Understanding the foreign exchange market

Amanda Nordström [*]
The author is a Senior Economist in the Riksbank's Monetary Policy Department

The foreign exchange market is an essential part of the global financial system and plays an important role in the economy. Over the last four decades, it has undergone large structural changes, from an opaque and slow-moving, clearly two-tiered market to today's fast-paced, interconnected yet fragmented market. Trading is becoming increasingly electronic and automated, and new participants, tools and strategies have entered the market. These structural changes have had considerable impact on the way foreign exchange is traded, priced and monitored. In this article I survey how the structure of the market has evolved over the last few decades, with a particular focus on the market for Swedish krona (SEK). I also discuss important mechanisms and features of the FX market; price discovery, liquidity and market functioning, and I present a measure of liquidity of the Swedish krona market.

1 Introduction

The foreign exchange (FX) market is an essential part of the global financial system and plays an important role in the economy. It is crucial in sustaining efficiency and arbitrage conditions in most other international financial markets, including the bond, stock and derivatives markets. The pricing mechanisms of the FX market affect financial conditions, resource utilisation and inflation, and so a proper understanding of these mechanisms is at the heart of central bank mandates and operations in many countries around the world. For the Riksbank, an inflation targeting central bank in a small open economy, understanding the drivers and fundamentals of the krona exchange rate, and how the FX market structure is evolving, is important to monetary policy and financial stability.

Over the last four decades, the FX market has undergone large structural changes. Beginning with the introduction of floating exchange rate regimes in the 1970s, currency trading has gone from an opaque and slow-moving, clearly two-tiered

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market to today's fast-paced and interconnected, yet fragmented, market with a growing number of participants and trading venues. Both price discovery and execution of trade, that is, the process by which trades are finalised, are to an increasing degree taking place electronically and automatically. As a result, new market participants, trading strategies and tools have emerged, affecting exchange rate determination and market functioning. In addition, the technological advances and increased competition between trading venues have resulted in enormous amounts of data being available to researchers and practitioners, albeit non-uniform in access and dispersed across multiple platforms.

Above and beyond changes to the structure of the FX market, exchange rate movements themselves are often difficult to explain, and even harder to predict. Conventional macroeconomic theory often assumes that exchange rates are determined as a price that equilibrates the returns to investing in foreign and domestic assets. In particular, these models rely on the so-called *uncovered interest rate parity (UIP)* condition*,* stating that the expected change in the exchange rate is determined by the interest rate differential between the two currencies in question. More specifically, the currency with the higher interest rate is expected to depreciate by the amount of the interest rate differential.

However, in reality, the empirical evidence of UIP remains elusive. Research offers many different explanations to this puzzling empirical fact, often related to the assumptions on which the UIP condition relies (for a survey of related research, see for example, Engel 2016). First, the UIP is based on the assumption of risk neutrality and, most often, empirical tests of UIP assume rational expectations among investors. Second, it assumes symmetric information among participants and that market prices immediately incorporate all available information. Since all participants have the same information set, which at any given point in time reflects the latest available information, only one price exists at any given point in time. Third, it requires a lack of trading costs or barriers and equal liquidity, maturity and default risk of the assets traded, see Engel (2014).

Few, if any, of these assumptions of market efficiency hold in the FX market and there is an extensive literature studying modified models that better capture exchange rate dynamics (see for example Fama 1984, Lyons 2001, Bacchetta and van Wincoop 2010 and Lustig and Verdelhan 2019). In fact, as this article will show in more detail, FX market participants are heterogeneous, transparency is limited and information is asymmetric. As a consequence, there are arbitrage opportunities that market participants are unable, or unwilling, to exploit because of the features of the FX market.

The structural changes to the FX market since the 1970s have had considerable impact on the way FX is traded, priced and monitored. Technological advances have made markets more efficient, reduced operational risks and lowered trading costs. Barriers to entering the FX market have been lowered, with new participants, trading venues and tools active in the market. The FX market of today is complex, fast-paced and highly fragmented; liquidity is deep but dispersed over a large number of venues that are to various extent interconnected to each other. Price formation is to an

increasing degree taking place outside of the conventional bank sphere, and as a consequence, agents or organisations wanting to monitor the market have had to turn to new venues and tools for information. The use of computers, algorithms and the ever-increasing speed of the FX market has also given rise to new challenges and risks. For instance, algorithms may amplify and intensify market movements, causing disorderly price movements even in the most traded and liquid instruments.

In sum, the lack of empirical support for traditional modelling of exchange rates and the rapid evolution of the FX market motivates a better understanding of the structure and functioning of this unique and complex market. Moreover, the FX market is integral to the international financial network and affects financial conditions. Therefore, in this article I survey the structure of the FX market: its current state and how it has evolved over the last few decades, with a particular focus on the market for Swedish krona (SEK). I also discuss important mechanisms and features of the FX market; price discovery, liquidity and market functioning, and present a measure of liquidity of the Swedish krona market.

The rest of this paper is structured as follows: the next two sections explore the evolution of the FX market structure from the 1970s to today. The fourth section discusses the implications of these developments for market monitoring, efficiency and market conditions. In addition, it covers the concept of market liquidity and presents an index for systematic measuring of liquidity in the SEK. The last section presents my conclusions.

2 FX market turnover and instruments

With a daily average turnover in 2019 of approximately USD 6.6 trillion, the global FX market is by far the largest and deepest of all financial markets.[1] It consists of several submarkets; the spot market, the FX swap market, the forwards market, the currency swap market and the options market being the largest five, see BIS (2019).[2] Every third year, the Bank for International Settlements (BIS) publishes statistical information on turnover in the FX market sorted by region, counterpart and instrument in the BIS Triennial Survey. It is the most comprehensive source of information on the size and structure of the global FX market, with data collections starting in 1986.[3] From this survey, we know that the Swedish krona, being one of the smallest of the ten most traded currencies (*G10 currencies*), has a daily turnover of around USD 134 billion. To put these numbers into perspective, daily global FX market

[1] Turnover is defined as the gross value of all new deals entered into during a given period, and is measured in terms of the nominal or notional amount of the contracts adjusted for double-counting, see BIS (2019).

[2] These five submarkets make up the majority of the total market in terms of turnover, although the list is not exhaustive. In addition, each submarket is divided into many additional markets depending on where and how contracts are traded.

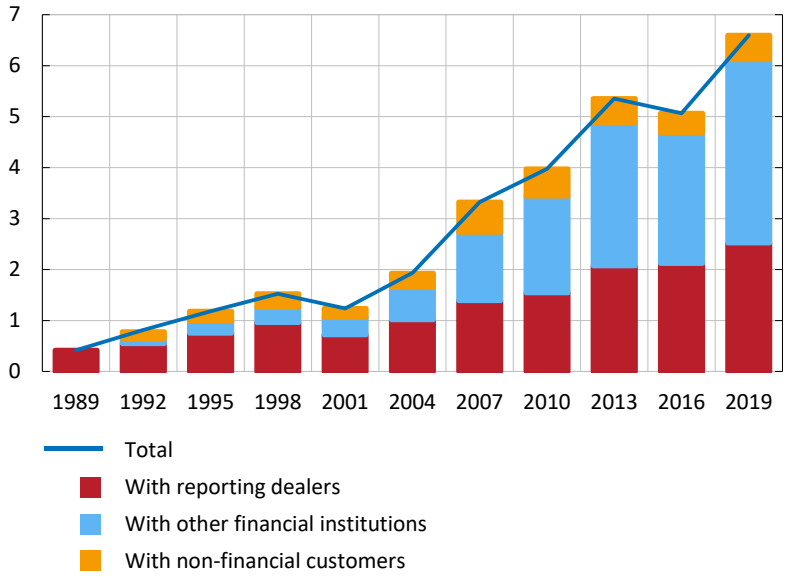
[3] The most recent edition, published in December 2019, took place in April 2019 and involved central banks and other authorities in 53 jurisdictions. These actors collected data from close to 1,300 banks and other dealers in their jurisdictions and reported national aggregates to the BIS, which then calculated global aggregates. Turnover data are reported by the sales desks of reporting dealers, regardless of where a trade is booked, and are reported on an unconsolidated basis, that is, including trades between related entities that are part of the same group, see BIS (2019).

turnover is approximately 27 times as large as daily world GDP, and turnover in SEK is over 90 times larger than the daily Swedish GDP.[4]

Non-financial customers, which is the client segment most closely linked to real economic activity, are counterparties in only a fraction of all FX trading. SEK turnover is, like the FX market in general, dominated by financial flows (see Figure 1 and 2). Financial institutions are counterparties in nearly 90 per cent of the turnover of all trades involving SEK.

Figure 1. Daily global turnover by counterpart

USD trillion

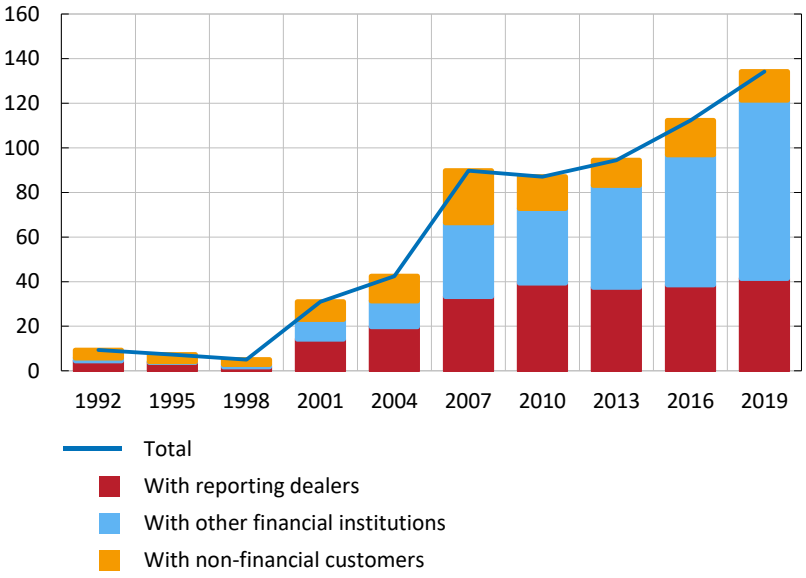


Source: BIS Triennial Survey (2019).

[4] The average daily global GDP in 2019 was approximately USD 240 billion while the Swedish daily average was around USD 1.45 billion per day. Daily GDP is calculated using the gross domestic product of 2019 in current USD, as reported by the World Bank, for the World and Sweden respectively, divided by the number of days in 2019 (365).

Figure 2. Daily SEK turnover by counterpart

USD billion



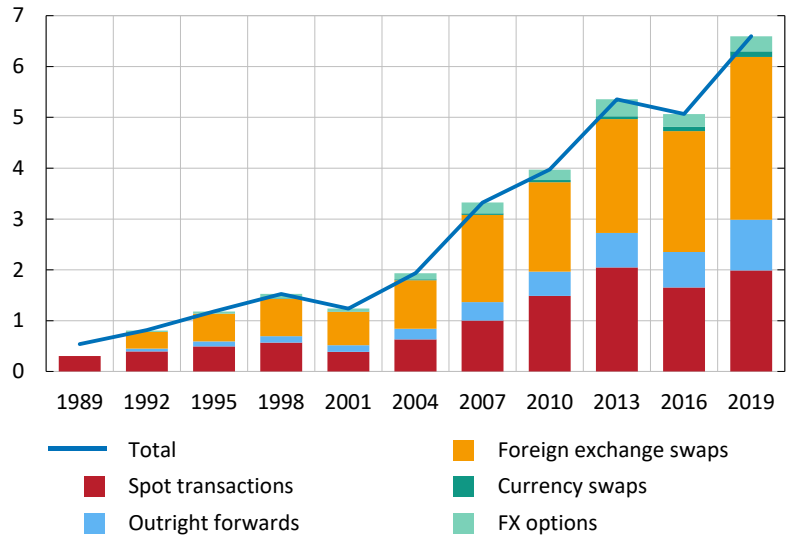
Source: BIS Triennial Survey (2019).

