The Perfect Storm: Forex Interventions, Global Banks' Limited Risk-Bearing Capacity, Deviations from Covered Interest Parity, and the Impact on the USD/ILS Options Market[1]

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Abstract

Using confidential daily foreign exchange interventions (FXI) data, we analyze the intervention episode of the Bank of Israel (BOI) from 2013 to 2019. We find that a purchase of 1 billion US dollars (USD) is associated with a depreciation of the New Israeli Shekel (ILS) by 0.82%, which is at the upper bound of the estimated impact in other studies. We show that this effectiveness can partially be explained by the limited risk-taking capacity of global banks. The (indirect) effect on the forward rate is smaller – the BOI's USD purchases have persistently widened the negative deviation from covered interest parity. Contrary to the findings in earlier studies, the higher-order moments of the risk-neutral probability distribution of future spot exchange rates are also affected. The USD purchases shift the whole distribution towards higher USD/ILS values while reducing crash risk. We also find that the USD/ILS options market partially anticipates intervention episodes and prices them in before they occur.

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1 Introduction

The unprecedented financial turbulence brought by the Great Financial Crisis (GFC) has changed the global monetary policy landscape. On the edge of a significant economic downturn, central banks across the globe slashed their key policy rates to near-zero levels, launching an era of persistently low interest rates. These actions forced central banks to adopt alternative monetary policy tools. One important tool, the focus of this paper, is intervention in the spot foreign exchange (FX) market.[1]

To explore this topic, we use the case of Israel as our empirical laboratory. The Bank of Israel (BOI) resumed its intervention activity in the spot FX market in March 2008, following an 11-year hiatus, and amassed 89.2 billion USD in FX reserves by the end of 2019. Characterized by frequent and fully sterilized[2] USD purchases, these FX interventions (FXI) offer a rich dataset for our investigation.

We take a fresh look and present a comprehensive approach to analyzing the effects of FXI which distinguishes us from previous research. As we will demonstrate, the impact of FXIs extends beyond just the spot market, creating a complex and multifaceted effect - a 'perfect storm'. However, we also offer a novel viewpoint on conditions under which sterilized FXI are highly effective in the spot market. Our discussion extends to the impact of monetary policy action on FX forwards and FX options and further expands to evaluate how FXI affect crash risk implied by the FX options market. This expansion is motivated by the pioneering work of Farhi and Gabaix (2016) who propose a rare disaster model of FX rates that links the price of insurance against a currency's crash risk to its spot rate.

Despite an abundance of research on the effectiveness of FXI in the spot market, their impact on market expectations, particularly in the derivatives markets, remains a largely unexplored territory. This gap can be ascribed to the early-stage evolution of FX derivatives markets, which are often characterized by low informational efficiency and low liquidity. However, the advent of electronic trading networks has spurred

[1] See Borio and Disyatat (2010), Domanski, Kohlscheen, and Moreno (2016) and Adrian, Erceg, Kolasa, Lindé, and Zabczyk (2021).

[2] Interventions are followed by open market operations that offset their impact on domestic money supply.

a radical transformation, fueling rapid growth in the global FX derivatives market,[3] making this market highly efficient and liquid.

In view of the importance of the FX derivatives market within the financial system, we argue that a more comprehensive understanding of how these markets interact with FXI in the spot market is essential for central banks implementing FXI strategies. For example, the presence of non-zero trading costs hampers the ability to dynamically replicate option contracts in practice (Tian and Wu, 2023). This means that when central banks analyze option markets, they can gain information that goes beyond what is already embedded in spot rates. We specifically aim to shed light on how sterilized FXI in the spot market influence expectations within the derivatives market, and its potential to exacerbate frictions in forward markets, thereby providing a practical toolkit for policymakers.

Our laboratory naturally raises the question, to what extent are our empirical findings externally valid? To anticipate a key insight of our paper, we find that our results are all consistent with the predictions of a model proposed by Amador, Bianchi, Bocola, and Perri (2020) where a central bank in a small open economy is able to implement a FXI regime in the spot market when the zero lower bound (ZLB) binds. This implies that our paper should be relevant for central banks in other small open economies confronted with a low interest environment.

