Blockchain-based Implementation of Smart Contract and Risk Management for Interest Rate Swap

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Abstract. Blockchain is a decentralized infrastructure that is widely used in digital cryptocurrencies. It has attracted more and more attention from financial institutions due to its irreplaceable advantages. We implemented a blockchain solution for interest rate swap based on the Corda platform. Based on Andersen, Pykhtin & Sokol [8], we derive a risk estimation model for blockchain empowered interest rate swap trading. We conjecture that most of problems in today's derivative markets could potentially be relieved. Through our numerical experiment, we find that with the blockchain transformation, both the expected risk exposure and dynamic initial margin decrease significantly, which reduces the risk in interest rate swap trading and increases market liquidity. Next, we plan to conduct more mathematical and numerical analysis and continue working on improving our blockchain based trading and risk management implementation.

Keywords: Blockchain, R3, Corda, Expected Risk Exposure, Dynamic Initial Margin, Interest Rate Swap.

1 Introduction

Blockchain is the technology foundation of Bitcoin, first appeared in Satoshi Nakamoto's "Bitcoin: a peer-to peer electronic cash system" [1].

In traditional financial industry, data are segregated in silos. Even synchronizing data between different ledgers requires a large amount of manual work, which is time-consuming and costly, not to say conducting "big data analysis" effectively. It is said the "data silo challenge" might be one of the root causes for the 2008 financial crisis. Blockchain technology may help eliminate a large part of the problem [2]. Besides, due to low margining frequency, the risk of interest rate swap derivatives is high even when banks and financial institutions post large initial and variation margin to protect themselves from risk. This leads to increase in default risk and decrease in market liquidity. However, our blockchain approach could hopefully alleviate these problems. Moreover, as our blockchain-based implementation substantially simplifies the traditional default process and time-line, we expect the risk management process will change accordingly. We developed a risk estimate model in accordance to our blockchain approach.

Our experiment show that not only the default process is substantially simplified, but also the risks are reduced and hence the margins needed are reduced significantly. Our work is based on Corda platform. It can handle arbitrary data types so many kinds of smart contracts can be implemented on this platform. Besides, the contract only contains functions, so contracts do not “have any kind of mutable storage” [2].

The remainder of the paper is structured as follows. In Section 2 we introduce the background of our problem. In Section 3 we overview related works. In Section 4 we present the challenges in the current market. In Section 5 we present our approach. In Section 6 we present the evaluation and discuss the results, along with our thoughts on future works. We conclude with Section 7.

2 Background

2.1 Interest Rate Swap

In the derivatives market, the rise of blockchain may help reduce costs and increase efficiency [3]. In this article, we focus on interest rate swaps. An interest rate swap is a forward contract in which two parties sign a series of future interest payments to be exchanged based on a specified notional amount. Interest rate swap usually involves exchange of a float interest for a fixed rate at the specified time in accordance with the contract [4-5]. It is very effective as an interest rate hedging instrument and a liability management tool [4], and can also reduce financing costs [6]. As a result, the total notional amount of interest rate swap has increased gradually since 1999, shown in **Fig. 2.**, and it has become one of the most important financial products.

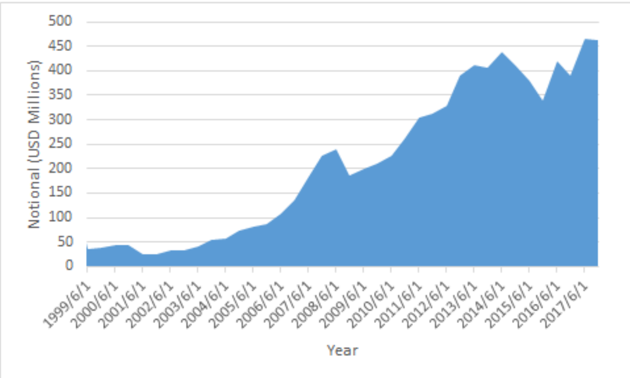

Fig. 1. Total notional amount of interest rate swap (data from BIS [7]).