The most direct form of FX trading is the *spot market*, which covers around 30 per cent of the total global turnover, thereby making it the second largest of the submarkets (see Figure 3). Spot transactions involve the exchange of two currencies at a rate agreed on the date of the contract for value or delivery in two business days or less. The FX *forward market* is the third largest, covering around 15 per cent of reported turnover.[5] Forward transactions are defined as contracts between two parties for the delayed exchange of two currencies in which the buyer agrees to purchase and the seller agrees to deliver, at an agreed future date at an agreed price, see BIS (2016).

[5] FX forward transactions should not be confused with *FX futures*, which are exchange-traded, standardised contracts. *Forward* contracts are traded OTC (over-the-counter) and are privately agreed upon between two parties. *Futures contracts* are traded on an exchange and have standardised terms. Futures contract prices are settled daily until expiry of the contract. With the exception of the futures for the Mexican peso and the South African rand, FX futures are physically delivered on the four International Money Market dates (the third Wednesday of March, June, September and December). Futures are not reported as part of the foreign exchange market in the BIS Triennial Survey, nor are they considered in this article.

Figure 3. Daily global turnover by instrument

USD trillion



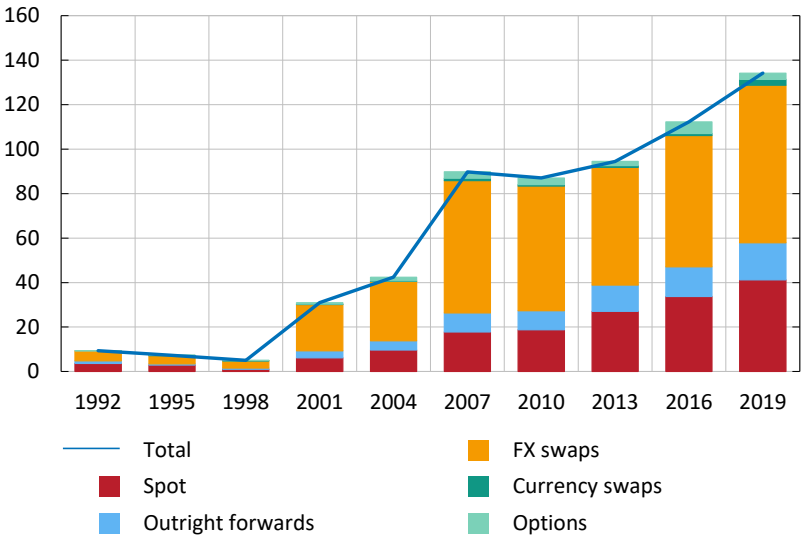
Source: BIS Triennial Survey (2019).

The largest FX submarket in terms of turnover is the FX *swap market*, which with its USD 3.2 trillion comprises almost half of the total turnover of the global FX market. An FX swap is a transaction involving the exchange of two currencies on a specific date at a rate agreed upon at the time of the start of the contract (the near leg), and a reverse exchange of the same two currencies at a date further in the future at a rate agreed at the time of the contract (the far leg), see Baba et al. (2008). The near leg may be a spot transaction or a forward transaction, while the far leg is a forward transaction. FX swaps are used to raise foreign currency, both for financial institutions and their customers, including exporters and importers, as well as institutional investors who wish to hedge their holdings of foreign assets. Swedish banks are frequent users of FX swaps, using them to swap foreign currency denominated financing (typically USD or EUR) into SEK. Swedish pension and investment funds and corporates are typical counterparts in the swaps, having an interest in obtaining foreign currency in exchange for SEK to invest abroad, at very little currency risk. Swedish banks, on the other hand, obtain relatively cheap financing in SEK through such swap agreements.[6] FX swaps comprise more than half of total SEK turnover (see Figure 4).

[6] See for example Sveriges Riksbank (2020) and Bertsch (2022).

Figure 4. Daily SEK turnover by instrument

USD billion



Source: BIS Triennial Survey (2019).

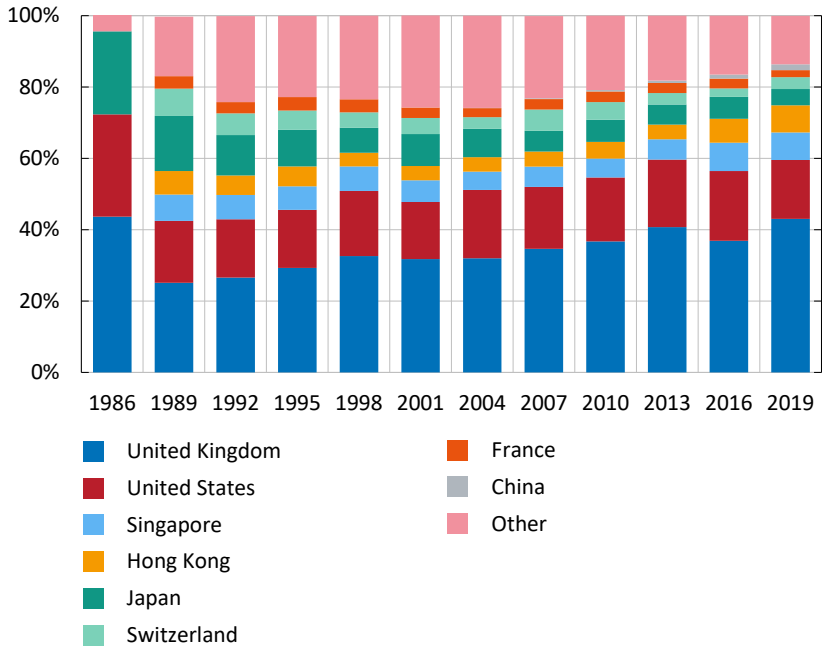
FX swaps should not be confused with *currency swaps*, known also as *cross-currency swaps,* which are contracts which commit two counterparties to exchange streams of interest payments in different currencies for an agreed period of time and/or to exchange principal amounts in different currencies at a pre-agreed exchange rate at maturity, see Baba et al. (2008). Hence, FX swaps and currency swaps are technically similar, but differ in that currency swaps also include the exchange of interest payments and principal amounts. In general, currency swaps also tend to have longer duration than FX swaps.

Finally, *options* are contracts that confer on the owner the right to buy or sell one currency for another currency at a specified exchange rate at a specified point in time. Currency swaps and options make up only a small part of the market as a whole and are normally traded separately from spot and forward contracts and for different purposes, see King et al. (2012).

Historically, most FX trading has been located in London and New York. In 2019, sales desks in these two locations intermediated around 60 per cent of all FX trading; 43 and 17 per cent, respectively, according to the BIS Triennial Survey. Indeed, trading has remained highly concentrated to a handful of trading hubs throughout the last four decades, with the United Kingdom, the United States, Singapore, Hong Kong SAR and Japan accounting for almost 80 per cent of all trading activity (see Figure 5). The internal distribution between these has varied over time, but the United Kingdom share has always been the largest.

Figure 5. Geographic distribution of global FX turnover

Percentage of total, all instruments

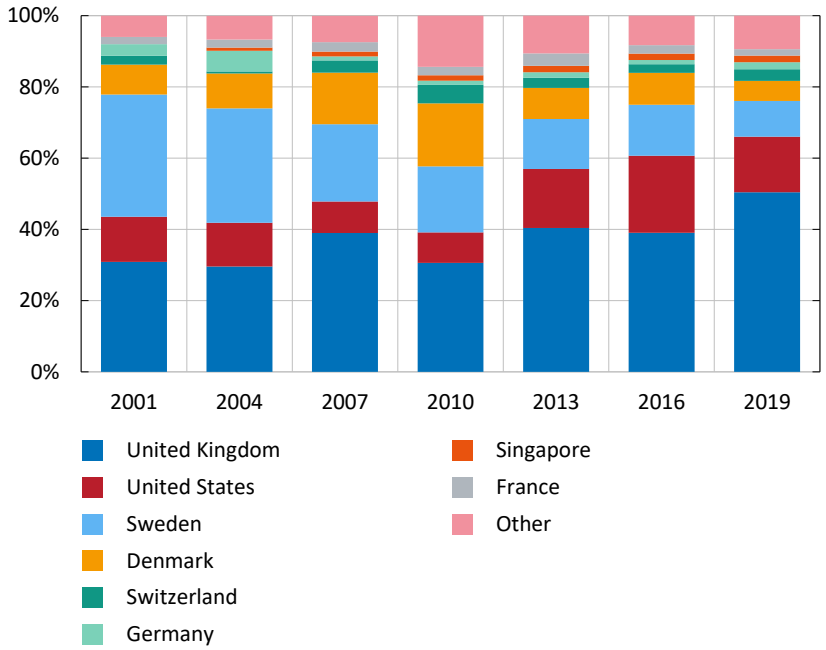


Source: BIS Triennial Survey 1986-2019. Author's own calculations.

Data on the geographical distribution of SEK turnover have been collected since 2001. The share of Sweden-based trading has decreased markedly since the beginning of the survey sample. In 2019, only 10 per cent of the SEK trading flows were intermediated by sales desks located in Sweden, compared to around 35 per cent in 2001 (see Figure 6). Similar to the situation globally, trading activity in SEK is highly concentrated to the United Kingdom and the United States. Contrastingly, the three remaining large trading hubs – Singapore, Hong Kong SAR and Japan – account for only a small share of all trades; around 4 per cent in total in 2019. Instead, the third largest geographical trading hub for the SEK is Sweden, followed by Denmark. However, only approximately 3 per cent of spot trading in SEK takes place in Sweden; the vast majority of spot SEK trading flows is done in the UK.

Figure 6. Geographic distribution of SEK turnover

Percentage of total, all instruments



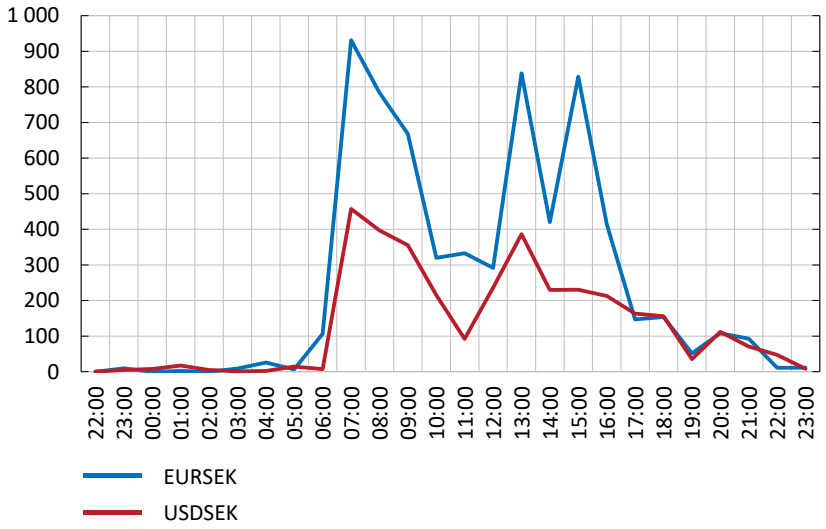
Source: BIS Triennial Survey 2001-2019. Author's own calculations.

