The Impact of Central Clearing on the Interest Rate Swaps Market

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Introduction

The 2006-2008 financial crisis, the most severe economic downturn since the Great Depression, led to the passage of the Dodd-Frank Wall Street Reform and Consumer Protection Act (DFA). A key provision of the DFA required certain financial contracts to be cleared through a central counterparty (CCP). This study investigates the causal impact of this clearing mandate on prices, volatility, and liquidity in the interest rate (IR) swaps market, a major derivatives market used for hedging or speculating on interest rate risk. Despite extensive theoretical literature on central clearing, empirical studies are limited. Earlier research focused on the credit default swaps (CDS) market using event studies. Event studies cannot isolate causal impacts due to potential confounding factors. This study addresses the gap in the literature by (1) examining the IR swaps market, which is larger and more widely used than the CDS market and (2) using a difference-in-differences approach to identify causal effects of the clearing mandate. Leveraging the fact that initial central clearing rules targeted IR swaps in the four largest currencies traded in the US, but did not apply to other currencies or regions, this research plausibly identifies the causal impact of the regulation on pricing, liquidity, and price volatility in the IR swaps market.

The paper is organized as follows: section 1 provides background on the IR swaps market, the financial crisis, and the clearing mandate's role in post-crisis market reforms; section 2 develops the theory of pricing, price volatility and liquidity for IR swaps under a clearing mandate; section 3 discusses the identification strategy; section 4 details my data; section 5 discusses the results and section 6 concludes.

1 Background

1.1 Interest Rate Swaps

IR swaps are financial derivatives used to hedge or speculate on interest rate movements. The three most common types of IR swaps include vanilla fixed-for-floating swaps, basis swaps, and cross-currency basis swaps. Vanilla fixed-for-floating swaps are the most prevalent. In this type of swap, one party exchanges fixed-rate coupon payments for floating-rate payments on a notional principal (the notional principal is never exchanged). Firms can use these instruments to convert floating-rate risk to fixed-rate risk, and vice versa. As a concrete example, imagine firm A can borrow at the London Interbank Offer Rate (LIBOR, a common variable interest rate used by banks when lending money to each other) or a fixed rate of 2.0%, while firm B can borrow at LIBOR + 0.25% or a fixed rate of 1.75%. Suppose firm A prefers borrowing at a fixed-rate and firm B prefers borrowing at a floating-rate (this could be because firm A owns fixed-income securities while firm B owns assets that pay a variable rate, and the firms would like to match their assets with their liabilities). Despite their preferences, firm A has a comparative advantage in borrowing at a floating-rate, and firm B in borrowing at a fixed-rate. To achieve their preferred arrangements, the firms can enter into an IR swap agreement with a $1M notional[1] principal, where firm A receives a floating rate of LIBOR from firm B and pays a fixed rate of 1.75% to firm B. This transforms firm A's floating-rate liability into a fixed-rate one and vice versa for firm B. The IR swaps market allows firms to borrow in the market they have a comparative advantage in and trade for their preferred interest rate arrangement.

IR swaps can be bespoke contracts, customizable to individual economic needs. As the largest over-the-counter (OTC) swaps market, it accounted for $465 trillion of the $601 trillion global OTC swaps market in 2010 (von Kleist and Mallo 2011) (the IR swaps market had increased to $715 trillion by June 2023 according to an updated version of the same report). For many currencies, there are “standardized” contracts, which have common features and are the most heavily traded. During the period of study, the standard US Dollar (USD)-denominated IR swaps contract had semiannual payments for one leg and quarterly payments for the other leg (that is either trading quarterly fixed-rate payments for semiannual floating rate payments, or vice-versa), with the 3-month USD-LIBOR curve used both as the floating-rate reference and for discounting future cash flows (see section 2.1 for further explanation). The standard Canadian Dollar (CAD)-denominated contract used 3-month CDOR as the reference floating rate. In addition to the currency, reference rates and payment frequency, there are many other contract details (such as day-count conventions, settlement and termination rules) that need to be specified, and these are listed in more detail in Appendix A. The CAD- and USD-denominated standard contracts use the

[1] The principal is “notional” because unlike a real bond it is never exchanged. It is only used to calculate fixed and floating rat payments.

ISDA master agreement, which details these contract specifications. Although contract specifications can be customized to meet the requirements of the counterparties, such non-standard contracts are likely to be less liquid than the standard contracts. Standard contracts denominated in other currencies (e.g. Euro [EUR], British Pound [GBP], and Japanese Yen [JPY]) have their own conventions as well.

The IR swaps market is dealer-dominated, with dealer-customer and dealer-dealer trades accounting for 80% of notional value (Bolandnazar 2020). Bolandnazar finds that 50% of trades (by notional value) are executed by the largest seven dealers, indicating market concentration among a few dealers. This concentration can impact pricing and market stability in several ways. Larger dealers might be able to reduce search costs by easily finding a counterparty from their large client base. They could also reduce costs by economizing over administrative and warehousing costs of contracts. However, because of their market position, they might have market power and be able to charge a premium over the price that would prevail in competitive markets. The failure of a large dealer (or a dealer's major counterparty) could also drastically reduce liquidity in the system and increase transactions costs.

1.2 Central Clearing

When a swap is cleared, the initial contract between the two parties is replaced (novated) by two contracts between each party and a central clearinghouse/derivative clearing organization (CCP, DCO or clearinghouse). The clearinghouse becomes the counterparty for each leg (that is, paying the fixed leg to the initial party receiving fixed-leg payments and paying the floating leg to the party receiving the floating leg-payments. It also receives the floating leg from the initial party paying the floating rate and the fixed leg from the initial party paying the fixed leg). If one party fails to meet their contractual obligation, the clearinghouse can still make sure the other party gets paid. For this purpose, CCPs practice risk-control measures and have additional resources to make a counterparty whole in case of default. When counterparties clear[2] their trade through a clearinghouse, they must put up collateral (initial margin) and contribute to a default fund. In case the risk position of the counterparty changes, it can be required to put up additional collateral

[2] The clearing counterparty is usually a dealer who is a clearing member at the CCP. "A clearing member is usually a trade intermediary that can deal directly with the CCP. Trade intermediaries that are not clearing members must clear their trades through a trade intermediary that is a clearing member" (McPartland 2009). Trade intermediaries that are clearing members will collect collateral from their non-clearing member clients and pass it on to the CCP.

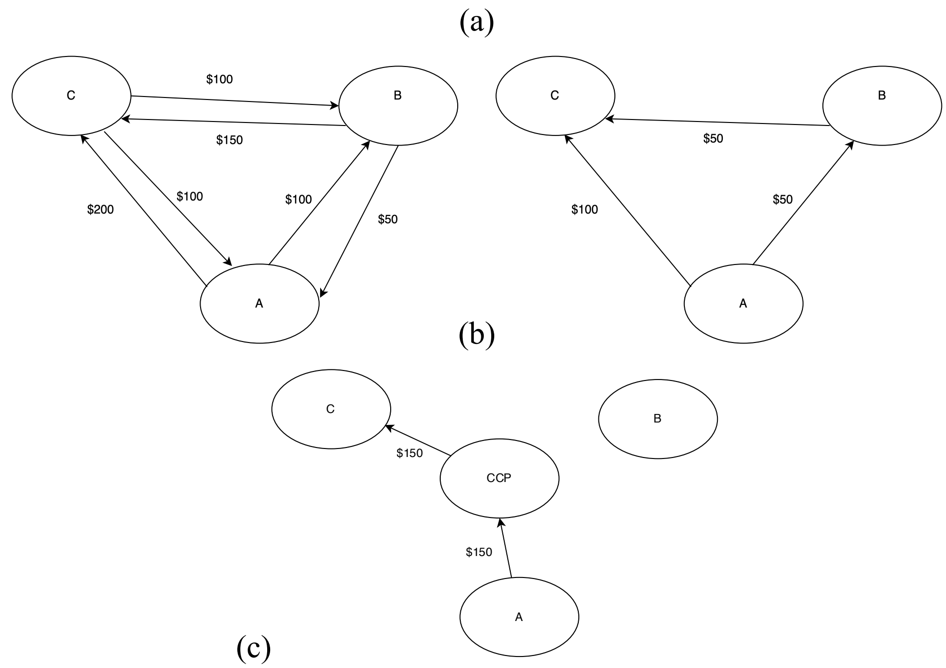
(variation margin). The CCP also has default fund contributions of other members, its own equity (CCP capital), and access to other lines of credit (such as the Federal Reserve discount window). The combination of these resources makes it unlikely that the failure of one counterparty would drastically affect the whole market. Since clearing members can lose their contribution to the default fund in case of the failure of a counterparty, clearing mutualizes counterparty risk among the members of the CCP.