This paper focuses on the FXI regime from 2013 to 2019, characterized by secret and fully sterilized USD purchases in the USD/ILS spot market. Our sample period, ending on December 31, 2019, was marked by historically low interest rates. We utilize a unique database containing confidential daily records of interventions provided by the BOI to analyze the multi-faceted effects of FXI.

Summary of Main results. We find that an FXI amounting to 1 billion USD[4] is on average associated with a significant 0.83% (0.82%) depreciation of the ILS vis-à-vis

[3] See e.g., King, Osler, and Rime (2012), King, Osler, and Rime (2013), Von Spreckelsen, Von Mettenheim, and Breitner (2014) and the "2022 Triennial Survey of turnover in OTC FX markets" (Bank for International Settlements, 2022) that documents that the daily turnover of FX options and outright forwards has increased by 648% and 1101% since 1995, compared to an increase of 326% for the spot FX market.

[4] Throughout the paper, we assess the effect of FXI by using 1 billion USD as the size of USD purchases. This amount is standard in the FXI literature and is unrelated to the BOI's actual FXI activity.

the USD (nominal effective exchange rate (NEER)) compared to a trading day without FXI, which is large by both historical and international standards. We identify the existence of financial frictions in the form of capital-constrained global banks as a key determinant of the effectiveness of these FXI.

We also find that the deviation from covered interest rate parity (CIP) – usually referred to as the cross-currency basis (CCB) – becomes significantly more negative on intervention days, as the USD/ILS forward rate increases by less than the spot rate. This result is one of the key predictions of the aforementioned Amador et al. (2020) model. We show that on impact, a 1 billion FXI widens the CIP deviation by 13 basis points and that the initial effect persists for at least 90 days.

Looking at the options market, we find that a higher USD/ILS risk reversal (RR), reflecting a more pronounced tilt towards a weaker ILS over the lifetime of this option strategy, is associated with higher future FXI. This finding suggests that the options market partially prices in future intervention episodes before they occur. We also find that the higher-order moments of the RND (e.g., the at-the-money implied volatility (ATMV), skewness and kurtosis) change significantly on FXI days, tilting option market expectations towards less volatile (lower ATMV) and less extreme spot rates (lower kurtosis) in the future, while accounting for the possibility of a large ILS depreciation (higher skewness) due to future FXI.

Focusing on tail probabilities, we find that FXI reduce crash risk, which is consistent with the just-mentioned lower kurtosis. Specifically, we find that the ILS appreciation pressure is significantly reduced on days the BOI intervenes in the spot market.

Related literature and our contributions. (i) Contrary to our findings, the few studies that have analyzed how FXI in the spot market affect market expectations about the future foreign value of a currency and its risk characteristics as reflected in the options market[5] document only a weak effect. We contribute to the FXI literature by adding a new empirical study that takes advantage of the matured options markets. As an extension to the existing literature, we do not limit ourselves to analyzing options with a specific maturity, but explore options with maturities ranging up to twelve months.

[5]See e.g. Bonser-Neal and Tanner (1996), Castrén (2004), Fratzscher (2005), Galati, Melick, and Micu (2005), Galati, Higgins, Humpage, and Melick (2007), Disyatat and Galati (2007), Morel and Teïletche (2008), Marins, Araujo, and Vicente (2017).

This extension is relevant for monetary policymakers, as they learn about the longer-term effect that FXI have on market expectations in the options market and therefore (indirectly) on the usefulness of FXI as an additional monetary policy tool in a zero interest environment.

(ii) We contribute to the strand of literature that estimates the effect that FXI have on the spot FX market,[6] which mostly have concentrated on the period before the GFC. The GFC triggered substantial changes in global financial markets which include the historically exceptional period of sustained low interest rates, the novel insight that financial frictions are key for the effectiveness of sterilized FXI (Popper, 2022), and the evolution of the FX market over the past three decades due to technological advancements (Chaboud, Rime, and Sushko, 2022). Moreover, most of these papers use only simplistic proxies (e.g. changes in a central bank's reserves) to estimate the actual size of FXI. This is mainly because most central banks do not disclose these operations. As extensively discussed in the literature,[7] these are only very coarse proxies. Therefore, to effectively assess the impact of FXI, it's important to have empirical results that use actual FXI data.

