

# Essay 1: 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 essay 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 essay 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 diff-in-diff 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 contracts denominated in other currencies, this essay plausibly identifies the causal impact of the regulation on pricing, liquidity, and price volatility in the IR swaps market using a difference-in-differences approach.

The essay 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 details my data; section 4 reviews the identification strategy; 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, with vanilla fixed-for-floating swaps being the most prevalent (“OTC Derivatives Statistics at End-June 2024” 2024). In this type of swap, one party exchanges fixed-rate coupon payments for floating-rate payments on a notional principal (Skarr and Szakaly-Moore 2007)<sup>1</sup>. 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 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 (Loon and Zhong 2016). 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 (Fett and Haynes 2017). During the period studied in this essay, the standard US Dollar (USD)-denominated IR swaps contract had semiannual payments for one leg and quarterly payments for the other leg, 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 Canadian Dollar Offer Rate (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

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<sup>1</sup> The principal is “notional” because unlike a real bond it is never exchanged. It is only used to calculate fixed and floating rate payments.

Appendix A. The CAD- and USD-denominated standard contracts use the ISDA Master Agreement, which details these contract specifications (Minton 1997). 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 (and these conventions are documented in Appendix A).

The IR swaps market is dealer-dominated, with dealer-customer and dealer-dealer trades accounting for 80% of notional value (Bolandnazar 2020). 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) (Duffie and Zhu 2011; Duffie, Scheicher, and Vuillemeys 2015). The clearinghouse becomes the counterparty for each leg (that is, receiving the fixed-rate payments from one party and paying the floating-rate payments to that party, while also receiving the floating-rate payments from the other party and paying it the fixed-rate payments). Under ordinary circumstances, the clearinghouse is a sort of “pass-through” organization that transmits payments from one counterparty to the other. However, if one party fails to meet their contractual obligation, the clearinghouse can still make sure the other party gets paid (Pirrong 2011). For this purpose, CCPs practice risk-control measures and have additional resources to make a counterparty whole in case of default<sup>2</sup>. When counterparties clear their trade through a clearinghouse, they must put

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<sup>2</sup> 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

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 (variation margin). The CCP also has default fund contributions from 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 (Pirrong 2011). Since the CCP can observe all trades that it is clearing, it has a better picture of overall riskiness compared to what market participants have in a bilateral market, where one party is generally unaware of other trades its partner is entering into, and thus does not have a thorough understanding of its partner's riskiness.

Clearing can reduce demand for collateral through a practice called netting (Duffie, Scheicher, and Vuillemeys 2015). 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., IR 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. Consider the following example involving 3 firms. The set of obligations between the firms are as follows: 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. The total collateral demand in the system is \$700 million. This initial set of obligations is visualized in Figure 1a, where the arrows indicate the direction of the obligation (which firm owes who). Without multilateral netting, the firms can still engage in bilateral netting, as shown in Figure 1b. In a bilateral netting regime, the firms “subtract” or “net out” their payment to each counterparty. Thus, the following payments would be made: firm A would pay firm B  $(\$100 - \$50) = \$50$  million and firm C  $(\$200 - \$100) =$

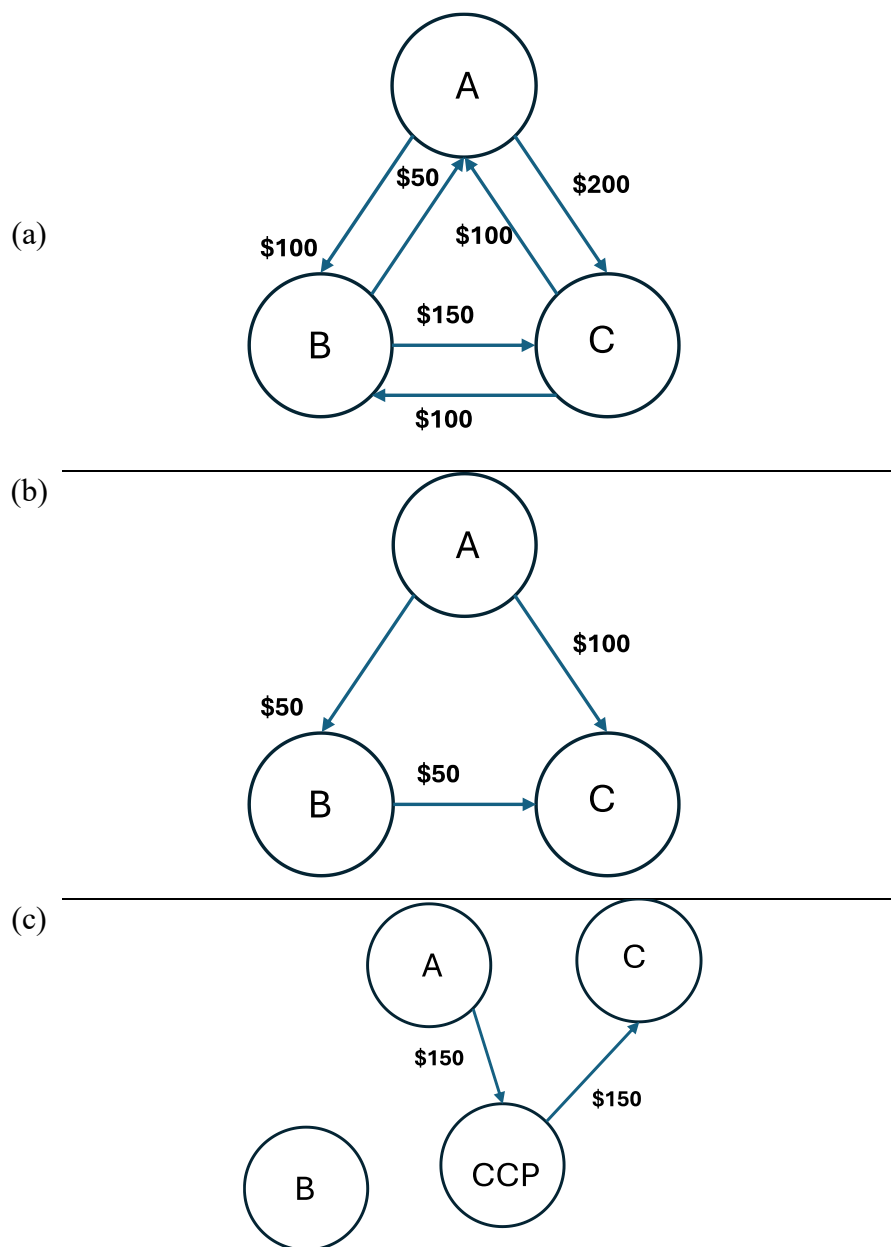
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clearing member” (McPartland 2009). Trade intermediaries that are clearing members will collect collateral from their non-clearing member clients and pass it on to the CCP.

\$100 million; firm B would pay firm C  $(\$150 - \$100) = \$50$  million. The total collateral demand would be \$200 million. As shown in the figure, under this arrangement, firm B acts like a pass-through entity that collects payment from firm A and transmits it to firm C. However, if firm B is unable to make the collateral payment, firm C loses some of the collateral it is due. Multilateral netting can eliminate this payment from firm B to firm C (with the CCP now acting as the pass-through entity). Under multilateral netting 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 1c graphically depicts this multilateral netting scenario.

Figure 1 Example of obligations between three firms

(a) without any netting (b) with bilateral netting (c) with multilateral netting. Arrows indicate the direction of obligations (for example in (a) firm C owes firm B \$100 million and firm B owes firm A \$50 million. Under bilateral netting, firms “net out” the obligations with each counterparty on a bilateral basis. Thus, the set of two obligations between firm B and C is replaced by one obligation of \$50 million from firm B to C, as shown in (b). Under central clearing, the payment from firm A to firm B can be eliminated and the clearinghouse can simply collect \$150 million in collateral from firm A and pass it directly to firm C, as shown in (c).



Originally created for members of futures and equities exchanges (Bernstein, Hughson, and Weidenmier 2019), clearinghouses became more significant with regulations like the DFA (2010) and European Market Infrastructure Regulation (EMIR, 2012) mandating central clearing of derivatives (Menkveld and Vuillemeij 2021). Mandated clearing can have macro and micro effects on the swaps market (Pirrong 2011). 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) (Benos et al. 2019). 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 2008 financial crisis, Congress passed the DFA to reform the entire US financial system. Since the OTC derivatives markets played a large role in the crisis, DFA aimed to significantly change how these markets worked. 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 (*Dodd-Frank Wall Street Reform and Consumer Protection Act* 2010). 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 (Commodity Futures Trading Commission, n.d.). 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 near real-time reporting and dissemination 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 regulatory margin/collateral to mitigate the effects of default). Table 1 summarizes the key CFTC rulemaking in these areas.

The whole set of DFA regulations (not only the central clearing mandate) are likely to affect swaps trading. To identify the causal impact of the central clearing mandate, I need to examine a period when other regulations are not varying. The CFTC implemented the DFA regulations piecemeal during the 2012-2014 period, thus leaving only small windows where the impact of the clearing mandate can be studied in isolation (this is discussed further in the Identification Strategy section). I discuss how some of the regulations in Table 1 could impact trading. One of the provisions of the DFA that the CFTC implemented at the earliest was the data-reporting/record-keeping requirement. This required certain characteristics of swaps trades, such as the agreed upon rates and prices, to be reported in near real-time through SDRs. The OTC IR swaps market was previously relatively opaque (where quotes were usually obtained on a bilateral basis). The greater price transparency available to market participants after the implementation of the data-reporting regulation is likely to affect pricing and volatility (for example, see (Tarbert and Grimm 2021) which studies the impact of reporting requirement changes on swaps pricing).

The CFTC also encouraged standardization of swaps contracts by requiring parties to put up additional collateral for non-standard contracts, and for standardized contracts to be traded on (electronic) swaps execution facilities (SEF)/exchanges. SEFs are likely to increase competition (because requests for quotes are transmitted to multiple dealers simultaneously), increase pricing transparency (because it would give market participants access to price history, market depth and other market statistics) and increase liquidity (because it will allow more participants, both dealers and end-users to participate in the market) (Mateus and Faltoni 2015; McAlley 2024).

CFTC rulemaking also targeted the business conduct of swaps dealers and major swaps participants. This included requiring such entities to register with the CFTC, develop and maintain internal business conduct standards, set aside capital or require margining for trades they enter, segregate customer funds and have plans for unwinding trades in case of bankruptcy. These



regulations are likely to reduce the risk/impact of a dealer default (counterparty risk) and to affect pricing and volatility through the reduced counterparty-risk channel.

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

*The CFTC interpreted the DFA to contain six major rule-making areas (as well as a seventh, “other” area for miscellaneous rules). Specific rules within each rule-making area are listed on the right (Commodity Futures Trading Commission, n.d.)*

<b>Rulemaking Area</b>	<b>Major Rules</b>
<b>Swaps Dealers and Major Swaps Participants</b>	<ul style="list-style-type: none"> <li>• Registration (Mar 2012)</li> <li>• Internal Business Conduct Standards (Jun 2012)</li> <li>• Capital and Margin for non-banks (2016; Sep-Nov 2020)<sup>3</sup></li> <li>• Segregation (Apr 2012) and Bankruptcy (Feb 2012)</li> </ul>
<b>Data Requirements</b>	<ul style="list-style-type: none"> <li>• Data recordkeeping and reporting requirements (Oct 2010, Dec 2010, Mar 2012)<sup>4</sup></li> <li>• Swap Data Repositories (SDR) Registration (Oct 2011)</li> <li>• Real Time Reporting (Mar 2012)</li> <li>• Large Swaps Trader Reporting (Sep 2011)</li> </ul>
<b>Clearing Requirements</b>	<ul style="list-style-type: none"> <li>• Establishment of Derivatives Clearing Organizations (DCO/CCP) (Jan 2012)</li> <li>• Clearing requirement for most common swaps (Mar-Sep 2013)</li> <li>• Margining requirements for uncleared swaps (Apr 2016)</li> </ul>
<b>Trading Requirements</b>	<ul style="list-style-type: none"> <li>• Establishment of Swaps Execution Facilities (SEF) (Jun 2013)</li> <li>• Made Available for Trade (MAT) designation/ requirement (Jun 2013)</li> </ul>
<b>Position Limits</b>	<ul style="list-style-type: none"> <li>• Position Limits and Aggregation of Positions (Jan 2012)</li> </ul>
<b>Enforcement</b>	<ul style="list-style-type: none"> <li>• Disruptive Trading Practices (Mar 2011)</li> <li>• Anti-Manipulation (Aug. 2011)</li> <li>• Whistleblowers (Aug 2011)</li> </ul>
<b>Other</b>	<ul style="list-style-type: none"> <li>• Reliance on Credit Ratings (July 2011)</li> <li>• Fair Credit Reporting Act (July 2011)</li> <li>• Investment Adviser Reporting (Nov 2011)</li> <li>• Volcker Rule (Jan 2014)</li> <li>• Cross-Border Applications (Jan 2013)</li> </ul>

<sup>3</sup> The CFTC proposed capital and margin requirements starting in 2016. However these were implemented in phases, starting with the requirements applying to the largest SD and MSP. The final phase became effective in Nov. 2020.

<sup>4</sup> The main record-keeping and reporting requirements became effective in March 2012. The CFTC created interim rules in 2010 for record-keeping and reporting for “transition swaps”, which are swaps that were created between the passage of the Dodd-Frank Act and the enactment of the final rules in 2012.

### 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 shared similar objectives 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 clearing requirements internationally. Note that the table focuses only on the central clearing mandate in a global context, although other regulations (like those described in Table 1 for the US) were also enacted internationally as well.

The US and EU acted nearly simultaneously in enacting the central clearing requirement. As part of the EU, these regulations also affected trading in the UK (where London is a major financial center of swaps trading). In Japan and Australia, authorities enacted mandatory central clearing slightly before the US and EU, for contracts designated in their respective local currency. Other financial centers, such as Hong Kong, Singapore and Switzerland enacted central clearing requirements around the 2016-2017 period. Importantly, Canada implemented a central clearing requirement in May 2017, creating a period where IR swaps contracts denominated in Canadian dollars did not need to be cleared either in the US or in Canada.

*Table 2 Summary of Central Clearing Requirements in Major Financial Centers.*

*Japan and Australia required mandatory clearing of JPY-denominated and AUD-denominated contracts traded in their jurisdictions starting at end of 2012. The US and EU required mandatory clearing (for contracts in various currencies) starting in the first half of 2013. Other countries enacted similar requirements between 2013 and 2017 .*

<b>Jurisdiction</b>	<b>Relevant Laws and Regulations</b>
<b>North America</b>	<ul style="list-style-type: none"> <li>• DFA (2010) and CFTC and SEC rulemaking requires mandatory clearing of IR swaps contracts denominated in USD LIBOR, GBP LIBOR, EURIBOR and JPY LIBOR by September 2013.</li> <li>• Additional currencies and classes of contracts are added to the clearing requirement in 2016 to harmonize regulations across jurisdictions.</li> <li>• Canada requires certain CAD-denominated swaps to be cleared starting in May 2017.</li> </ul>
<b>Europe</b>	<ul style="list-style-type: none"> <li>• EMIR passes in 2012 and requires clearing of certain IR swaps contracts. Regulations come into effect in March 2013.</li> <li>• Bank of England releases financial market regulatory guidance in April 2013, reiterating the applicability of EMIR to UK-based traders.</li> <li>• Additional currencies and classes of swaps are added to the EU clearing requirements in 2016.</li> <li>• Switzerland established a clearing mandate for Switzerland based swaps in 2017.</li> </ul>
<b>Asia</b>	<ul style="list-style-type: none"> <li>• Japan Financial Stability Authority (JFSA) requires JPY denominated IR swaps referencing JPY LIBOR to be cleared by end of 2012.</li> <li>• Hong Kong requires HKD denominated swaps to be cleared starting July 2017.</li> <li>• MAS requires SGD contracts to be cleared by December 2017.</li> </ul>
<b>Australia</b>	<ul style="list-style-type: none"> <li>• Australian Council of Financial Regulators (CFR) pass legislation requiring mandatory clearing of Australian dollar (AUD) denominated IR swaps by end of 2012.</li> </ul>

## *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 IR 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 IR swaps is differences between firms' costs to borrow at fixed vs. variable rates 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 IR 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 IR 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 IR 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 IR 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 statistically 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 2.2. Several papers empirically examine liquidity in the IR 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 IR 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 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 IR 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 fire-sales 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 types of assets into insolvency. A prominent real-world example of this scenario is the 1998 crisis at Long Term Capital Management (LTCM) (Liu, Longstaff, and Mandell 2006). LTCM was a hedge fund that used a highly leveraged portfolio of IR 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. These types 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 short term. 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. These types of models are explored by Bebhuk & 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 risks (moral hazard and adverse 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 Model of Swaps Pricing

#### 2.1.1 Pricing Without Credit Risks

An IR swap can be thought of as an exchange of a series of fixed payments by one party for a series of variable (floating) rate payments by the other party involved in the swap. For the fixed leg, the present value of the payments is given by (Darbyshire 2022):

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

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:

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

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:

$$PV = PV_{floating\ leg} - PV_{fixed\ leg} \quad (3)$$

(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 (Darbyshire 2022). For instance, if the floating leg payment is based on USD LIBOR, a USD



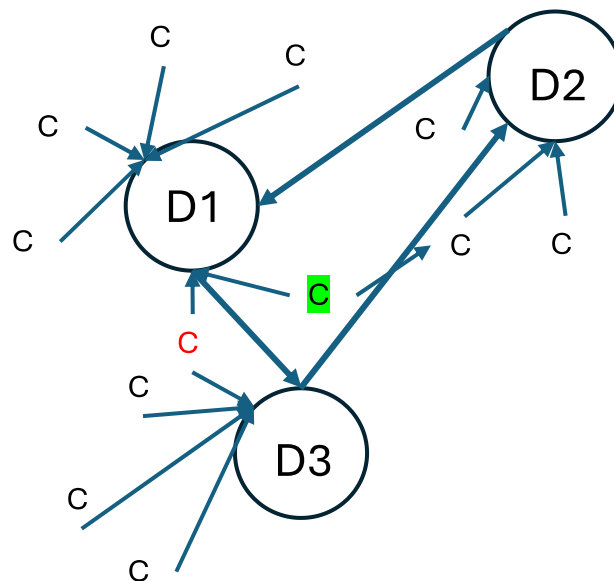
LIBOR curve, constructed by interpolating short-term deposit rates, medium-term Eurodollar futures, and long-term instruments like forward rate agreements and existing swaps, is used (Bloomberg L.P. 2024). At the outset of the contract, its value ( $PV$ ) is zero. This is achieved by determining the present value of the floating leg using the forecasted payments (e.g. using the USD LIBOR yield curve) and then setting the fixed rate payment  $CF$  in (3) such that the present values of both legs equal. The payments are discounted using the same LIBOR yield curve.