Many of the floating exchange rate currencies can be traded 24 hours a day, every day of the year. However, although the FX market is always open to some extent, trading mainly starts when markets open in Sydney and ends when markets close in New York, with the bulk of traded volumes passing through markets from London opening to New York closing. This pattern is highly visible in the two most actively traded currency pairs with SEK on one side, EURSEK (the exchange of euro against SEK and vice versa) and USDSEK (the exchange of US dollars against SEK and vice versa), see Figure 7. Trading flows for individual currency pairs are typically consistent with UK and US trading hours, with the European currencies being traded most actively during London opening hours and the North American currencies during New York hours (King et al., 2011).[7]

[7] It should be noted that global intraday turnover exhibits three "peaks" rather than only two; Asian trading hours are typically associated with heightened activity as well. However, the UK and US trading hours dominate intraday trading activity.

Figure 7. Intraday spot trade volume

USD million



Note: Intraday spot trade volumes in EURSEK and USDSEK submitted to the settlement firm CLS on 2019-01-01 to 2019-02-02.[8] London local time.

Source: CLS.

Technological advances in FX trading have generally begun within the spot, and to some extent the forwards markets, and have also been most pronounced within these segments. The more complex instruments, such as swaps and options, are following the developments in spot and forwards, albeit with a slower uptake of the new technologies. Given this, the rest of this article will focus mainly on the spot and forward markets.

3 Structural developments of the FX market[9]

3.1 1970s to 1980s

Since the introduction of floating exchange rate regimes in many advanced economies in the early 1970s, the global FX market has undergone large structural changes. Far from today's volumes, the global daily average turnover in 1989, the farthest the BIS Triennial Survey goes back in time, was approximately USD 540 billion. The SEK, at that time a managed exchange rate fixed to a basket of currencies, recorded an average turnover of USD 6 billion per day.

During the 1970s and the 1980s, currencies were almost exclusively traded directly via telephone, in an over-the-counter (OTC) market. The OTC market structure refers to

[8] CLS is the world's largest FX settlement firm, providing settlement for around USD 460 billion in daily spot volumes globally (November 2021). Their data are adjusted to equate to the same reporting convention used by the Bank for International Settlements (BIS).

[9] Sections 3.1–3.2 are largely based on the extensive *Handbook on Foreign Exchange*, in particular King et al. (2013). More on the evolution of the FX market structure may also be found in Lyons (2001), Sager and Taylor (2006), King et al. (2012), Moore et al. (2016) and Schrimpf and Sushko (2019a,b).

bilateral transactions not conducted on a formal exchange. A small number of major *dealer banks* were the main *liquidity providers*, financial institutions which intermediate in the FX market by selling and buying the same currency. [10] In the FX market, these dealers emerged to solve the search problem among market participants to match opposing exchange flows. Non-bank financial institutions and large corporations constituted the major part of the client base, the *liquidity consumers.*[11] Their motives for currency trading stemmed primarily from the exchange of currencies due to international trade of goods and services, including financial services, and hedging of FX exposures owing to foreign-currency assets and liabilities.

The FX market consisted of a clearly delineated two-tiered system where dealers constituted the *primary* market tier, called the *interbank* or *interdealer market*, and dealer-to-client trades took place in the *secondary* market tier. In the interbank market, dealer banks managed their currency flows between each other (dealer-to-dealer trading). Interbank prices are the prices banks quote to each other. Trades in both tiers took place directly and predominantly via phone, so called "voice trades". In the interbank market, dealers could also choose to trade indirectly, using a *voice broker* as an intermediary.

Voice brokers are human intermediaries active in the interbank market, matching dealer trades with each other. They receive quotes and orders via telephone from a set of dealer banks connected to the brokerage, and then match corresponding orders into trades without disclosing the identity of parties pre-trade, that is, before the parties have agreed upon transaction. This type of brokering is referred to as *direct dealing*, see Melvin and Wen (2013). Upon receiving an order to, for example, sell US dollars against the Swedish krona, voice brokers would shout out the current best bid and ask prices into all open telephone lines connected to dealers. The *bid price* in this example is the price at which a dealer is willing to buy US dollars in exchange for Swedish krona. Vice versa, the *ask price (offer)* is the price at which a dealer is willing to sell US dollars in exchange for Swedish krona.

Since currency trading always involves the purchase of one currency and the sale of another, the concept of a buyer and a seller might be somewhat confusing, especially when both counterparts are dealers. In this article, and as is conventional in FX trading, it will depend on who initiates the trade. If dealer A posts a bid price with the voice broker, she wants to purchase the base currency (she is the price *maker*). If dealer B accepts dealer A's bid price, she sells the base currency to dealer A (she is the price *taker*). Market practice is to always express the *base currency* first in labelling currency pairs, that is, the units of a given currency to purchase one unit of the base

[10] Dealers are financial intermediaries whose primary business is to enter both buy and sell transactions and which seek profit by taking the associated inventory risk, see Committee on the Global Financial System (2001). Liquidity provision is a term used to describe the practice of continually trading in and out of relatively short-term positions. Liquidity providers are essentially market-makers of the FX market: they sell and buy the same currency pairs, acting as intermediaries for other participants by entering and holding currency positions, normally to make a profit on the difference between the purchasing (bid) price and the selling (ask) price.

[11] Liquidity consumers are clients of the liquidity providers. They typically buy *or* sell currencies for reasons such as international trade or hedging by entering one side of a trading agreement.

currency. Most exchange rates are expressed as units of a currency in order to purchase one US dollar (USD), with the exception of the euro (EUR), the British pound (GBP), the Australian dollar (AUD) and the New Zealand dollar (NZD).[12] For example, the exchange rate of the Swedish krona (SEK) against the US dollar is conventionally expressed as USDSEK, meaning SEK per USD. In this example, the US dollar is the base currency. A buyer of USDSEK purchases USD using SEK as payment; a seller of USDSEK sells USD and receives SEK as payment.

The FX market of the 1970s and the 1980s was characterised by an opaque *price discovery process* (the process through which prices are determined and set) with large discrepancies between the interbank market prices and the prices set to end clients. Information about trades were proprietary to the two counterparties and no market-wide source of information was accessible for end clients. Dealer banks, however, arguably had an information advantage relative to end clients. In addition to small, informal networks among banks, they had access to the voice brokers who would continuously announce the current market prices. Brokers do not enter positions, and could, at least in theory, not trade upon the information they received.[13] End clients would not see the prices traded interbank, only the final price quoted by their dealer bank(s). Post-trade, that is, after the trade had been agreed upon between the counterparties, the parties would exchange physical paperwork to settle the transaction, making the process cumbersome and prone to human error.

3.2 Late 1980s to 2000s

Computers made their first real entrance into FX trading in 1987, when Thomson Reuters Dealing was introduced. This computer system, available only to dealers, offered an alternative to telephone communication, enabling electronic messages to be sent amongst dealers while enhancing operational efficiency by the creation of electronic records of trading. Around the same point in time, Thomson Reuters also released their FXFX product, a proprietary computer site within the Reuters Terminal where dealers' *indicative quotes* for the most commonly traded currencies were shown in real time.[14] Both Reuters Dealing and FXFX quickly became popular and as such, important information hubs for price discovery and trading, see King et al. (2013). The FXFX page contributed to greater transparency in the interbank market, but as indicative quotes are not tradeable per se, the informational content of FXFX quotes as an indicator of the tradeable current exchange rates was questionable, see Martens and Kofman (1998).

[12] In order: euro, British pound, Australian dollar, New Zealand dollar and US dollar. For example, the exchange rate of euros against US dollars is expressed as EURUSD and the exchange rate of British pounds against Australian dollars is expressed as GBPAUD.

[13] Brokers that also act as dealers are called *broker-dealers* or *dealing desk brokers.* When a broker-dealer acts as an *agent*, the trade is on behalf of the client (broker), and when acting as *principal,* the trade is on its own account (dealer).

[14] Indicative prices are prices quoted by dealers that are not necessarily tradable. Dealers submit indicative prices to give clients an indication of the price they are willing to trade at without being committed to trade. For example, if a client requests a quote without specifying the volume, dealers would normally provide an indicative quote. In contrast, tradable quotes are typically attached to a specified volume.

In the early 1990s, FX trading took another crucial step towards electronification when a new type of broker emerged: the *electronic brokering systems*, or *electronic brokerages (EB)*. These electronic systems automatically match orders submitted by dealers to buy and sell currencies. The two main electronic brokerages were run by EBS and Thomson Reuters Matching, both of them available only for interbank trading. These are often referred to as the *primary venues*, see BIS (2019).[15] Similar to stock market exchanges, electronic brokerages are structured so that the *limit orders* (bids to buy and/or offers to sell a given amount of a currency at a given price) with the highest bid price and the lowest ask price are prioritised and matched first with incoming *market orders* (orders to trade a certain amount at the current market price). Dealers submit limit orders in a *centralised limit order book (CLOB).* The brokerage system then automatically matches these offers and bids with incoming orders from other dealers. Both EBS and Reuters Matching operated anonymous limit order books, meaning that the identities of counterparties were unknown prior to the trade. Instead of having to reveal their interest in trading prior to the actual trading, dealers could now post their quotes anonymously on the CLOB. In addition, the CLOB offered not only indicative prices but actual tradeable prices, "firm" liquidity and more reliable information on the price discovery process.

The introduction of electronic brokering made FX trading more efficient; it increased competition between dealer banks and made interbank risk-sharing more effective, requiring fewer trades to distribute a given volume within a given set of constraints, see Evans and Rime (2019). Nevertheless, much of the electronification in the 1980s and 1990s focused on the interbank market and left the dealer-client relationship largely intact. While operational efficiency increased and execution costs decreased in the interbank market, leading to smaller bid-ask spreads in the primary tier, the bid-ask spreads of the secondary tier remained virtually unchanged until the end of the 1990s. Dealers, who profit from the spreads charged on the liquidity they provide, could earn substantial revenue from their informational advantage and the large difference in trading costs between the tiers.

