Systemic Risk : Modeling and Measurement

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***Abstract*— This article offers a new conceptual framework for modeling and measurement of systemic risk factors at individual institutions level. The empirical results show that, there are strong negative correlations between domestic futures market with systemic risk factors. Domestic futures exposed to systemic risk. Further research should take into account such international risk exposure.**

***Index Terms*—Commodity futures, expectation, systemic risk, systemic risk factors**

I. Introduction

THERE is widespread increasingly concerns about systemic risk, about the causes, measurement and regulation of systemic risk, and uncertainty about how to control it.

On the other hand, neglecting systemic risk in the existing pricing models was indeed in common practice.

For example, commodity futures pricing models are dependent on the underlying factors assumed and the stochastic processes they followed. The underlying factors inside the model are usually specified as known. For example, spot price and convenience yield are two important variables in commodity futures pricing model [1].

However, in reality, neither the futures pricing model, nor the underlying factors are known. These problems are even more complex in emerging markets. There is neither evidence nor consensus regarding which factors are best for explaining the behaviour of the domestic futures markets in developing countries such as China.

This immediately led to the question whether these no-arbitrage based models, built on international developed markets, can be used in the current sovereign debt crisis without necessary modification.

Systemic risk is the dominant risk in the current sovereign debt crisis, therefore central to the commodity futures pricing models.

This article offers a new conceptual framework for modeling systemic risk factors and measurement of systemic risk exposure at institutions level. We take it as a first step to lay the microfoundation for financial stability.

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In our view, the potential systemic risk rooted in current global financial system, which is characterized by international monetary systems : the dollar, the euro, and the constantly expansion monetary policy of central banks.

Consequently, systemic risk focuses on risks to the international financial system, such global impact are systematic at first, soon or later may be systemic .

In this paper, we define systemic risk as sets of important factors on international financial system, which cannot be diversified away and therefore affects most market participants.

Neglecting in such factors at the individual institution level may significantly underestimate systemic risk .

Therefore, institution level systemic risk factors identification and measurement have a important role in reducing systemic risk.

Key questions include : Which factors are main risks to the global financial system ? How market participants measure and respond to such global risk exposure ?

Current researches focus on direct spillover effects such as counterpart credit risk. The study of systemic risk requires also the study of indirect spillovers that occur through markets prices [2] .

II. Literrature Review

The current literature on systemic risk can be split into several related concepts.

First, systemic risk may be understood as the risk of experiencing systemic events, and the heart of systemic risk are contagion effects or various forms of external effects [3].

Similarly, systemic risk may be defined as the risk that an economic shock triggers either the failure of a chain of markets or a chain of significant losses to financial institutions [4].

Second, systemic risk may arise as common exposures to macroeconomic risk factors across institutions [5].

Third, systemic risk contribution, corresponds to a negative externality associated with a financial institution, focuses on how an individual bank contributes to systemic risk [6].

There are at least two types of systemic risk, the first type of systemic risk is financial shock causes a set of markets or institutions fail to function simultaneously, the second type is the failure of a financial institution will be transmitted to others due to linkages among them [7].

In a word, systemic risk focuses on risks to the financial system [4]. Systemic risk is the risk faced by the financial system as a whole [8].

Consequently, an alternative definition is : systemic risk involves risk that arises because of the structure of the financial system and interactions between financial institutions [9]. This definition of systemic risk will underlie

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the analysis in the remainder of this article. But we stressed the importance of an international perspective.

From the above definition, at least three factors identified contribute to systemic risk : fractional reserve banking, tendency for institutions to engage in correlated strategies and network externalities [10].

Furthermore, due to lack sufficient incentive, absent regulation, systemic risk may results from the actions of market participants [11]. In turn, market participants' actions depend on their perceived risk.

In general, from an international perspective, the risks impacting financial system are attributable to the international monetary systems, constantly expansion monetary policy of central banks, fractional reserve banking, correlated actions of market participants.

Market participants' actions depend on their perceived risk or expectation, such considerations lead to the use of methods that explicitly address the expectation formation.

Our work is related to two research directions in the literature. First, we relate to the work on system risk identification . Another research interest relates to the work is the construction of systemic risk measures.

We show that these system risk concepts can be extended to expectation models in the form of Ito processes, which we modeled system risk as a derivative product of such risk factors.

III. Modeling of Systemic Risk factors

Let x_i indicates the unobserved (or observed) systemic risk factors identified by financial institutions. For example, this could be the mispricing in some assets markets, the leverage of the financial system as a whole, or credit default swaps index.

We denote the risk measurement of the entire financial system as a function of these systemic risk factors : $F(x_1, x_2, x_3, ..., x_k, t)$.

Once the systemic risk function $F(x_1, x_2, x_3, ..., x_k, t)$ defined and risk factors identified, we can construct measures of systemic risk exposure.