(iii) We also contribute to the literature that attempts to rationalize the CIP deviations observed since the onset of the GFC.[8] To the best of our knowledge, as we explain in the main body of our paper, we are the first to empirically quantify the effect that FXI have on the CCB. We find that FXI widen this metric, which is consistent with the theoretical prediction of the Amador et al. (2020) model, whereby FXI lead systematically to CIP violations when the ZLB of nominal interest rates binds. Our finding therefore supports their idea that part of the CIP deviations observed after the GFC are due to a conflict between exchange rate policies and the ZLB.

(iv) For sterilized FXI to be effective, we need some type of financial friction, as otherwise financial market participants would instantaneously arbitrage away any FX rate misalignments (e.g., resulting from FXI). In addition, it is now both theoretically

[6] See Sarno and Taylor (2001), Neely (2005), Fratzscher (2005), Égert and Komárek (2006), Disyatat and Galati (2007), Fatum (2015), Ribon (2017), Caspi, Friedman, and Ribon (2022), Adler, Lisack, and Mano (2019), Nedeljkovic and Saborowski (2019)), and Arango-Lozano, Menkhoff, Rodríguez-Novoa, and Villamizar-Villegas (2020).

[7] See Dominguez, Hashimoto, and Ito (2012), Adler, Chang, Mano, and Shao (2021) and Fratzscher, Heidland, Menkhof, Sarno, and Schmeling (2022).

[8] Du, Tepper, and Verdelhan (2018), Avdjiev, Du, Koch, and Shin (2019) and Du and Schreger (2021).

and empirically accepted that the effect of sterilized FXI is much lower when nominal interest rates are essentially zero.[9] We analyze the role of financial frictions systematically and find that the more capital-constrained global banks are, the larger the impact of FXI.

This finding provides empirical support to the recent theoretical research that rationalizes the effectiveness of sterilized FXI in the spirit of Gabaix and Maggiori (2015), a model that has revitalized the theoretical FXI literature that was dormant since the pioneering work of Backus and Kehoe (1989). To the best of our knowledge, this empirical finding is new in the FXI strand of literature and provides guidance to central banks about what type of financial friction makes sterilized FXI in the spot market more effective.

(v) To the best of our knowledge, we are the first paper providing empirical evidence on the effect of FXI on tail probabilities. When analyzing this nexus, we consider the response of these probabilities over different horizons, which is important for central banks to get a better sense of the strength of their monetary policy actions. As the shape of the RND changes with these probabilities, our contribution allows central banks to understand why the risk perception of market participants attached to extreme events changes on FXI days.

(vi) Last but not least, we contribute with empirical evidence on secret FXI, which is scant and still heavily under-researched (Naef and Weber, 2023). In view of the fact that central banks often intervene in the FX spot market secretely (Fratzscher, Gloede, Menkhoff, Sarno, and Stöhr, 2019) implies that the empirical results in the FXI literature are tilted towards the effectiveness of public FXI. We try to fill this gap.

This paper is structured as follows. In Section 2 we describe our methodology, our estimation strategy and the data that we use. Section 3 presents and discusses our main results. We start by analyzing the response of the spot and the forward market in Section 3.1, where we also assess the role of financial frictions in explaining the effectiveness of the BOI's FXI activities. In Sections 3.2 and 3.3 we study the relationship between FXI and the options market. Finally, Section 4 concludes.