Early examples of electronic solutions for end clients started emerging around the middle of the 1990s (for example FX Connect and Hotspot FX), but the main shift towards electronification of the secondary tier of the FX market began first around 1999, when the electronic *multi-bank trading platform* Currenex was launched. Multi-bank platforms (*MBPs*, also known as *multi-dealer platforms*) are electronic trading venues which connect a set of clients with its dealers and enables electronic negotiation and execution in competition. They facilitate electronic price discovery and execution in a competitive environment as several dealers are connected to the network at the same time. Currenex, and a number of platforms with similar business ideas that followed, gave end clients access to several dealer banks simultaneously

[15] The term primary venue is often used with specific reference to a certain currency pair. Traditionally, Refinitiv (Reuters) Matching is referred to as the primary venue for the Commonwealth currencies and the Scandinavian currencies, while EBS is the primary venue for the euro, the US dollar, the Japanese yen, the Swiss franc and the Chinese renminbi.

through tools such as *request-for-quote* (RFQ) and electronic limit order books directed at end clients rather than dealers alone.[16]

Many of the pioneers of end-client trading platforms were independent *non-bank firms*, often related to the booming tech sector of those years around the turn of the millenium.[17] Spurred by competition for customer business, the number of new, electronic trading venues virtually exploded. To retain some of the information flows and the market dominance that characterised their role in the 1980s, several of the major dealer banks formed a consortium and launched the multi-bank trading platform FXall in 2001, see King et al. (2013). FXall gave members of the platform access to several dealers simultaneously through an RFQ solution. At approximately the same time, dealer banks started introducing their own proprietary electronic platforms, so called *single-bank platforms* (*SBTs,* also *single-dealer platforms*). Single-bank platforms typically offer similar solutions as non-bank and multi-bank platforms, but are owned and run by the dealer bank itself.

Both single- and multi-bank platforms are in different ways and to various extent interconnected with each other and with other trading venues, and dealers typically operate on several platforms simultaneously. They may be disclosed or anonymous, that is, either the counterparty identities are or are not known pre-trade. Trading venues for dealer-to-client transactions are sometimes referred to as *secondary venues*, as opposed to the interbank primary markets. Generally, at least one of the main brokerages is connected to the trading platforms.[18]

Another important impetus for the development of the FX market was *prime brokerage.* The service emerged in the early 1990s, and is offered by banks that allow clients to get access to multiple executing dealers while maintaining a credit relationship and placing collateral and settlement with a single entity, the prime broker, see Federal Reserve Bank of New York (2010). While electronic brokering provides access to dealers, practical aspects of trading such as credit agreements and settlement instructions are needed for each single dealer. Although this is feasible for large clients, it is often too costly for smaller entities. Instead, with prime brokerage accounts clients are given the opportunity to access the primary market through top FX dealers. Clients then trade directly in the bank's name with its established counterparties, subject to credit limits. Prior to the introduction of prime brokerage, dealer banks would charge smaller investors high transaction costs, as their trades were considered too small to be economically interesting. With trade now grouped

[16] When using the RFQ function, clients simultaneously ask several banks to supply them with a price that they are willing to trade on. The dealer banks are required to respond to the request within a few seconds, and the client may then choose which bank to trade with.

[17] The term *non-banks* generally refers to institutions which perform services traditionally associated with banks, but which lack banking licences.

[18] To exemplify, Refinitiv (Reuters) FX Matching is the electronic broker (for interbank trading) on the Refinitiv multi-bank platform FXall (for dealer-to-client trading, or "all-to-all" trading), accessed via the desktop platform FX Trading, all connected to the financial analysis tool Eikon. Although primary venues' market share has decreased since its introduction, EBS (NEX) and Refinitiv FX Matching (Reuters) remain two of the largest brokerages globally, as are their respective platforms, see Euromoney (2019).

together into much larger trade sizes, dealers were willing to trade with prime brokers at more attractive prices.

The effect of these technological changes was to accelerate the pace and increase the volume of FX trading that could be intermediated at a given time. Transparency and trading efficiency increased with access to price streams provided by electronic brokerages and trading platforms. Client-access solutions helped narrow bid-ask spreads faced by clients in the second tier vis-à-vis interbank pricing. New types of intermediaries, particularly the introduction of prime brokerage, gave smaller clients access to more competitive prices and deeper liquidity. Nonetheless, the technological revolution of the FX market had only begun; the 2000s would see a rapid evolution of electronic execution, new participants, the introduction of algorithmic trading and a fragmented, interconnected and fast-paced electronic FX market.

3.3 2000s to today

Today's FX market is complex, consisting of a large number of trading platforms; market participants wanting to trade FX have more than 75 different venues to choose from, see Sinclair (2018). This proliferation has been driven by technological advances as well as competition between both banks and new market participants seeking to capture, or maintain, a share of the FX market. Electronification in FX first took off in interbank trading, but it is the dealer-to-customer segment that has seen the strongest rise in electronification in recent years, see Schrimpf and Sushko (2019b). The resulting market structure is fragmented yet highly interconnected. According to the 2019 BIS Triennial FX survey, 56 per cent of all FX trading, and 70 per cent of all FX spot trading, takes place electronically (BIS, 2019). Or perhaps even more, as according to a study from 2013, some market reporters suggested that as much as 95 per cent of all spot transactions could in fact be electronic, as most voice trades are booked electronically due to the practical benefits from electronic execution, see Rime and Schrimpf (2013).

Modern market participants rely on technologically advanced and sophisticated trading solutions. *Algorithms* became available in FX trading around the early 2000s and grew rapidly with the availability and improvement of data, becoming a tool for navigating an increasingly fragmented market, see Markets Committee (2020). In addition, reporting requirements and regulations have increased the demand for traceable execution, which in turn has contributed to the growth of electronic and automated trading (see below for more details on reporting requirements and regulation). Algorithms are used in many areas of trading, such as the execution of trades, statistical algorithmic trading and high-frequency trading.[19] As executable liquidity is dispersed over a large number of venues, algorithms have also become a tool to source liquidity from many different venues simultaneously.

[19] In statistical algorithmic trading, algorithms are used to collect and analyse large amounts of data to identify favourable trading opportunities and strategies. This type of trading includes, for example, the employment of algorithms to analyse historical time series data to identify whether a currency is suitable for buying, selling or keeping, and portfolios based on mathematical mean-reversion models.

Execution algorithms use mathematical models and automated trading programs to create specific sets of trading rules and models and then automatically execute orders and transactions. For example, traders commonly place limit orders using algorithms. When a pre-defined limit value is reached, the algorithm is programmed to automatically execute or cancel. Since their introduction, they have evolved from simple mechanical forms to highly sophisticated and adaptive types based on machine learning techniques that respond to real-time changes in market conditions. As of 2020, execution algorithms are estimated to account for around 10–20 per cent of global FX spot trading, but are less frequently used in other types of FX trading, see Markets Committee (2020).

Users and usage of algorithms have also evolved during these years, and today, algorithmic solutions are available to a range of market participants. With the advent of *retail trading platforms*, algorithmic trading was also made available for non-bank participants, see King et al. (2013).[20] A Greenwich Associates study from 2021 showed that nearly 40 per cent of financial FX traders used algorithms in 2020 and that approximately as many saw their usage increase in 2021, see Greenwich Associates (2021). Measured since autumn 2018, the Riksbank's Financial Markets Survey shows that approximately 90 per cent of the participants active in the market for SEK often or always use electronic platforms in trading, but only 20 per cent of participants often or always use algorithms.[21]

Algorithms are also the key building blocks of *high-frequency trading (HFT)*. HFT refers to the use of algorithms for the purpose of arbitrage on slower market players by very high speed and high frequency, also called *latency arbitrage*. The nature of HFT is typically speculative and as with algorithmic trading in general, it has its roots in equity markets where it has been common since the late 1990s. Several of the pioneering HFT firms are becoming increasingly important to the FX market in their roles as liquidity providers.

As data quality improves, so do the prospects of using *machine learning* techniques.[22] Algorithms can handle massive amounts of unstructured data; sort, analyse and act upon it in fractions of the time it would take a human trader. The term *artificial intelligence* (AI) is frequently used to describe this human-like intelligence that today is possible to program into electronic systems, making machines trade like humans but without human involvement or intervention. Several major international dealer banks have launched adaptive algorithms; algorithms that self-adapt to the ongoing market conditions, see Greenwich Associates (2021). Still, AI and machine learning

[20] Retail trading platforms are trading solutions, typically software programs, available for retail clients. One example is MetaTrader4, launched in 2005.

[21] See Sveriges Riksbank (2021).

[22] Machine learning is a technique in which a computer processes data and essentially writes its own program based on the statistical relationships it discovers, see Ford (2015). The technique is used in many everyday functions, such as the recommendations of what to watch on streaming platforms or spam filters in emailing software. In finance, one example of machine learning techniques is that used for scraping data, in which a computer program extracts data from human-readable output coming from another program. Noting the entrance of AI and machine learning as separate from algorithms may be slightly precarious. Algorithms have undergone a series of evolutions since their first emergence, with AI and machine learning techniques developing alongside rather than at separate stages in history.

techniques have only recently started to play an important role in transforming electronic FX trading (see for example Refinitiv 2019 and Golden 2021). Despite the rapid evolution of technology, this type of trading is highly resource demanding, both in terms of human skill and computer power.

As trading has become increasingly electronic and automated, it has also gained markedly in speed. The BIS describes the FX market as a *fast-paced electronic market,* a market where the price development predominantly occurs via electronic means, and which is characterized by a sizeable penetration of high-speed, algorithmic-driven order placements. Along with an increase in the use of electronic brokerages, the introduction of *data aggregators* and live *price feeds* has resulted in an increase in the updating frequency of data feeds.[23] As an example, the EBS platform increased its pricing update frequency from every 100 milliseconds to every 20 milliseconds in 2016, and further to every 5 milliseconds for selected platform participants in 2017, see Markets Committee (2018).

3.3.1 Market participants

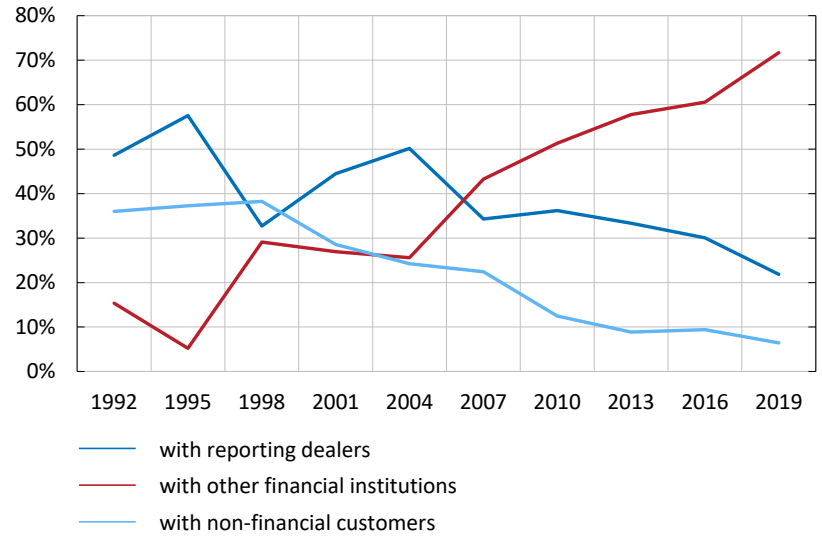
The new, digital infrastructure of the FX market has led to the emergence of new players, functions and possibilities. Nearly half of all reported turnover in spot trading went through prime brokerage accounts in 2019, according to the BIS Triennial Survey, see BIS (2019). For the currencies of small open economies, 56 per cent of all spot turnover of the SEK was prime brokered, which is similar to the Australian, Canadian and New Zealand dollars as well as the Norwegian krone. Higher turnover currencies, such as the British pound, the US dollar, the Japanese yen and the Swiss franc, have a smaller share of transactions conducted through prime brokerage accounts.