### 2.1.2 Pricing with Counterparty Risk (Credit/Debit Valuation Adjustment)

The IR 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 provide buy (bid) and sell (ask/offer) 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 A dealer-intermediated market without central clearing.*

*Three dealers (labeled D1 through D3) trade with many customers (labeled C). Dealers can engage in interdealer trades (shown with thicker arrows), and customers can trade with multiple dealers (such a customer is highlighted in red) or with other customers directly (such a customer is highlighted in green).*



In the figure, three dealers (D) each trade with their set of clients (C). Dealers might engage in interdealer trading (indicated by thicker 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 amongst themselves (indicated by arrows going from C to C). However, bilateral trades typically have low volume. Dealer-centric network structure lowers search costs compared to a direct customer-to-customer market (Bolandnazar 2020).

In practice, customers and dealers must account for the risk associated with counterparties defaulting. The "risk-free" present value pricing in equations (1)-(3) 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:

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

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

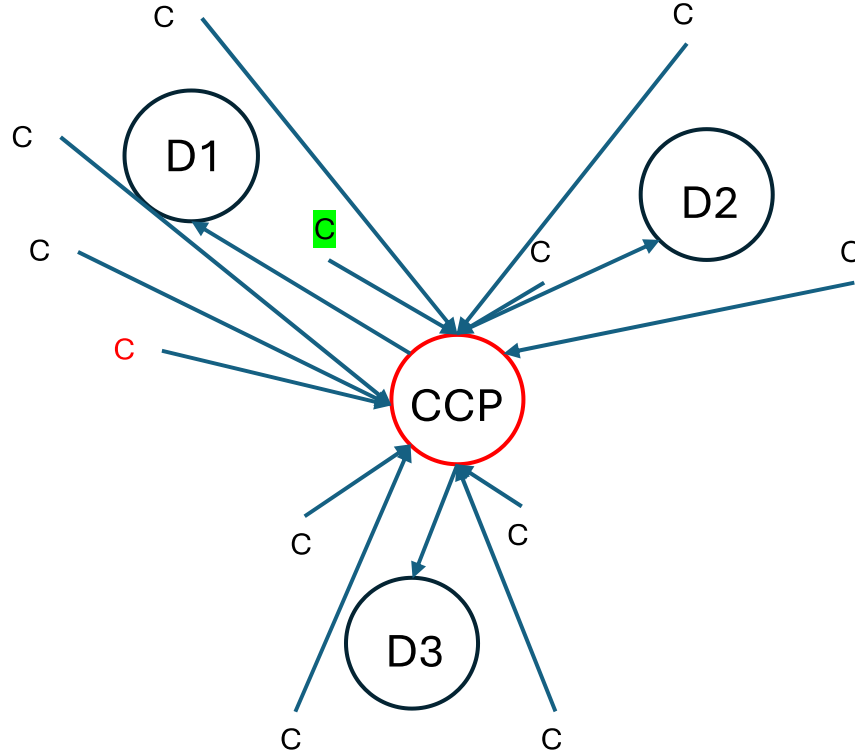
(Note that a swap's valuation with counterparty risk requires two adjustments. Only the credit valuation adjustment [CVA] is shown above. However, if one's counterparty defaults, one no longer has to make their obligated payments to the other party either, which would increase the value of the contract.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

### 2.1.3 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.

The obligations between customers and dealers, customers and customers, and between dealers are replaced by obligations between the CCP and the counterparty (dealer/customer).



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.

## 2.2 Model of Liquidity (Bid-Ask Spreads)

### 2.2.1 Liquidity with no Counterparty Risk

I adapt the model from Biais (1993) for centralized trading. I preserve the essential relationships between risk-aversion, volatility, dealers' inventory levels and the observed bid-ask spread but simplify the model to ease exposition. In the original model, traders (both liquidity traders and dealers) face trading costs. In addition, each market participant faces a fixed cost if they choose to become a dealer (these costs could be due to efforts dealers need to expend to monitor the market, maintain a presence on the trading floor, engage in risk-control and back-office activities). At the

start of the sequential game outlined by Biais,  $M$  of the  $N$  market participants choose to become dealers based on their costs and expected profits from market-making activities. However, this aspect of Biais' model is not consequential to the fundamental relationship between the bid and ask prices quoted by dealers and the volatility of underlying prices. To simplify exposition, I modify the sequential game to involve exactly 2 dealers and one liquidity trader (that is, players no longer choose their type but are predetermined to either be dealers or a liquidity trader). In addition, I drop the fixed trading costs for dealers, as this only adds a constant level to dealers' reservation quotes.

The model is a sequential game where all market participants (players) can observe the quotes (bids and asks) and (market) orders of other market participants. In the first stage, two competing dealers (liquidity providers) receive a random inventory position in the risky asset between  $[-R, R]$ . In stage 2, dealers set their bid and ask prices. In the next stage there is a liquidity shock with probability  $\lambda$ . 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). They then decide 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  $\alpha$  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  $z \sim \mathcal{N}(0, \sigma^2)$ .

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

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

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  $p_b^*$ . The liquidity trader will maximize expected utility  $\mathbb{E}[U(w)] = \mathbb{E}[-\exp \alpha((L - Q)p + Q \cdot p_b^*)]$ . The optimal quantity is:

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

where I have used the fact that  $\mathbb{E}[\exp(z)], z \sim \mathcal{N}(\mu, \sigma^2) = \exp\left(\mu + \frac{\sigma^2}{2}\right)$  and  $\mu = 0$ .

If dealer 1 has the best price, they receive the order flow and have wealth:

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

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

$$w = I_1 p$$

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

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

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

where the price is subscripted with  $r$  to emphasize it is the reservation price. A similar analysis holds for the ask price (when dealers are competing over market sell orders in response to a negative liquidity shock):

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

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

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

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

I analyze the case of the optimal bid quote for dealer 1, assuming the competing dealer does not observe the other's inventory level, but both assume that the other's inventory is drawn uniformly from  $[-R, R]$ . A dealer can increase their probability of winning the order flow by improving their bid price but must balance this against the fact that they pay more for each unit acquired. The dealer would not like to increase the quote beyond their reservation price. The optimal bid quote for dealer 1 is:

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

Similarly, the optimal ask quote is:

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

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

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

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

The observed bid ask spread is:

$$S = \max[p_i^b] - \min[p_i^a] \quad (15)$$

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

### 2.2.2 Sensitivity to Specification of Utility Function

In the above, I derived expressions for the bid-ask spread using a Constant Absolute Risk Aversion (CARA) utility function for all market participants. In this section, I show that when the utility function is switched to Constant Relative Risk Aversion (CRRA) utility, the optimal bid-ask spreads are qualitatively similar.

Consider the same game-theoretic setup described previously. However, now market participants have utility functions:

$$u(w) = \begin{cases} \frac{w^{1-\gamma}}{1-\gamma}, & \gamma \neq 1 \\ \ln w, & \gamma = 1 \end{cases} \quad (16)$$

The final wealth of the liquidity trader is given by:

$$\begin{aligned} w(Q) &= Q \cdot p_b + (L - Q) \cdot (1 + z) = Q(p_b - 1) + (L + Q)z \\ z &\sim \mathcal{N}(0, \sigma^2) \end{aligned} \quad (17)$$

Let  $\mu_w = \mathbb{E}[w(Q)]$  be the expected final wealth. If we expect the size of the liquidity shock and order size to be relatively small, we can approximate the utility function around  $\mu_w$  by a second-order Taylor series approximation:

$$u(w) \approx u(\mu_w) + (w - \mu_w)u'(\mu_w) + \frac{1}{2}(w - \mu_w)^2 u''(\mu_w) \quad (18)$$

then

$$\mathbb{E}[u(w)] \approx u(\mu_w) + \frac{1}{2} u''(\mu_w) \mathbb{E}[(w - \mu_w)^2] \quad (19)$$

where I have used  $\mathbb{E}[w - \mu_w] = 0$

Since  $\mathbb{E}[(w - \mu_w)^2] = (L - Q)^2 \sigma^2$ . We have:

$$\mathbb{E}[u(w)|w = \mu_w] \approx \frac{\mu_w(Q)^{1-\gamma} - 1}{1-\gamma} - \frac{\gamma}{2} \mu_w(Q)^{-\gamma-1} (L - Q)^2 \sigma^2 \quad (20)$$

where I write  $\mu_w = \mu_w(Q)$  to emphasize that the trader's expected wealth is a function of their order quantity. To find the optimal order quantity, we can set the derivative of the expected utility to zero:

$$d \frac{\mathbb{E}[u(w(Q))]}{dQ} = 0 \quad (21)$$

We can solve this to obtain  $Q^*$ :

$$Q^* = L + \frac{(p_b - 1) \mu_w(Q)^{2\gamma+1}}{\gamma \sigma^2} \quad (22)$$

This is similar the optimal order quantity we derived under CARA (see equation (6)) with an additional  $\mu_w^{2\gamma+1}$  term in the numerator, showing the order quantity is sensitive to the expected level of wealth of the trader.

We can similarly derive the reservation prices for the dealers. For simplicity, I work through the reservation bid price for dealer 1.

Dealer 1 receives a random inventory position  $I_1$ ,  $I_1 \sim Unif(-R, R)$ . If they post the best bid price and receive the trade and their wealth at the end of the period is:

$$w = (I_1 + Q)(1 + z) - p_b^1 Q \quad (23)$$

If they do not have the best price, they do not trade, and their wealth will be:

$$w^{NT} = I_1(1 + z) \quad (24)$$

At some price  $p_{b,r}^1$  the dealer will be indifferent between trading and not trading. This will occur when  $\mathbb{E}[u(w(p_{b,r}^1))] = \mathbb{E}[u(w^{NT})]$ .

Let  $\mu_w$  be the expected wealth  $\mathbb{E}[(1 + Q)(1 + z) - p_{b,r}^1 Q] = I_1 + Q(1 - p_{b,r}^1)$

The second order Taylor-series expansion about  $\mu_w$  is:

$$u(w)|w = \mu_w \approx u(\mu_w) + (w - \mu_w)u'(\mu_w) + \frac{1}{2}(\mu_w - w)^2 u''(\mu_w) \quad (25)$$

Taking expectations:

$$\mathbb{E}[u(w)|w = \mu_w] \approx \mathbb{E}[u(\mu_w)] + \frac{1}{2}(w - \mu_w)^2 u''(\mu_w) \quad (26)$$

Using the fact that  $\mathbb{E}[w - \mu_w]^2 = (I_1 + Q)^2 \sigma^2$  we obtain:

$$\mathbb{E}[u] \approx \frac{I_1 + Q(1 - p_{b,r}^1)^{1-\gamma} - 1}{1 - \gamma} + \frac{1}{2}(I_1 + Q)^2 \sigma^2 (-\gamma(I_1 + Q(1 - p_{b,r}^1)^{-\gamma-1}) \quad (27)$$

We can similarly take the Taylor Series approximation of the utility function at the no-trade level of wealth:

$$\mathbb{E}[u(w_{NT})] \approx \frac{(w_{NT}^{1-\gamma} - 1)}{1 - \gamma} - \frac{\gamma}{2} I_1^2 \sigma^2 w_{NT}^{-\gamma-1} \quad (28)$$

We can substitute  $w_{NT} = I_1(1 + z)$  and  $w = (I_1 + Q)(1 + z) - p_b^1 Q$  into the expressions above and set  $\mathbb{E}[u(w)|w = \mu_w] = \mathbb{E}[u(w_{NT})]$ . We obtain the reservation price:

$$p_{b,r}^1 \approx \frac{\gamma \sigma^2}{2} \mu_w (p_{r,b}^1) \quad (29)$$

We cannot solve for  $p_{b,r}^1$  explicitly, but note it has a similar form to the CARA reservation price.

In competitive markets, the dealer's markup will tend to zero and prices will tend to the reservation prices.

Thus, we find that using CRRA utility function, the optimal order quantity and bid-ask spreads are qualitatively similar to the CARA utility case, except quantities and spreads are sensitive to the level of expected wealth of the market participants.

### 2.2.3 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 they no longer need to make payments). I model this as an additional shock to the realized value of the asset:  $p = (1 + z + y)$ ,  $y \sim \mathcal{N}(0, \delta^2)$ . The analysis remains essentially the same, but the optimal market order size, reservation quotes, and optimal quotes now become:

$$Q^* = \frac{1}{a \cdot (\sigma + \delta)^2} (p_b - 1) + L \quad (30)$$



$$p_{r,i}^b = \alpha(\sigma + \delta)^2(L + 2I_i) - 1 \quad (31)$$

$$p_{r,i}^a = \alpha(\sigma + \delta)^2(L - 2I_i) - 1 \quad (32)$$

$$p_i^a = p_{r,i}^a + \alpha \cdot (\sigma + \delta)^2 \frac{(R + I_i)}{2} \quad (33)$$

$$p_i^b = p_{r,i}^b + \alpha \cdot (\sigma + \delta)^2 \frac{(R - I_i)}{2} \quad (34)$$

The optimal order size is reduced from  $Q^* \propto \frac{1}{\sigma^2}$  to  $Q^* \propto \frac{1}{(\sigma + \delta)^2}$ , the reservation quotes are increased from  $p_r \propto \sigma^2$  to  $p_r \propto (\sigma + \delta)^2$  and the mark-up from the reservation prices are similarly affected. With counterparty risk, the market order size is smaller, and the bid-ask spread is larger than under no counterparty risk.

Since Central Clearing is supposed to mitigate counterparty risk (and lower volatility, see next section), I expect observed bid-ask spreads under central clearing to be somewhere between the no counterparty risk and counterparty risk case.

### 2.3 Model of Price Volatility

#### 2.3.1 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) is i.i.d Normal with variance  $\sigma_\epsilon^2$ :

$$OF_t \sim \mathcal{N}(0, \sigma_\epsilon^2) \quad (35)$$

Market-makers adjust their next period price ( $P_{t+1}$ ) based on the current period's observed price ( $P_t$ ) and order-flow ( $OF_t$ ):

$$P_{t+1} = P_t + \alpha \cdot OF_t \quad (36)$$

where:  $\alpha$  is a parameter for the market-makers' sensitivity to order-flow.