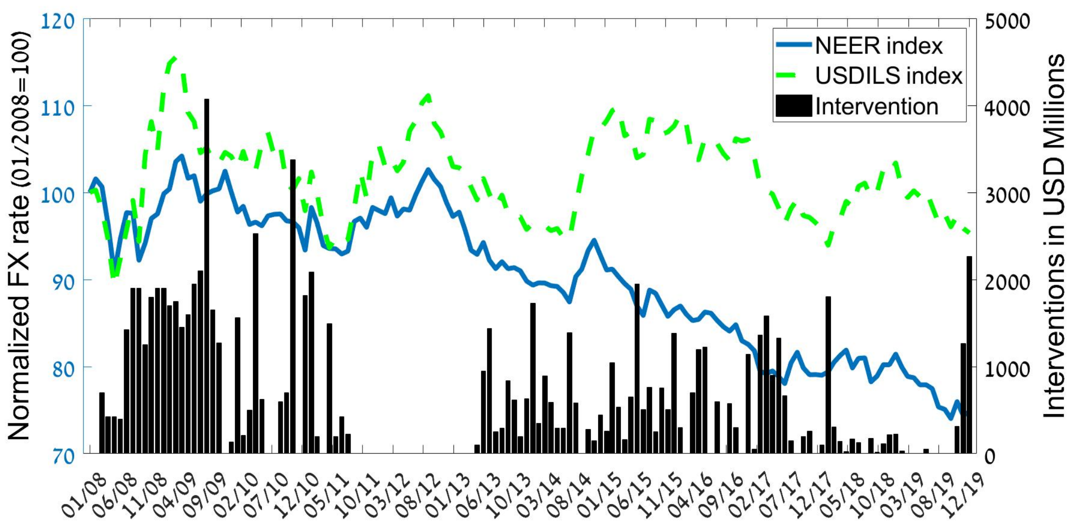
[9] Evidence from Japan shows that FXI lose almost half of their impact when the ZLB binds (Iwata and Wu, 2012).

2 Methodology

This section elucidates the methodology used in the empirical analysis undertaken in this paper. We first describe the data used in the estimation after which we turn to present the general lines of the estimation.

2.1 Data

Figure 1: Foreign value of the ILS and the size of foreign exchange interventions



Notes: The figure displays monthly averages of the nominal effective exchange rate (NEER) and the USD/ILS spot rate (both on the left axis), as well as the monthly total volume of interventions in USD millions (right axis). The NEER and the USD/ILS are both computed as indices and normalised to 100 as of January 2008. Both indices are defined in units of the domestic currency per unit of foreign currency. A decrease in the index level therefore indicates an appreciation of the domestic currency. The data covers the period from January 2008 to December 2019.

Our data are daily and cover the period of 01/01/2013–31/12/2019. During this period, the BOI started to secretly intervene in the FX market in April 2013 by buying dollars in the spot market.[10] To give a broader prespective, Figure 1 displays the aggregated monthly volume of FXI, which is published by the BOI on a monthly basis, the NEER[11] of the ILS and the USD/ILS spot rate from January 2008 to December 2019.[12] We see a steep appreciation of the ILS by 10% (almost 30%) appreciation of the

[10]We initiate the estimation process prior to our first intervention observation to prevent omitting any intervention data. This approach is essential because our identification strategy is based on lagged variables.

[11]This index is measured as the geometric average of the ILS FX rate vis-à-vis 24 currencies representing 31 countries, Israel's major trading partners by proportion of trade (Friedman and Galo (2015) and https://www.boi.org.il/en/Markets/ExchangeRates/Pages/efectinf.aspx).

[12]Note that both FX rates are displayed as an index for the ease of comparison.

ILS vis-à-vis the USD (the NEER) from 2008 until the end of our sample.[13] In tandem, the bank intervened in the USD/ILS spot market, particularly during periods of strong appreciation pressure.

In the period displayed in Figure 1, the BOI changed its intervention strategy several times. The BOI even stopped intervening in July 2011 for the following 21 months. For interested readers, we provide an overview of the six different regimes since 2008 in online Appendix A.