Driven by the proliferation of prime brokerage, smaller banks, hedge funds and other players have entered the market to much greater extent than previously. Today, some of the top providers of spot liquidity are non-banks, see Euromoney (2019). The market is no longer centered solely on the dealers; the share of global FX market turnover accounted for by interdealer trading in the BIS Triennial Surveys has declined considerably since the 1990s, from 67 per cent of the total global FX turnover in 1992 to below 40 per cent in 2019, see BIS (2019). They make up even less of the turnover in SEK, their share falling from 48 per cent in 1992 to just above 30 per cent in 2019. In the SEK spot market, only 22 per cent of the turnover have reporting dealers as counterpart (see Figure 8). Interestingly, this is similar to the NOK spot market, but markedly lower than that of the other G10 currencies. Instead, financial institutions other than the dealer banks now represent one side of 60 per cent of all turnover in SEK and over 70 per cent of all SEK spot turnover.

[23] A data aggregator is a technological service where prices are streamed from several liquidity providers and/or platforms simultaneously.

Figure 8. Turnover by counterpart, SEK spot market

Per cent



Source: BIS Triennial Survey (2019).

An increasingly important new group of participants in the FX market are the *principal trading firms (PTFs,* also known as *proprietary trading firms)*. PTFs are firms that invest, hedge or speculate for their own account, not on behalf of clients. They are sophisticated non-banks which provide and consume liquidity primarily through high-frequency and algorithmic trading and typically trade with high speed and frequency to turn over large volumes. This heterogeneous group of players, which includes HFT firms, gains access to the FX market via prime brokers and accounts for roughly a third of total turnover in electronic FX spot markets see BIS (2019). Their share of turnover in the spot market for SEK is lower; around 18 per cent.

In recent decades, several non-bank PTFs have transformed into market-making liquidity providers that have taken over parts of the FX market that were previously exclusive to dealer banks. This subset of PTFs is sometimes referred to as *non-bank electronic liquidity providers*, or *non-bank electronic market-makers.* While banks rely on large balance sheets and client relationships that can generate volumes of flows that may be matched with one another, the non-bank PTFs instead use their speed and technological advantage to intermediate in the markets.

Another reason for dealers' declining share of turnover is that major dealing banks net more trades internally. Typically, dealers would quickly, or even immediately, try to match the opposite side of a client's trade within the interbank market. This is sometimes referred to as "hot-potato trading" or *externalisation*, see Butz and Oomen (2019).[24] On the opposite, *internalisation* refers to the process of warehousing one client's transaction flow until it is offset against an opposing client's flow. Through internalisation, dealers are able to match more client trades directly on their own books, which reduces the need to offload and hedge risk via the traditional interbank

[24] Dealers engage in hot-potato trading when offloading their exposure to open positions onto the interbank market (King et al. 2012).

market, see Schrimpf and Sushko (2019a). With more trades managed internally, hot-potato trading, and thereby also interbank trading, becomes less necessary.

Internalisation ratios are highest within the spot market and have increased along with electronic execution (see Moore et al. 2016 and Schrimpf and Sushko 2019b). Similarly, the use of algorithms has been shown to reinforce the growing trend towards internalisation among dealer banks, see Markets Committee (2020). Internalisation has also coincided with an increase in market concentration: the average number of banks covering 75 per cent of total FX turnover has about halved since first measured in 1989, to a count of 7 in 2019, see Schrimpf and Sushko (2019b).[25] Arguably, internalisation and high market concentration are mutually reinforcing. Dealer banks with large and diverse trading flows can internalise trades more efficiently, allowing them to offer competitive prices and attract even more client flows. Butz and Oomen (2018) show that internalisation is both quicker and less risky among large dealers, who benefit from their size and the possibility of reducing costs doing so. This is in line with the finding that internalisation ratios tend to be higher for large trading centres, as this is typically where the largest dealer banks are located, see Schrimpf and Sushko (2019b).

In addition, the Global Financial Crisis of 2007-2009 brought on a rapid decline in dealer banks' *proprietary trading* (trading for direct market gain, contrary to earning commission on client trades). Increased regulatory scrutiny and greater risk-aversion were important drivers of this development, see King et al. (2011). Banks' balance sheets have become more constrained and costly to deploy in the aftermath of the crisis, which has resulted in a notable reduction in risk appetite and principal risk warehousing, see Debelle (2018).[26]

Nonetheless, the major international banks still constitute an important part of the market as liquidity providers, but are now accompanied by other types of financial institutions that intermediate in the market. This development has dissolved the clearly delineated market structure of the 1980s, and there are no longer two well-defined market tiers with just as well-defined roles of its participants. The distinction between liquidity provider and liquidity consumer is also becoming less clear, both because trading can occur without intermediation and because new types of participants have entered the market.[27]

The BIS Triennial Surveys also illustrate how consumers of liquidity have evolved during the last few decades. Today, FX trading volumes mostly reflect financial motives, as opposed to needs arising directly from real economic activity. As noted earlier, FX trading volumes continue to be dominated mostly by financial institutions, with the share of non-dealer financial institutions growing from below 12 per cent in 1992 to nearly 55 per cent of all trading in 2019. Non-dealer financial institutions

[25] Although interdealer trading, that is, trading with dealer banks as both counterparts, has declined, banks remain one of the counterparts in most FX trading.

[26] Providing algorithms has thus become a tool for banks to transfer the risk bearing onto the end client, as algorithms rely less on liquidity providers' capacity to absorb risk (BIS 2020).

[27] Clients wishing to trade FX no longer *require* a dealer to do so. Today, while clients may access liquidity with various degrees of intermediation: from client-to-client in disclosed or anonymous liquidity pools all the way to the more traditional alternative of using a dealer and a broker.

include market participants such as smaller banks, pension and investment funds, hedge funds and PTFs.

3.3.2 Reporting requirements and regulation

Despite its size and importance, the FX market is subject to relatively little regulation and reporting requirements. There is no central regulatory body, instead, local jurisdictions are set up across the globe. Two influential legislations are the Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act) in the US and the MiFID II legislation in the EU.[28] Neither of these applies to the FX spot market.[29]

The Dodd-Frank Act was written in the aftermath of the 2008-2009 financial crisis to reduce risk, increase transparency and provide accountability for market participants. Enacted in July 2010, it is a widely encompassing federal law that applies to US-based financial companies. The Dodd-Frank Act applies to all FX derivatives, although some instruments are mainly subject to reporting requirement. All FX derivatives except FX swaps and outright forwards, are subject to certain mandatory derivatives requirements, including central clearing and exchange trading.

The MiFID II regulation, adopted in January 2018, applies to all financial participants across the EU, including fund managers, banks, exchange trading venues, pension funds and retail investors. MiFID II aims to make markets safer, fairer and more efficient. For instance, the MiFID II legislation requires reporting and record-keeping on transactions of all financial instruments in the EU. It does not apply to the spot market, which is not considered to be a financial instrument according to the European Securities and Markets Authority (ESMA), but to all of the other major FX instruments including forwards and swaps. Firms need to take “all sufficient steps” to obtain the best possible results for their clients when executing orders, referred to as *best execution*. The adaptation of the MiFID II regulation has led to firms taking a more systematic approach to monitoring their trades, increasing the demand for so-called *transaction cost analysis* (TCA). While it is not legally mandatory for the spot FX market, demand for such analysis has increased there, too.

Instead of formal legislation, the FX market has largely been governed by informal rules and codes of conduct, often regional. Following a number of high profile FX misconduct cases in 2013 and 2014, the BIS Markets Committee was commissioned to develop a single, global code of conduct for the wholesale FX market to restore trust and confidence in the market. The Global Code of Conduct was developed through a partnership of central banks and private sector market participants under the auspices of the BIS Markets Committee, and the first complete version was launched in 2017. The code is maintained by the Global FX Committee (GFXC), established in 2017. The GFXC is a forum of central banks and private sector participants that aim to promote a robust, liquid, open and appropriately transparent FX market. The code does not impose any legal or regulatory obligations on market participants, rather it is

[28] The UK implemented the UK MiFID II in December 2020, which essentially mirrors the EU MiFID II framework.

intended to serve as a supplement to any and all local law, rules and regulations by identifying global good practises and processes. Sveriges Riksbank is a member of the GFXC and its local Scandinavian committee, the Scandinavian FX Committee (SFXC), and signed the Terms of Commitment in 2017.

4 A fragmented, fast-paced and electronic FX market

With electronification, barriers to entering the FX market have been lowered and transparency has increased. New players have entered the market, both as providers and consumers of liquidity. Technological advances have made comparable and tradeable prices easily available and updated with high frequency, reduced operational risks and lowered trading costs. Sophisticated tools of trading have become available to an increasingly large and heterogeneous group of FX traders. But as always, development brings new challenges. The FX market is complex, fast-paced and highly fragmented, which has implications for market monitoring and analysis, market efficiency and market conditions.

4.1 Information flows and market monitoring

As a consequence of trading taking place simultaneously on a bilateral basis and at many different trading venues, there is no unique market exchange rate at any given point in time. Rather, the same currency can simultaneously be traded at different exchange rates at different trading venues. The lack of common reference points makes it costly and difficult to obtain a representative overview of the market as a whole, and complicates comparison between venues and providers. The electronic information systems of the primary market venues, EBS and Refinitiv (previously Reuters), are often used by practitioners and researchers as representative references for volume and price data.[30] However, while they remain important sources of information, their market share has dwindled in recent years, and many alternative trading venues and liquidity pools have emerged and taken over market shares, see Schrimpf and Sushko (2019a).[31]

Moreover, the electronification of FX trading results in enormous amounts of data and information being produced and collected. A widespread commoditisation of such data has led to an increased availability via different technological solutions, but this typically entails high costs, advanced quantitative analysis skills and large storage requirements. For those with access, it allows for analysis of order flows, positioning, technical levels, liquidity conditions and trading patterns – information previously exclusive to the interbank dealers. However, the fragmentation of the market causes this information to be dispersed over a large number of trading venues. In this sense, somewhat paradoxically, electronification has increased the amount of information available but made market monitoring and surveillance more difficult. The structure of the FX market, combined with minimal regulation and reporting requirements,

[30] The FX trading unit of Thomson Reuters was renamed Refinitiv in 2018.

[31] Liquidity pools are centralised trading volumes created by orders executed on an exchange or other trading venue.

results in there being no consolidated record of the turnover at any given point in time.

Many central banks, including Sveriges Riksbank, track turnover in their respective FX markets, but relatively few central banks publish this information regularly. In addition, the international nature of the FX market ultimately complicates compilation and consolidation of statistical data. For instance, the data collected by Sveriges Riksbank are reported by the major Swedish banks. Trading of SEK between other market participants, including reporting dealers domiciled abroad, will not be registered in the Riksbank's statistics. This means that trading between non-Swedish dealers and non-bank participants is not captured by the Riksbank statistics, although provided that at least one of two counterparts in a trade report to any of the other central banks participating in the BIS survey, such trading will be captured by the BIS statistics.