The expression for the volatility in this case is:

$$vol = \sqrt{Var(P_{t+1} - P_t)} = \alpha \cdot \sigma_\epsilon \quad (37)$$

### 2.3.2 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:

$$OF_{t+1} = \rho OF_t + \epsilon_{t+1} \quad (38)$$

where  $\epsilon_{t+1} \sim \mathcal{N}(0, \sigma_\epsilon^2)$  and  $\rho$  is a coefficient of how much next period's order flow adjusts to the current period's order flow. For the order flow time series to be stationary we require  $|\rho| < 1$ . If  $\rho = 1$ , the series is non-stationary (random walk) and the variance grows over time without bound, and if  $\rho > 1$  than the series explodes.

The expression for the price change becomes:

$$\Delta P = (P_{t+1} - P_t) = \alpha OF_{t+1} \quad (39)$$

$$vol = \sqrt{Var(\Delta P)} = \alpha^2 Var(OF_{t+1}) \quad (40)$$

$$Var(OF_t) = \frac{Var(\epsilon_{t+1})}{1 - \rho^2} = \frac{\sigma_\epsilon^2}{1 - \rho^2} \quad (41)$$

$$vol = \alpha \sigma_\epsilon \sqrt{\frac{1}{1 - \rho^2}} \quad (42)$$

where I have used the fact  $Var(OF_{t+1}) = Var(OF_t)$  in equation. (41) and that  $Var(\epsilon_{t+1}) = \sigma_\epsilon^2$ .

## 2.4 Summary of Theoretical Findings

I summarize what I expect to find in the empirical section from my theory:

1. Pricing: I expect the prices/premia for swaps to increase in the post-clearing period via the demand channel. That is, at any given price, the demand for IR swaps in the post-clearing

period will be greater since counterparty default risk is now lower. This will translate to higher markups/prices for IR swaps.

2. Liquidity: I expect a narrowing of bid-ask spreads in the post-clearing period due to a decline in the unobservable  $\delta$  term in equations (33)-(34). This term represents “extra volatility” to prices due to counterparty defaults and should be lower (or zero) if central clearing reduces (eliminates) counterparty risk.
3. Volatility: I expect a lower volatility in the post-clearing period through a reduction in the  $\sqrt{\frac{1}{1-\rho^2}}$  term in (42). I expect  $\rho \rightarrow 0$  (the no counterparty risk case as in (36)) as counterparty risk decreases, which would reduce the observed volatility.

### 3 Data

#### 3.1 Data Sources and Collection

The primary dataset used in this analysis consists of trade-level information on IR swaps obtained from Bloomberg's Swaps Data Repository (SDR) screen. Bloomberg compiles and disseminates this data from the Depository Trust and Clearing Corporation's Swaps Data Repository (DTCC SDR), one of the largest repositories designated by the Commodity Futures Trading Commission (CFTC) to collect and maintain records of swap transactions.

The data collection process is governed by the reporting requirements introduced under the DFA. Specifically, the CFTC mandated that swap counterparties report detailed transaction-level data to registered SDRs, such as DTCC, shortly after trade execution (*Swap Data Recordkeeping and Reporting Requirements* 2012). These reporting obligations, which became effective starting in late 2012, aimed at increasing market transparency and improving regulatory oversight by providing near real-time access to key trade characteristics.

The DTCC SDR dataset from Bloomberg captures detailed trade information, including trade date and time, swap currency, notional value, fixed and floating rates, contract tenor, payment frequency, capped notional indicators, and clearing status. The dataset spans the windows around the phased implementation of the CFTC's central clearing mandate, providing comprehensive coverage for analyzing the causal impact of the regulation on pricing, liquidity, and volatility of IR swaps.

In order to price swaps properly, I need relevant yield curves. I also obtain the data for this from the Bloomberg Terminal (YC function). I detail the exact curve building methodology (including the specific curves used) in a later section.

When evaluating the impact of central clearing on liquidity and volatility, I include some macro indicators of financial market conditions. These indicators are the returns and volatilities in the relevant equities markets. For the US market, I use the total daily returns on the S&P 500 index as a proxy for equity market return, and the Chicago Board of Options Exchange (CBOE) VIX index for the equity market volatility. The data are obtained through Yahoo! Finance. For the Canadian market, I use the S&P TSX Composite Index and the S&P TSX VIX Index. Data are obtained from Standard and Poor's.

### *3.2 Raw Data Description*

The raw dataset comprises individual trade-level observations of IR swaps from the DTCC SDR, accessed via Bloomberg's terminal. Each trade observation includes detailed contract characteristics used in my analysis:

- **Trade Date and Time:** Minute-by-minute timestamp indicating when each swap trade was executed.
- **Effective and Maturity Dates:** When the swap agreement begins and terminates
- **Swap Currency:** Denomination currency of the swap (primarily USD and CAD in this essay).
- **Notional Value:** The principal amount used to calculate payments exchanged by counterparties.
- **Other Payment:** Whether an initial (upfront) payment is made and if so, how much is this payment amount.
- **Fixed and Floating Rates:** The fixed interest rate agreed upon in the swap contract, and the reference rate for floating payments (e.g., LIBOR for USD swaps and CDOR for CAD swaps). Also, any adjustments to the floating rate reference (e.g. LIBOR + 25 bps).
- **Contract Tenor:** Duration of the swap contract from effective date to maturity.
- **Payment Frequency:** Interval at which payments are exchanged (semiannual for fixed leg, quarterly for floating leg).

- **Capped Notional Indicators:** Indicators specifying if swaps have capped notional amounts.
- **Clearing Status:** Indicator specifying whether a swap was centrally cleared or uncleared.

The dataset covers trades conducted around the three implementation phases of the CFTC's central clearing mandate: Phase 1 (March 11, 2013), Phase 2 (June 10, 2013), and Phase 3 (September 9, 2013). The periods included in the dataset are the ten trading days before and after each implementation phase, ensuring comparability across pre- and post-regulatory environments.

Table 3 shows the counts and total notional values by floating leg reference. LIBOR was the most common floating leg reference for USD denominated contracts, used for more than 95% of all USD contracts (by transaction count or total notional value). The CDOR was the most common reference rate for CAD-denominated contracts for more than 95% of CAD-denominated contracts. Other reference rates for USD contracts included the Fed Funds Rate, Prime Rate, OIS Rate, and several municipal rate indices. There are several contracts that use a foreign reference rate (COOBIVR is the Colombian overnight rate, IBR is the Colombian equivalent of LIBOR, CLP-TNA is a Chilean rate, CLICP is a Chilean price index). These are likely contracts that are hedging or speculating foreign interest rate or inflation risk but want to be paid in USD. For CAD-denominated contracts, besides the CDOR, the other reference rate was the Canadian Overnight Repo Rate Average (CORRA, which is an overnight rate). Clearing trended from 61% prior to implementation of phase 1, to 78% after phase 1, and 89% after phase 2. It stayed at 89% following the implementation of phase 3. For CAD-denominated swaps, clearing hovered between 48%-59%.

Table 3 Number of contracts and notional values by clearing status and reference rate

For USD and CAD IR swaps (unfiltered data set). Data are presented for each phase separately. Within each phase, the pre-implementation and post-implementation period are reported separately.

Pre phase 1 implementation (Feb 25 – Mar 8)						
CUR	Floating Leg	Cleared (Count)	Cleared (Notional Value)	Uncleared (Count)	Uncleared (Notional Value) (in millions)	Percent Cleared
USD	LIBOR	3,518	203,345.90	3,071	131,242.01	61%
	USD-Federal Funds-H.15	0	0.0	16	2,183.00	0%
	USD-PRIME-H.15	0	0.0	2	6.00	0%
	USD-PRIME-H15	0	0.0	2	4.00	0%
	USD SPRDL MANUAL	0	0.0	1	100.00	0%
	USD-AAA_MUNI-	0	0.0	4	31.00	0%
	USD-OIS-3	0	0.0	1	6.00	0%
	IBR	0	0.0	2	200.00	0%
	CLICP	0	0.0	1	100.00	0%
	TIS	0	0.0	1	1.00	0%
	USD-USPSA-BLOOMBERG	0	0.0	1	4.00	0%
CAD	CAD-BA-CDOR	225	18,811.40	308	20,363.10	48%
	CAD-REPO-CORRA	0	0.00	3	410.00	0%
Post phase 1 implementation (Mar 11 – Mar 22)						
CUR	Floating Leg	Cleared (Count)	Cleared (Notional Value)	Uncleared (Count)	Uncleared (Notional Value)	Percent Cleared
USD	LIBOR	4,342	262,257.70	2,125	76,649.65	77%
	USD-Federal Funds-H.15	0	0.00	24	3,353.00	0%
	IBR	0	0.00	6	1,050.00	0%
	USD-SIFMA Municipal Swap Index	0	0.00	6	60.00	0%
	USD-PRIME-H.15	0	0.00	2	6.00	0%
	USD-PRIME-H15	0	0.00	2	3.00	0%
	USD-Prime-H.15	0	0.00	1	2.00	0%
	USD-USPSA-BLOOMBERG	0	0.00	2	20.00	0%
	CLICP	0	0.00	3	450.00	0%
	USD-AAA_MUNI-	0	0.00	2	25.00	0%
	USD-BMA Municipal Swap Index	0	0.00	2	6.52	0%
CAD	CAD-BA-CDOR	126	9,578.00	140	11,137.31	46%
	CAD-REPO-CORRA	0	0.00	3	780.00	0%
	CDOR	0	0.00	5	105.60	0%

Pre phase 2 implementation (May 27 – Jun 7)						
CUR	Floating Leg	Cleared (Count)	Cleared (Notional Value)	Uncleared (Count)	Uncleared (Notional Value)	Percent Cleared
USD	LIBOR	6,870	426,753.26	2,954	118,388.28	78%
	USD-Federal Funds-H.15	0	0.00	29	4,463.00	0%
	COOVIBR	0	0.00	9	1,800.00	0%
	CLP-TNA	0	0.00	6	1,200.00	0%
	USD FORM 3750	0	0.00	1	100.00	0%
	USD-AAA_MUNI-	0	0.00	2	13.00	0%
	USD-BMA Municipal Swap Index	0	0.00	1	7.00	0%
	USD-PRIME-H.15	0	0.00	12	62.90	0%
CAD	CAD-BA-CDOR	180	14,726.00	169	14,290.70	51%
Post phase 2 implementation (Jun 10 – Jun 21)						
CUR	Floating Leg	Cleared (Count)	Cleared (Notional Value)	Uncleared (Count)	Uncleared (Notional Value)	Percent Cleared
USD	LIBOR	7,975.00	461,124.51	1,449.00	53,548.33	90%
	USD-Federal Funds-H.15	0.00	0.00	33.00	5,068.00	0%
	USD-PRIME-H.15	0.00	0.00	5.00	26.00	0%
	USD-PRIME-H15	0.00	0.00	1.00	9.00	0%
	USD-Prime-H.15	0.00	0.00	1.00	2.00	0%
	COOVIBR	0.00	0.00	21.00	3,750.00	0%
	CLP-TNA	0.00	0.00	7.00	700.00	0%
	USD BMA MANUAL	0.00	0.00	1.00	45.00	0%
	USD-AAA_MUNI-	0.00	0.00	3.00	20.00	0%
	USD-BMA Municipal Swap Index	0.00	0.00	2.00	10.00	0%
CAD	CAD-BA-CDOR	176.00	11,322.08	174.00	7,969.50	59%

Pre phase 3 implementation (Aug 26 – Sep 6)						
CUR	Floating Leg	Cleared (Count)	Cleared (Notional value)	Uncleared (Count)	Uncleared (Notional Value)	Percent Cleared
USD	LIBOR	6,112.00	396,744.28	1,398.00	47,355.82	89%
	USD-Federal Funds-H.15	0.00	0.00	36.00	4,539.00	0%
	USD-PRIME-WEIGHTED-AVERAGE	0.00	0.00	2.00	200.00	0%
	USD-PRIME-H.15	0.00	0.00	5.00	7.00	0%
	USD-PRIME-H15	0.00	0.00	8.00	35.56	0%
	USD-AAA_MUNI-	0.00	0.00	1.00	10.00	0%
	USD-SIFMA Municipal Swap Index	0.00	0.00	1.00	5.00	0%
CAD	CAD-BA-CDOR	128.00	9,697.20	134.00	7,487.11	56%
	CAD-REPO-CORRA	0.00	0.00	1.00	35.00	0%
Post phase 3 implementation (Sep 9 – Sep 20)						
CUR	Floating Leg	Cleared (Count)	Cleared (Notional Value)	Uncleared (Count)	Uncleared (Notional Value)	Percent Cleared
USD	LIBOR	7,481	485,507.61	1,461	58,912.20	89%
	USD-Federal Funds-H.15	0	0.00	19	3,606.00	0%
	TREASURY_DTCC_GCF_REPO_INDEX	0	0.00	4	850.00	0%
	USD FORM 3750	0	0.00	1	30.00	0%
	USD-AAA_MUNI-	0	0.00	9	56.00	0%
	USD-BMA Municipal Swap Index	0	0.00	3	13.00	0%
	USD-BMA-BMA	0	0.00	1	22.00	0%
	USD-BMA-REFB	0	0.00	2	12.75	0%
	USD-PRIME-H.15	0	0.00	7	17.00	0%
	USD-PRIME-H15	0	0.00	7	64.00	0%
	USD-Prime-H.15	0	0.00	1	1.00	0%
	USD-SIFMA Municipal Swap Index	0	0.00	5	52.75	0%
CAD	CAD-BA-CDOR	210	14,099.00	354	15,561.41	48%
	CDOR	0	0.00	1	5.00	0%
	CDOR.CAD	0	0.00	4	106.00	0%



### 3.3 Data Filtering and Cleaning

To ensure accuracy and comparability, several filtering and cleaning steps were applied to the raw dataset:

- **Pricing Threshold:** Trades with a price (fixed rate) outside  $\pm 50$  basis points (bps) relative to Bloomberg's fair valuation of a similar swap contract were excluded. These outliers likely involve unique or non-standard features not captured in the dataset.
- **Currency and Reference Rate Filtering:** Only contracts denominated in USD and CAD with USD LIBOR (for USD) or CDOR (for CAD) as the floating reference rates were retained, as these are most relevant for the essay.
- **Contract Characteristics:** Single-payment (zero-coupon) swaps and contracts with non-standard payment frequencies were excluded due to significant pricing differences compared to standard contracts.
- **Voluntary Clearing Status:** Contracts that were voluntarily cleared before the central clearing mandate or remained uncleared due to specific exemptions after the mandate were excluded to isolate the causal impact of mandatory clearing.
- **Trade Delay:** Contracts whose effective dates were more than 90 days after the trade date were excluded. These contracts have a lower volume than contracts that either execute within 2 days of the trade date or the next international money market date. They have less liquidity and might be priced differently<sup>5</sup>.

In addition, the following data cleaning steps were taken: (1) if the original rates were expressed in basis points (detected by the rate being greater than 10), they were converted to percentages by dividing by 100 and (2) usually the 'Rate 1' is the fixed leg and 'Rate 2' is the variable leg in the dataset; in some records these legs are "flipped" and corrections were made to account for this.

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<sup>5</sup> There are two types of standardized plain-vanilla interest rate swaps contracts commonly traded on the market. Spot-starting swaps become effective within two business after the trade date (T+2), following standard market conventions for USD swaps. Market Agreed Coupon (MAC) swaps have standardized pricing (for example 5Y swaps have a tick size of 25 bps, so you won't observe rates like 4.3%), standardized tenors (e.g. 2Y, 5Y, 10Y up to 30Y) and standardized coupon payment schedules. They become effective at the next International Money Market (IMM) date. Since the next IMM date can be up to a quarter (~90 days) away, I keep swaps that become effective within 90 days of the trade date. Non-standard contracts often have trade dates out into the future (these are called forward starting swaps). For further discussion, see (Fett and Haynes 2017).

### 3.4 Yield Curve Construction

To calculate the theoretical counterparty-riskless price of IR swaps, I forecast future floating rate payments and discount the payments using the appropriate yield curve. I use a single curve method, the prevalent pricing method during the study period (subsequently, the market switched to a dual-curve method of pricing swaps, where one curve was used to calculate future floating-rate payments, and another curve to discount those payments to their present value). For USD swaps, I obtain the USD semiannual fixed-floating rate curve (curve S23) for each trading day from Bloomberg. I similarly obtain the Canadian yield curve (curve S11) from the Bloomberg Terminal for pricing Canadian swaps. I use curve S45 for EUR denominated contracts, curve S10 for GBP denominated contracts and S12 for CHF denominated contracts.

I use the QuantLib-python library to construct the forward curve (Ametrano and Ballabio 2003a). For the USD swaps curve, the short-end (3M or less) of the curve is anchored by LIBOR rates; the medium-end (6M – 18M) of the curve is anchored by Eurodollar futures; and the long-end (24M onward) of the curve is anchored by US swap rates (Bloomberg L.P. 2024).