2.1.1 Foreign exchange interventions data

Table 1 displays descriptive statistics of the aforementioned publicly available aggregated monthly FXI data for the period of January 2013 to December 2019. The descriptive statistics indicate that, the BOI purchased 594 mUSD per month on average, with a minimum of 2 mUSD and a maximum of 2.27 billion USD. The monthly FXI volumes are relatively volatile, as reflected by its standard deviation. In total, we have 69 out of 84 months with at least one trading day, where the BOI intervened in the USD/ILS spot market. The table also suggests that the distribution of the FXI data might be right-skewed, as the mean is larger than the median, i.e., few observations are large compared to all other FXI data. This is confirmed in an untabulated histogram.

Table 1: Descriptive statistics of the monthly foreign exchange interventions data

	Mean	Median	Std	Min	Max	N
FXI	0.594	0.350	0.545	0.002	2.266	69

Notes: The table shows descriptive statistics of the publicly available monthly aggregated intervention data in USD billions (columns 2–6) and the total number of months in the period of interest with at least one intervention day (column 7). The data covers the period from January 2013 to December 2019.

To give a better sense of the magnitude of FXI relative to other metrics, Table 2 includes information about the average size of FXI relative to Israeli GDP and the daily USD/ILS spot market turnover (which is confidential data from the BOI), as well as the average length of all the FXI episodes.

[13] Both FX rates equal the price of one unit of foreign currency (or a basket of foreign currencies) in units of the domestic currency. An increase then indicates a depreciation of the domestic currency.

Table 2: Descriptive statistics of the daily foreign exchange interventions data

Indicator	Total
Average daily intervention size as share of GDP (%)	0.05
Average daily intervention size as share of daily traded FX volume (%)	8.16
Average length of episode in seven days	1.46
Average length of an episode in a trading week (in days)	1.73

Notes: The table displays the descriptive statistics of the daily intervention data. The GDP series is in US dollars and is compiled by the Israeli Central Bureau of Statistics (row 1). The daily traded volume in the USD/ILS market is compiled by the BOI (row 2). Row 3 displays the average length of an intervention episode within any given week (i.e. from Monday to Monday, from Tuesday to Tuesday, etc.). The average length of an episode in a trading week (row 4) shows the average number of consecutive days of daily interventions in a calendar week. The data covers the period from January 1, 2013 to December 31, 2019.

From this table we learn that the size of the BOI's FXI is large in terms of domestic GDP. Fratzscher et al. (2019), for instance, document that the size of FXI by countries with a free-floating regime amounts to 0.02% of GDP on average, which is around 60% smaller than in the case of the BOI. Also, relative to the average daily turnover in the USD/ILS spot and forward market, the size of the FXI is large. For instance, Fatum (2015) who analyzes the Bank of Japan's (BOJ) FXI activity from 1999 to 2004 reports an average size of USD purchases amounting to 1.3% of the daily market turnover, compared to 8.16% in the case of the BOI.

We also see that the BOI participates in the USD/ILS spot market for only 1.46 trading days on average, which is rather short by international standards. Disyatat and Galati (2007), for instance, report that the Czech National Banks's (CNB) FXI activity spanned a period of eight trading days on average. The BOI, nevertheless, seems to intervene on more than one trading day in a given trading week (for instance, at the beginning and at the end of a trading week). As explained in Miyajima (2013), FXI in the spot market aimed at also affecting market expectations should combine intervention episodes with days of no activity so that FX derivatives market participants can evaluate the expected longer-term effect of these interventions – the BOI apparently follows this advice.

2.1.2 Exchange rates and financial variables

Table 3 provides selected descriptive statistics of the main variables that we use in the empirical section of our paper. These variables are recorded on a daily basis and span the period from January 1, 2013 to December 31, 2019.