The main idea is to model the potential systemic risk factors as stochastic processes, and take the complex interactions among these risk factors as a kind of derivative product.

Assume that systemic risk factor x_i follows the Itô process :

$$dx_i(t) = \mu(x_i, t)dt + \sigma(x_i, t)dW(t), \tag{1}$$

where W(t) is the standard Wiener process, $\mu(x_i,t)$ is the instantaneous drift and $\sigma(x_i,t)$ is the instantaneous volatility.

Assuming $F(x_1, x_2, x_3, ..., x_k, t)$ is twice continuously differentiable function of x_i and t.

By Itô's lemma, we have

$$dF(x_1, x_2, x_3, ..., x_k, t) = \frac{\partial F}{\partial t} + \sum_{i=1}^{k} \frac{\partial F}{\partial x_i} dx_i + \sum_{i,j=1}^{k} \frac{\partial^2 F}{\partial x_i \partial x_j} dx_i dx_j . \tag{2}$$

If $F(x_1, x_2, x_3, ..., x_k, t)$, $\mu(x_i, t)$ and $\sigma(x_i, t)$ are known functions, we can easily measure the changing of systemic risk using time series observations.

However, in general, both $F(x_1, x_2, x_3, ..., x_k, t)$, $\mu(x_i, t)$ and $\sigma(x_i, t)$ are unknown : they are about movements of potential systemic risk factors.

In order to solve the problem, we propose to apply an expectation oriented approach, which is borrowed from the standard derivative pricing approach under complete information. However, the underlying economic mechanisms are quite different.

For simplicity, as a first step, the financial institution's subjective expectation model on systemic risk may be constructed below:

$$F(x_1, x_2, x_3, ..., x_k, t) = \Pi x_i^{\alpha_i}. \tag{3}$$

The expectation function considered here is to model the comprehensive impact created by a set of risk factors (x_i) identified .

Here, the expectation function F(.) is not a derivative asset in the usual sense, it is a subjective expectation to be verified.

Systemic risk factors (x_i) identified may be known to the financial institution, but the systemic risk function F(.) and parameters (α_i) are unknown to be determined.

Clearly, there is no partial differential pricing equation existed with such unknown functions. The final pricing formula is completely different and still unknown.

Because

$$\frac{\partial F}{\partial x_i(t)} = \frac{\alpha_i F}{x_i(t)},$$

$$\frac{\partial^2 F}{\partial x_i(t) \partial x_j(t)} = \frac{\alpha_i \alpha_j F}{x_i(t) x_j(t)}. \tag{4}$$

$$\frac{dF}{F} = \sum \frac{\alpha_i dx_i(t)}{x_i(t)} + \frac{1}{2} \sum_{i,j=1}^{k} \frac{\alpha_i \alpha_j}{x_i x_j} dx_i dx_j . \tag{5}$$

$$r_F = \sum_{i=1}^{3} \alpha_i r_{x_i} + \frac{1}{2} \sum_{i,j=1}^{k} \alpha_i \alpha_j r_{ij} . \tag{6}$$

$$r_F \cong \frac{dF}{F}, r_{x_i} \cong \frac{dx_i(t)}{x_i(t)}, r_{ij} \cong \frac{dx_i dx_j}{x_i x_j}. \tag{7}$$

With such subjective systemic risk function, we can measure the changes in systemic risk as a linear combinations of changes in risk factors and their interactions (6).

More important , with such defined systemic risk function we can measure the systemic risk exposure of financial institution.

IV. Measurement of Systemic Risk Factors

To demonstrate this methodology for systemic risk factors identification and measurement, we carry out an correlation analysis on the daily returns on the China commodity futures markets with potential risk factors.

According to our experience, three international factors are taken as potential systemic risk factors to China

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commodity futures markets : the risk from US Dollar, the risk from European Sovereign Debt Crisis, investor sentiment to these factors.

The U.S. Dollar Index (USDX) is an index of the value of the United States dollar relative to a basket of foreign currencies. We choose USDX as a measure of potential systemic risk resulting from Federal Reserve's expansionary monetary policy .

The CBOE Volatility Index (VIX), conveyed by S&P 500 stock index option prices, is considered to be a measure of market expectations and investor sentiment .

Five year sovereign credit default swaps (CDS), priced in spread (premium payment/year), are considered to be measure of sovereign credit risk. CDS data include Portugal, Italy, Ireland, Spain, German, France and UK.

We use data from domestic and corresponding international futures market : gold, copper, aluminium futures prices series of Shanghai Futures Exchange (SHFE), copper, aluminium futures prices series of London Metal Exchange (LME), cotton and sugar futures prices of Zhengzhou Commodity Exchange (ZCE) and IntercontinentalExchange (ICE), gold futures prices series of COMEX .