Furthermore, the structural changes to the FX market during the last four decades have had an impact on the price discovery process. Fundamentally, the idea is that trading is an integral part of the price discovery process through which information relevant to exchange rate determination becomes embedded in the market price. Information flows, a concept frequently explored in the research fields of market microstructure and order flow analysis, are at the core of the price discovery process (see for example Bacchetta and van Wincoop 2006, Breedon and Vitale 2010). Essentially, informed agents have information about the currency's fundamental value, and this information becomes embedded in the price when the trade is executed.

Early research on information flows focused on consumers of FX liquidity as the most informed, as they would have information on trading flows of foreign and domestic assets, but several empirical studies contradict this (see for example Bjønnes et al. 2005, Evans and Lyons 2006, Nolte and Nolte 2014, Osler and Vandrovych 2009, King et al. 2010, Bjønnes et al. 2014). More recent research instead points to FX market dealers as the most informed participants (see for example Evans and Lyon 2002, Moore and Payne 2011, Chaboud et al. 2020). Information appears to become embedded in the market price through at least three steps. First, end clients reveal their information to dealers by trading. Second, the information becomes embedded in interbank prices, and third, information is dispersed into the general market as dealer-to-client quotes are adjusted to reflect interbank prices, see King et al. (2011).

Dealers' information advantage as central counterparts with large electronic networks of client relationships, their analytical muscles and their ability to quickly act upon new information suggest that dealers are the most well-informed FX market participants. In line with this, market monitors have generally turned to the banks and to the primary electronic venues for information on exchange rate developments. At the same time, even though some of the major dealer-banks have managed to retain some of their information advantage via their own trading platforms, several of the largest trading venues of today belong to non-banks. Trading on primary venues has fallen markedly. As a result, part of these information flows has migrated from the interbank market to external networks.

These structural changes have had implications not only for the monitoring and surveillance of FX trading, but potentially also for the price discovery process itself. As long as central banks and other monitoring agents rely on banks and primary venues as their main source of information, they might overlook information important to exchange rate determination, because banks might not be informed, or because the price discovery process is increasingly taking place outside of the banks' sphere. Central banks have therefore had to diversify their FX monitoring from the usual electronic brokerage screens and voice contact with dealers to monitoring more electronic platforms and obtaining information about market conditions from a broader range of market actors (for a detailed report on how monitoring of the FX market has evolved over time, see Markets Committee 2018).

4.2 Technological advance, market conditions and market efficiency

The use of ever-more advanced financial technology is steadily increasing in a pursuit of more efficient and faster trading. Technological advances and an increase in both the number and variety of participants active in the market have forced the traditional players of the FX market to charge more competitive prices in order to maintain their market shares. To exemplify, the spread between bid and ask prices has in general narrowed as the market has become increasingly electronic, see Rime and Schrimpf (2013). Ding and Hiltrop (2010) demonstrated that the introduction of electronic trading systems narrowed both the immediate and long-term bid-ask spreads. This finding is in line with early studies on the topic, such as Pagano and Roell (1996) and Flood et al. (1999), who suggested that electronic systems should lead to narrower spreads due to lower operation costs, inventory risk and the costs of attaining information. With comparable and tradeable prices easily accessible and updated with high frequency the price discovery process has become less opaque, especially to end clients and even non-active participants. In a more recent study, Geromichalos and Jung (2018) suggested that the introduction of dealer-to-client platforms led to lower spreads by lowering the bargaining power of dealers.

However, quite interestingly, Ding and Hiltrop (2010) also showed that large dealers tended to quote relatively wider spreads on multibank platforms. This, they argued, was indicating that these dealers were compensating for the loss of the information advantage they used to possess in the more opaque market prior to the introduction of electronic trading venues. On the other hand, their research focused on the primary venues, Reuters and EBS, while data indicate that dealers are shifting away from these, see Schrimpf and Sushko (2019a). Instead, dealers are turning to single-bank platforms and direct price streams, a development that is driven principally by the growing trend of internalising trades. The largest dealer banks are reporting internalisation ratios as high as 90 per cent, see Moore et al. (2016).

While internalisation may be beneficial for both dealers and end clients, it is also associated with lower visibility (known as *hidden liquidity*). On the positive side, internalisation may benefit dealers by reducing intermediation costs, while end clients may benefit from a reduction in information leakage and consequently market impact (see for example Butz and Oomen 2019 and Markets Committee 2020). On the negative side, internalisation shifts trading volumes from more transparent venues (so

called *lit* venues) to more opaque internal liquidity pools. Hence, for the same reason that electronic brokerages have had a positive impact on the transparency of price formation, internalisation has the potential of obscuring it.

The growing use of algorithmic execution has been shown to improve overall market functioning by increasing the efficiency of the matching process between liquidity providers and liquidity consumers (see for example Rime and Schrimpf 2013 and Chaboud et al. 2020). Assessing liquidity in a fragmented market is challenging, but with more counterparties connected to each other, search costs have decreased and the velocity of trading has increased, see Rime and Schrimpf (2013).[32] Moreover, studies indicate that algorithmic trading has had a positive impact on *price informativeness* in the FX market (see for example Biais et al. 2015, Roşu 2019 and Chaboud et al. 2014).[33] Simply put, computers are better at finding and exploiting arbitrage opportunities. The increasing use of algorithmic trading has therefore led to a more efficient market by speeding up the price discovery process, thereby improving informational efficiency. Chaboud et al. (2020) find that the price discovery process has become faster during the last decade, consistent with improvements in market efficiency during the same period, potentially a result of the increase in algorithmic trading participation.

Nevertheless, algorithms, machines and the ever-increasing speed of the FX market give rise to new challenges and risks. For instance, algorithms may amplify and intensify market movements, causing disorderly price movements even in the most traded and liquid instruments.

Flash events are perhaps the most dramatic examples of this, with the flash rally of the Japanese yen in January 2019 being one of the most recent.[34] Flash events are unforeseen, abrupt and volatile movements in prices within a very short period of time (typically seconds). Flash events to date have generally proved short-lived and without immediate consequences for financial stability. But even though they may happen rarely, they are important tests of the market's resilience to stress. If reoccurring and with lasting impact on financial market pricing, such events have the

[32] King et al. (2012) suggest that trading, and in extension exchange rates, should be modelled as a search problem. Constraints and costs that are related to this search are in turn affected by the structure of the market.

[33] The term price informativeness is used to describe the ability of the price of an asset to convey all information that is available to all traders at any given time.

[34] On January 3rd 2019, the Japanese yen appreciated sharply during the early Asian trading hours, most notably against the Turkish lira and the Australian and US dollars. Liquidity is generally scarce during these hours, which was further exacerbated by a public holiday in Japan. Previous to the event, Japanese retail investors had been building up currency positions in high-interest yielding currencies, speculating that the Japanese yen would not strengthen above a certain level. After news reports of Apple's profit warning on January 2nd, the yen started appreciating sharply – but orderly – triggering so called *loss-cuts*. Loss-cuts are part of a regulation put on all FX firms in Japan that will be executed if a client's margin deposits falls below a required amount and the client does not deposit the required amount by the deadline (issued in a so-called *margin call*). In this particular case, the appreciation of the yen caused large-enough losses to the retail investors' positions, which were then automatically closed, causing the yen to appreciate even more as the high-yielding currency was sold off and yen bought back. Consequently, more positions had to be closed. In just 5 seconds, the yen appreciated approximately 4 per cent against the US dollar (and approximately 9 and 7 per cent against the Turkish lira and the Australian dollar), before retracing over half of the move within a few seconds. For more details, see Reserve Bank of Australia (2019).

potential to undermine confidence in financial markets and hence impact the real economy. When currencies swing very sharply, a certain depth of liquidity is needed to absorb those moves and allow firms to unwind positions. Hence, it is important to continue to develop a deeper understanding of modern market structure and its associated vulnerabilities, see Markets Committee (2017). Nonetheless, initial observations from the COVID-19 pandemic suggest that the risk of algorithmic execution giving rise to self-reinforcing loops, exacerbating sharp movement in prices, may not be as acute as previously believed, see Markets Committee (2020).

The fragmentation and speed of the market also implicate a risk of *liquidity mirage*: a phenomenon that arises due to the combination of highly fragmented and interconnected market venues and liquidity providers. Typically, several trading venues show the same liquidity providers' interest to trade simultaneously, which in aggregation creates an illusion of deep market liquidity. Combined with high speed, there is a risk that the liquidity suddenly vanishes when an order is executed at the quoted price, as the transacted amount is then withdrawn from several platforms at once. In this new electronic context, the market dynamics of a multitude of liquidity venues need to be taken into consideration.

In addition, trend-driven trading, also known as momentum trading, may exacerbate otherwise small movements. These strategies are typically built on algorithmic programs that identify trends in exchange rates and trade in that direction. Anecdotal evidence from market participants indicate that in periods of low liquidity and in absence of human traders, these trend-driven trades gain momentum as they move markets in their traded direction (see for example Engel 2014).

4.3 Liquidity in the FX market

In general, market liquidity makes transactions smoother and more cost-effective, rendering liquid assets more attractive to investors. Liquid markets improve allocation and information efficiency, allowing for more efficient risk-sharing and thereby permitting financial institutions to accept larger asset-liability mismatches. As such, market liquidity is essential for a well-functioning market, and a sudden disappearance of liquidity from markets may develop into a systemic crisis. For instance, a decline in FX liquidity affects funding costs, impairs hedging strategies and increases rollover risks due to the common practice of using the FX swap market for short-term funding, see Mancini et al. (2013).[35]

Liquidity is a prerequisite for an efficient market that eliminates opportunities for arbitrage, see Shleifer and Vishny (1997). As a result, varying liquidity conditions likely disrupt FX market efficiency and alter exchange rate dynamics. The nature and development of the FX market, which has resulted in limited transparency, a high degree of fragmentation and heterogeneity of agents, have important implications for

[35] Brunnermeier and Pedersen (2009) distinguish between an asset's market liquidity (that is, the ease with which it is traded) and traders' funding liquidity (that is, the ease with which they can obtain funding). This article focuses mainly on what Brunnermeier and Pedersen term market liquidity; costs of trade execution and the ability to trade large volumes without sizeable market impact. Nonetheless, these concepts of liquidity are profoundly linked. Under certain conditions, the two are mutually reinforcing and may lead to liquidity spirals.

both price and liquidity patterns. Several studies suggest that foreign exchange rates contain liquidity premia and that there are noticeable differences in the level of systematic liquidity across currency pairs and time (see for example Engel 1992, Christiansen at al. 2011 and Banti et al. 2012). Furthermore, liquid markets also generally contribute to a more stable and efficient monetary transmission process through the financial system, see Sarr and Lybek (2002). Understanding FX market liquidity and market conditions therefore is important, not only from a financial stability perspective but also for the transmission of monetary policy. Even so, there is no consensus on why and how liquidity in the FX market materialises, not even on what constitutes liquidity, see Karnaukh et al. (2015).

4.3.1 Measuring FX market liquidity

Both theoretically and in practice, market liquidity is a multifaceted concept. A widely recognised definition of market liquidity is the ability to rapidly trade large volumes of a financial instrument at low or no transaction cost without the transaction noticeably and adversely affecting the market price of the instrument, see IMF (2015). In the FX market, this translates into the ability to rapidly trade large volumes of a currency against another at low cost without having a large impact on the effective exchange rate. Kyle (1985) summarised the characteristics of liquid markets as tight, deep and resilient.