Table 3: Descriptive statistics of the main variables

	Mean	Median	Std	Min	Max	AR(1)	N
Exchange rates (in logs and in %):							
ΔUSD/ILS	−0.004	0.00	0.38	−2.32	2.41	−0.01	1826
ΔEUR/USD	−0.009	0.01	0.47	−2.30	2.95	0.01	1826
ΔNEER	−0.014	−0.02	0.32	−2.02	2.34	0.02	1826
Δ ln(3M forward)	−0.005	−0.02	0.37	−2.29	1.59	0.05	1826
Misc (in %):							
USD/ILS CCB	−0.19	−0.17	0.16	−0.94	0.26	0.94	1826
5-year Israeli CDS	0.80	0.74	0.20	0.48	1.52	0.99	1826
VIX	14.86	13.89	3.81	9.14	40.74	0.93	1763

Notes: The table presents descriptive statistics of the main variables. The data is recorded on a daily basis and spans the period from January 1, 2013 to December 31, 2019. There are a maximum of 1826 trading days. The FX rates are expressed in log changes and in percent. Both FX rates (USD/ILS and EUR/USD) and the 5-year Israeli CDS spread are retrieved from Bloomberg. The NEER series is constructed such that it is synchronized with the USD/ILS trading time (see online Appendix B for more information). 3M forward is the three-month USD/ILS forward rate retrieved from Bloomberg. The USD/ILS CCB is the three-month cross currency USD/ILS basis which we calculate according to Equation 3. VIX measures the implied volatility from S&P 500 index options at US closing time and is provided by the CBOE. It has less trading days than the other variables due to US holidays.

The upper panel of the table ("Exchange rates") shows the daily exchange rate returns (in percent and in logs) of the USD/ILS and the EUR/USD FX rate, the NEER, and the 3-month USD/ILS forward rate. As evidenced, the ILS appreciated on average, which is consistent with the time series displayed in Figure 1. In the lower panel ("Misc") we display descriptive statistics for the 3-month USD/ILS cross-currency basis, the 5-year Israeli CDS spread, and the VIX as a proxy measure of global uncertainty.

2.1.3 The USD/ILS options market

Table 4 displays descriptive statistics for the USD/ILS options data that we use. The data is retrieved from Bloomberg and recorded on a daily basis. The data include the ATMVs (upper panel), the 10-Δ and 25-Δ[14] butterfly (BF) spreads (middle panel) and the 10-Δ and 25-Δ RRs[15] (lower panel) for six maturities, ranging from one week ("1w") to twelve months ("12m").[16] The price quotes are measured in implied volatilities and

[14]By market convention, FX options are quoted in terms of the Garman and Kohlhagen (1983) (GK) model. A 10-Δ call (put), for instance, corresponds to a GK option delta of 0.1 (-0.1).

[15]See online Appendix C for details on risk reversals and butterfly spreads.

[16]Tables D.2, D.3 and D.4 in online Appendix D display the coefficients of the cross-correlation between the log returns of these option contracts. The cross-correlations indicate that the option prices

displayed in percent, following the options markets' quoting convention (Reiswich and Wystup, 2010).

As the price quotes of these option strategies are highly persistent (column "AR(1)"), we use them in first differences in the following analysis. Untabulated results show that the first difference eliminates this persistence. We also note that the price quotes of the one-week BF spreads (for both option deltas) exhibit a much lower persistence than the other price quotes. This is also true, but to a much lesser extent, for the one-week RRs (also for both option deltas) and the one-week ATMV. This lower persistence may indicate stale prices and a lack of liquidity, which brings us to our next topic.

Liquidity. As we use options data extensively in our paper, we assess how liquid the Israeli FX option market is by international standards. To this end, we look at the most recent BIS triennial central bank survey[17] that currently covers 54 countries and includes data on FX turnover collected from close to 1300 banks and other dealers. Our calculations (see Table E.1 in online Appendix E) reveal that the ratio of the OTC-traded FX option volume to the total FX transaction volume[18] in Israel equaled 6.2% in 2019, which is large by international standards, as Israel is ranked in the top five of all surveyed countries in 2019 and in all previous surveys that have been conducted every three years since April 2007 (untabulated results).