In addition to financial resources, CCPs exercise prudent risk control measures such as monitoring members trading positions and liquidating distressed assets in an orderly fashion. Since the CCP can observe all trades that it is clearing, it has a better picture of overall riskiness. Compare this to a bilateral market, where one party is generally unaware of other trades its partner is entering, and thus does not have a thorough understanding of its partner's riskiness.

Clearing can reduce demand for collateral through a practice called netting. There are two types of netting practices common in the industry: cross-product netting and multilateral netting. For a CCP that clears multiple types of contracts (e.g. interest rate swaps, forward rate agreements, overnight-index swaps, credit default swaps, etc.) cross-product netting involves netting across different derivatives products. For example, if firm A owes the CCP \$10 million in collateral for IR swaps, but the CCP owes firm A \$8 million for CD swaps, then firm A can just pay the CCP \$2 million in net collateral.

Multilateral netting involves netting payments across multiple firms. For example, consider the following series of obligations: firm A owes firm B \$100 million and firm C \$200 million; firm B owes firm A \$50 million and firm C \$150 million; firm C owes firm A \$100 million and firm B \$100 million. Without multilateral netting, the firms can still engage in bilateral netting. In a bilateral netting regime, the following payments would need to be made: firm A would need to pay firm B (\$100 - \$50) = \$50 million and firm C (\$200 - \$100) = \$100 million; firm B would need to pay firm C (\$150 - \$100) = \$50 million. The total collateral demand would be \$200 million. With multilateral netting by the CCP, the \$50 million payment from firm B to firm C can be eliminated. Firm A would pay the CCP \$150 million and the CCP would pay firm C \$150 million (while firm B would not make any payments at all). The total collateral demand would be \$150 million. Figure 1 graphically depicts the various netting scenarios described above.

Figure 1 Example of obligations between three firms (a) without any netting (b) with bilagteral netting (c) with multilateral netting



Originally created for members of futures and equities exchanges, clearinghouses became more significant with regulations like the DFA (2010) and European Market Infrastructure Regulation (EMIR, 2012) mandating central clearing of derivatives. Mandated clearing can have macro and micro effects on the swaps market. At the macro level, clearing could reduce volatility but also strain the market through collateral demand during volatile or illiquid periods. Large enough losses could threaten clearinghouse solvency, transmitting effects to all members. At the micro level, central clearing may change the types of trades firms enter, potentially leading to riskier trades due to mutualized default risk (adverse selection) and riskier post-trade activities (moral hazard). Clearing is subject to economies of scale and scope, which could lead to natural monopolies. However, regulators are likely to prevent this through antitrust regulations and “local clearinghouse” requirements (that is, even though a single clearinghouse for both the US and Europe might have lower costs, US and EU regulators might require separate clearinghouses in each jurisdiction). While clearinghouses can reduce default risk and collateral demand, they also require resources for risk management activities, which may increase trading costs.

1.3 Regulatory Background

1.3.1 US Context

Following the financial crisis, Congress passed the DFA to enhance the US financial system's reliability. Since OTC derivatives markets played a role in the crisis, DFA aimed to significantly reform this market. Key objectives included improving trade data availability for regulators and market participants, requiring real-time reporting of certain trade characteristics, and mandating confidential trade data reporting to swaps data repositories and regulators.

To reduce default risk for large swaps dealers, DFA requires dealers to register with the Commodities Futures Trading Commission (CFTC) or the Securities and Exchange Commission (SEC), adhere to internal business conduct standards and maintain adequate capital. To enhance liquidity, price discovery and transparency, it encourages trading to take place in centralized Swaps Execution Facilities (SEFs, usually electronic trading venues) or Designated Contract Markets (DCMs). To make trade data more readily available, it requires real-time reporting of price information to swaps data repositories (SDRs) and submitting additional data (called primary economic terms) to SDRs and regulators in a timely fashion. Furthermore, the DFA mandates most contracts be centrally cleared (and for uncleared contracts, requires parties to post margin to mitigate default effects). Table 1 summarizes the CFTC key rulemaking in these areas.

Table 1 Major Rule-Making Areas of the Dodd-Frank Act

Rulemaking Area	Major Rules
Swaps Dealers and Major Swaps Participants	• Registration • Internal Business Conduct Standards • Capital and Margin for non-banks • Segregation and Bankruptcy
Data Requirements	• Establishment of Swap Data Repositories (SDR) • Data recordkeeping and reporting requirements • Real Time Reporting • Large Swaps Trader Reporting
Clearing Requirements	• Establishment of Derivatives Clearing Organizations (DCO/CCP) • Clearing requirement for most common swaps • Margining requirements for uncleared swaps
Trading Requirements	• Establishment of Swaps Execution Facilities (SEF) • Made Available for Trade (MAT) designation/requirement
Position Limits	• Position Limits and Aggregation of Positions
Enforcement	• Anti-Manipulation • Disruptive Trading Practices • Whistleblowers
Other	• Investment Adviser Reporting • Volcker Rule • Reliance on Credit Ratings • Fair Credit Reporting Act • Cross-Border Applications

1.3.2 International Context

Considering the global nature of the financial system, regulators collaborated internationally to harmonize regulatory requirements. In Europe, the EU passed EMIR in 2012, which shares similar aims as the DFA, while the Bank of England (BoE) issued regulations mandating clearing for most trades involving UK-based entities. In Asia, the Japanese Financial Services Authority (JFSA) required yen-denominated IR swaps and certain CD swaps to be cleared by the end of 2012; the Monetary Authority of Singapore (MAS) and the Securities and Futures Commission (SFC) of Hong Kong released consultation papers expressing their intentions to clear swaps denominated in certain Asian currencies. Table 2 summarizes the international context.

Table 2 Summary of Central Clearing Requirements in Major Financial Centers

Jurisdiction	Relevant Laws and Regulations
North America	• DFA (2010) and CFTC and SEC rulemaking requires mandatory clearing of IR swaps contracts denominated in USD, GBP, EUR and JPY LIBOR by September 2013. • Additional currencies and classes of contracts are added to the clearing requirement in 2016 to harmonize regulations across jurisdictions. • Canada requires certain CAD-denominated swaps to be cleared starting in May 2017.
Europe	• EMIR passes in 2012 and requires clearing of certain IR swaps contracts. Regulations come into effect in March 2013. • Bank of England releases financial market regulatory guidance in April 2013, reiterating the applicability of EMIR to UK-based traders. • Additional currencies and classes of swaps are added to the EU clearing requirements in 2016. • Switzerland established a clearing mandate for Switzerland based swaps in 2017.
Asia	• Japan Financial Stability Authority (JFSA) requires yen denominated IR swaps referencing LIBOR to be cleared by end of 2012. • Hong Kong Monetary Authority (HKMA) and the Securities and Futures Commission (SFC) release consultation paper in 2011 on clearing of certain IR swaps denominated in Asian currencies. • Hong Kong requires HKD denominated swaps to be cleared starting July 2017. • Monetary Authority of Singapore (MAS) releases consultation paper in 2011 on plans for clearing of certain Singapore Dollar denominated IR swaps. • MAS requires SGD contracts to be cleared by December 2017.
Australia	• Australian Council of Financial Regulators (CFR) pass legislation requiring mandatory clearing of Australian dollar denominated IR swaps by end of 2012.