Here, we define a set of terminology and notions [8]:

- B : The bank side. All the subsequent calculations and definitions are based on the perspective of the bank.
- C : The counterparty, that is, the party that may default.

- Risk exposure: The quantified potential for loss as a result of an investment.
- Expected risk exposure: The expected value of risk exposure in the model.
- Fixed leg: The party who will be paying the fixed rate.
- Floating leg: The party who will be paying the floating rate.
- Counterparty risk: The risk to parties in the contract that the counterparty will not fulfill its obligations.
- VM: Variation margin. It is a variable margin paid by participants to their respective clearing houses in a transaction because of the adverse price movements of the futures contracts they hold.
- IM: Initial margin. It provides additional default protection for banks. Typically, it is calculated at the beginning of the trade.
- Dynamic IM: Dynamically refreshed IM to "cover portfolio-level close-out risk" [8].

2.2 Corda Platform

The Corda platform is a distributed ledger developed by R3 Alliance consisting mutually untrusted nodes.

Compared to Bitcoin, the Corda platform can handle with any typed data rather than only the quantities of bitcoin in a Bitcoin transaction. Besides, only one part of the contracts is used to synchronize the whole system so that the function is "pure and stateless" [2]. Also, the Corda platform is designed for registered financial institutions, only information related to the transaction is revealed to the parties to the transaction.

The Corda platform supports smart contracts defined by Clack, Bakshi, and Braine [9]. Smart contracts are generally executed automatically but also support manual input and control. Smart contracts can link business logic and data to relevant laws and regulations so that financial contracts on the platform have legal enforcement [2].

The Corda platform is based on contract states objects as shown in **Fig. 2**. It ensures that all participants can maintain consensus when the contract state changes.

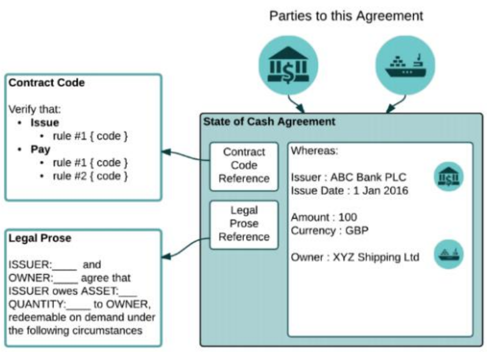

Fig. 2. diagram of a State object representing a cash claim of £100 against a commercial bank, owned by a fictional shipping company [2].

The Corda platform updates the records of state objects through transactions. Each transaction overwrites the existing state object and generate new state objects [2].

3 Related Work

Prior to our research, there was also a program implementation for interest rate swap in the case of non-blockchain [10]. However, the interest rate curve was pre-set and could not be updated in real time. There were also papers discussing "central bank money on blockchain" [11] but only evaluates possible scenarios without an actual implementation. Domain-specific language implementation in Ethereum as a marketplace [12] can also be found. It allows certain contracts to be traded but lacks precise timing method due to Ethereum's causal timestamps. Besides, blockchain transformations for currency forward contract [13] were implemented and evaluated to reduce concentration and counterparty risk in the foreign exchange forward contract market. However, the author only predicted the potential advantage of blockchain application without numerical experiments or analytical processes.

There were also many models that fitted the risk exposure and market value of interest rate swap products, but these models had many problems. Sometimes, in order to simplify the mathematical derivation, or to speed up the calculation, many assumptions and simplifications are made in modeling, such as assuming zero default risk in the transaction process [14], or assuming symmetrical risk of both sides in the transaction [15]. However, the details of OTC (over-the-counter) derivatives trading are complicated. Simplification of models may lead to model errors or even model risks to a certain extent, resulting in a great difference between the fitting results and the actual data [16-20].

4 Challenges

Currently, without blockchain technology, time-consuming and manual effort are necessary to keep disparate ledgers synchronized, which may be replaced with blockchain transformation. Besides, due to the low margining frequency, the risk exposure of interest rate swaps is still high even with the protection of large IM, which decrease the liquidity of banks and financial institutions.