Figures E.2-E.4 in online Appendix E add further support to our argument. These figures show the box plots of the bid-ask spreads (BAS) divided by the mid-quote (the so-called relative BAS) of the three USD/ILS option strategies that we use in our paper for 28 currency pairs across six maturities.[19] The results show that: (i) The relative BAS is consistently higher for the one-week contracts. We therefore omit these contracts in

are highly correlated with each other, especially for longer maturities. These tables also show that the options data is positively correlated with the daily change of the USD/ILS FX rate. This contemporaneous relationship was documented in McCauley and Melick (1996), Malz (1997) and Campa, Chang, and Reider (1998) for RRs and in their view implies that investors assign a more pronounced tilt towards a further depreciation (appreciation) of the ILS vis-à-vis the USD (i.e. a higher RR), when the ILS has already weakened (strengthened), reflecting a kind of momentum. Note, however, that the rare disaster model of FX rates proposed by Farhi and Gabaix (2016) offers an alternative explanation for this correlation.

[17] Source: `https://www.bis.org/statistics/rpfx19.htm`.

[18] Including transactions in the FX spot, FX forward, FX option and FX swap market.

[19] As the ATMV levels vary across currencies, we divide the BAS by the mid-quote to make this metric comparable across currency pairs.

Table 4: Descriptive statistics of the USD/ILS options data

	Mean	Median	Std	Min	Max	AR(1)	N
At-the-money implied volatilities:							
ATMV1w	6.63	6.35	1.49	3.54	11.43	0.947	1826
ATMV1m	6.56	6.35	1.29	3.96	10.33	0.994	1826
ATMV3m	6.64	6.47	1.14	4.29	9.72	0.997	1826
ATMV6m	6.73	6.54	1.05	4.76	9.41	0.998	1826
ATMV9m	6.81	6.61	1.00	5.07	9.21	0.999	1826
ATMV12m	6.86	6.67	0.96	5.18	9.05	0.999	1826
Butterfly spreads:							
10-Δ:							
BF101w	0.794	0.90	0.44	-1.67	1.92	0.429	1826
BF101m	0.738	0.73	0.12	0.46	1.12	0.918	1826
BF103m	1.008	0.98	0.21	0.59	1.45	0.976	1826
BF106m	1.186	1.14	0.25	0.65	1.73	0.982	1826
BF109m	1.269	1.19	0.29	0.69	1.92	0.983	1826
BF1012m	1.452	1.41	0.32	0.78	2.20	0.985	1826
25-Δ:							
BF251w	0.136	0.20	0.30	-2.45	1.20	-0.052	1826
BF251m	0.236	0.23	0.04	0.14	0.37	0.945	1826
BF253m	0.327	0.31	0.07	0.19	0.50	0.984	1826
BF256m	0.384	0.37	0.08	0.21	0.59	0.986	1826
BF259m	0.419	0.39	0.10	0.22	0.63	0.990	1826
BF2512m	0.474	0.46	0.11	0.25	0.71	0.990	1826
Risk reversals:							
10-Δ:							
RR101w	0.658	0.60	0.43	-0.42	2.77	0.95	1826
RR101m	1.088	0.93	0.67	-0.12	3.33	0.99	1826
RR103m	1.438	1.14	0.87	-0.05	3.58	0.997	1826
RR106m	1.649	1.31	0.98	0.00	3.76	0.998	1826
RR109m	1.750	1.41	1.05	0.16	4.12	0.998	1826
RR1012m	1.950	1.67	1.09	0.26	4.30	0.998	1826
25-Δ							
RR251w	0.396	0.37	0.26	-0.12	1.49	0.976	1826
RR251m	0.597	0.5	0.37	-0.07	1.83	0.994	1826
RR253m	0.782	0.61	0.47	-0.02	1.92	0.998	1826
RR256m	0.892	0.70	0.53	0.01	1.99	0.998	1826
RR259m	0.949	0.78	0.57	0.10	2.13	0.999	1826
RR2512m	1.045	0.88	0.58	0.18	2.24	0.999	1826

Notes: The table displays descriptive statistics for the daily USD/ILS options data quoted in implied volatilities and in percent (except columns “AR(1)” and “N”) for the period from January 1, 2013 to December 31, 2019, a total of 1826 trading days. The data includes at-the-money implied volatilities (“ATMV”), 10-delta and 25-delta butterfly spreads (“BF10” and “BF25”) and 10-delta and 25-delta risk reversals (“RR10” and “RR25”). In each case the data is available for six different maturities, ranging from one week (“1w”) to twelve months (“12m”). Data source: Bloomberg.

the following analysis. (ii) The relative BAS for each of the three option strategies is ranked in its corresponding interquartile range, which makes us confident that our option market data is not significantly affected by low liquidity.