Table 4 shows sample data for CAD and USD yield curves on September 11, 2013. Note that futures rates need to have a convexity adjustment applied to them since due to daily settlement, futures payoffs differ from payoffs for other instruments (Bloomberg L.P. 2024). The values reported in the table have this convexity adjustment applied. Values between the “pillars” (observed data points) of the yield curve need to be interpolated. I use piecewise linear interpolation. I verify the curve by pricing contracts using my constructed curve and comparing against calculations by Bloomberg SWPM function. I can match the output of Bloomberg’s SWPM up to 4 decimal places.

Table 4 Sample data for construction of USD and CAD swaps curves.

The “short end” of the curve is based on observed deposit rates (such as the overnight Canadian Call Loan Rate and the 1-month and 2-month Canadian Offer Rate). The “medium leg” of the curve is constructed using data from futures contracts (note that a convexity adjustment needs to be applied to quoted futures prices due to differences in settlement between swaps and futures) and the “long end” of the curve is constructed using data from observed IR swaps. (Bloomberg L.P. 2013)

Tenor	Bloomberg CUSIP	Yield	Data Source <sup>6</sup>
<b>3M</b>	EDU13 Comdty	0.2575	BGN
<b>6M</b>	EDZ13 Comdty	0.294	BGN
<b>9M</b>	EDH14 Comdty	0.3574	BGN
<b>12M</b>	EDM14 Comdty	0.4402	BGN
<b>15M</b>	EDU14 Comdty	0.5675	BGN
<b>18M</b>	EDZ14 Comdty	0.7341	BGN
<b>2Y</b>	USSWAP2 BGN Curncy	0.5957	BGN
<b>3Y</b>	USSWAP3 BGN Curncy	1.0014	BGN
<b>4Y</b>	USSWAP4 BGN Curncy	1.45	BGN
<b>5Y</b>	USSWAP5 BGN Curncy	1.865	BGN
<b>6Y</b>	USSW6 BGN Curncy	2.2145	BGN
<b>7Y</b>	USSWAP7 BGN Curncy	2.501	BGN
<b>8Y</b>	USSW8 BGN Curncy	2.7305	BGN
<b>9Y</b>	USSW9 BGN Curncy	2.919	BGN
<b>10Y</b>	USSWAP10 BGN Curncy	3.0765	BGN
<b>11Y</b>	USSWAP11 BGN Curncy	3.2103	BGN
<b>12Y</b>	USSWAP12 BGN Curncy	3.322	BGN
<b>15Y</b>	USSWAP15 BGN Curncy	3.551	BGN
<b>20Y</b>	USSWAP20 BGN Curncy	3.7315	BGN
<b>25Y</b>	USSWAP25 BGN Curncy	3.815	BGN
<b>30Y</b>	USSWAP30 BGN Curncy	3.8565	BGN

*Note: USD Swaps Curve. Last Updated Date: 9/11/13*

Tenor	CUSIP	Yield	Data Source <sup>6</sup>
<b>1D</b>	CCLR Index	1.00	CMPN
<b>1M</b>	CDOR01 Index	1.22	CMPN
<b>2M</b>	CDOR02 Index	1.2475	CMPN
<b>3M</b>	BAU13 Comdty	1.275	BGN
<b>6M</b>	BAZ13 Comdty	1.2997	BGN
<b>9M</b>	BAH14 Comdty	1.3491	BGN

<sup>6</sup> The “data source” column is the Bloomberg terminal reported methodology/source for the values in the yield column. BGN refers to Bloomberg Generic and CMPN refers to Composite of Real-Time Contributed Prices. The BGN source is derived from contributions from market participants, executable quotes, and Bloomberg’s own pricing models. CMPN is based on actual contributions from dealers, such as bid/ask quotes and indicative prices. I do not cite BGN or CMPN in references.

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<b>12M</b>	BAM14 Comdty	1.4584	BGN
<b>15M</b>	BAU14 Comdty	1.6275	BGN
<b>18M</b>	BAZ14 Comdty	1.8164	BGN
<b>2Y</b>	CDSW2 BGN Curncy	1.6195	BGN
<b>3Y</b>	CDSW3 BGN Curncy	1.9372	BGN
<b>4Y</b>	CDSW4 BGN Curncy	2.235	BGN
<b>5Y</b>	CDSW5 BGN Curncy	2.4855	BGN
<b>6Y</b>	CDSW6 BGN Curncy	2.6885	BGN
<b>7Y</b>	CDSW7 BGN Curncy	2.8595	BGN
<b>8Y</b>	CDSW8 BGN Curncy	3.003	BGN
<b>9Y</b>	CDSW9 BGN Curncy	3.1335	BGN
<b>10Y</b>	CDSW10 BGN Curncy	3.254	BGN
<b>12Y</b>	CDSW12 BGN Curncy	3.457	BGN
<b>15Y</b>	CDSW15 BGN Curncy	3.6713	BGN
<b>20Y</b>	CDSW20 BGN Curncy	3.7915	BGN
<b>25Y</b>	CDSW25 BGN Curncy	3.7555	BGN
<b>30Y</b>	CDSW30 BGN Curncy	3.693	BGN

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*Note: CAD Swaps Curve. Last Updated Date: 9/11/13*

### 3.5 *Descriptive Statistics*

Table 5 shows summary statistics of the control variables used in the regressions (see sections 4 and 5). Wednesday was the most active trading day and Monday and Friday were the least active trading days. The dataset includes two trading holidays (Monday May 27, 2013, was Memorial Day and Monday, September 2, 2013, was Labor Day). Data from these days are included in the analysis, but trading volume is low. I split the trading day into 4 sessions based on the reported trade time: 8:00 AM – 10:59 AM (Morning), 11:00 – 1:59 PM (Mid-Day), 2:00 PM – 4:59 PM (Afternoon) and 5:00 PM – 7:59 AM (After Hours). The midday trading session was the most active, but all on-hour (i.e. during business hours) trading sessions have similar levels of activity. Trading in the off-hour trading session was lighter and accounted for about 16% of all contracts that were traded (contrast with 8:00 AM – 5:00 PM trading that accounted for 84% of the volume). The median notional value of the contract was \$50M (with a range between \$1,000 and \$260M). The median tenor was about 7 years (with a range between 2 months and 43 years).

Table 5 Selected contract characteristics.

The dataset is filtered to only include observations that use USD LIBOR or CAD CDOR as the reference rate, are not voluntarily cleared, are not zero-coupon swaps and are within 50-bps of “fair rate” for the swap reported by Bloomberg. (Source: Bloomberg L.P. and author’s own calculation)

	<b>Trading Day</b>
Monday	4,096
Tuesday	5,372
Wednesday	6,733
Thursday	6,001
Friday	5,008

	<b>Trading Session</b>
Morning	7,193
Mid-Day	7,845
Afternoon	7,684
After Hours	4,488

	<b>Capped</b>
Capped	18,837
Not Capped	8,373

	<b>Tenor</b>
Min	2 months
1st Quartile	5 years
Median	7 years
3rd Quartile	10 years
Max	43 years
Mean	9 years, 9 months

	<b>Notional</b>
Min	1,000
1st Quartile	16,000,000
Median	50,000,000
3rd Quartile	100,000,000
Max	260,000,000
Mean	56,426,143

### 3.6 Limitations

There are several limitations to the DTCC SDR dataset. Firstly, it does not identify the counterparties. The identity of the counterparty (and more importantly, its creditworthiness) could have a significant impact on the swap price. In addition, the dataset does not mark which counterparty is the dealer (that is, whether the dealer is receiving the fixed rate or paying the fixed rate). When receiving the fixed rate (and paying the floating leg), the dealer is likely to require a premium over the fair price (to compensate them for taking inventory and adverse selection risks, and for order processing costs). When paying the fixed rate, the dealer is likely to require a discount below the fair price. I am also unable to observe non-standard contract characteristics such as early termination provisions, collateral arrangements and day-count and settlement conventions. The standard version of the IR swaps contract uses the International Swaps and Derivatives Association (ISDA) Master Agreement for specifying these contract terms. Deviations from the ISDA Master Agreement could affect the liquidity and pricing of the contract.

## 4 Identification Strategy

This essay aims to analyze the impact of a policy intervention (specifically, a change in central clearing rules) on various aspects (such as prices, bid-ask spreads, and realized volatility) of certain observational units (e.g., contracts, trading days). Adapting the notation of Rubin (1976), let  $Y_i(1)$  denote an outcome of interest for unit  $i$  when treated, and  $Y_i(0)$  denote the outcome when untreated. The causal effect on unit  $i$  is represented by  $Y_i(1) - Y_i(0)$ . Since both outcomes cannot be observed simultaneously, I focus on estimating the Average Treatment Effect on the treated (ATT),  $\mathbb{E}[Y_i(1) - Y_i(0) | \text{Treatment}_i = 1]$ , by identifying an appropriate comparison group to estimate the counterfactual  $Y_i(0)$ .

Modern causal inference offers several methods to estimate this ATT, including randomized control trials (RCT), natural experiments, regression discontinuity designs (RDD), instrumental variables (IV), matching, and difference-in-differences (diff-in-diff) (Angrist and Pischke 2009; 2010; Cunningham 2021). I discuss the challenges of applying some of these methods to the research question.

In an RDD, units above a threshold value of a covariate receive treatment, while those below do not (e.g., scholarships granted to students above a specific test score). If units cannot precisely

control their position relative to the threshold, assignment is “as good as random” close to the threshold, allowing for causal inference (Lee and Lemieux 2010). However, in the context of the clearing mandate, the contract characteristics (e.g., currency, notional value, floating rate index, tenor) can be precisely controlled by market participants. Thus, the assumptions necessary for RDD are not met.

The IV approach relies on an instrument that affects the likelihood (or intensity) of treatment assignment. When the treatment variable is endogenous, a straightforward comparison between treated and untreated units could yield biased results. For a valid IV approach, the instrument must be relevant (associated with treatment assignment), independent (free from unobserved confounding variables), and satisfy the exclusion restriction (influencing the outcome solely through treatment) (Angrist and Pischke 2009). This approach is also unsuitable here, as CFTC-defined criteria determine clearing, and no external instrument influences clearing likelihood.

The approach adopted in this essay is the diff-in-diff method. In this method, an appropriate comparison group (e.g., Canadian Dollar-denominated contracts) is selected, though it may differ from the treatment group in important ways (especially as it relates to the outcome variable). Initially, a pre-treatment difference between the comparison and treatment groups is calculated. This difference is then compared to the difference after treatment to estimate the causal effect. A key assumption in diff-in-diff is that of parallel trends—that, in the absence of treatment, both groups would have followed similar trends and the gap between the outcomes would remain constant (Angrist and Pischke 2009). This is generally not true for Canadian and U.S. swaps markets, given Canada’s export-oriented economy, distinct market participants, and unique monetary and fiscal policies, all of which influence pricing, volatility, and liquidity.

However, I argue that for short periods (e.g., the 20 trading-day windows studied in this essay), the U.S. and Canadian swaps markets are highly coupled. This is supported by visual inspection of parallel pre-treatment trends in pricing, volatility, and liquidity over short periods, as well as formal tests for parallel trends (see sections 4.1, 4.2, and 4.3).

#### *4.1 Pricing*

I investigate the causal impact of the central clearing mandate on IR swap prices by comparing the premium over 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 diff-in-diff identification strategy, with the CAD denominated swaps acting as the comparison group, which allows me to plausibly isolate the causal effect of the mandate on the swap premiums by exploiting the variation in timing of policy implementation.

I begin by selecting a sample of IR 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 comparison 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 diff-in-diff regression model, which takes the following form:

$$Y_{it} = \alpha + \beta_1 * Treatment_i + \beta_2 Post_t + \delta(Treatment_i \times Post_t) + X_i' \Gamma + \epsilon_{it} \quad (43)$$

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 (comparison group),  $Post_t$  is an indicator variable equal to 1 for the period after the mandate was implemented, and  $X_i$  is a vector of control variables. The coefficient of interest is  $\delta$ , which captures the causal effect of the central clearing mandate on swap premiums.

The control variables included in  $X_i$  are the day of the week in which the contract is traded, the time (categorized as morning, mid-day, afternoon or off-hours) at which the contract is traded, the logarithm of the notional amount, whether the variable rate is capped, and the tenor of the contract (measured in months). The trading day variable is included because there is some discussion in the asset pricing literature of pricing differences on certain days (e.g., the “Monday effect” for equities. See (Cross 1973; French 1980)). Trading time is also similarly included to account for differences in pricing behavior during certain trading sessions during the day. For example, trading is often concentrated to the midday session, with less trading activity happening in off-hours sessions (see section 3). The lack of liquidity during those sessions can affect pricing. The logarithm of the notional value is included, as there is some discussion in the literature (Fock 2024; Randall 2015) that market participants prefer larger contracts (perhaps to economize over fixed costs) and due to

the higher liquidity of these larger contracts, they may be priced differently than smaller contracts. If the notional amount is “capped,” the true nominal value of the contract is not reported. These are usually for large block trades and often involve large counterparties (“SDR View, Capped Notional Changes” 2013). Finally, the tenor (length of the contract) is included as some tenors (e.g., 10-year contracts) have more liquidity than others.

To ensure the validity of the identification strategy, I test the parallel trends assumption both by visually inspecting and by statistically verifying the pre-treatment trends of swap premiums for both treatment and comparison groups and conducting placebo tests. I begin by formally testing the parallel trends assumption by regressing the fixed rate against the treatment indicator (i.e. the currency of the contract), time (trade date) and  $treatment \times time$  interaction effect, for the two-week period prior to the period of study for phase 1 (that is, from Jan 28, 2013 to Feb 22, 2012). I also include some controls for contract characteristics (a subset of the control variables discussed earlier). I run the regression:

$$Y_i = \alpha + \beta_1 * Treatment_i + \beta_2 Time + \delta(Treatment \times Time) + X_i' \Gamma + \epsilon_{it} \quad (44)$$

where: *Treatment* is an indicator variable of whether the contract is in the comparison group (currency is CAD) or treatment group (currency is USD) and *time* is now a *continuous* variable (the trade date). This regression is run separately for each tenor of contract (since pricing for different tenors are different).

Table 6 shows the results of such a regression for the two-year, five-year, and ten-year contracts. The interaction term (Currency: USD \* Trade Date) is not significant, suggesting the two groups were following parallel trends prior to the implementation of the mandatory clearing policy. Note that there is a 30-88 bps difference between USD and CAD swaps prices (with the Canadian swaps being priced here; statistically significant). However, the two groups followed parallel during this pre-trend period. The control variables were generally not statistically significant, except for Log Notional for the 10-year contract, which showed a 3 bps increase in price for every 1% increase in the notional value. Although statistically significant, the effect is not large. I defer further discussion of the control variables until my results section.

Table 6 Parallel Trends Pre-Trend Tests for Pricing

The period of data are from contracts traded between Jan 28 – Feb 22, 2013 (i.e. twenty trading days prior to the study period of phase 1). If parallel trends hold, we expect the interaction term (Currency\* Trade Date) to be not statistically significant

Pre-trend Analysis			
	Dependent variable:		
	Fixed Rate		
	2-year contracts	5-year contracts	10-year contracts
Currency: USD	-0.882*** (0.122)	-0.675*** (0.053)	-0.309*** (0.053)
Trade Date	-0.002 (0.002)	-0.0004 (0.001)	-0.0003 (0.003)
Log Notional	0.0004 (0.016)	-0.009 (0.036)	0.033*** (0.013)
Capped	0.178 (0.167)	0.173* (0.098)	0.084 (0.052)
Currency USD* Trade Date	0.001 (0.008)	0.004 (0.004)	0.002 (0.004)
Constant	1.392*** (0.299)	1.915*** (0.589)	1.846*** (0.210)
Observations	158	635	921
R <sup>2</sup>	0.338	0.064	0.031
Adjusted R <sup>2</sup>	0.316	0.057	0.026
Residual Std. Error	0.530 (df = 152)	0.740 (df = 629)	0.521 (df = 915)
F Statistic	15.513*** (df = 5; 152)	8.651*** (df = 5; 629)	5.950*** (df = 5; 915)
Note:			* ** *** p<0.01

(Standard errors clustered by Trade Date in parentheses.)

I also examine whether the parallel trends assumption holds by visually inspecting the swap rate (fixed rate of the IR swaps contract) prior to each phase of the implementation of the clearing mandate. I examine the three most common tenors of USD and CAD IR swaps (2-year, 5-year and 10-year swaps). The data are 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 a sample of these trends, specifically the trends for pre-phase 1 for 10-year swaps and the pre-phase 2 for 2-year swaps. Other periods and phases show similar parallel trends but are not included here for brevity. The swaps rates show a parallel pre-trend prior to the implementation of the clearing mandate, with the Canadian swaps rate always 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.