1.4 Review of Literature

1.4.1 Interest Rate Swaps

Formal swap agreements were first seen in financial markets in 1981/1982. Bicksler and Chen (1986) find three uses of interest rate swaps in the market: (1) to manage mismatches in assets and liabilities (for example, depository institutions hold long-term fixed rate assets such as mortgages and short-term liabilities such as demand deposits; on the other hand, insurance companies often invest in short term assets that pay a variable rate, such as money market funds, and have long-term fixed-rate liabilities); to lower fixed-rate borrowing costs (borrowers with poor credit can often borrow at a lower cost in the floating rate market) and to manage their debt mix. The primary economic rationale for the existence of interest rate swaps is differences between firms' costs to borrow at fixed rate vs. variable rate arising due to market imperfections (differences in regulations or credit market imperfections can give firms comparative advantage in borrowing in one market over another).

Smith, et. al. (1988) present two models of pricing swaps. One model replicates the payoff of a swap through a portfolio of forward or futures contracts. The other model replicates the payoff through a portfolio of floating rate and fixed rate corporate bonds. They note that for a portfolio of bonds, there is an exchange of the principal at the end of the bond term, while for an interest rate swap the principal is usually not exchanged (that is, it is a "notional" principal). Thus, the impact of a default is greater for a corporate bond than for an interest rate swap. Futures contracts on the other-hand are exchange-traded, cleared, and settled daily, so the risk of loss due to counterparty default is close to zero. For forwards, the contract value is realized only at the end of the contract period and has greater potential for counterparty default than for futures. An interest rate swap is somewhere in-between: it is periodically settled (on the payment dates).

Minton (1997) examines these valuation models. He finds that the fixed rate of the interest rate swap is discounted by ~4 bps compared to a replicating portfolio of Eurodollar futures (Eurostrips) and that movements in swap rates and Eurodollar futures rates are highly correlated. When evaluating the portfolio of bonds model, he finds that actual swap rates fall between the rate derived from a portfolio of corporate bonds and the rate derived from Eurodollar futures. Proxies for counterparty credit quality also have a significant explanatory power, suggesting counterparty risk is a factor in observed swaps pricing.

1.4.2 Liquidity

Biais (1993) proposes a model for a dealer intermediated market and derives the optimal bid-ask spreads quoted by dealers with constant absolute risk aversion (CARA) (note that this is a model of general asset pricing in dealer-intermediated markets, and not specific to the IR swap market). A basic version of Biais' model motivates the liquidity model in section 2.4. Several papers empirically examine liquidity in the interest rate swap market: Sun, et. al. (1993) examine the effect of dealer credit rating on bid-ask spreads using data from Merrill Lynch and AIG Financial Products. They find that dealers with AAA credit ratings charge a spread of around ~10 bps while lower rated dealers only charge a spread of ~4 bps. Boudiaf, et. al (2024) examine the impact of monetary policy tightening on liquidity of EUR denominated swaps using a variety of liquidity measures. They find that their liquidity measures are impacted by monetary policy (specifically volatility in key policy rates reduces liquidity in the swaps market). Liu, et al (2006) decompose the "spread" between interest rate swaps and corresponding treasury bills into a credit spread and liquidity spread (arising from the lower liquidity of swaps over US government bonds). They find that the credit component of the spread is ~31 bps while the liquidity component is ~7 bps. Benos, et. al (2020) examine the impact of another Dodd-Frank mandate (trading on SEFs) on swap liquidity. They find a 12%-19% improvement in liquidity in the post-regulation market, driven by competition among dealers. Loon and Zhong (2014) examine liquidity in the credit default swap (CDS) market following the passage of the Dodd-Frank Act. They find that central clearing in the CDS market is associated with more liquidity.

1.4.3 Price Volatility

Compared to studies of pricing and liquidity, studies of price volatility in the interest rate swap market are rare. Azad, et. al (2012) decompose volatility in the US and UK market into high-frequency and low-frequency components using asymmetric spline GARCH (AS-GARCH). They then regress the low frequency component of the volatility against several macroeconomic variables (volatility of consumer price index, volatility of industrial production, volatility of short-term interest rates, volatility of foreign exchange rates, slope of the term-structure, unemployment rate and money supply). They find that volatility of short-term interest rates affects IR swap price volatility. In addition, for GBP based contracts, the money supply is negatively associated with IR swap volatility. For USD based contracts, the volatility of industrial production and the slope of the yield curve also affects IR swap volatility.

1.4.4 Systemic Risk and Contagion

Jackson and Pernoud (2021) outline two main avenues of contagion (that is financial distress at one institution spreading throughout the financial system): firstly, through defaults and firesales of assets that diminish the value of interconnected financial institutions (the network channel) and secondly, through feedback effects such as bank runs and credit freezes. For the first avenue, consider the case when a large financial institution fails. The values of other institutions that do business with the failing institution are also diminished and can cause a cascading series of failures. Each failure leads to additional bankruptcy costs and the final cost to the system at the end of the process can vastly exceed the size of initial shock. Such models are explored by Rochet & Tirole (1996) and Allen & Gale (2007; 2000).

Another way that financial institutions are interconnected are through the assets they trade. That is, even though two financial institutions might not directly do business with each other, they might own assets that are highly correlated. When a bank becomes insolvent, it often must sell assets at distressed prices. Such sales can also depress prices of related assets and drive institutions that hold those assets to insolvency. A prominent real-world example of this scenario is the 1998 crisis at Long Term Capital Management (LTCM). LTCM was a hedge fund that used a highly leveraged portfolio of interest rate swaps and foreign bonds (especially Russian bonds) to earn high market returns. When Russia defaulted on its debt in 1998 and devalued the Ruble, LTCM's portfolio took a large loss. In addition, market participants became more risk-averse and stopped lending to any institutions that employed a similar trading strategy to, or held similar assets as, LTCM. This created a system-wide credit crunch. The Federal Reserve eventually organized a bailout of the fund to prevent further damage to the financial system. Other prominent examples of this type of contagion are the Asian and Eurozone financial crises, where the potential default of one country led to distressed financial conditions in neighboring countries, as market participants became more risk averse. This type of models are explored by Kiyotaki & Moore (1997) , Cifuentes et al. (2005), Gai & Kapadia (2010), Capponi & Larsson (2015) and Greenwood et al. (2015).

Besides the network avenue, contagion can also occur through feedback loops and multiple equilibria. The classic Diamond and Dybvig (1983) model illustrates how multiple equilibria can lead to panic and bank runs. Banks lend out money long term and take in deposits for short terms. If enough depositors demand to withdraw their funds at once, the bank cannot repay all of them. In fact, if depositors believe a bank is insolvent (or they believe that other depositors believe that the bank is insolvent), they have an incentive to be the first in line to pull their funds out. Thus, a change in belief about the solvency of a bank can lead to a self-fulfilling insolvency, without any decrease in the value of the bank's actual portfolio of loans. Similarly, banks' beliefs about the creditworthiness of their counterparties can lead them to pull back their lending, leading to the very adverse credit condition and defaults that they were anticipating. This chain of defaults can cast doubts about the solvency of other banks, eventually leading to a systemwide freeze where banks stop lending to each other. This type of models are explored by Bebchuk & Goldstein (2011), Brunnermeier (2009) and Diamond and Rajan (2011).