There is no universally accepted unequivocal measure of FX market liquidity that captures all of these dimensions, and it is not obvious that each of these characteristics of liquidity remain the same over time. For example, volume-based measures such as the turnover rate may be used as a proxy for market liquidity as more active markets also tend to be more liquid. But while the FX market generally is perceived to be extremely liquid given its massive daily turnover volumes, an increase in turnover may not always be associated with increasing liquidity conditions. As documented in Melvin and Taylor (2009), FX trading activity rose sharply during the financial crisis, which they attribute to the so called “hot-potato trading” rather than an actual increase in liquidity.

Certainly, the turmoil during the onset of the COVID-19 pandemic in spring 2020 was also characterised by large increases in volumes and quite poor liquidity (see for instance Dobrev and Meldrum 2020 and CLS 2020). For example, the NOK, which was heavily affected by the turbulence in financial markets, experienced large but one-sided flows (selling of NOK against foreign currencies) and severely deteriorating liquidity conditions in March 2020, see Alstadheim et al. (2021). Naturally, a volume-based measure such as turnover would provide a false reflection of the actual liquidity situation.

Furthermore, the FX market lack both a consolidated measure of turnover (at least one that is updated more frequently than that of the BIS Triennial Survey) and a proper denominator; there is no measureable stock of foreign exchange or outstanding number of instruments to be turned over.[36] Instead, bid-ask spreads may

[36] However, Sarr and Lybek (2002) suggest that the sum of exports, imports and capital transactions or the level of central bank reserves, potentially including short-term net foreign assets of the banking system,

be better suited as a proxy for market liquidity. Indeed, most liquidity measures for the FX market focuses on bid-ask spreads and exchange rate volatility, see Sarr and Lybek (2002).

Bid-ask spreads provide a simple and easily available measure of liquidity. However, although many of the trading venues provide tradable bid-ask prices, trades are not always executed at the posted bid and ask quotes – some trading is hidden, some is bilateral and once again, dispersed over venues and alternative trading methods, see Mancini (2013).

Electronic brokerages generally also have live and recorded data of order books at any given point of time, which may be used to calculate the *order book depth*; a metric based on the quantity available at any given price level. A thin order book may result in quickly changing prices, while deep order books means more liquidity is available at prices at or close to the top prices in the book. This metric may be useful as a real-time indicator of liquidity conditions or for event studies or short-run analysis of liquidity conditions. For example, microdata from brokerages on order depth were used to analyse the British pound (sterling) flash event in 2016 (see for example Noss et al. 2017 and BIS 2017).

Another measure of liquidity is *price impact on execution*, also called *slippage*. It is defined as the difference between the expected market price when requesting to trade and the actual price that the trade is executed at. The higher the price impact, the more the exchange rate moves following a trade, reflecting lower liquidity. While relatively simple to calculate for any specific transaction post-trade, this metric requires vast amounts of data on millisecond frequency, including the identified direction of single transactions, to use as a systematic measure of liquidity conditions.

Finally, to capture the cost aspect of liquidity, another frequently used measure is the *effective cost* of transactions. Similar to slippage, measuring the effective costs is an attempt to capture the actual trading cost and compare it with the price quoted at the point of execution. As such, the measure can be used as a benchmark measure of (the inverse of) liquidity. Examples are found in Mancini et al. (2013) as well as Karnaukh et al. (2015).

4.3.2 A liquidity index for the Swedish krona

Liquidity is thus a complex and multifaceted concept and no single measure is able to capture all aspects of liquidity. Several measures require vast amounts of detailed and precise high-frequency data, which restricts the analysis to a few of the major currencies and a limited time period historically. In addition, such data are typically expensive and the data handling and filtering techniques necessary are time consuming and cumbersome. Moreover, while the research on FX market liquidity is indeed evolving, it tends to focus heavily on the major currencies: the euro, the US dollar, the British pound and to lesser extent the Japanese yen and the Swiss franc.

could be used as potential proxies for the outstanding value of FX. As for turnover, transaction data from any of the larger trading venues or settlement institutions could be used as a proxy.

In an attempt to capture systematic liquidity specifically in terms of the SEK, I construct a Krona liquidity index. The index is based on Karnaukh et al. (2015), who offer a method to accurately measure systematic market liquidity using daily and readily available data. Evaluating several low-frequency measures against a high-frequency benchmark capturing the effective cost of transactions, they demonstrate that a low-frequency index based on bid-ask spreads and the Corwin-Schultz (2012) method accurately captures how liquidity changes over time.[37] The Corwin-Schultz estimates combine high and low values over one day with high and low values over two days, assuming that daily high prices are buyer-initiated trades and daily low prices are seller-initiated trades. The ratio of high-to-low prices for a day therefore reflects both the fundamental volatility of the currency pair and its bid-ask spread.

The Krona liquidity index is based on daily prices of bilateral exchange rates of 21 currencies quoted against the SEK.[38] Data are retrieved from Bloomberg, spanning 2001-2021.[39] Bid-ask spreads are relative, computed by averaging the daily bid-ask estimates over time. Corwin-Schultz estimates are calculated using daily high bid prices and daily low ask prices adjusted for overnight returns, see the appendix for more details. The index is constructed by first calculating monthly averages of the relative bid-ask spreads across all daily bid-ask estimates for each individual currency pair. Second, monthly averages across all positive two-day Corwin-Schulz estimates are computed, also for each individual currency pair. Third, all series are standardised by subtracting the mean and dividing it by the standard deviation. Fourth, the two measures are combined by taking a simple average across them for each individual currency pair. The last step is to form an average across all currency pairs. A global liquidity index based on the same 30 currency pairs as Karnaukh et al. (2015) is computed for comparison (see Figure 9).[40]

[37] Karnaukh et al. (2015) use precise intraday data to calculate a high-frequency benchmark measure for evaluating the accuracy of their low-frequency measure. The high-frequency measure is constructed from tradable best bid and ask quotes, transaction prices and volume indicators where the direction of trades is known. Using these, they compute the midpoint of best bid and ask quotes and log return based on the transaction price of deals, which capture the effective cost measure described in section 4.3.1. They conclude that a low-frequency measure based on bid-ask spreads and the Corwin-Schultz model (2012) offer the highest correlation with the high-frequency measure. Their results are robust to several high-frequency measures.

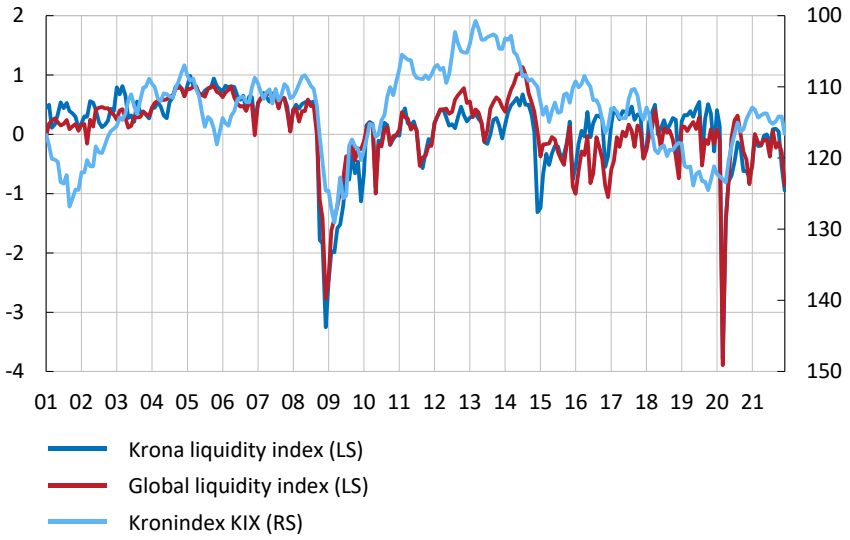
[38] The currencies used are those that are part of KIX ("Kronindex"). KIX is a currency index for the Swedish krona based on currencies from the OECD countries, China, India, Brazil and Russia. The index consists of 32 countries and 21 currencies. For more information on KIX, see Alsterlind (2006).

[39] For some currency pairs, data availability starts already in January 1991. However, due to poor coverage in many other currency pairs, I have chosen to restrict the sample to a period with higher coverage in pricing data in both the SEK currency pairs and the pairs included in the global index.

[40] Currency pairs are listed in the Appendix.

Figure 9. Systematic FX liquidity indices and Kronindex (KIX)

Standard deviation (left) and index units (inverted, right)



Note: Liquidity indices (left hand scale) capture systematic liquidity conditions in a set of currency pairs across time (currency pairs listed in the appendix). Negative values indicate worse liquidity conditions relative to a historical average, and vice versa for positive values. The KIX ("Kronindex") index (right-hand scale) is inverted so that downwards movements illustrate a depreciation of the krona, and vice versa for upwards movements.

Source: Sveriges Riksbank and Bloomberg. Author's own calculations.

Quite interestingly, there is no clear indication of systematic improvements in liquidity conditions across this time period in any of the indices. Given the decrease in bid-ask spreads documented in for example Ding and Hiltrop (2010), this may seem somewhat surprising. Improvements in transparency and efficiency suggest that liquidity should as well have improved systematically during these few decades. On the other hand, Ding and Hiltrop's findings indicate that it was the introduction of electronic trading that significantly caused bid-ask spreads to decrease, which would suggest that the major improvement in liquidity took place during an earlier stage in time than is covered by this sample. In contrast, the 2000s have been characterised by increasing fragmentation and complexity. In addition, Ding and Hiltrop's finding that large dealers actually even quoted larger spreads on multibank platforms may also be part of the explanation of why systematic liquidity seems to be fairly stable in this sample, given that Bloomberg is such as venue.[41]

Both indices show a clear pattern of deteriorating liquidity conditions around periods of financial distress, with the 2008-2009 financial crisis and the COVID-19 pandemic crisis in 2020 by far being the most severe. The European debt crisis that escalated throughout the early 2010s is also associated with negative spikes in liquidity conditions. The link between financial turmoil and deteriorating FX liquidity conditions is related to several different factors. Karnaukh et al. (2015) provide empirical support

[41] In addition, Rime and Schrimpf (2013) showed that the trend towards more narrow bid-ask spreads between 2004 and 2013 was driven solely by emerging markets' currencies; currency pairs of advanced economies were approximately unchanged during the period. The currency sample therefore also affects the dynamics of the liquidity indices across time.

that FX liquidity systematically worsens with more severe funding constraints and global risk. Sudden drops in liquidity have been key in several currency crashes: when liquidity is low, traders become reluctant to take on positions, which in turn contribute to lower liquidity, see Brunnermeier and Pedersen (2009). In addition, lower liquidity leads to higher volatility, which may exacerbate such liquidity spirals even further if it increases the risk of financing a trade, thus increasing the capital requirements of margins. Market-wide systematic liquidity also tend to deteriorate when both global stock and bond markets are more volatile and illiquid, suggesting spillovers from related markets (Mancini et al. 2013).

Moreover, the correlation between the two indices across the time sample is close to 90 per cent, indicating that liquidity conditions in the krona are strongly linked to global liquidity conditions. This is in line with previous research on commonality in liquidity across currencies, suggesting that individual currencies share drivers of liquidity. Brunnermeier and Pedersen (2009) point to shocks to funding constraints of investors as an explanation for commonality across financial markets, suggesting that financial turmoil affect funding constraints of investors across all asset classes. Research also points to general market conditions (risk aversion) and supply- and demand-side factors such as flight-to-quality dynamics, carry trades and the propensity of intermediaries to provide liquidity being such common factors (see for example Karnaukh et al. 2015, Lustig et al. 2011, Mancini et al. 2013 and Menkhoff et al. 2012).