There are two kinds of cash flows, which are transaction flows and margin flows, between the parties involved in an interest rate swap. Transaction flow is brought by transaction itself, including contract cash flow, physical settlement, etc. According to ISDA/CSA, once delay happened in a transaction flow, which is regarded as a serious credit event, it will lead to a default alert, or even a transaction interruption. However, when the two parties exchange margin flows, there may be delay due to disputes. In the current market, margin disputes not only have subjective reasons, but also have objective reasons including the inconsistency of valuation models of bilateral transactions mentioned above. The subjective reason is that some counterparties will deliberately use margin disputes to procrastinate the transaction time, which is often the prelude to default. But banks are often reluctant to immediately take unilateral measures and make a default warning.

Since the 2008 financial crisis, most large financial institutions have revised their VM values on a daily basis and have required margin posting from counterparties based on the results. In practice, however, financial institutions often take up a few days after the valuation and calculation of the collateral to actually acquire it. Take banks as an example. Suppose the bank collects and solidifies the market data after the market closes on day 1. Usually it can only evaluate the collateral during the working hours and notify the counterparty on day 2, and successfully collect the collateral at least on day 3. This is one of the main reasons why the collateral VM cannot completely offset the risk of the counterparty's default. There are also a number of simplified models in practical applications that assume that the bank's daily calculated collateral is real-time, and the collateral's coverage and protection is real-time and sufficient, and such idealized simplification leads to greater model risk.

Based on Andersen, Pykhtin & Sokol [8], we analyze the risk exposures theoretically from the perspective of banks. In this work, we take the risks caused by the inability to clear the collateral in time into consideration.

5 Our Blockchain Approach

Next, we propose a solution based on blockchain.

1. Assume that cash flow operations such as trade flows and margin flows occur on an integer lattice of Δ (For example, assume that Δ equals to one hour).
2. Both parties confirm the jointly accepted valuation model and margin model before the transaction begins, and write the smart contract to be solidified into the blockchain. It will run automatically, so there will be no dispute in the future.
3. Smart contracts automatically perform real-time valuations (here assuming the portfolio valuation is fast enough) every Δ hours and transfer corresponding assets instantly.
4. Suppose that the parties agree to give a grace period of ϕ for such delay as default. (For example, assume that $\phi = 2\Delta$).

We can first implement the automatic adjustment of the interest rate swap transaction flow based on externally provided market rate data. Based on this, hourly atomic payment operations are implemented according to the atomic payment process designed as follows.

Algorithm 1: Framework of atomic swap in our system

Input: *Data class* : *Contract with hash(key), cash to pay*
Output: *Transaction*

B generates and sends the Contract to C;
if *Contract.cash* $\equiv$ *cash to pay* **then**
    C pays the cash flow;
if *The amount of money B received* $\equiv$ *cash to pay* **then**
    B sends the key to C;
else
    B sends 0 to C;
if *hash(the key C received)* $\equiv$ *Contract.hash(key)* **then**
    C redeems the Contract;

Here, the password can be either artificially input or automatically generated by transaction time. The atomic payment process is shown in **Fig. 3**.

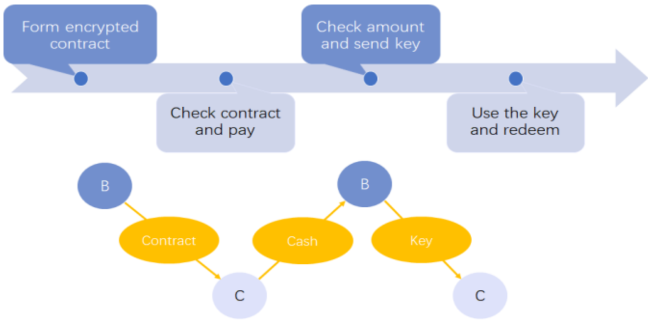

Fig. 3. Sketch map for atomic swap process.

In Corda platform, the atomic swap starts with B's generating and sending encrypted smart contract to C. After C automatically checks the amount of the payment according to the contract and market rate data provided, C transfers cash to B. Then B checks the cash flow and send C the key and C will use the key to redeem the contract to obtain B's cash flow.