1.4.5 Central Clearing

The policy and market implications of a central clearing mandate are discussed extensively by Pirrong (2011). Per Pirrong, CCPs should clear liquid, standardized products, as illiquid products can pose substantial risks to the CCP. CCP's can reduce the disruptive effect of defaults by drawing on additional sources of capital and facilitating orderly liquidation of positions. However, they can also increase systemic risk by requiring additional margin during periods of financial stress. In addition, by mutualizing the risk of default, they can induce market participants to take more risk (moral hazard and selection issues). CCPs are also subject to economies of scale and scope (that is, the market will converge to one or few large CCPs that can economize over costs of warehousing and multiproduct netting). Since a CCP is likely to become a systemically important financial institution, regulators must monitor it closely and have prudent measures (such as a resolution plan if the CCP collapses).

Duffie and Zhu (2011) show that theoretically concentrating clearing to one CCP can economize on collateral. Benos et al. (2019) explore the issue of economies of scale/scope among CCPs. Regulators in Europe and United States have required "local CCPs" to clear contracts that originate in their jurisdiction. They find that the same contracts trade at different prices when cleared through two different clearinghouses (LCH in the UK/Europe and CME Clearing in the US) and suggest that this difference arises due to increased collateral costs when clearing is fragmented.

Bernstein, et al. (2019) look at the impact of central clearing on equities pricing by examining the prices of the same stocks traded on New York Stock Exchange (NYSE) and Consolidated Stock Exchange (CSE). The NYSE established a clearinghouse in 1892 while the CSE did not. They find that the same stocks on the NYSE traded for 90-173 premium over the CSE price.

2 Theory

2.1 Pricing Without Credit Risks

An interest rate swap can be thought of as an exchange of a series of fixed payments by one party for a series of variable (floating) payments by the other party involved in the swap. For the fixed leg, the present value of the payments is given by (Skarr and Szakaly-Moore 2007):

$$PV_{fixed\ leg} = \sum_{i=0}^{T} \frac{CF}{(1+r_i)^{t_i}} \tag{1}$$

where: CF is the (fixed) cash flow, r_i is the risk-free rate for period i, t_i is the time at which CF will be received and T is the tenor (total length of the swap contract)

The present value of the floating leg is:

$$PV_{floating\ leg} = \sum_{i=0}^{T} \frac{CF_i}{(1+r_i)^{t_i}} \tag{2}$$

where: CF_i is the floating leg payment at period i, and all the other variables are as defined previously.

The present value of the contract for the party paying the fixed leg and receiving the floating leg is:

$$PV = PV_{floating\ leg} - PV_{fixed\ leg} \tag{3}$$

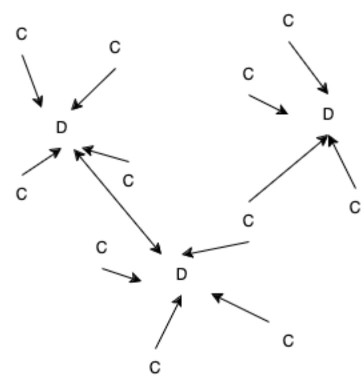
(The counterparty's value is given by a similar formula, but with the signs reversed on the right-hand side.)

Floating rate payments are unknown in advance but are usually forecasted by a relevant yield curve. For instance, if the floating leg payment is based on USD LIBOR, a USD LIBOR curve, constructed by interpolating short-term deposit rates, medium-term Eurodollar futures, and long-term instruments like forward rate agreements and existing swaps, is used. At the outset of the contract, its value (PV) is zero. This is achieved by determining the present value of the floating leg using the forecasted payments (using the LIBOR yield curve), and then setting the fixed rate payment CF in (3) such that the present values of both legs equal.

2.2 Pricing with Counterparty Risk (Credit/Debit Valuation Adjustment)

The interest rate swap market is dominated by a handful of substantial swap dealers (SDs) and Major Swap Participants (MSPs) rather than many atomistic market participants (Bolandnazar 2020). These SDs and MSPs offer buy and sell quotes for swaps, potentially finding other participants to balance their swap exposures. Figure 2 depicts a hypothetical network model of such a market.

Figure 2 Dealer-based Market without Central Clearing



In the figure, three dealers (D) each engage with their set of clients (C). Note that dealers might engage in interdealer trading (indicated by bi-directional arrows between dealers) and bulk futures markets trading (not shown) for cash flow or risk management purposes. Customers can trade with multiple dealers (indicated by arrows going from C to multiple Ds) or occasionally engage in bilateral trades (indicated by arrows going from C to C) amongst themselves. However, bilateral trades typically have low volume. It is believed that the dealer-centric network structure lowers search costs compared to a direct customer-to-customer market.

In practice, customers and dealers must account for the risk associated with counterparties defaulting. The "risk-free" present value pricing above needs to be adjusted for this risk. If S_i represents the survival probability of the counterparty at period i, the expected present value of the fixed leg is:

$$PV = \sum_{i=0}^{T} \frac{CF_i \cdot S_i}{(1 + r_i)^{t_i}} \tag{4}$$

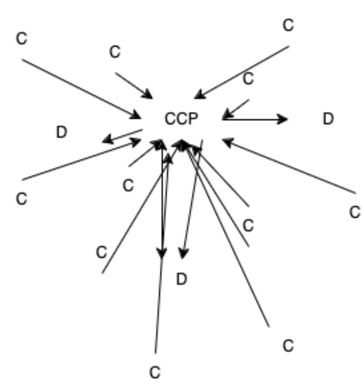
The fixed rate payment CF needs to account for the modified PV of the floating leg.

(Note that a swap's valuation with counterparty risk requires two adjustments. Only the credit valuation adjustment [CVA] is shown above. However, if one’s counterparty defaults, one no longer has to make his/her obligated payments to the other party either, which would increase the value of the contract. This adjustment is called the Debit Value Adjustment [DBA] and not shown above).

2.3 Pricing Under Central Clearing

The structure of a dealer-dominated market means that a dealer's failure (possibly due to inadequate risk management or correlated customer defaults) could affect other dealers and potentially the entire market. To counter this, regulators introduced central counterparties (clearinghouses). These clearinghouses void (novate) the initial swap contract and establish two new contracts, mirroring the original, with each counterparty. Now participants only need to be concerned about the clearinghouse's potential default, rather than their counterparties. Owing to their robust capitalization, regulation, and sound risk management, clearinghouses are perceived to decrease default and contagion risks. Figure 3 visualizes a hypothetical market structure with mandated central clearing. In this picture, the bilateral obligations between dealers (D) and customers (C) have been replaced by contracts between the dealer, customer and the CCP.

Figure 3 Dealer-based Market with Central Clearing



If clearinghouses can reduce or eliminate counterparty risk, swaps values should be closer to the risk-free case rather than the case with counterparty risk. However, even if clearinghouses are successful at eliminating counterparty risk, additional cost of compliance (such as clearing fees and margin requirements) could keep swaps prices from reaching the risk-free valuation.

2.4 *Model of Liquidity (Bid-Ask Spreads)*

2.4.1 Liquidity with no Counterparty Risk

I adapt the model from Biais (1993) for centralized trading where all market participants can observe the bids, asks and market orders of their market participants. The model is a sequential game. In the first stage, two competing dealers (liquidity providers) receive a random inventory position in the risky asset between [-R, R]. In stage 2, the dealers set their bid and ask prices. In the next stage there is a liquidity shock with probability λ. If there is a liquidity shock, a liquidity trader (liquidity demander) receives an inventory of quantity L with probability $\frac{1}{2}$ (or a short position of size $-L$ with the same probability). The liquidity trader then decides the size of the optimal market order, which is executed at the best bid or ask price posted by the dealers. If there is no liquidity shock, no trade takes place. In the final stage, the price of the risky asset is realized, and players receive their utility.