Finally, I test the validity of the parallel trends assumption by performing a placebo diff-in-diff. I pick the 20 trading days before the study period. I create a “placebo” treatment, as if there was a transition to mandatory clearing mandate on the 11<sup>th</sup> trading day. That is, I run the same type of diff-in-diff described earlier but pick a period when no treatment actually took place. Table 7 shows the results. The placebo diff-in-diff does not show an increase in premia (coefficient of the Group \* Period term), further strengthening my belief that the increase in premia discussed in the results section (see sections 5.1 and Table 8, Table 9) is real. (I again defer discussion of the control variables until section 5.1).

Figure 4 Pre-trends for swap pricing

For 2-year swaps during phase 2 and 10-year swaps during phase 1 of the clearing mandate implementation. Red, dashed vertical line indicates when the clearing mandate went into effect. Highlighted area is the period of study and the pre-trend is to the left of highlighted area.

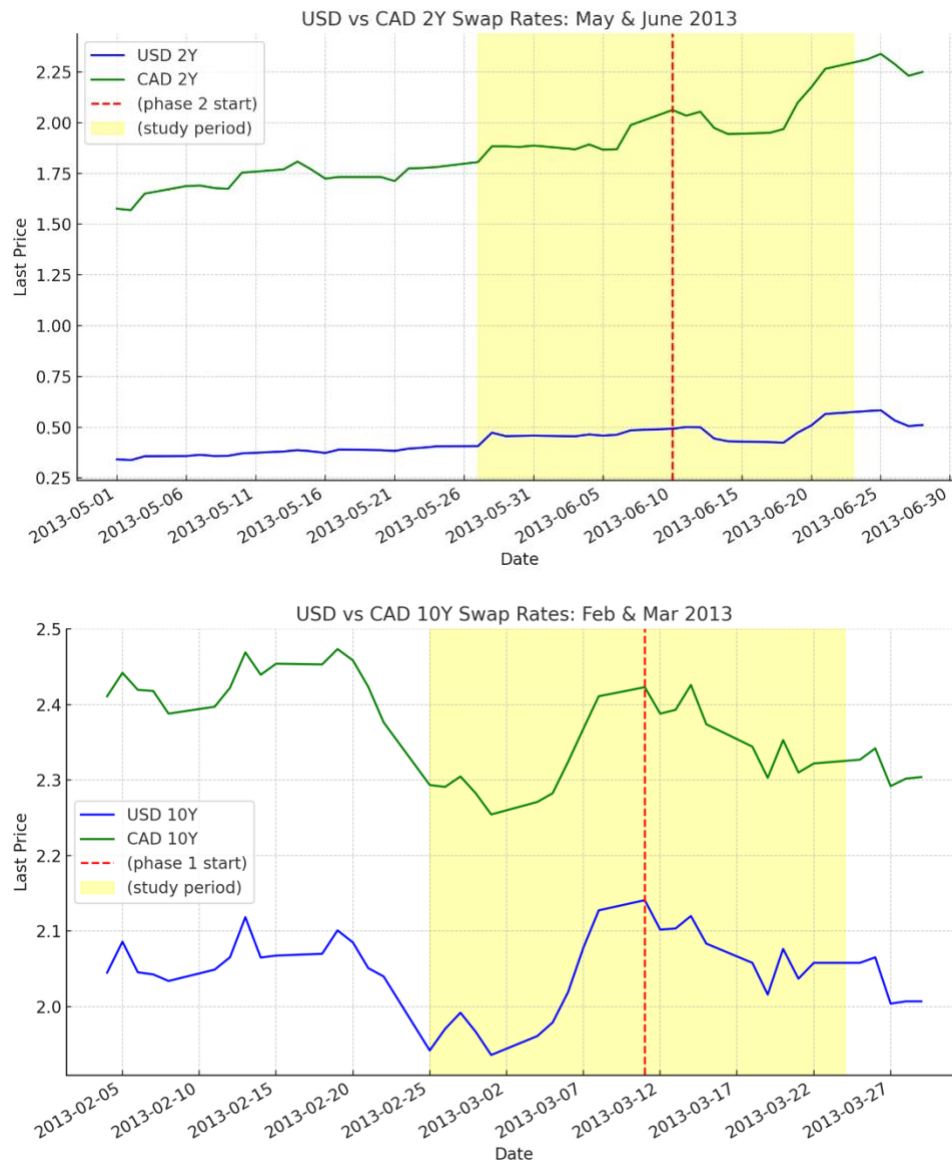


Table 7 Placebo diff-in-diff results.

The placebo diff-in-diff is the same type of diff-in-diff analysis described in the identification strategy section, but during a period where there was no variation in central clearing requirements. I examine the 20 trading days before the study period of each phase and perform a “placebo” analysis as if the central clearing mandate had been implemented on the the eleventh trading day. If the diff-in-diff method is sound, we should not see the interaction Group \* Period term be significant. However, if the method shows spurious results, then Group \* Period could be significant.

Placebo Diff-in-Diff Results		
	Dependent variable: Premium	
	Basic Model <sup>7</sup>	Full Model
	(1)	(2)
Group	1.6566*** (0.4343)	1.4077*** (0.4357)
Period	-0.5706 (0.5826)	-0.4838 (0.5799)
Tenor (Years)		0.0301*** (0.0077)
Log Notional		-0.0219 (0.0595)
Capped		-0.8827*** (0.1572)
Morning Session		0.2761* (0.1520)
Afternoon Session		0.3836** (0.1600)
Off Hours		0.0617 (0.1802)
Monday		0.7955*** (0.1954)
Tuesday		0.5999*** (0.1800)
Thursday		1.7587*** (0.1744)
Friday		1.7827*** (0.1822)

<sup>7</sup> The basic model regresses premia against group (USD or CAD), period (pre-treatment or post-treatment) and group×period interaction (parameter of interest). The full model adds additional covariates: tenor, log notional, capped, trading day and trading session (time).

Group * Period	0.1694 (0.5975)	0.1696 (0.5952)
Constant	-1.2876*** (0.4197)	-1.9215* (1.1216)
Observations	20,794	20,794
R <sup>2</sup>	0.0020	0.0136
Adjusted R <sup>2</sup>	0.0019	0.0130
Residual Std. Error	8.4872 (df = 20790)	8.4398 (df = 20780)
F Statistic	13.8615*** (df = 3; 20790)	22.0214*** (df = 13; 20780)
<i>Note:</i>		*p<0.1; **p<0.05; ***p<0.01

## 4.2 Liquidity

Liquidity is a broad concept defined as how easily one can convert financial assets to cash with minimal impact to prices of those financial assets. That is, the concept covers both trading costs and the price impact of trading. 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 (ask/offer) and buy (bid) 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 diff-in-diff strategy to identify the impact of the central clearing mandate on liquidity, with CAD denominated contracts serving as the comparison 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 2.2 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 as a percentage around the mid-quote:

$$spread = \frac{bid - ask}{\frac{bid + ask}{2}} \quad (45)$$

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 is “low frequency” (collected at the end of day) 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 a proxy common in the literature: the Roll measure. The measure, proposed by Roll (1984) estimates the effective spread using the time series of observed prices under assumptions of market efficiency:

$$Roll = 2 \cdot \sqrt{-cov(\Delta p)} \quad (46)$$



where  $cov(\Delta p)$  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 contracts). 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.

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 in 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 illiquidity measure (Amihud and Mendelson 1986):

$$Amihud_t = \frac{|R_t|}{Volume_t} = \frac{|P_{t-1} - P_t|}{Volume_t} \quad (47)$$

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 illiquidity measure, which normalizes inter-period price changes by the market size (volume) is a measure of how much prices move, scaled by the trade size. I calculate a daily version of the Amihud illiquidity measure for US and Canadian 2-year, 5-year, and 10-year contracts for each trading date (using the contract notional as the swap equivalent of volume and using the average of the absolute log of the trade-by-trade differences in the fixed rate of contracts with same characteristics as the return on the asset):

$$Daily\ Amihud_t = \frac{1}{N_t} \sum_{n=1}^{N_t} \frac{|\Delta \ln p_n|}{notional_n} \quad (48)$$

where  $p_n$  is the fixed rate of the  $n^{\text{th}}$  trade,  $N_t$  is the total number of trades on day  $t$  and  $notional_n$  is the notional amount for the  $n^{\text{th}}$  contract.

For each liquidity measure discussed above, I run a diff-in-diff model:

$$Y_{i,t} = \beta_0 + \beta_1 Treatment_i + \beta_2 Post_t + \delta(Treatment_i \times Post_t) + \Gamma X_{i,t} \epsilon_{i,t} \quad (49)$$

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 comparison (Canadian-dollar denominated market) group,  $Post_t$  is an indicator variable for whether the observation is in the post- or pre implementation period.  $\delta$  is the parameter of interest and  $X_{i,t}$  are control variables (return on equities and equity market volatility for a given day for US or Canada).

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 illiquidity measure, and Roll measure for twenty trading days before the period of the study. Figure 5 shows the path of the relative spread measure for 2-year contracts and 10-year contracts in phase 1 and phase 2 respectively (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 2-year and 10-year USD and CAD IR swaps contracts for phase 1 and 2 respectively (other tenors show similar trends). Note that due to the limitation previously discussed (negative covariance or days with limited trading volume), 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 again for 2-year and 10-year USD and CAD IR swaps contracts in phase 1 and phase 2, respectively. As expected, the Amihud illiquidity measure is larger (indicating less liquidity) for the Canadian market, due to its smaller size. As is the case with the Roll measure, the Amihud illiquidity measure is not computable for each tenor for each day (for example, if there are less than 5 observations for a given contract specification on a given day). There is not enough data to conclude whether the parallel trend assumptions hold for the Amihud illiquidity measure.

Figure 5 Pre-trends for relative bid-ask spreads

For 2-year swaps during phase 2 and 10-year swaps during phase 1 of the clearing mandate implementation. Red, dashed vertical line indicates when the clearing mandate went into effect. Highlighted area is the period of study and the pre-trend is to the left of highlighted area.

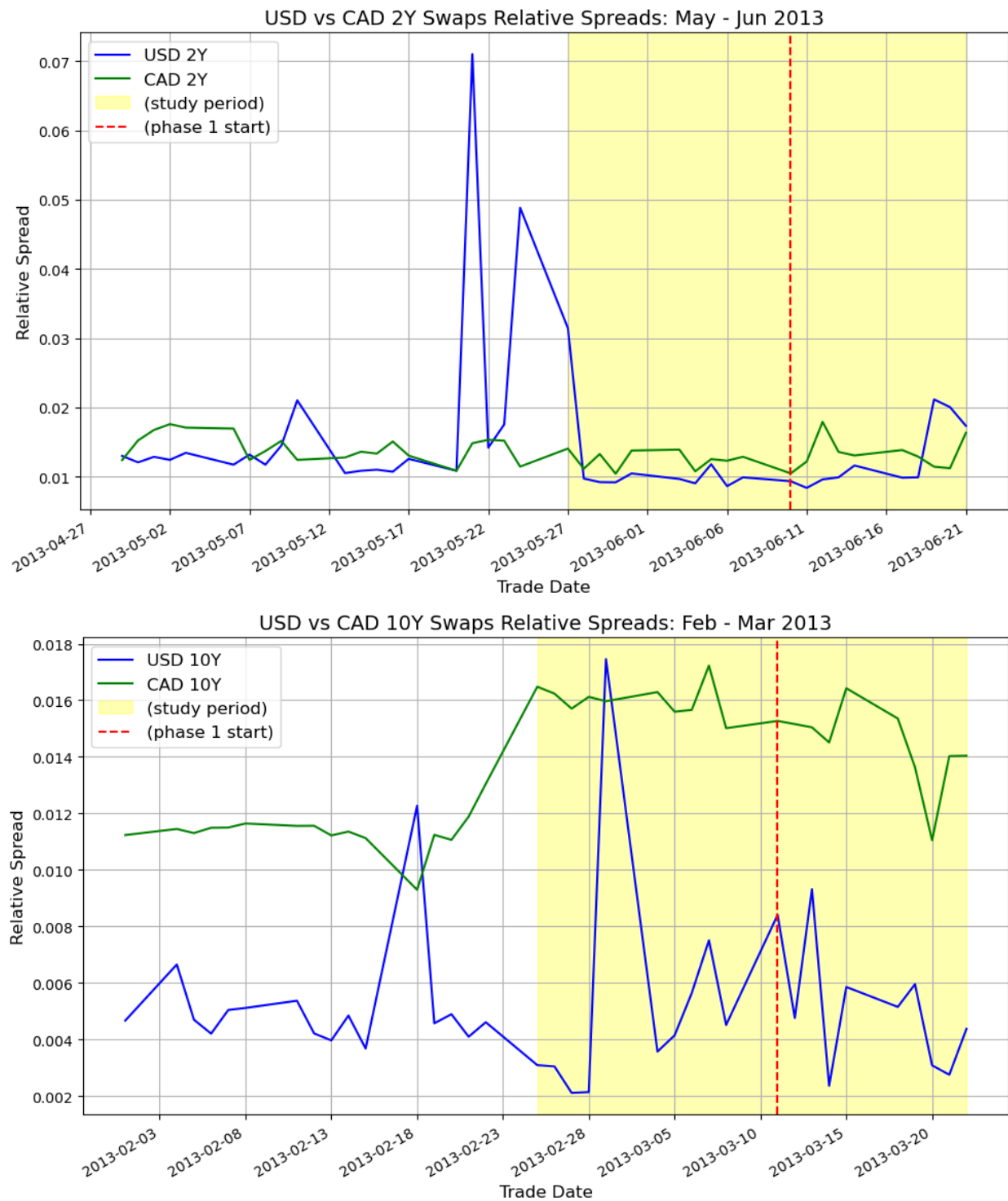


Figure 6 Pre-trends for Roll's Measure

For 2-year swaps during phase 2 and 10-year swaps during phase 1 of the clearing mandate implementation. Red, dashed vertical line indicates when the clearing mandate went into effect. Highlighted area is the period of study and the pre-trend is to the left of highlighted area. Markers (x) show the value at a given date. Data are not available for all contracts at all dates.