Furthermore, quarter- and year-ends seem to be connected to sharp but short-lived drops in liquidity in both indices, especially since 2014 (see Figure 9). Part of the explanation may be related to regulatory requirements and banks' balance sheet management. In line with previous research, Krohn and Sushko (2022) find additional support of FX funding conditions being correlated with market liquidity and strong indications of co-movement in FX spot and swap market liquidity. They also show that this link has strengthened significantly since mid-2014, which coincides with the introduction of the Basel III framework for global systemically important banks (G-SIBs).[42] They demonstrate that G-SIBs tend to cut back significantly on their quoting activity around quarter- and year-ends, which causes liquidity to deteriorate. Given the strong link between the two, worsening liquidity conditions in the swap market might provide at least a partial explanation to quarter- and year-end drops in liquidity conditions in the spot market.

Given the global and interconnected nature of the FX market, tight links between liquidity conditions are unsurprising. Nonetheless, there are differences between the indices that seem to indicate that liquidity conditions are not only common across

[42] The Basel III framework was introduced in 2011, with the regulation on loss absorbency covering global systemically important banks (the G-SIB buffer) being introduced in 2014. Some regulatory requirements did not become fully binding until 2018, although banks started shifting to the Basel III reporting templates around 2014, see Krohn and Sushko (2022). While liquidity always has tended to deteriorate slightly around quarter-ends, the effect has become several times larger since 2014, when the G-SIB buffer was introduced. FX swaps are counted as more complex assets, which adds on the complexity score component of the G-SIB framework. A higher complexity score might put the bank into a higher G-SIB bucket, which means the bank will be subject to higher loss absorbency requirements via additional capital surcharges. As a result, G-SIBs have an incentive to pull out of the FX swap market around regulatory reporting periods.

currencies; some are idiosyncratic to the Swedish krona. For instance, the Krona index tends to show slightly sharper drops in liquidity during periods of high financial stress, which might imply that the currency pairs used in the Krona index are in general riskier than those in the Global index.[43] Karnaukh et al. (2015) find that such currencies are more likely to suffer larger liquidity drops when global risk, such as global stock and bond volatility, increases.

Furthermore, empirical studies document that the krona tends to depreciate in response to financial stress (see for example Bacchetta and Chikhani 2021 and Ceh 2020). Gardberg (forthcoming) finds that the krona is particularly sensitive to changes in global risk; among all G10 currencies, the krona responds the most.[44] This pattern is visible also in Figure 9, where the above mentioned episodes of elevated financial stress are associated with not only a drop in liquidity but also a weaker krona in terms of the krona currency index KIX. In addition, improvements in liquidity conditions seem to be associated with an appreciation of the krona.

As noted in Markets Committee (2017), sudden shifts in liquidity conditions may exacerbate otherwise orderly movements in exchange rates. In addition, existing research on liquidity risk premia imply that liquidity risk is priced in the FX market; investors demand compensation for holding assets that exhibit low liquidity. This suggests that monitoring the liquidity conditions of the krona might be helpful in understanding krona exchange rate movements, both in short-term and medium-term analysis. Nevertheless, further research is necessary to fully understand the dynamics and relations between liquidity conditions and how liquidity premia might impact price formation. The rapid changes and increasing complexity of the market structure further complicates the question; both depth and ability to trade are important aspects of liquidity, but in today's FX market, tradeable quotes are mixed with indicative ones, all quoted on several platforms simultaneously. With the increasing availability of comprehensive data sets, the effects of such structural aspects particular to the FX market are hopefully to become subject to further research.

In sum, a comparison of the Krona liquidity index and the Global liquidity index indicates that liquidity conditions show a high degree of commonality. Liquidity tends to deteriorate in periods of financial stress, most recently during the onset of the COVID-19 pandemic. The krona tends to be weaker during such periods of financial stress, while improvements in liquidity seem to be associated with the krona appreciating. Interestingly, however, not all movements in the Krona liquidity index can be explained by changes in global liquidity conditions, indicating that some components of liquidity conditions are idiosyncratic to the krona.

[43] Here, riskier currencies refer to currencies bearing larger exposure to systematic risk factors such as carry trade risk and volatility risk (see for example Lustig et al. 2011 and Menkhoff et al. 2012).

[44] Gardberg (forthcoming) show that currencies in countries with large private net external debt, particularly net portfolio debt and other investment liabilities, tend to depreciate during financial turbulence. She uses VIX, an option-implied index of investors' willingness to hedge themselves against large price movements in the American stock market index S&P 500, as a proxy for global risk. All currencies are quoted with USD as the base currency.

5 Conclusion

The FX market has undergone significant structural changes during the last four decades. Both trading and price formation are to an increasing degree taking place electronically and new participants, venues and strategies have emerged. The clear division between the interbank and the end-client tiers that characterised the FX market in the 1970s and 1980s has effectively been dissolved into the fragmented yet interconnected fast-paced electronic market of today. Moreover, the rapid evolution of electronic trading, particularly the use of algorithms, has increased trading efficiency and the speed of trading, but has also had an impact on market liquidity conditions, with potential risks to financial stability and the pricing mechanisms as a consequence. Furthermore, these structural changes have had considerable implications for liquidity distribution and market conditions, and market participants wanting to monitor the market have had to diversify their sources of information. Finally, this article has presented a Krona liquidity index in an attempt to capture changes to the structural liquidity conditions in the krona specifically. Commonality links are strong between global liquidity conditions and those for the krona, although some changes in liquidity appear to be specific to the krona.

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APPENDIX A – Liquidity index calculations

The data used are retrieved from Bloomberg, see field names in Table 1 and currency pairs in Table 2 and Table 3.

Table 1. Bloomberg field names

Ticker	Description
XXXYYY Curncy	Code for currency pair (i.e. EURUSD Curncy)
PR002	Bid price (closing value)
PQ690	High bid price
PQ677	Low bid price
PR004	Ask price (closing value)
PQ678	High ask price
PQ691	Low ask price

Note: As of 3 January, 2022.

Source: Bloomberg.

Table 2. Currency pairs in the Krona liquidity index

Currency pair	Description
AUDSEK	Swedish krona per Australian dollar
BRLSEK	Swedish krona per Brazilian real
DKKSEK	Swedish krona per Danish krone
EURSEK	Swedish krona per Euro
INRSEK	Swedish krona per Indian rupee
ISKSEK	Swedish krona per Icelandic krona
JPYSEK	Swedish krona per Japanese yen
CADSEK	Swedish krona per Canadian dollar
CNYSEK	Swedish krona per Chinese renminbi
MXNSEK	Swedish krona per Mexican peso
NOKSEK	Swedish krona per Norwegian krone
NZDSEK	Swedish krona per New Zealand dollar
PLNSEK	Swedish krona per Polish zloty
RUBSEK	Swedish krona per Russian rubel
CHFSEK	Swedish krona per Swiss franc
GBPSEK	Swedish krona per British pound
KRWSEK	Swedish krona per South Korean won
CZKSEK	Swedish krona per Czech koruna
TRYSEK	Swedish krona per Turkish lira
HUFSEK	Swedish krona per Hungarian forint
USDSEK	Swedish krona per US dollar

Table 3. Currency pairs in the Global liquidity index

Currency pair	Description
EURUSD	US dollar per euro
USDJPY	Japanese yen per US dollar
GBPUSD	US dollar per British pound
AUDUSD	US dollar per Australian dollar
CADUSD	US dollar per Canadian dollar
USDCHF	Swiss franc per US dollar
EURJPY	Japanese yen per Euro
EURGBP	British pound per Euro
EURCHF	Swiss franc per Euro
USDSEK	Swedish krona per US dollar
EURCAD	Canadian dollar per Euro
EURAUD	Australian dollar per Euro
GBPAUD	Australian dollar per British pound
GBPCAD	Canadian dollar per British pound
GBPCHF	Swiss franc per British pound
GBPJPY	Japanese yen per British pound
EURNOK	Norwegian krone per Euro
GBPNOK	Norwegian krone per British pound
USDNOK	Norwegian krone per US dollar
EURNZD	New Zealand dollar per Euro
GBPNZD	New Zealand dollar per British pound
NZDUSD	New Zealand dollar per US dollar
GBPSEK	Swedish krona per British pound
USDINR	Indian rupee per US dollar
USDMXN	Mexican peso per US dollar
EURSGD	Singapore dollar per Euro
GBPDGD	Singapore dollar per British pound
USDSGD	Singapore dollar per US dollar
GBPZAR	South African rand per British pound
USDZAR	South African rand per US dollar

Data are cleaned following Brownlees and Gallo (2006). Observations are removed from the sample if both bid and ask prices are zero or if the price p_{t_i} is such that:

$$\left|p_{t_i} - \bar{p}_i(\alpha, k)\right| > 3s_i(\alpha, k) + \nu$$

Where $\bar{p}_i(\alpha, k)$ and $s_i(\alpha, k)$ denote the α-trimmed sample mean and standard deviation based on k observations in the neighbourhood of t_i, respectively. ν is added on the right side of the inequality to avoid zero variance for a sequence of equal

prices and is set to equal one pip (that is, 0.0001). α is set to 5 percent and k is set to 100.

Bid-ask spread estimates BA_t are calculated according to:

$$BA_t = (ask_t - bid_t) \div \frac{(ask_t + bid_t)}{2}.$$

To calculate the Corwin-Schultz estimates, data are first corrected for overnight returns. If the low value at day $t+1$ is higher than the closing value at day t, both the high and the low values for day $t+1$ are decreased by the amount of the overnight spread. If the high value at day $t+1$ is lower than the closing value at day t, both the high and the low values for day $t+1$ are increased by the amount of the overnight spread.

Corwin-Schultz estimates are thereafter calculated according to:

$$CS_t = \frac{2(e^{\alpha} - 1)}{1 + e^{\alpha}} \approx \alpha$$

for small values of $\alpha \in [-0.25, 0.25]$, where

$$\alpha = \left(1 + \sqrt{2}\right)\left(\sqrt{\beta} - \sqrt{\gamma}\right),$$

$$\beta = \left[ln\left(\frac{H_t}{L_t}\right)\right]^2 + \left[ln\left(\frac{H_{t+1}}{L_t+1}\right)\right]^2 \text{ and } \gamma = \left[ln\left(\frac{H_{t,t+1}}{L_t,t+1}\right)\right]^2,$$

where H_t and L_t denote the observed high and low prices on day t (also for day $t+1$), while $H_{t,t+1}$ and $L_{t,t+1}$ are the high and low over two days (t to $t+1$).

All negative two-day spreads are excluded.

Monthly averages are calculated as simple averages for both estimates.

Both series of estimates are standardised (individually) by subtracting the mean and dividing by the standard deviation. The two standardised series are then combined by taking the simple average across them.

Finally, the index is computed by taking the simple average of the liquidity measure across all currency pairs and taking the negative of the series so that negative values indicate worse conditions and positive values indicate better conditions than the historical average.