I assume that the two dealers are identical except for their inventory positions. All market participants have constant absolute risk aversion (CARA) utility $U(w) = -\exp(-\alpha \cdot w)$, where w is the trader's wealth and α is a risk-aversion parameter. If there is a liquidity shock, the liquidity trader observes the market prices and selects the quantity (size) of the market order. The final price of the risky asset is $p = 1 + z$, where $z \sim \mathbb{N}(0, \sigma^2)$.

I analyze the case where the liquidity trader receives a liquidity shock $+L$ (the case where the liquidity trader receives a $-L$ shock will be analogous). At the end of the game, once the asset price is realized, this trader receives wealth:

$$w = p(L - Q) + Q \cdot p_b^* \tag{5}$$

where $L - Q$ is the net position of the trader in the risky asset at the end of the game and $(Q \cdot p_b^*)$ is the cash from selling Q units of the risky asset at the best (highest) bid price. The liquidity trader will maximize his expected utility $\mathbb{E}[U(w)] = \mathbb{E}[-\exp \alpha\big((L - Q)p + Q \cdot p_b^*\big)]$. The optimal quantity is:

$$Q^* = \frac{1}{a \cdot \sigma^2}(p_b^* - 1) + L \tag{6}$$

where I have used the fact that $\mathbb{E}[\exp z], z{\sim}N(\mu, \sigma^2) = \exp\left(\mu + \frac{\sigma^2}{2}\right)$

If dealer 1 has the best price, s/he receives the order flow and has wealth:

$$w = (I_1 + Q^*)p - p_1^b Q \tag{7}$$

where: p_1^b is the bid price set by dealer 1, Q^* is the size of the market order and I_1 is his random inventory position (a number between $[-R, R]$). If dealer 1 does not have the best price, s/he receives:

$$w = I_1 p$$

Dealer 1 is indifferent between trading and not trading when the expected utility from both actions is the same. This happens when:

$$p_{r,1}^b = \frac{\alpha\sigma^2}{2}(Q^* + 2I_1) \tag{8}$$

$$p_{r,1}^b = \alpha\sigma^2(L + 2I_1) - 1 \tag{9}$$

where the price is subscripted with r to emphasize it is the reservation price. A similar analysis holds for the ask price:

$$p_{r,1}^a = \alpha\sigma^2(L - 2I_1) - 1 \tag{10}$$

and in general, for dealer i, the reservation prices are:

$$p_{r,i}^b = \alpha\sigma^2(L + 2I_i) - 1 \tag{11}$$

$$p_{r,i}^a = \alpha\sigma^2(L - 2I_i) - 1$$

I analyze the case of the optimal bid quote for dealer 1, assuming competing dealers do not observe the other's inventory levels, but both assume that the others inventory is drawn uniformly from $[-R, R]$. By increasing his/her bid quote, a dealer increases his/her probability of winning the order flow but must balance this against the fact that s/he pays more for each unit acquired. S/He would not like to increase the quote beyond his/her reservation price. The optimal bid quote is:

$$p_1^b = p_{r,1}^b + \alpha \cdot \sigma^2 \frac{(R - I_1)}{2} \tag{12}$$

Similarly, the optimal ask quote is:

$$p_1^a = p_{r,1}^a + \alpha \cdot \sigma^2 \frac{(R + I_1)}{2} \tag{13}$$

and in general, the optimal bid and ask quotes for dealer i are:

$$p_i^a = p_{r,i}^a + \alpha \cdot \sigma^2 \frac{(R + I_i)}{2} \tag{14}$$

$$p_i^b = p_{r,i}^b + \alpha \cdot \sigma^2 \frac{(R - I_i)}{2}$$

The observed bid ask spread is:

$$S = \max[p_i^b] - \min[p_i^a] \tag{15}$$

note: Under competition with many dealers, the second term on the RHS of the (14) $\left[\alpha \cdot \sigma^2 \frac{(R \pm I_i)}{N}\right]$ approaches 0 as $N \to \infty$, and the bid ask quotes become the reservation quotes.

2.4.2 Liquidity with Counterparty Risk

Under the scenario where there is counterparty risk, if the counterparty defaults the value of the asset is impaired (the holder of the non-defaulting leg no longer receives expected cash flows). However, for the defaulter, the value of the asset is enhanced (as he no longer needs to make payments). I model this as an additional shock to the realized value of the asset: $p = (1 + z + y), y \sim N(0, \delta^2)$. The analysis remains essentially the same, but the optimal market order size, reservation prices, and optimal quotes now become:

$$Q^* = \frac{1}{\alpha \cdot (\sigma + \delta)^2}(p_b - 1) + L \tag{16}$$

$$p_{r,i}^b = \alpha(\sigma + \delta)^2(L + 2I_i) - 1 \tag{17}$$

$$p_{r,i}^a = \alpha(\sigma + \delta)^2(L - 2I_i) - 1 \tag{18}$$

$$p_i^a = p_{r,i}^a + \alpha \cdot (\sigma + \delta)^2 \frac{(R + I_i)}{2} \tag{19}$$

$$p_i^b = p_{r,i}^b + \alpha \cdot (\sigma + \delta)^2 \frac{(R - I_i)}{2} \tag{20}$$

2.5 *Model of Price Volatility*

2.5.1 Volatility without Counterparty Risk

I develop an original model of price volatility. There are two sets of agents: market-makers who post bid and ask prices, and liquidity traders who post market orders. Assume that order-flow (net market-buy or market-sell orders) in one period are i.i.d Normal with variance σ_ϵ^2:

$$OF_t \sim N(0, \sigma_\epsilon^2) \tag{21}$$

Market-makers adjust their next period price based on the current period's observed order-flow:

$$P_{t+1} = P_t + \alpha \cdot OF_t \tag{22}$$

where: α is a parameter for the market-makers sensitivity to order-flow.

The expression for the volatility in this case is:

$$vol = \sqrt{Var(P_{t+1} - P_t)} = \alpha \cdot \sigma_\epsilon \tag{23}$$

2.5.2 Price Volatility in Markets with Counterparty Risk

I modify the above model to include additional order-flow dynamics related to counterparty risk. Assume that when the current period's order-flow is negative, there is additional sell-off of the risky asset in the next period due to (perceived) additional counterparty risk, and when the current period's order flow is positive, there is additional buying of the risky asset in the next period due to (perceived) reduction in counterparty risk. The order-flow dynamics are now given by:

$$OF_{t+1} = \rho OF_t + \epsilon_{t+1} \tag{24}$$

Where: $\epsilon_{t+1} \sim N(0, \sigma_\epsilon^2)$

The expression for the price chance becomes:

$$\Delta P_t = (P_{t+1} - P_t) = \alpha OF_{t+1} = \alpha \cdot (\rho \cdot OF_t + \epsilon_{t+1}) \tag{25}$$

$$\begin{aligned} vol = \sqrt{Var(\Delta P_t)} = \sqrt{\alpha^2 \cdot \rho^2 Var(OF_t) + \alpha^2 Var(\epsilon_{t+1})} = Var(OF_{t+1}) \\ = \rho^2 Var(OF_t) + Var(\epsilon_{t+1}) \end{aligned} \tag{26}$$

$$Var(OF_t) = \frac{Var(\epsilon_{t+1})}{1-\rho^2} \tag{27}$$

$$vol = \alpha\sigma_\epsilon \sqrt{\frac{1}{1-\rho}} \tag{28}$$

where I have used the fact $Var(OF_{t+1}) = Var(OF_t)$ on the 3rd line and that $Var(\epsilon_{t+1}) = \sigma_\epsilon^2$.

3 Identification Strategy

3.1 Pricing

I investigate the causal impact of the central clearing mandate on the interest rate swap prices by comparing the premium above the fair rate (that is, the difference between the "riskless fixed rate" described in section 2.1 and the observed fixed rate on an actual contract) on USD denominated swaps versus the premium on CAD denominated swaps before and after the mandate. I employ a difference-in-differences (DiD) identification strategy, with the CAD denominated swaps acting as the control group, which allows me to plausibly isolate the causal effect of the mandate on the swap premiums by exploiting the variation in the timing of the policy implementation.