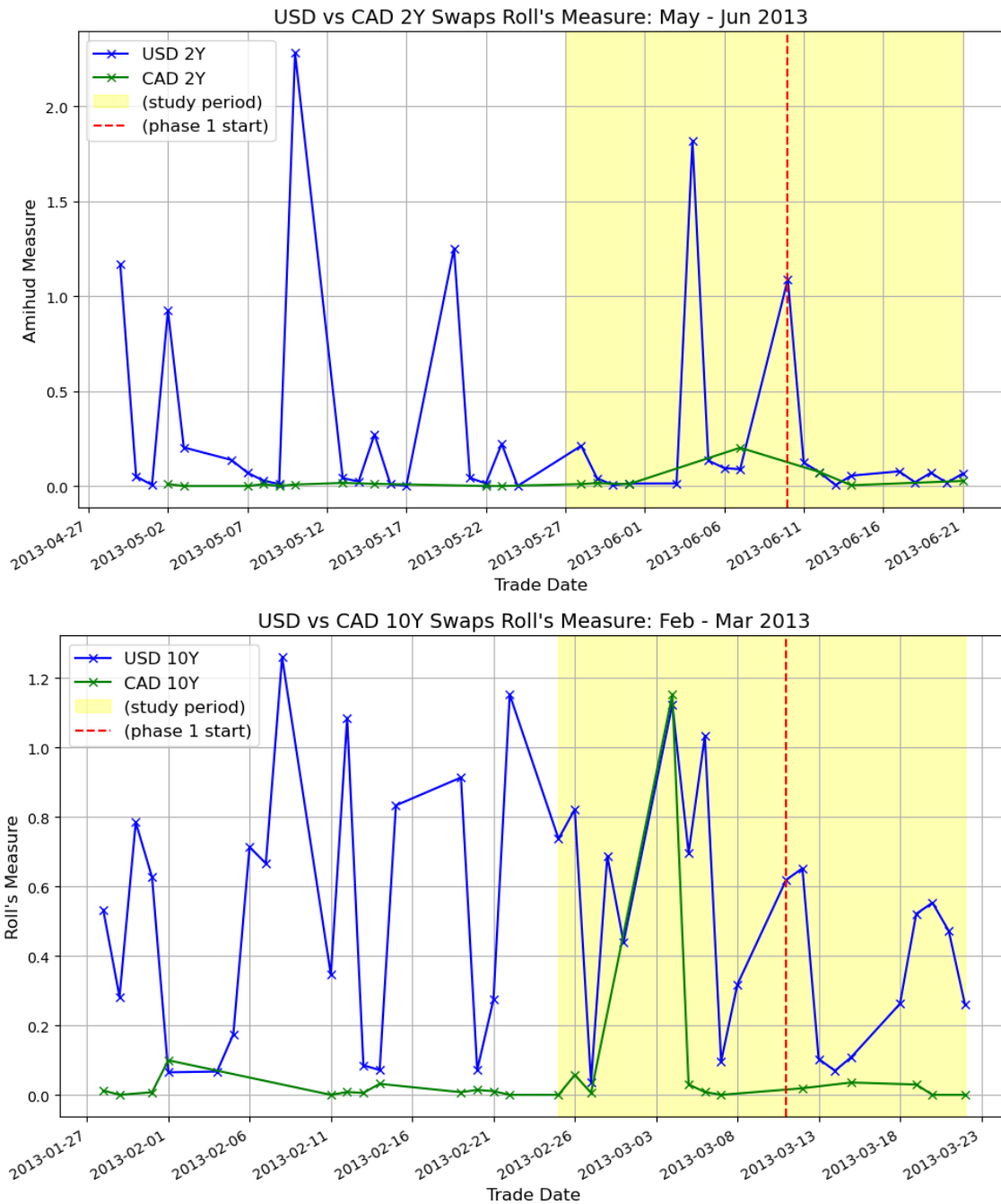
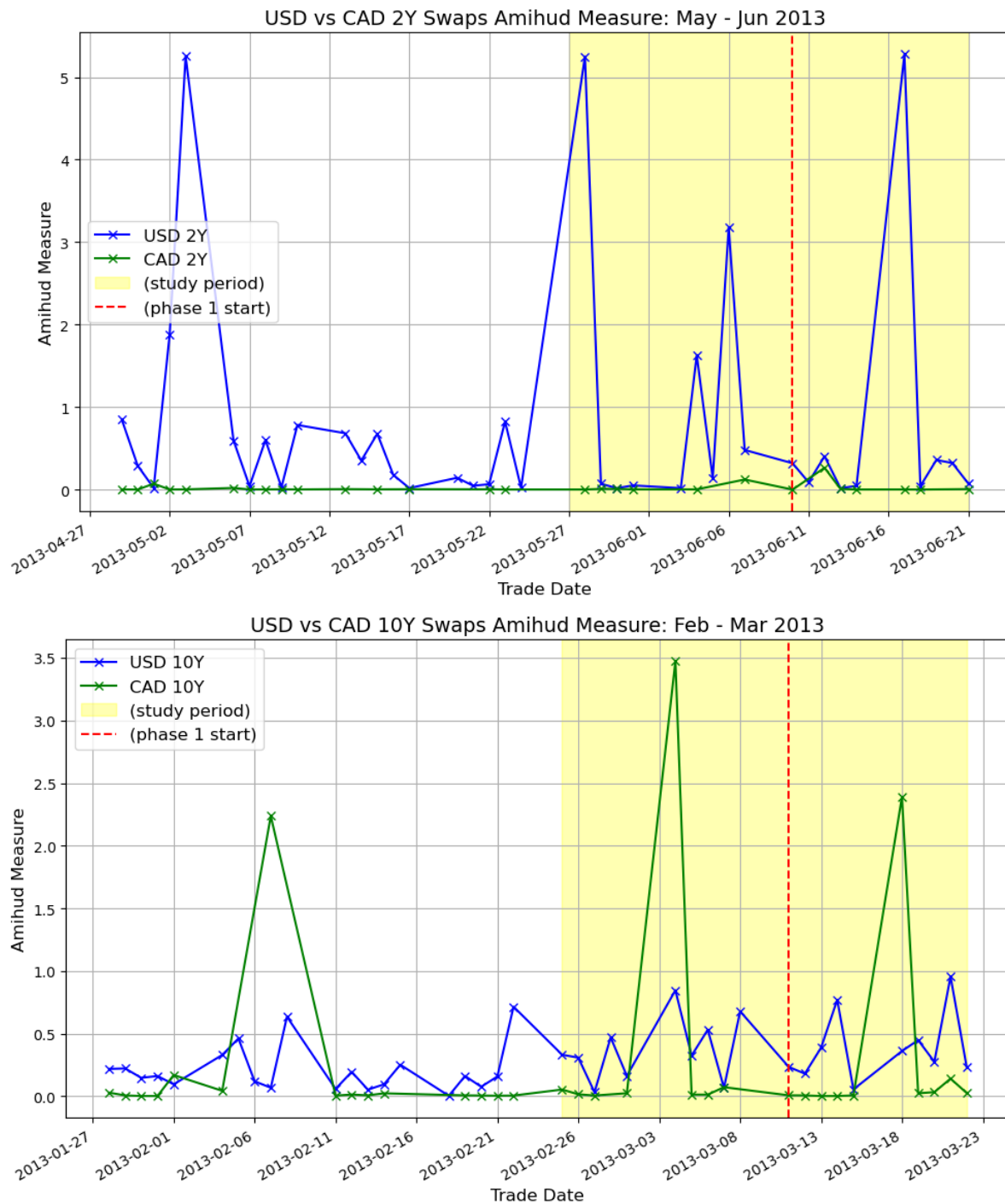


Figure 7 Pre-trends for Amihud Illiquidity Measure

For 2-year swaps during phase 2 and 10-year swaps during phase 1 of the clearing mandate implementation. Red, dashed vertical line indicates when the clearing mandate went into effect. Highlighted area is the period of study and the pre-trend is to the left of highlighted area. Markers 'x' show the value at a given date. Data are not available for all contracts at all dates.



### 4.3 Volatility

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

$$r_n = \log\left(\frac{P_n}{P_{n-1}}\right) \quad (50)$$

The realized daily volatility of the return for day  $t$  is then:

$$RV_t = \sqrt{\sum_{n=1}^{N_t} (r_n)^2} \quad (51)$$

where:  $N_t$  is the number of contracts traded in the day. I compute a modified version of this metric:

$$(\widetilde{RV})_t = \frac{1}{N_t} \sqrt{\sum_{n=1}^{N_t} (r_n)^2 - (\bar{r})} \quad (52)$$

where  $\bar{r} = \frac{1}{N_t} \sum_{n=1}^{N_t} (r_n)$  is the average return. For high-frequency data,  $\bar{r}$  is zero or small, so this modified realized volatility is simply scaled by the number of trades. This is important because the number of trades in the US and Canadian swaps market on a given day are vastly different.

For each trading day, I select contracts with “whole number tenor years” between 1 and 10 years, as well as 15-years and 30-years (I exclude contracts that are “partial years” such as 18-, 21- and 30-month 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 observations when less than 5 contracts with a given specification are traded on a given day). The filtered dataset captures 90% of Canadian contracts traded during the period studied in the essay, and I can calculate volatility of several tenors for each trading day<sup>8</sup>. However, for some 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 60 trading days (1,440 observations in total, one for each currency-tenor combination for each

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<sup>8</sup> 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.

day). However, since sometimes 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 comparison 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 diff-in-diff regression:

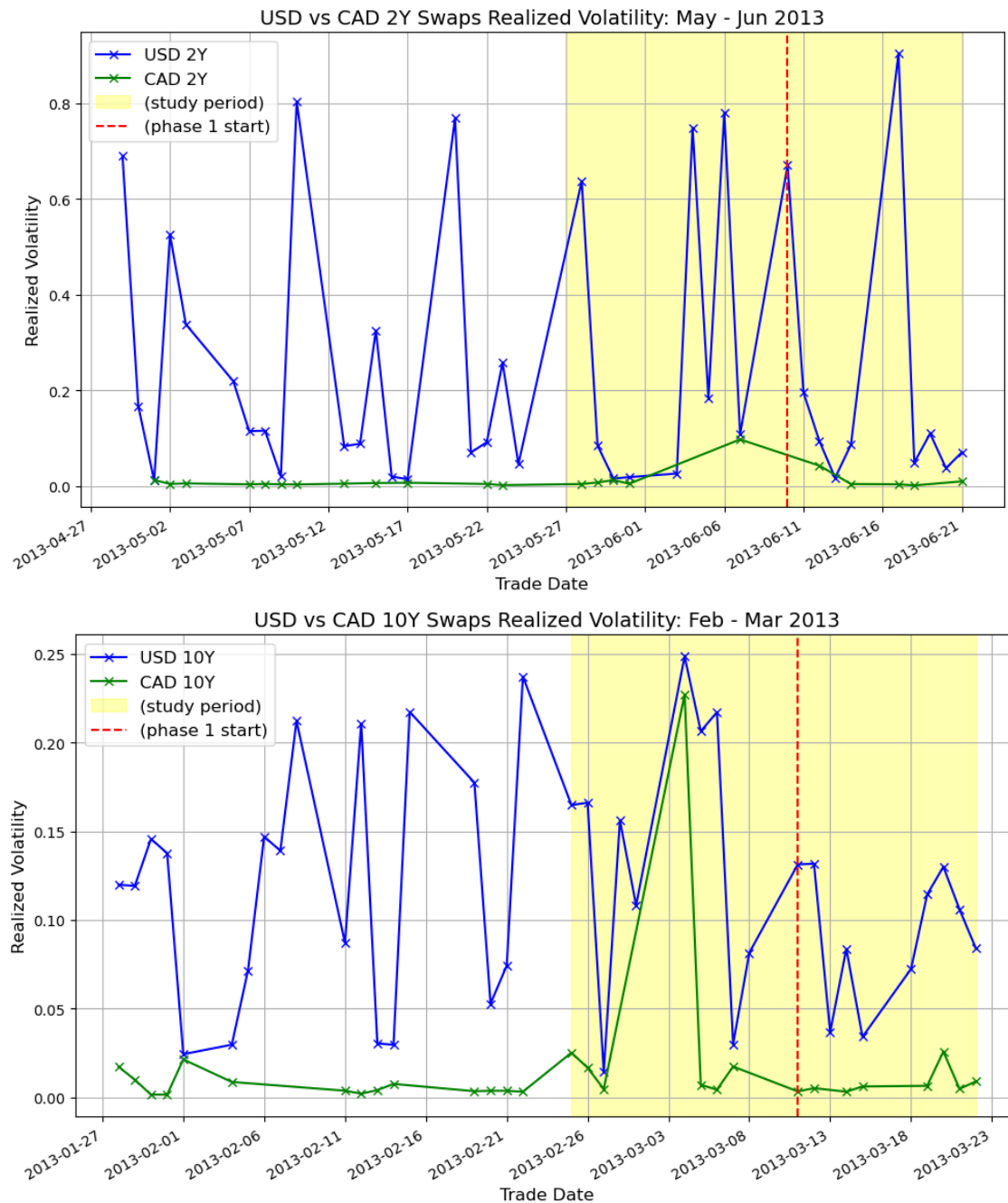
$$RV_{i,t} = \beta_0 + \beta_1 Treatment_i + \beta_2 Period_t + \delta(Treatment_i \times Period_t) + X'_{i,t}\Gamma + \epsilon_{i,t} \quad (53)$$

where  $RV_{i,t}$  is the realized volatility for contract specification  $i$  in period  $t$  and the rest of the variables are as described in the liquidity section.  $\delta$  (the interaction between group and pre/post-treatment period) is the parameter of interest. I use the same controls (equity market returns and equity market volatility) as in the liquidity section.

As with the other diff-in-diff 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, 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 Pre-trends for Realized Volatility

For 2-year swaps during phase 2 and 10-year swaps during phase 1 of the clearing mandate implementation. Red, dashed vertical line indicates when the clearing mandate went into effect. Highlighted area is the period of study and the pre-trend is to the left of highlighted area. Markers 'x' show the value at a given date. Data are not available for all contracts at all dates.





## 5 Results

### 5.1 Pricing

For analyzing the impact of the clearing mandate on prices, I compare USD denominated contracts using LIBOR as the floating rate index, against CAD denominated contracts using the CDOR as the floating rate index. The USD LIBOR contracts are subject to the CFTC clearing mandate while the CAD CDOR contracts are not. Table 8 lists the diff-in-diff results for the swap premium, pooling data from all phases. Column 1 shows a basic model without any controls for contract characteristics. Column 2 (full model) shows the effects additional controls, such as the (log) notional value of the contract, day of the week, and period of trading and whether the notional value was “capped” (i.e., the exact value was not reported to the trade repository).

Per the basic model, the clearing mandate causes a ~14 bps rise in premia across the three phases in this model. In the full model with additional controls for contract characteristics, premia rise by ~13 bps. These results are qualitatively in line with the theoretical model that reducing the riskiness of the contract increases its price.

Examining the control variables, beginning with the trading day, and using Wednesday as the reference level, I note that there is a 1.0-3.0 bps increase in the premium depending on the trading day. There is also a 1.0-1.3 bps decrease in the premium for trading in morning, afternoon or off hours trading sessions (as compared to midday). Both results contrast with assumptions of “efficient markets,” where there should be no arbitrage opportunities by trading during special days or times. A one percent increase in the notional value is associated with a 0.77 bps increase in the premium. Again, this contrasts with expectations from “efficient market” assumptions because arbitrage opportunities exist (for example, a dealer can make a riskless profit by agreeing to receive a fixed rate on a higher-priced “large” contract and agreeing to pay the fixed-rate for two lower-priced “small” contracts). Finally, a one-year increase in the tenor is associated with a 0.03 bps increase in the premium. It is difficult to determine whether this represents a riskless-arbitrage opportunity or a difference in perceived riskiness for longer-dated contracts. Although many of the covariates are statistically significant, the magnitudes of the effects are small, ranging from 0.03 to 3 bps.

Table 9 shows the result of a diff-in-diff analysis on each phase separately. In phase 1, there is a ~5.3 bps increase in premia after the implementation of the mandate. As noted previously, there

was a 16% increase in the cleared volume following implementation of phase 1. In phase 2, there was an additional ~2.6 bps increase in premia. In phase 3, premia increased by ~16 bps. These results generally hold to the idea that as more of the market is cleared, there is a perceived reduction in counterparty risk and swap premia rise. The results are consistent with the pooled diff-in-diff, with most of the effect occurring during the third phase of the mandate.

Table 10 shows the results of a similar regression using an alternative currency pair. The CFTC clearing mandate also affected contracts denominated in GBP using the LIBOR as the reference rate (with the same implementation dates as the USD clearing mandate). These contracts now serve as the treatment group. The clearing mandate did not apply to Swiss Franc (CHF) denominated contracts, and these contracts now serve as the comparison group. The clearing mandate had a similar (but smaller) impact on prices of GBP-denominated swaps, further strengthening my belief that clearing reduces counterparty risk and increases contract premia.

Table 8 Diff-in-diff results for prices pooling all phases together.

Column 1 shows results for a basic diff-in-diff model without controlling for any covariates. Column 2 controls for contract characteristics such as the tenor (in years), (log) notional value, whether notional is capped, whether the swap was traded on an electronic swap execution facility, the trading session and the trading day. The parameter of interest is the interaction term *Group \* Period*, which shows an effect of 13.4-14.2 bps increase in premia for the treatment group once clearing is enacted.

Diff-in-diff Regression Results		
	Dependent variable: Premium	
	Basic Model	Full Model
	(1)	(2)
Group	-0.8889*	-0.7683
	(0.4917)	(0.4900)
Period	-13.6369***	-13.2955***
	(0.6641)	(0.6610)
Tenor		0.0362***
		(0.0086)
Log Notional		0.7755***
		(0.0671)
Capped		-0.9311***
		(0.1849)
SEF		0.6922
		(2.5197)
Morning Session		-1.0238***
		(0.1843)
Afternoon Session		-1.2368***
		(0.1814)
Off Hours		-1.2907***
		(0.2125)

Monday		1.5672*** (0.2244)
Tuesday		2.3944*** (0.2070)
Thursday		2.7672*** (0.2005)
Friday		0.9566*** (0.2124)
Group * Period	14.2183*** (0.6833)	13.4103*** (0.6839)
Constant	-0.2415 (0.4718)	-14.1707*** (1.2407)
<hr/>		
Observations	27,210	27,210
R <sup>2</sup>	0.0283	0.0444
Adjusted R <sup>2</sup>	0.0282	0.0440
Residual Std. Error	11.3530 (df = 27206)	11.2607 (df = 27195)
F Statistic	264.3342*** (df = 3; 27206)	90.3482*** (df = 14; 27195)
<hr/>		
<i>Note:</i>		* p<0.1; ** p<0.05; *** p<0.01

Table 9 Diff-in-diff results for prices by each implementation phase separately.