All of above data are taken from bloomberg.com, corresponding spot markets data are taken from fuyoo software (www.fuyoo.net). The data used consist of daily observations, ranging from 9/15/2011 to 11/25/2011, and calculated as daily returns .

Fig.1 plots the 5 year sovereign credit default swap spread time series . These CDS series exhibit a similar pattern. We may use one of them as a proxy of sovereign credit risk, for example, CDS of Portugal.

First, to demonstrate sovereign CDS, USDX and VIX are risky factors, as we anticipated, table I exhibits the high negative correlations on the daily returns between gold futures with these factors.

Table I I exhibits the high correlations on the daily returns between sovereign CDS series with the other risky factors considered : USDX and VIX.

Because of these similar high correlations among them, for simplicity, we use a simple two factor (USDX and VIX) model as a approximation for the three factor risk model (sovereign credit, USDX,VIX) in the follow analysis.

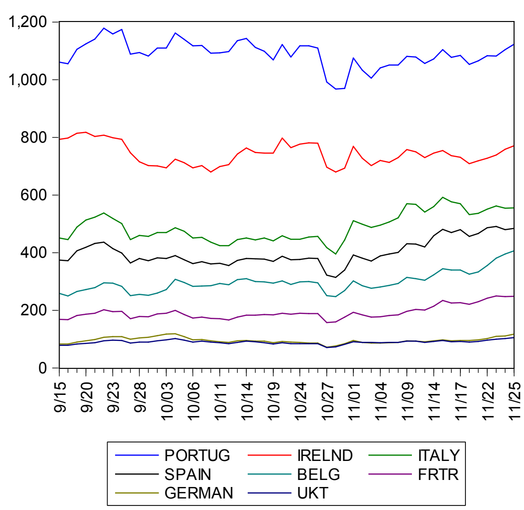

Fig. 1. 5 year sovereign credit default swap spread time series .

TABLE I
CORRELATIONS BETWEEN GOLD FUTURES AND RISK FACTORS

	SHFE_gold	COMEX_gold
SHFE_gold	1	0.741218
COMEX_gold	0.741218	1
VIX	-0.30886	-0.34545
USDX	-0.29792	-0.48169
portugal	-0.06836	-0.34297
italy	-0.06259	-0.27404
ireland	-0.02109	-0.28265
german	-0.22912	-0.44399
france	-0.16998	-0.40969
uk	-0.19141	-0.41913

Furthermore, if USDX and VIX are systemic risk factors, they should affect all assets markets, including commodity futures markets in China.

Therefore, by systemic risk function defined in (3), (6) suggests we can observe more influence in these factors on commodity futures returns than traditional factors, such as spot market prices, convenience yield .

As we expected, table III witness the highly negative correlations between the daily returns of SHFE copper futures with the systemic risk factors.

First, both domestic spot market and international futures market (LME) play little role in the SHFE copper futures market, but international futures market (LME) has a great influence on the copper spot market in China.

Second, systemic risk factors (USDX and VIX) may have influence on LME copper futures, but they give a great influence on the SHFE copper futures market, which can not be resulted in transmission from these factors to LME copper futures. This suggests that systemic risk factors affect domestic copper futures market directly.

These results are supportive of our hypothesis : highly negative correlations suggests USDX and VIX are systemic risk factors to domestic futures markets .

To further verify our intuition, we examine whether the same pattern existed in domestic aluminium futures market from SHFE (Shanghai Futures Exchange) and cotton and sugar futures markets from ZCE (Zhengzhou Commodity Exchange).

As we anticipated, Table IV, V and VI exhibits the high negative correlations on the daily returns between the domestic futures markets with the systemic risk factors.

TABLE II
CORRELATIONS BETWEEN SOVEREIGN CDS WITH USDX VIX

	USDX	VIX
Portugal	0.606016	0.415058
Italy	0.726438	0.636026
Ireland	0.560551	0.406886
Spain	0.739324	0.606447
German	0.770556	0.579924
France	0.765113	0.571726
UK	0.768953	0.560888

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TABLE III
CORRELATIONS BETWEEN COPPER AND RISK FACTORS

	SHFE_copper	spot_copper	LME_copper
SHFE_copper	1	-0.01506	0.021303
spot_copper	-0.01506	1	0.753398
LME_copper	0.021303	0.753398	1
VIX	-0.49715	0.047269	-0.12306
USDX	-0.46461	-0.03395	-0.17093

TABLE IV
CORRELATIONS BETWEEN ALUMINUM AND RISK FACTORS

	SHFE_aluminum	spot_aluminum	LME_aluminum
SHFE_aluminum	1	0.098656	0.318307
spot_aluminum	0.098656	1	0.008704
LME_aluminum	0.318307	0.008704	1
VIX	-0.44294	0.113127	-0.64521
USDX	-0.38924	-0.03058	-0.7029

Contrary to the SHFE copper futures market, table IV exhibits the highly negative correlations between LME aluminium futures with the systemic risk factors. This suggests another complex pattern existed in SHFE aluminium futures market : systemic risk factors may affect domestic futures market both directly and indirectly (systemic risk factors affect international futures market, international futures market affects domestic futures market).