I begin by selecting a sample of interest rate swaps denominated in both USD and CAD from the ten trading days before and after the central clearing mandate was implemented. I create two groups based on the currency of denomination: (1) the treatment group, consisting of USD denominated swaps that were affected by the central clearing mandate, and (2) the control group, consisting of CAD denominated swaps that were not subject to the mandate during the same period. By comparing the swap premiums between these two groups before and after the mandate, I can plausibly identify the causal effect of the policy on swap premiums if both groups would have followed parallel trends in the absence of the clearing mandate.

To estimate the causal effect of the central clearing mandate on swap premiums, I employ a DiD regression model, which takes the following form:

$$Y_{i,t} = \alpha + \beta_1 * Treatment_i + \beta_2 Post_t + \delta(Treatment_i \times Post_t) + X'_{i,t}\Gamma + \epsilon_{it} \tag{29}$$

where Y_{it} is the swap premium for swap i at time t, $Treatment_i$ is an indicator variable equal to 1 if the swap is denominated in USD (treatment group) and 0 otherwise (control group), $Post_t$ is an indicator variable equal to 1 for the period after the mandate was implemented, and $X_{i,t}$ is a vector of control variables. The coefficient of interest is δ, which captures the causal effect of the central clearing mandate on swap premiums.

To ensure the validity of the identification strategy, I test the parallel trends assumption by visually inspecting the pre-treatment trends of swap premiums for both treatment and control groups and conducting placebo tests. Additionally, I use alternative control and experimental groups to lend further support to my findings.

I examine whether the parallel trends assumption holds by visually inspecting the swap rate (fixed rate of an interest rate swaps contract) prior to each phase of the implementation of the clearing mandate. I examine the three most common tenors of USD and CAD interest rate swaps (2-year, 5-year and 10-year swaps). The data is reported by Bloomberg and is usually the average of 11 or more contracts traded around 11:00 AM Eastern Time of the trading day that meet contract specifications (described earlier). Figure 4 shows these trends for the periods described above. The swaps rates show a parallel trend prior to the implementation of the clearing mandate, with the Canadian swaps rate being higher than the US rate. This is likely due to differences in key policy rates between the US (lower Fed Funds target rate 0%) and Canada (key policy rate target 1%). There was no change to these policy rates in 2013.

Figure 4 Pre-trend for pricing

3.2 Liquidity

Liquidity is a broad concept defined as how easily one can convert financial assets to cash with minimal impact to prices. Several measures try to capture this notion: *bid-ask spreads* measure the cost of trading (small quantities) of an asset at the best quoted sell and buy prices; *market depth* measures how much of an asset is available to trade at given price points; *price impact* measures how much prices react to buying and selling. As in the case of pricing (premium), I employ a difference-in-differences strategy to identify the impact of the central clearing mandate on liquidity, with CAD denominated contracts serving as the control group and USD denominated contracts serving as the treatment group. I use several measures of liquidity to capture the different notions discussed above.

As discussed in section 2.4 risk-averse dealers adjust their bid-ask spreads in the face of market orders from liquidity traders. To be able to compare spreads for contracts with different prices, I calculate a relative bid-ask spread based on the mid-quote:

$$spread = \frac{bid - ask}{\frac{bid + ask}{2}} \tag{30}$$

where the numerator $(bid - ask)$ is the "raw" spread and the denominator $\frac{bid-ask}{2}$ is the mid-quote. I collect end-of day bid and ask data from the Bloomberg terminal for US-dollar and Canadian-dollar denominated 2-year, 5-year and 10-year contracts for the ten-day trading period before and after the implementation of phase 1, phase 2 and phase 3 of the of the clearing regulation.

The bid-ask spread measure discussed above is "low frequency" and does not necessarily reflect the costs traders may face throughout the trading session. To estimate the intraday liquidity that traders may experience, I use two proxies common in the literature: the Roll measure and the Amihud Illiquidity (price impact) measure.

The first measure proposed by Roll (1984) estimates the effective spread using the time series of observed prices under assumptions of market efficiency:

$$Roll = 2 \cdot \sqrt{-cov(\Delta p)} \tag{31}$$

where Δp is the first-order serial covariance of price changes. I group the contracts by tenor and calculate the Roll measure for each trade date. I focus the analysis on 2-year, 5-year and 10-year contracts (the most actively traded contacts). For some trading days and tenors, the quantity under the radical is negative. These observations are excluded from the dataset. I also exclude any days where the number of contracts traded is less than five.

In general, market liquidity is a measure of "how easily" traders can exit or enter the market. The bid-ask spread (and the Roll measure) is a common metric for how easily traders can enter or exit *small positions*. However, when trading larger positions, this liquidity may not be available (only a limited number of contracts may be available to trade at the best bid and ask prices, and dealers can change their quoted prices in the face of large market orders). A common measure of the "price impact" of a trade is the Amihud liquidity measure:

$$Amihud_t = \frac{|R_t|}{Volume_t} = \frac{|P_{t-1} - P_t|}{Volume_t} \tag{32}$$

where R_t is the return on an asset at time t and $Volume_t$ is the total volume of contracts traded (calculated as the sum of the gross notional contract value in period t). The Amihud liquidity measure, which normalizes inter-period price changes by the market size (volume) is a good measure of how much prices move, scaled by the trade size. I calculate the daily Amihud liquidity measure for US and Canadian two-year, five-year, and ten-year contracts for each trading date (calculating average daily returns using price changes from trade to trade within a day. I use the total notional amount on a given day as the volume measure in the denominator).

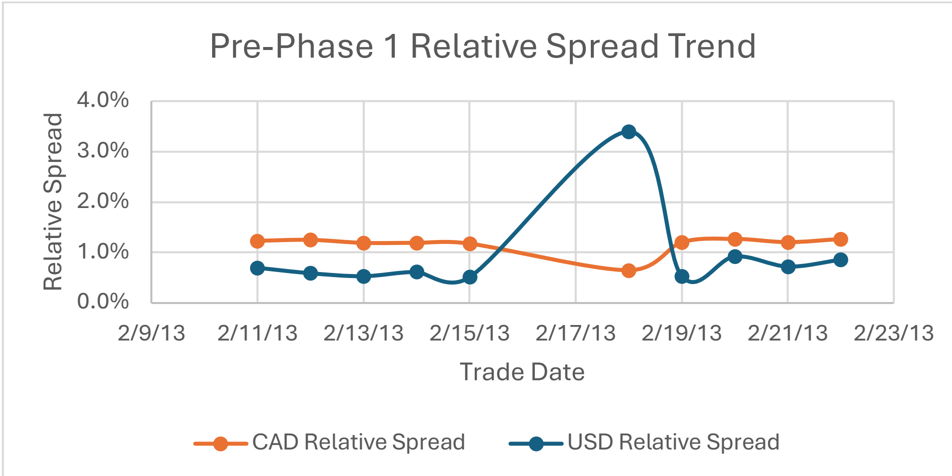
For each liquidity measure discussed above, I run a simple difference-in-differences model:

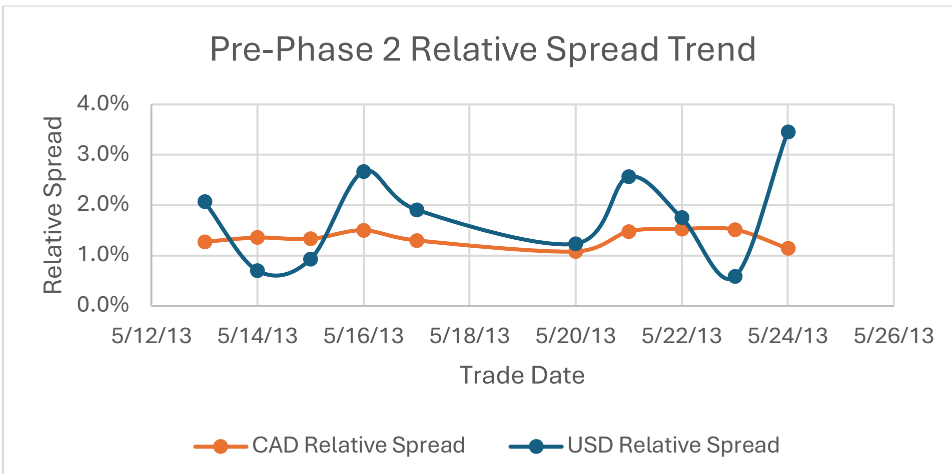
$$Y_{i,t} = \beta_0 + \beta_1 Treatment_i + \beta_2 Post_t + \delta(Treatment_i \times Post_t) + \epsilon_{i,t} \tag{33}$$

where $Y_{i,t}$ is the liquidity measure of interest, $Treatment_i$ is an indicator variable for whether the observation is in the treatment (US-dollar denominated market) or control (Canadian-dollar denominated market) group, $Post_t$ is an indicator variable for whether the observation is in the post- or pre implementation period. δ is the parameter of interest.

For the identification strategy to be valid, the underlying variables must follow parallel trends if there was no intervention. I visually test this by plotting the time-series of the relative spread, Amihud measure, and the Roll measure for the twenty trading days before the period of the study. Figure 5 shows the path of the relative spread measure for 5-year contracts for the USD and CAD denominated markets (other contract tenors show a similar trend). As in the case for the price premium, the relative bid-ask spread measure in the US and Canadian contracts generally follow a parallel trend before the implementation of the clearing mandate. The Canadian market has higher relative spreads, likely due to the smaller size of the market. Figure 6 shows the Roll measure for the 5-year USD and CAD interest rate swaps contracts (other tenors show similar trends). Note that due to the limitation discussed above, the Roll measure is not observable on all trading days. It is difficult to make a conclusion about parallel trends due to the lack of data availability. Figure 7 shows the Amihud illiquidity measure for 5-year USD and CAD interest rate swaps contracts. As expected, the Amihud measure is larger (indicating less liquidity) for the Canadian market, due to its smaller size. As is the case with the Roll measure, there is not enough data to conclude whether the parallel trend assumptions hold for the Amihud illiquidity measure.

Figure 5 Relative Bid-Ask Spread for five year contracts (Pre-Trend of ten trading days before study period)