The successful implementation of atomic swap process is a result of two functions of the Corda platform. First, *EventScheduling* method is used in this smart contract. Smart contracts can inherit the *SchedulableState* class and implement the *nextScheduledActivity* function, enabling it to automatically run events at a specified time. There are two kinds of timed events. One of them is to update the floating rate floating leg needs to pay according to the schedule specified in the contract based on the provided market rate data. The other is to exchange cash flows according to the schedule. Second, in the Corda platform, when two parties to the contract communicate, if one cannot receive the required format information (cash flows or password transmissions for atomic payment process), the program stops and reports an error. These feature enables that Corda smart contracts run atomic swaps according to the above timeline.

This kind of atomic payment process can only be completed by a trusted third party in a non-blockchain application, because the two steps of checking cash amount and sending redemption password cannot be bounded off the chain. The cash and password need to be handed over to the trusted third party first. This will lead to delay in trading and a higher default risk. Blockchain implementations enable that receiving cash and sending redemption passwords are bound to a single function, thus achieving point-to-point real-time transactions, increasing the speed of transactions and reducing the risk.

However, in the existing blockchain implementation, the smart contract cannot automatically issue an electronic notification letter with legal effect after error is reported. In this sense, the operation of smart contracts is semi-automatic. With the rise of Chinese Internet Court [21], it could become more and more automatic gradually.

In our design, cash flow transactions are scheduled for the working hours of both parties (assumed here to be between 9 a.m. and 5 p.m. local time). Once an error occurs, it can be guaranteed that a staff member will promptly handle it and notify the transaction parties to terminate the transaction in advance and proceed to the next step. Moreover, electronic legal notice that are recognized by the Internet Courts can be used.

In response to the characteristics of blockchain atomic payment, we have retrofitted the traditional default timeline. Here we assume that the grace period $\phi = 2\Delta$.

1. Time $\mathrm{T} - \Delta$: C paid the cash flow in full for the last time, including margin and transaction flow.
2. Time T: At this time, a suspected breach of contract occurred in C, failing to submit the deposit or delivery transaction in full and on time. At this point, the smart contract begins to report errors, and B must issue an electronic reminder letter in time. As explained in the smart contract feature above, the payment is an atomic operation, and C does not update the margin at the same time, and temporarily deducts all transaction flow operations.
3. Time $\mathrm{T} + \Delta$: No operations while both sides are waiting for the solution.
4. Time $\mathrm{T} + 2\Delta$: At this time, our assumed grace time has been up. If C’s problem is solved, the margin flow and transaction flow will resume as usual; if C’s problem has not been solved, the default procedure will be entered, and an electronic notification letter with legal effect will be issued to notify the parties of the transaction to terminate early. At this point, we can call other smart contracts to automatically inquire on the block chain and seek the average. Other operations that are agreed upon at the contract can also be executed in order to clear, settle and transfer fund immediately.

Based on Andersen, Pykhtin & Sokol [8], we can use examples and criteria in the market and take the time required for one party to fail to pay the margin until the other party confirms the counterparty's default as a model parameter. Then, using Local Gaussian Approximation, we can get an effective ratio of IM, that is, expected risk exposure with IM divided by expected risk exposure without IM.

6 Evaluation and Discussion

We can calculate the risk exposure of the same interest rate swap under the current market circumstance compared with our blockchain approach. At present, the Monte Carlo method is commonly used to calculate the IM and risk exposure for each example (path). In the calculation process, a method of simulating the risk factor and the transaction flow at a daily frequency is usually employed. [22-26].

After increasing the margining frequency, it can be expected that the aforementioned problems in current industry practice can be greatly alleviated. In particular, there will be smaller risk peaks in risk exposure due to unilateral payments, as shown in our numerical simulation [27-28].

The risk exposure can be calculated using Open Source Risk Engine which is an open source software for financial quantitative analysis [29-30]. The software offers a Monte Carlo framework so that we can do the simulation using our own model.

In the simulation, the notional amount is $10,000,000 with 0.02 fixed interest rate, fixed legs and floating legs are paid quarterly. The following plots were obtained by comparing the out simulation results with the data in the literature [8].