Table V exhibits a similar pattern existed in ZCE sugar futures markets, however, international futures market (ICE) has a great influence on domestic futures market than systemic risk factors.

Table VI exhibits the same pattern existed in ZCE cotton futures markets : systemic risk factors may affect domestic futures market both directly and indirectly .

Whether systemic risk factors affect domestic futures market directly, or indirectly (systemic risk factors affect international futures, international futures affect domestic futures), the transmission mechanisms matter.

Anyway, these empirical results show that, there are strong correlations between domestic futures with systemic risk factors. That is to say, domestic futures exposed to systemic risk.

This suggests that measurement of systemic risk exposure at institutions level is important, further research on commodity futures pricing in emerging markets should take into account such international risk factors, which may play more important role than domestic spot market .

We take it as a first step to lay the microfoundation for systemic risk management and global financial stability.

Once we accepted these factors are systemic risk factors affect all assets markets, we can measure the systemic risk exposure of financial institutions.

TABLE V
CORRELATIONS BETWEEN SUGAR AND RISK FACTORS

	ZCE_sugar	spot_sugar	ICE_sugar
ZCE_sugar	1	-0.0693	0.61519
spot_sugar	-0.0693	1	-0.01464
ICE_sugar	0.61519	-0.01464	1
VIX	-0.23227	0.005744	-0.45335
USDX	-0.16208	-0.17449	-0.46261

For example, consider the systemic risk exposure for a Chinese copper related enterprise.

According to table III, for the domestic spot market, no systemic risk factors identified, LME copper futures as the determinant factor is a non-systemic risk factor.

For the SHFE copper futures market, USDX and VIX are systemic risk factors, no non-systemic risk factor existed.

For example, the systemic risk function F(.) may be constructed as below :

$$F(x_1, x_2, t) = x_1^{\alpha_1} x_2^{\alpha_2}, \tag{8}$$

where x_1, x_2 Indicates USDX and VIX respectively.

The changes in systemic risk can be measured as a linear combinations of changes in risk factors and their interactions (9).

$$r_F = \sum_{i=1}^{2} \alpha_i r_{x_i} + \frac{1}{2} \sum_{i,j=1}^{2} \alpha_i \alpha_j r_{x_i} r_{x_j}. \tag{9}$$

For a Chinese copper futures market related enterprise, its risk exposure identified are USDX and VIX. So, we can use (9) to measure the systemic risk exposure on commodity futures markets in China .

Thus the unknown parameters (α_i) can be determined by constraint least squares regression :

$$r_{SHFE} = \sum_{i=1}^{2} \alpha_i r_{x_i} + \frac{1}{2} \sum_{i,j=1}^{2} \beta_{ij} r_{x_i} r_{x_j}, \beta_{ij} = \alpha_i \alpha_j, \tag{10}$$

where r_{SHFE} Indicates the daily returns of SHFE copper futures .

TABLE VI
CORRELATIONS BETWEEN COTTON AND RISK FACTORS

	ZCE_cotton	spot_cotton	ICE_cotton
ZCE_cotton	1	0.01175	0.461736
spot_cotton	0.01175	1	0.155541
ICE_cotton	0.461736	0.155541	1
VIX	-0.41664	-0.14226	-0.41137
USDX	-0.36985	0.007957	-0.41464

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However, the least squares results show that, the simple systemic risk function (8) may not be specified well, further research on better systemic risk function needed.

V. CONCLUSION

Traditional commodity futures pricing models focuses on risks within the financial system, thus ignores systemic risk.

These problems are even more complex in emerging markets : systemic risk may arise not only as common exposures to domestic macroeconomic risk factors but also as exposures to international financial systems.

Neglecting in such systemic factors at the individual institution level significantly underestimate systemic risk exposures. Such underestimations may result in systemic risk or even financial crisis.

Therefore, institution level systemic risk identification and measurement has a important role in commodity futures pricing and reducing systemic risk.

The empirical results show that, there are strong correlations between domestic futures with systemic risk factors. That is to say, domestic futures exposed to systemic risk.

This suggests that further research on commodity futures pricing in emerging markets should take into account such international risk factors. Other underlying factors, such as international futures market prices, may play more important role than traditional spot or convenience yield in emerging markets.

Although the simple systemic risk function provided may not be specified well, we take the conceptual framework as a first step for modeling systemic risk factors and measurement of systemic risk exposure at institutions level. The quest for new commodity futures pricing models , focuses on risks with the global financial system , is a important research direction in the future.

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