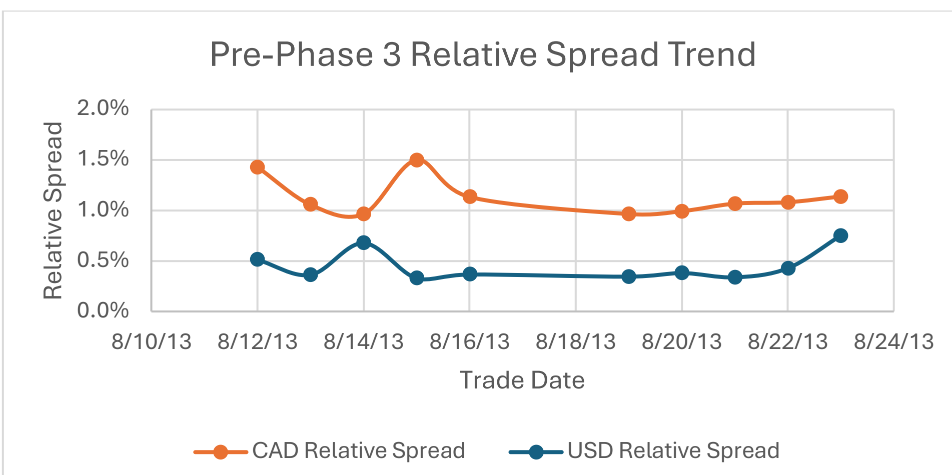


Figure 6 Roll Measure Pre-Trend

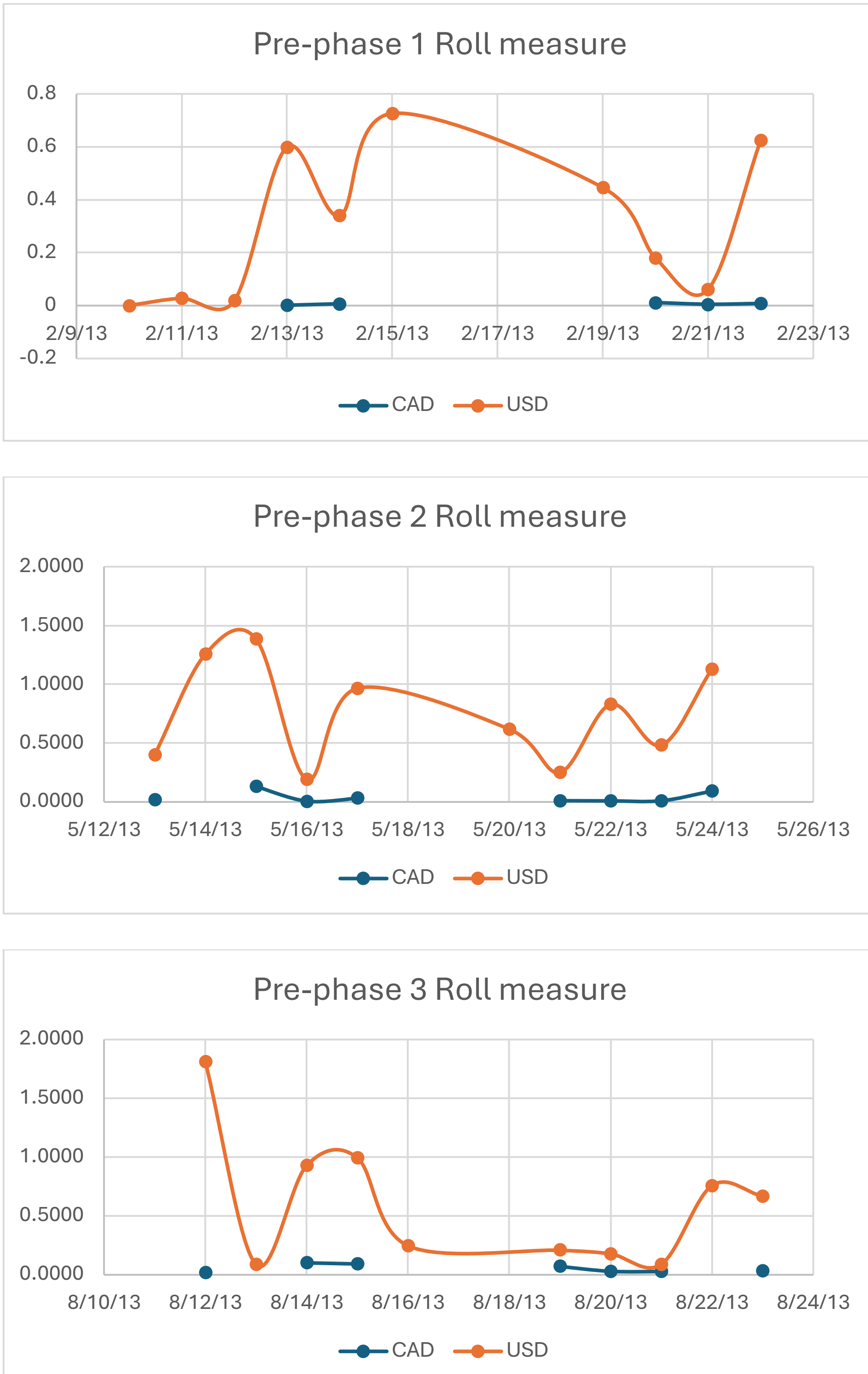
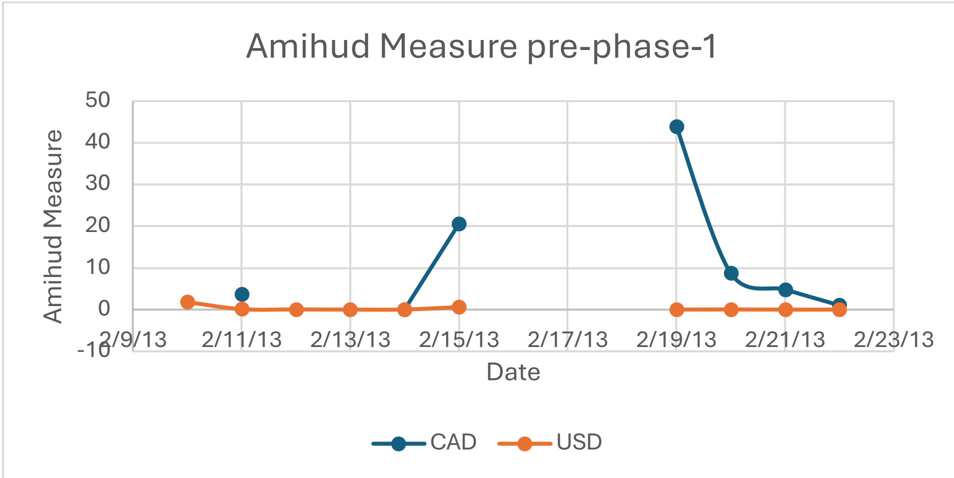
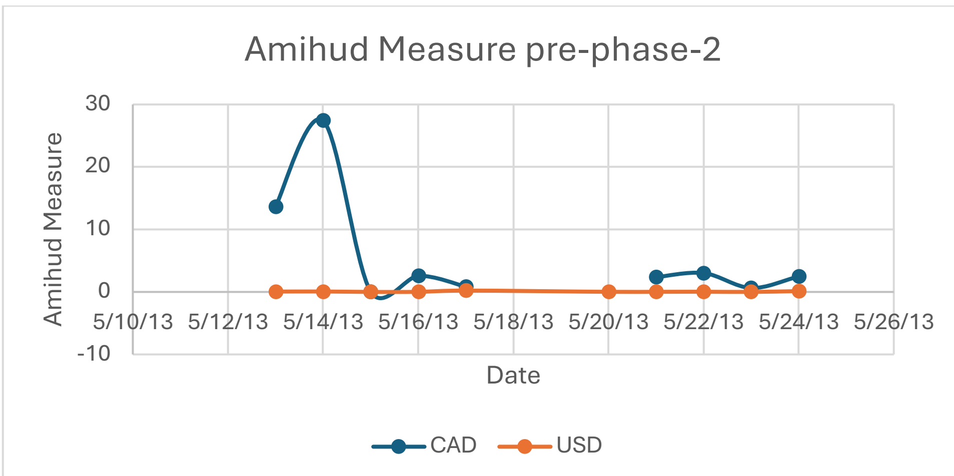
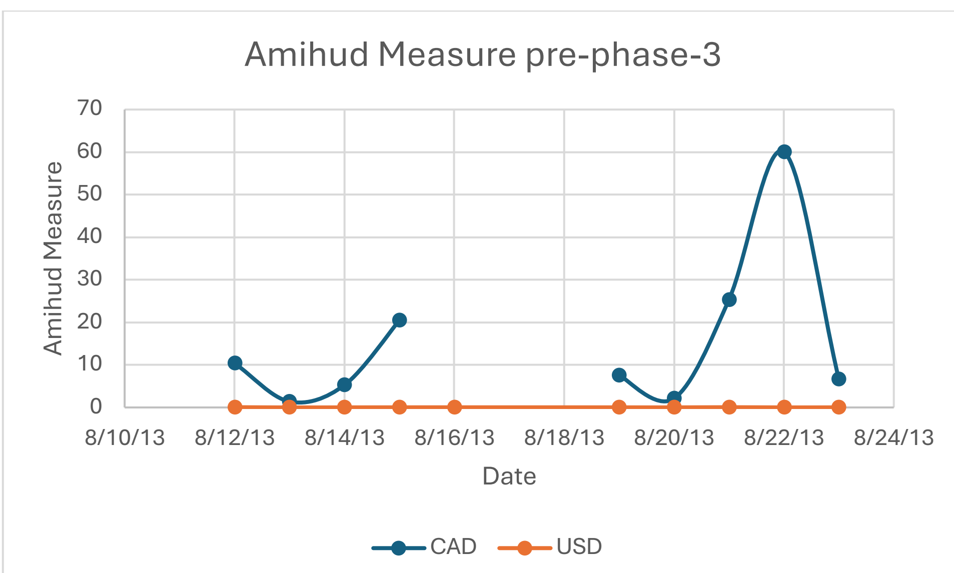


Figure 7 Amihud Measure Pre-Trend







3.3 Volatility

As is common practice in literature, I use the realized volatility as my measure of volatility. If the return on an asset in the period $[t-1, t]$ is defined as:

$$r_t = \log\left(\frac{P_t}{P_{t-1}}\right) \tag{34}$$

The (annualized) realized volatility of the return is then:

$$RV = \sum \frac{252}{n} (r_t)^2 \tag{35}$$

where: n is the number of trading days in the sample period and 252 is the approximate number of trading days in a year.

For each trading day, I select contracts with "whole number tenor years" between 1 and 10 years (that is, I exclude contracts that are "partial years" such as 18-, 21- and 30-month contracts), as well as 15- and 30-year contracts. For the Canadian market, these are the most actively traded contracts. Calculating volatility requires several observations of each tenor for each trading day. I group contracts by currency, tenor, and trading day (I exclude the Memorial Day and Labor Day holidays as too few contracts are traded on those days to calculate realized volatility). The filtered dataset captures 90% of Canadian contracts traded during the period of the study, and I can calculate volatility of several tenors for each trading day[3]. However, for several tenors (such as 4-year, 6-year, 8-year and 9-year contracts), no trades or only one or two trades occur in the Canadian market on certain dates, and I cannot calculate the volatility measure for that tenor for the Canadian-dollar denominated contract on that trading date. Ideally, I would have 24 observations for each of the 58 trading days (one for each currency, for each tenor between 1 and 10 years, 15 years, and 30 years). However, since no Canadian contract of a particular tenor is traded on certain dates, I end up with 914 observations in my data set.

Like liquidity and pricing calculations, I classify each observation as either in the control group (if currency is CAD) or treatment group (if currency is USD), and whether it is in the pre-treatment or post-treatment period. I then perform a difference-in-difference regression:

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[3] I exclude discussion regarding the data availability of US-dollar denominated contracts. In general, there are enough contracts traded for each trading day and contract specification that a realized volatility measure can be calculated for each. The availability of data for the US market is not a limiting factor in my analysis.

$$RV_{i,t} = \beta_0 + \beta_1 Treatment_i + \beta_2 Period_t + \delta(Treatment_i \times Period_t) + \epsilon_{i,t} \tag{36}$$

where $RV_{i,t}$ is the realized variance for contract specification i in period t and the rest of the variables are as described in the liquidity section. δ (the interaction between group and pre/post-treatment period) is the parameter of interest.

As with the other difference-in-differences specification, for the identification strategy to be valid, the two groups need to follow parallel trends in the absence of an intervention. I plot the time series (Figure 8) of the realized volatility measure for the 2-year, 5-year and 10-year contracts for the twenty trading days before the implementation of the clearing mandate. In general, the volatility measure follows a parallel trend for the US-dollar denominated and Canadian-dollar denominated markets.

Figure 8 Realized Volatility Pre-Trend