progresses in the understanding of the limits of arbitrage may help envision ways of reducing substantially the impact of financial downturns on income and wealth distributions.

Shiller (2014) advocates the emergence of markets for claims on the flows of gross domestic products and other macroeconomic aggregates, arguing that such markets would help countries share their risks. At a micro level as well, according the Nobel laureate, financial innovation may help improve the stability of income distributions (with people hedging themselves in occupational markets). Making markets for such claims means having dealers trading such claims with finite capacity of absorbing market imbalances. Along such perspectives, hopefully, our approach to the

limits of arbitrage may turn out to define sound building blocks of analysis. In fact, the impact of "radical uncertainty" discussed by King (2016) makes it difficult for prices to drive markets towards equilibrium, since, to put it simply, "there are too many missing markets" (ivi, p. 301).

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