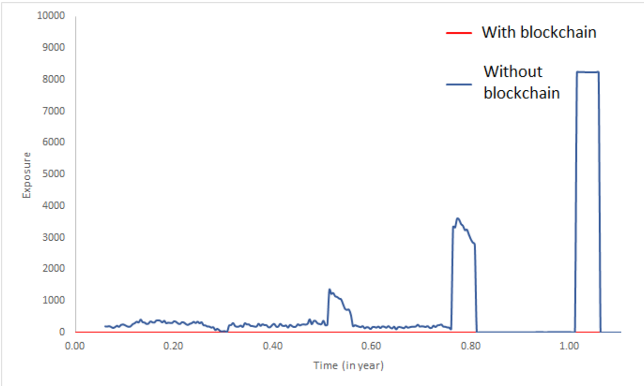

Fig. 4(a). Expected exposure without IM protection with and without blockchain.

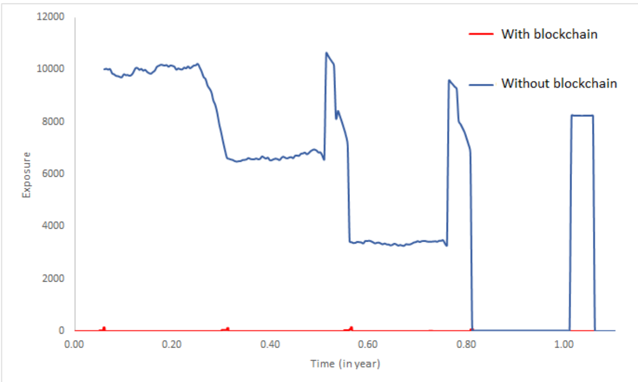

Fig. 4(b). Expected exposure with IM protection with and without blockchain.

We can see from **Fig. 4**. **(a) and (b)** that the expected risk exposure of interest rate swaps is lower than that of traditional market models regardless of protection by IM. Especially in the case with IM protection, the expected exposure is always 0 in blockchain circumstance.

As the expected risk exposure is an estimation of the risk of a financial derivative, we can see from the plots that in general, the interest rate swap under our blockchain approach has lower risk than under current market circumstance. There are peaks near transaction flows because B is always the net payer when transaction flow exists, which leads to the upward peaks in the exposure value. When the counterparty does not pay the margin, the party must continue to pay the transaction flow and submit the collateral without the counterparty paying the collateral because it cannot confirm whether it has really defaulted. In case of transaction expiration, etc., the party even has to return the collateral that the counterparty has paid. And peaks will appear in the numerical plot. When the peaks appear, the dealer lost protection and increased exposure. These greatly reduce the effectiveness of margin. And with atomic swap, such unliteral payment will reduce and risk peaks will be smaller.

In summary, thanks to the atomic swap, blockchain helps increase margining frequency and makes near-real time clearing possible. Under our blockchain model, the interest rate swaps will be safer and banks will have to pay less IM to protect the derivative. As a result, banks will reduce risk and improve liquidity while trading. Next, we plan to conduct more mathematical and numerical analysis and continue working on improving our blockchain based trading and risk management implementation.

7 Conclusion

In current industry practice, there are a number of problems in the estimation of interest rate swap risk exposure. There are inaccurate pricing problems for existing interest rate swap products, and there is also large risk exposure due to low margining frequency. Its intuitive performance in the numerical simulation is that near each trading flow, there is an upward spike in the expected risk exposure, which necessitates a higher initial margin amount. Despite of the larger initial margin amount, the interest rate swap is still not well protected.

One of our main contributions is that we implemented a blockchain program to realize atomic swap for interest rate swap. We also ran numerical simulations to show that blockchain does help alleviate problems mentioned above. By using blockchain, we can not only automatically adjust the transaction cash flow to be paid by both sides according to the floating interest rate announced by the market periodically, but also design an atomic transaction process to increase margining frequency. As a result, with blockchain, we can reduce the required initial margin amount and the expected risk exposure of the transaction.

In addition, since all transaction records are stored in the blockchain, the transaction process is more convenient for government regulation, making open, transparent and near-real time penetrative supervision possible.

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