This analysis uses the same “full model” described earlier (controlling for contract characteristics). There is a 5.3 bps increase in premia in phase 1, a 2.7 bps increase in premia in phase 2 and a 16.2 bps increase in premia in phase 3 (coefficients on the *Group \* Period* term).

By Phase Results: Full Model			
	Dependent variable: Premium		
	Phase 1	Phase 2	Phase 3
	(1)	(2)	(3)
Group	-2.789*** (0.525)	2.327*** (0.886)	3.139*** (1.205)
Period	-4.898*** (0.875)	-4.150*** (1.309)	-12.360*** (1.338)
Tenor	-0.050*** (0.013)	0.064*** (0.013)	0.086*** (0.016)
Notional	-0.489*** (0.094)	0.685*** (0.109)	1.506*** (0.125)
Capped	-0.727*** (0.268)	-0.583** (0.287)	-1.575*** (0.345)
Morning Session	-0.387 (0.265)	0.788*** (0.292)	-2.375*** (0.340)
Afternoon Session	-1.170*** (0.264)	-0.571** (0.280)	-0.538 (0.342)
Off Hours	-1.196*** (0.309)	1.594*** (0.334)	-5.542*** (0.392)
Monday	2.017*** (0.323)	6.666*** (0.367)	-5.821*** (0.409)
Tuesday	0.741**	8.913***	-3.854***

		(0.312)	(0.326)	(0.377)
Thursday		2.025***	8.909***	-3.700***
		(0.306)	(0.306)	(0.376)
Friday		1.642***	5.832***	-4.480***
		(0.325)	(0.320)	(0.402)
Group * Period		5.308***	2.658**	16.277***
		(0.899)	(1.336)	(1.408)
Constant		11.804***	-22.064***	-27.840***
		(1.654)	(2.101)	(2.446)
<hr/>				
Observations		7,561	10,856	8,793
R <sup>2</sup>		0.025	0.109	0.179
Adjusted R <sup>2</sup>		0.024	0.108	0.178
Residual Std. Error		8.635 (df = 7547)	11.002 (df = 10842)	11.861 (df = 8779)
F Statistic		15.068*** (df = 13; 7547)	102.336*** (df = 13; 10842)	147.232*** (df = 13; 8779)
<hr/>				
<i>Note:</i>			* p<0.1; ** p<0.05; *** p<0.01	

Table 10 Diff-in-diff using alternative currency pair

GBP denominated contracts serve as the treatment group and CHF denominated contracts serve as the comparison group. The interaction term Group \* Period shows a 7.5-8.3 bps increase (depending on model) for the treatment group once clearing becomes mandatory.

Alternative Currencies Diff-in-diff Results (GBP vs. CHF)		
	Dependent variable: Premium	
	Basic Model	Full Model
	(1)	(2)
Group	-0.2734 (1.2232)	-0.9492 (1.2023)
Period	-6.6242*** (1.4576)	-8.2303*** (1.4435)
Tenor		0.0974*** (0.0193)
Log Notional		0.6572*** (0.1811)
Capped		-0.4361 (0.5052)
Morning Session		-0.9820** (0.4967)
Afternoon Session		-2.5981*** (0.4186)
Off Hours		-2.4152*** (0.7555)
Monday		3.1430*** (0.5643)
Tuesday		3.5697*** (0.5050)
Thursday		3.0135*** (0.4984)
Friday		1.5464*** (0.5515)
Group * Period	7.4610*** (1.5404)	8.2859*** (1.5143)
Constant	-3.7350***	-15.0964***

	(1.1343)	(3.1718)
Observations	3,522	3,522
R <sup>2</sup>	0.0168	0.0580
Adjusted R <sup>2</sup>	0.0159	0.0546
Residual Std. Error	10.3965 (df = 3518)	10.1905 (df = 3508)
F Statistic	20.0170*** (df = 3; 3518)	16.6288*** (df = 13; 3508)
<i>Note:</i>		*p<0.1; **p<0.05; ***p<0.01



## 5.2 *Liquidity*

As noted previously, liquidity is a broad concept with several measures. I begin by examining the impact of the central clearing mandate on the relative bid-ask spread prevalent at the end of the trading day, a measure of the trading cost scaled for the price of the contract. Table 11 shows the results of a diff-in-diff regression for this measure. In the full model, I include the contract tenor as a control variable, as the relative bid-ask spread varies significantly with the contract tenor (for example, the median relative spread for Canadian contracts 1.17% for 10Y contracts to 1.51% for 2Y contracts. For US contracts, the median relative spread varied between 0.27% for 10Y contracts to 1.04% for 2Y contracts). Since the period of study is relatively short and since liquidity is a “market wide,” rather than an individual contract-based measure, the opportunity to control for variables that impact liquidity is limited to market-wide metrics<sup>9</sup>. If a longer period were being studied, variables that impact liquidity, such as monetary policy and credit availability could be added as controls. However, these variables did not vary during the brief period studied and cannot be controlled for. Two control variables that proxy financial market conditions are added to the full model: a measure of equity market volatility and a measure for equity market return. For the volatility measure, I use the CBOE Volatility Index (CBOE VIX) and the TSX 60 VIX Index, which measure the 30-day expected realized variance of the S&P 500 Index and its Canadian equivalent, respectively. The Canadian VIX index was launched in April 2021, but S&P provides hypothetical historical values. For equity market returns, I use the returns of the S&P 500 for the US and the S&P/TSX 60 Composite for Canada.

The diff-in-diff results suggest that the clearing mandate does not impact liquidity as measured by relative bid-ask spreads. In the theory section, I argued that we should expect reductions in counterparty risk to cause a narrowing of the bid-ask spread, as the spread is charged by dealers to offset their expected losses from holding inventory, and a reduction in counterparty risk reduces these expected losses. However, the spread is also driven by supply and demand conditions in the market (i.e., the quantity and market order size discussed in the theory section). A reduction in riskiness of IR swaps increases their demand. If the swaps market is monopolistic (that is, new

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<sup>9</sup> That is, it doesn’t make much sense to talk about the liquidity of a particular 10-year contract. Rather, we look at the liquidity for all 10-year standardized swaps contracts on a given trade date.

swaps dealers face barriers to entry), then incumbent dealers can choose not to adjust their bid-ask spreads and pocket the additional profits from the higher demand.

Examining the control variables, as expected, USD contracts have a slightly smaller (but statistically significant) relative spreads, indicating the USD market is more liquid. Both the equity market volatility and equity market return variables are statistically more significant. This could indicate that when financial market conditions are green, there is a narrowing of the spread (greater liquidity). Finally, the tenor indicators are significant, suggesting shorter length contracts are less liquid.

I examine two additional measures of liquidity. Roll's measure is an estimate of bid-ask spreads that might have prevailed during the trading day and is obtained from transaction data (fixed rate and trade time). Table 12 shows the results of a diff-in-diff regression for this measure. The contract tenor as well as the equity market volatility and equity market return variables from the previous discussion are included as control variables in the full model. As with the relative bid-ask spread, Roll's measure does not show a statistically significant (at the 5% level) change in trading costs due to the clearing mandate.

The Amihud illiquidity measure is an estimate of the average price impact. I use the notional contract amount as the "order size" and the (log) difference in the fixed rate between two trades as the (percent) change in price. I express the results in percent change per million dollars of order quantity for easier interpretation. Table 13 show the results for the Amihud illiquidity measure diff-in-diff analysis. The Amihud illiquidity measure shows a statistically significant but small (0.36 percentage point change in price/million dollars) impact of the clearing mandate.

Table 11 Diff-in-diff analysis of relative bid-ask spreads.

The dependent variable is the Relative Bid-Ask Spread from the last quote of the trading day. For the full model, control variables are the contract tenor, relevant stock market (TSX or S&P 500) returns and volatility. Stock market returns are calculated as the percent change from the previous trading day's adjusted closing price (where adjustments are made for dividends, stock splits and other rights offers). The volatility measures are the CBOE VIX and TSX 60 VIXI indices.

<b>Relative Bid-Ask Spread diff-in-diff Analysis</b>		
	<i>Dependent variable:</i>	
	Relative Spread	
	Simple Model	Full Model
	(1)	(2)
Group	-0.005*** (0.001)	-0.005*** (0.001)
Period	0.0001 (0.001)	-0.0001 (0.001)
Tenor (2Y)		0.006*** (0.001)
Tenor (5Y)		0.003*** (0.001)
Equity Return		-0.056* (0.031)
Volatility		-0.0003** (0.0001)
Group*Period	-0.001 (0.001)	-0.001 (0.001)
Constant	0.014*** (0.001)	0.016*** (0.002)

Observations	360	351
R <sup>2</sup>	0.204	0.486
Adjusted R <sup>2</sup>	0.198	0.476
Residual Std. Error	0.005 (df = 356)	0.004 (df = 343)
F Statistic	30.459*** (df = 3; 356)	46.369*** (df = 7; 343)
<hr/>		
<i>Note:</i> *p<0.1; **p<0.05; ***p<0.01		

Table 12 Diff-in-diff analysis of Roll's Measure.

The dependent variable is the daily Roll's Measure (a proxy of the bid-ask spread during the trading day). Control variables are the contract tenor, relevant stock market (TSX or S&P 500) returns and volatility. Stock market returns are calculated as the percent change from the previous trading day's adjusted closing price (where adjustments are made for dividends, stock splits and other rights offers). The volatility measures are the CBOE VIX and TSX 60 VIXI indices.

<b>Roll's Measure diff-in-diff Analysis</b>		
	<i>Dependent variable:</i>	
	Roll's Measure	
	Simple Model	Full Model
	(1)	(2)
Group	0.368*** (0.041)	0.377*** (0.040)
Period	0.040 (0.063)	0.042 (0.062)
Tenor (2Y)		-0.113*** (0.042)
Tenor (5Y)		0.044 (0.040)
Equity Return		4.289* (2.591)
Volatility		-0.009 (0.011)
Group * Period	-0.139* (0.079)	-0.133* (0.078)
Constant	0.069** (0.032)	0.213 (0.159)

Observations	551	548
R <sup>2</sup>	0.149	0.183
Adjusted R <sup>2</sup>	0.144	0.173
Residual Std. Error	0.393 (df = 547)	0.387 (df = 540)
F Statistic	31.924*** (df = 3; 547)	17.303*** (df = 7; 540)
<hr/>		
<i>Note:</i> *p<0.1; **p<0.05; ***p<0.01		

Table 13 Diff-in-diff analysis of Amihud's Illiquidity Measure.

The dependent variable is Amihud's Measure (expressed in absolute % change in the fixed rate of the contract per a million dollar of notional value traded). Control variables are the contract tenor, relevant stock market (TSX or S&P 500) returns and volatility. Stock market returns are calculated as the percent change from the previous trading day's adjusted closing price (where adjustments are made for dividends, stock splits and other rights offers). The volatility measures are the CBOE VIX and TSX 60 VIXI indices.

<b>Amihud Illiquidity Measure diff-in-diff Analysis</b>		
	<i>Dependent variable:</i>	
	Amihud Illiquidity Measure	
	Simple Model	Full Model
	(1)	(2)
Group	0.348*** (0.068)	0.367*** (0.068)
Period	0.362*** (0.099)	0.364*** (0.098)
Tenor (2Y)		0.018 (0.072)
Tenor (5Y)		0.206*** (0.070)
Equity Return		12.328*** (4.469)
Volatility		0.025 (0.019)
Group * Period	-0.365*** (0.133)	-0.386*** (0.132)
Constant	0.106**	-0.344

	(0.051)	(0.280)
Observations	641	635
R <sup>2</sup>	0.048	0.077
Adjusted R <sup>2</sup>	0.043	0.066
Residual Std. Error	0.733 (df = 637)	0.727 (df = 627)
F Statistic	10.674*** (df = 3; 637)	7.445*** (df = 7; 627)
<i>Note:</i> *p<0.1; **p<0.05; ***p<0.01		



### 5.3 Volatility

I measure price volatility as the daily realized variance of the fixed-rate leg and estimate its response to the clearing mandate with the diff-in-diff specification in equation (53). Each observation is a tenor–currency–day cell; the sample pools the three mandate windows, giving 829 observations after filtering for data availability.

Table 14 reports the diff-in-diff results. Volatility is systematically higher for USD contracts than for CAD contracts: the “Group” coefficient is 6.7 bps (simple model) and 9.5 bps (full model) and is statistically significant at the 1 percent level. By contrast, the “Period” term is economically small ( $\approx 1$  bps) and statistically insignificant, indicating no general drift in volatility over the twenty-day windows around each phase. Most importantly, the interaction term is indistinguishable from zero (point estimates are 0.2 bps in the simple model and  $-0.6$  bps in the full model, both with standard errors  $\approx 2.5$  bps). Thus, clearing did not measurably dampen day-to-day rate volatility under “normal” market conditions.

Control variables behave as expected. Short-dated contracts are more volatile (the 1-year tenor adds 24 bps relative to the 10-year benchmark), while the 15- and 30-year contracts are less volatile. Equity-market returns and VIX-style measures have no incremental explanatory power once swap-specific covariates are included. The modest  $R^2$  (about 3 percent in the simple specification and 25 percent in the full specification) is typical for daily RV regressions and reflects the near-random-walk behavior of swap rates in quiet periods.

Theory suggest that any stabilizing benefit of central clearing should be most visible when counterparty-credit concerns flare up. To test this prediction, I re-estimate the diff-in-diff over the June 27–July 13, 2015, window, bracketing the announcement and resolution of the Greek EU referendum<sup>10</sup>. The sample shrinks to 104 observations, and CAD swaps provide a noisy comparison because of their limited exposure to euro-area risk. Table 15 shows that the mandate’s interaction term is  $-1.6$  bps with a 11.9 bps standard error (again not statistically significant).

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<sup>10</sup> Between June 27 and July 13, 2015, Greece faced a severe financial crisis culminating in a national referendum held on July 5. On June 27, Prime Minister Alexis Tsipras called the vote after rejecting the austerity terms proposed by the European Commission, European Central Bank, and International Monetary Fund as conditions for further bailout funding to be held on July 5. In the referendum, over 61% of Greeks voted “No” to the proposed terms, signaling public rejection of more austerity. In response, Greece imposed capital controls and temporarily closed banks to prevent financial collapse. Despite the referendum outcome, Tsipras ultimately agreed to even harsher bailout terms on July 13 to keep Greece in the eurozone, effectively neutralizing the referendum’s mandate and averting a potential “Grexit.” See (Sherlick, n.d.) for a full timeline.

Realized volatility would have had to fall by roughly 35 bps (one-third of the sample mean) to achieve conventional significance levels in this small window.

Two factors likely explain the null findings. First, the model in Section 2.5 emphasizes order-flow shocks ( $\sigma$ ) as the primary driver of short-horizon price changes; reducing counterparty-risk therefore moves  $\alpha\sigma^2$  only at second order. Second, contemporaneous regulatory changes particularly greater post-trade transparency and the migration to SEF trading may have compressed volatility in both USD and CAD markets, biasing the diff-in-diff toward zero.

Table 14 Diff-in-diff analysis of volatility of the fixed rate for USD and CAD IR swaps contracts.

The dependent variable is the (modified) realized volatility. Tenor is used as an unordered categorical variable. Equity marker returns are daily total returns on the S&P 500 (for US) or TSX 60 (for Canada). Equity market volatility is the level of the CBOE VIX (for the US) or the S&P VIXI (for Canada)

<b>Daily volatility diff-in-diff Analysis</b>		
	<i>Dependent variable:</i>	
	Realized Volatility	
	Simple Model	Full Model
	(1)	(2)
Group	0.067*** (0.020)	0.095*** (0.018)
Period	0.009 (0.024)	0.018 (0.021)
Equity Mkt Return		0.906 (0.704)
Equity Mkt Volatility		0.003 (0.003)
Tenor 15Y		-0.053** (0.024)
Tenor 1Y		0.240*** (0.025)
Tenor 2Y		0.047** (0.021)
Tenor 30Y		-0.070*** (0.023)

Tenor 3Y		-0.038*
		(0.022)
Tenor 4Y		-0.052**
		(0.023)
Tenor 5Y		0.043**
		(0.020)
Tenor 6Y		-0.053**
		(0.024)
Tenor 7Y		-0.036
		(0.024)
Tenor 8Y		-0.067***
		(0.024)
Tenor 9Y		-0.074***
		(0.024)
Group * period	0.002	-0.006
	(0.027)	(0.024)
Constant	0.027	-0.029
	(0.017)	(0.047)
<hr/>		
Observations	829	829
R <sup>2</sup>	0.031	0.247
Adjusted R <sup>2</sup>	0.028	0.232
Residual Std. Error	0.161 (df = 825)	0.143 (df = 812)
F Statistic	8.935*** (df = 3; 825)	16.612*** (df = 16; 812)
<hr/>		
<i>Note:</i>	*p<0.1; **p<0.05; ***p<0.01	

Table 15 Diff-in-diff analysis of price volatility during second Grexit referendum

<b>Diff-in-diff Analysis of Volatility During GREXIT</b>	
	<i>Dependent variable:</i>
	Volatility (Daily Return)
Period	-0.002 (0.087)
Group	0.012 (0.090)
Period x Group	-0.016 (0.119)
Constant	0.039 (0.065)
Observations	104
R <sup>2</sup>	0.001
Adjusted R <sup>2</sup>	-0.029
Residual Std. Error	0.300 (df = 100)
F Statistic	0.018 (df = 3; 100)
<i>Note:</i>	*p<0.1; **p<0.05; ***p<0.01

## 6 Conclusion

This essay investigated the causal impact of the central clearing mandate on the IR swaps market, focusing on key outcomes such as pricing, liquidity, and volatility. Using a diff-in-diff approach, I can isolate the effects of the clearing mandate, providing a comprehensive view of its influence on market dynamics.

The findings suggest that central clearing plays a significant role in reducing counterparty risk, as evidenced by the consistent rise in swap premia following the mandate. This reflects an increased valuation for cleared contracts, indicating market participants place a higher premium on reduced risk exposure. However, the anticipated improvements in liquidity were not observed. Measures such as the bid-ask spread, Roll measure, and Amihud illiquidity measure show no substantial change in liquidity because of the clearing mandate. This suggests that in monopolistic or concentrated dealer markets, the decrease in counterparty risks does not necessarily lead to narrower spreads or improved liquidity conditions.

Regarding price volatility, the results indicate that under normal market conditions, the mandate has little to no effect on volatility. The realized volatility measures reveal that prices generally follow a random walk during stable periods, making it difficult to detect significant changes due to the clearing requirement.

While the mandate may have succeeded in reducing counterparty risk, its impact on liquidity and volatility appears more nuanced. The clearinghouse structure has not necessarily resulted in a more liquid market, and its effect on volatility is more pronounced during periods of financial stress rather than regular market conditions. These results can be important for regulators and market participants to consider, as they highlight both the strengths and limitations of central clearing in maintaining market stability.

Future research could delve deeper into the long-term effects of central clearing, particularly in crisis periods, and explore whether different market structures or alternative clearing mechanisms might enhance both liquidity and stability in the IRS market.

## Appendix A Contract Characteristics

This appendix lists the detailed characteristics of the “standard” (most liquid) interest-rate swaps contract for the currencies studied in this essay.

Table 23 Contract characteristics for common contracts (Source: Bloomberg L.P.)

Currency	USD	CAD	GBP	CHF
Settlement	T+2	T+0	T+0	T+2
Fixed Leg				
Day Count	30I/360	ACT/365.FIXED	ACT/365.FIXED	30E/360
Convention				
Payment Frequency	Semiannual	Semiannual	Semiannual	Annual
Business Day	Modified	Modified	Modified	Modified
Adjustment Convention	Following	Following	Following	Following
Adjustment Type	Accrual and Payment Dates	Accrual and Payment Dates	Accrual and Payment Dates	Accrual and Payment Dates
Roll Convention	Backward	Backward	Backward (EOM)	Backward
Accrual Calculation	US Federal Reserve and Bank of England	Canada	Bank of England	Switzerland
Pay Delay	0 days	0 days	0 days	0 days
Floating Leg				
Day Count	Actual/360	ACT/365.FIXED	ACT/365.FIXED	Actual/360
Convention				
Payment Frequency	Quarterly	Semiannual	Semiannual	Semiannual
Reference Index	USD LIBOR 3M	CDOR 3M	GBP LIBOR 6M	CHF LIBOR 6M
Reset Frequency	Quarterly	Quarterly	Semiannual	Semiannual
Business Day	Modified	Modified	Modified	Modified
Adjustment	Following Business Day	Following	Following	Following

Adjustment Type	Accrual and Payment Dates	Accrual and Payment Dates	Accrual and Payment Dates	Accrual and Payment Dates
Roll Convention	Backward	Backward	Backward (EOM)	Backward
Calculation	US Federal	Canada	England	Switzerland
Calendar	Reserve, England			
Fixing Calendar	England	Canada	England	England
Fixing Lag	2 business days	0 days	0 days	2 business days
Pay Delay	0 days	0 days	0 days	0 days
Reset Position	Advance	Advance	Advance	Advance

## Definitions

### Settlement

Settlement refers to the number of business days after the trade date when the swap contract is finalized, and payments are made (Hull 2022). The most common conventions are T+0, T+2, and T+3, where "T" represents the trade date, and the number indicates how many business days after the trade date settlement occurs. For example, in a T+2 settlement, the settlement occurs two business days after the contract is executed.

### Fixed Leg

The fixed leg of an interest rate swap refers to the portion of the swap where the payer makes periodic payments at a fixed interest rate, which is predetermined and remains constant throughout the life of the swap (Hull 2022). The characteristics below describe various conventions associated with this leg.

- Day Count Convention (Ametrano and Ballabio 2003b): This convention determines how interest accrues over time, using fractions of a year based on the number of days between two dates . Common conventions include:
  - 30I/360: Assumes each month has 30 days and a year has 360 days. It simplifies calculations but may deviate slightly from actual time. If the start date of the day count is on 31st, it is treated as if it is the 30<sup>th</sup>. If the end date is on the 31<sup>st</sup>, then it can either be treated as the 30<sup>th</sup> or the 31<sup>st</sup> depending on the start date. It also



includes special rules for when either the start or end date of the day count convention is Feb 28/29.

- 30E/360: Like the 30I/360 convention, but if either the start or end dates are on the 31<sup>st</sup>, they are treated as if they are on the 30<sup>th</sup>. February 28/29 is always treated as 30<sup>th</sup>.
- ACT/365.FIXED: Uses the actual number of days in a period, dividing by a fixed 365-day year for calculating partial year interest rate accrual.
- Actual/360: Uses the actual number of days between dates, but assumes the year has 360 days when calculating partial year interest payments.
- Payment Frequency (Ametrano and Ballabio 2003b): This defines how often payments are made on the fixed leg. For instance, "semiannual" means payments are made twice a year, while "annual" means once a year.
- Business Day Adjustment Convention (Ametrano and Ballabio 2003b): When a payment date falls on a non-business day, this convention dictates how the date is adjusted. All the contracts in this study use a "modified following" convention. A modified following convention means payments are pushed to the next business day unless that day falls in the next month, in which case payments are moved backward to the preceding business day.
- Adjustment Type (Ametrano and Ballabio 2003b): Adjustment type refers to which dates are adjusted when a business day adjustment is necessary. For example, in "Accrual and Payment Dates" adjustment, both the accrual period and the payment date will be adjusted if necessary.
- Roll Convention (Ametrano and Ballabio 2003b): The roll convention specifies how payment dates are set relative to a reference date, typically whether payments move forward or backward when adjusting for business days. A "backward" roll moves the date to the nearest preceding business day, while "Backward (EOM)" additionally ensures payments align with end-of-month periods.
- Accrual Calculation Calendar (Ametrano and Ballabio 2003b): This calendar determines which set of business days are considered in calculating the accrual of interest payments. For example, the "US Federal Reserve" calendar includes only U.S. federal holidays, while the "England" calendar takes U.K. public holidays into account.

- **Pay Delay (Bloomberg L.P.):** Pay delay refers to the number of days between the payment due date and the actual date the payment is made. For instance, "0 days" means payments are made on the due date.

### **Floating Leg**

The floating leg of the swap is where payments are made based on a variable interest rate, which changes over time based on a reference index (Hull 2022). The conventions below describe how these payments are structured.

- **Reference Index (Hull 2022; Ametrano and Ballabio 2003b):** The reference index is the benchmark interest rate that dictates the floating payments. Common indices include:
  - USD LIBOR 3M: U.S. Dollar London Interbank Offered Rate for a 3-month period.
  - CDOR 3M: Canadian Dollar Offered Rate for 3 months.
  - GBP LIBOR 6M: British Pound LIBOR for 6 months.
  - CHF LIBOR 6M: Swiss Franc LIBOR for 6 months.
- **Reset Frequency (Ametrano and Ballabio 2003b):** This determines how often the floating rate is recalculated or "reset." For example, a quarterly reset means the floating rate is updated every three months.
- **Fixing Calendar (Hull 2022; Ametrano and Ballabio 2003b):** This refers to the calendar used to determine when the floating rate is fixed or set. For example, the "England" fixing calendar means rates are set according to U.K. business days.
- **Fixing Lag:** Fixing lag defines how many days in advance the floating rate is determined before the payment period begins. For instance, a "2 business days" fixing lag means the floating rate is set two days before the payment is due.
- **Reset Position:** "Advance" reset position means the floating rate is set at the beginning of the interest period and applied throughout the period.

## Appendix B Robustness Tests

This appendix provides several robustness tests to my analysis. Firstly, in essay 1, in the analysis of the clearing mandate on swap pricing, I filtered out observations that were +/- 50 bps from the Bloomberg terminal calculated fair rate. I now present an alternate version of tables Table 8 and Table 9, now including these outliers. Overall, there were 1,101 such outliers (representing about 4% of the overall dataset). Results continue to be very similar to the results found in the main essay. In this broader dataset, clearing causes a 12-bps rise in swaps prices for USD contracts in the overall dataset. Most control variables also show similar results to what is found in the main essay. The notable exceptions are tenor (where a one-year increase in the tenor is now associated with a 0.03 bps increase in the premium instead of a 4-bps decrease) and Friday trading (which is now associated with a 0.95 bps increase in the premium rather than a -0.78-bps decrease). The group difference (that is the difference in baseline premium for USD over CAD contracts) also becomes not statistically significant. Note that the effect of these control variables is small (less than 1 bps).

*Table 24 Diff-in-diff results after including all pricing outliers*

<b>Diff-in-diff Regression Results</b>		
	Dependent variable: Premium	
	Basic Model	Full Model
	(1)	(2)
Group	6.4783*** (1.2754)	7.1186*** (1.2786)
Period	-16.8364*** (1.6893)	-16.6251*** (1.6921)
Tenor		-0.0552** (0.0226)
Log Notional		0.5606***

		(0.1730)
Capped		-0.3432
		(0.4880)
SEF		-4.2437
		(6.5996)
Morning Session		-2.6170***
		(0.4843)
Afternoon Session		-2.4587***
		(0.4762)
Off Hours		-3.5615***
		(0.5589)
Monday		2.8288***
		(0.5910)
Tuesday		1.6594***
		(0.5454)
Thursday		1.1212**
		(0.5274)
Friday		-0.7841
		(0.5581)
Group * Period	12.8246***	12.1513***
	(1.7395)	(1.7539)
Constant	-3.4148***	-11.6213***
	(1.2252)	(3.1911)
<hr/>		
Observations	28,311	28,311
R <sup>2</sup>	0.0139	0.0182
Adjusted R <sup>2</sup>	0.0138	0.0177

Residual Std. Error	30.2838 (df = 28307)	30.2239 (df = 28296)
F Statistic	133.0846*** (df = 3; 28307)	37.4453*** (df = 14; 28296)
<i>Note:</i>		*p<0.1; **p<0.05; ***p<0.01

Table 25 diff-in-diff results after including pricing outliers. By phase analysis.

By Phase Results: Full Model			
Dependent variable: Premium			
	Phase 1	Phase 2	Phase 3
	(1)	(2)	(3)
Group	7.200*** (2.241)	6.368*** (2.151)	12.806*** (2.331)
Period	-2.813 (3.751)	-16.738*** (2.926)	-5.274** (2.617)
Tenor	-0.305*** (0.055)	0.021 (0.031)	0.039 (0.035)
Notional	-2.382*** (0.391)	0.653** (0.257)	2.108*** (0.257)
Capped	1.164 (1.141)	0.031 (0.689)	-1.834** (0.729)
Morning Session	-5.318*** (1.121)	0.581 (0.702)	-2.231*** (0.716)
Afternoon Session	-3.678*** (1.110)	-1.300* (0.673)	-0.882 (0.718)
Off Hours	-6.020***	0.474	-6.191***

	(1.311)	(0.803)	(0.826)
Monday	-0.927	9.518***	-4.437***
	(1.361)	(0.883)	(0.866)
Tuesday	-2.788**	8.744***	-3.307***
	(1.315)	(0.787)	(0.794)
Thursday	-2.880**	9.627***	-5.501***
	(1.292)	(0.736)	(0.790)
Friday	-2.307*	4.595***	-4.177***
	(1.373)	(0.768)	(0.848)
Group * Period	-3.568	11.873***	11.274***
	(3.848)	(3.007)	(2.755)
Constant	50.354***	-21.877***	-50.813***
	(6.877)	(4.958)	(4.895)
Observations	7,819	11,233	9,259
R <sup>2</sup>	0.025	0.036	0.073
Adjusted R <sup>2</sup>	0.023	0.035	0.071
Residual Std. Error	37.150 (df = 7805)	26.916 (df = 11219)	25.619 (df = 9245)
F Statistic	15.137*** (df = 13; 7805)	32.443*** (df = 13; 11219)	55.763*** (df = 13; 9245)

*Note:*

\*p<0.1; \*\*p<0.05; \*\*\*p<0.01

Also, as is sometimes done in literature, I drop observations on the first trading day of each phase that the clearing mandate went into force (to mitigate the effects of program implementation effects). Results continue to show similar patterns as found in the main body of the essay. The mandate causes a 12-bps rise in premiums for US-contracts after implementation. Control variables show similar signs and magnitude as is discussed in the main body of the paper.

*Table 26 Diff-in-diff results excluding the first day the treatment went into effect*

<b>Diff-in-diff Regression Results</b>		
	Dependent variable: Premium	
	Basic Model	Full Model
	(1)	(2)
Group	-0.8889*	-0.7596
	(0.4942)	(0.4928)
Period	-11.4254***	-11.1961***
	(0.7048)	(0.7007)
Tenor		0.0305***
		(0.0089)
Log Notional		0.6367***
		(0.0693)
Capped		-0.7166***
		(0.1920)
SEF		0.4531
		(2.5989)
Morning Session		-0.9881***
		(0.1916)
Afternoon Session		-1.1930***
		(0.1877)
Off Hours		-1.2874***

		(0.2193)
Monday		2.6462***
		(0.2662)
Tuesday		2.3934***
		(0.2081)
Thursday		2.7678***
		(0.2016)
Friday		0.9347***
		(0.2137)
Group * Period	12.0888***	11.5072***
	(0.7234)	(0.7226)
Constant	-0.2415	-11.9859***
	(0.4742)	(1.2767)
<hr/>		
Observations	25,613	25,613
R <sup>2</sup>	0.0175	0.0335
Adjusted R <sup>2</sup>	0.0174	0.0330
Residual Std. Error	11.4106 (df = 25609)	11.3196 (df = 25598)
F Statistic	152.0776*** (df = 3; 25609)	63.4120*** (df = 14; 25598)
<hr/>		
<i>Note:</i>		*p<0.1; **p<0.05; ***p<0.01

Finally, given the low  $R^2$  values of some of the regression results, I try alternative regression specifications. Table 27 shows the results of a model with second-order terms for the continuous control variables tenor and notional. Although these higher order terms are statistically significant, the model still suffers from the same low  $R^2$  as the model used in the main body of the essay. The overall conclusion remains the same (clearing causes a 13-bps increase in premium for USD contracts). Control variables also show similar signs and magnitudes as in the main body of the essay.



Table 27 Diff-in-diff with alternative model specifications

Diff-in-diff Regression Results	
	Dependent variable: Premium
	Full Model
Group	-0.6567 (0.4897)
Period	-13.3189*** (0.6611)
Tenure <sup>2</sup>	0.0007*** (0.0003)
(Ln notional) <sup>2</sup>	0.0235*** (0.0021)
Capped	-1.0574*** (0.1883)
SEF	0.7100 (2.5202)
Morning	-1.0268*** (0.1843)
Afternoon	-1.2300*** (0.1814)
Off Hours	-1.3042*** (0.2125)
Monday	1.5552*** (0.2245)
Tuesday	2.3847*** (0.2071)

Thursday	2.7650*** (0.2006)
Friday	0.9402*** (0.2125)
Group * Period	13.4560*** (0.6840)
Constant	-7.6601*** (0.7760)
<hr/>	
Observations	27,210
R <sup>2</sup>	0.0441
Adjusted R <sup>2</sup>	0.0436
Residual Std. Error	11.2629 (df = 27195)
F Statistic	89.5578*** (df = 14; 27195)
<hr/>	
<i>Note:</i>	*p<0.1; **p<0.05; ***p<0.01