2.2 Estimation

We begin our analysis with OLS regressions, consciously setting aside the potential for endogeneity biases in order to gauge their potential magnitude:

$$\Delta s_t = \alpha + \beta \text{FXI}_t + X_t^T \delta + \epsilon_t, \tag{1}$$

where Δs_t is the log exchange rate return of the USD/ILS spot rate, NEER or three-month USD/ILS forward rate, FXI_t the size of interventions and X_t a vector of control variables that are correlated with the dependent variable (e.g., relevant macroeconomic surprises, changes in global uncertainty that may trigger safe haven flows or changes in the EUR/USD spot rate that would affect the USD/ILS spot rate through cross rates).

These biases could surface because central banks typically utilize FXI to 'lean against the wind', i.e., to revert or contain a sustained trend in the foreign value of the domestic currency (see e.g., Neely (2005), Fratzscher (2005), Tashu (2014), Naef (2023)). This simultaneity leads to OLS estimates that underestimate the real impact of FXI. However, by using daily data, as in our methodology, we significantly reduce the risk of reverse causality and confounding factors introducing bias into our estimated coefficients, as supported by Rogers and Siklos (2003) and Menkhoff, Rieth, and Stöhr (2021).

Identification Strategy. Using daily data may not be enough to circumvent endogenity issues. Therefore, in our main analysis we use an idenfication strategy that relies on instrumental variables common to the intervention literature within a General Method of Moments (GMM) framework. Running GMM regressions is one of the standard econometric solutions in the FXI literature (see Adler and Tovar (2011) and Adler et al. (2019)), as the basic idea of the instrumental variables regression to control for this endogeneity can easily be cast into a GMM framework by combining Equation (2) with a central bank intervention reaction function for spot market interventions:

$$\text{FXI}_t = \phi + X_t^T \delta + Z_t^T \gamma + \varepsilon_t, \tag{2}$$

where Z_t is a vector of instrumental variables (e.g., the lagged size of interventions).

Specifically, we use the continuously updated generalized method of moments (CU-GMM) estimator proposed by Hansen, Heaton, and Yaron (1996) with a heteroskedasticity and autocorrelation (HAC) consistent covariance matrix. We opt for this estimator, as it often exhibits better small sample properties than the two-step (or iterated) GMM estimator.

3 Results

This section presents the main results of the paper. We begin our empirical analysis by focusing on the effect interventions have on the spot rate, the forward rate and deviation from CIP. We then turn to the effect interventions have on the FX options market.

3.1 Effect of interventions on the spot rate, the forward rate and the cross-currency basis

Informal event study. We begin with an informal event study: Figure 2 displays the average cumulative returns of the USD/ILS spot rate, starting 9 days prior to a FXI episode (starting at the beginning of day t) and ending 11 days after the first FXI day.[20] The average cumulative returns are weighted using the relative size of FXI,[21] as we have learned from Table 1 that the distribution of FXI might be right-skewed. For ease of comparison, we also display the cumulative returns assigning equal weights to each FXI episode. This weighting scheme tilts the results in favour of episodes characterized by small FXI volumes.

We see that the BOI's FXI contain the appreciation trend of the foreign value of the ILS and create a depreciation of the ILS by the end of the first FXI day.[22] There is also a slight continuation of this "trend reversal" on day $t+1$, which in some cases may reflect a second day with FXI. The figures also show that weighting the returns by the FXI volumes results in more pronounced trends around day t. This finding suggests that the BOI seems to intervene more heavily when there is a more pronounced (or steeper) appreciation trend prior to the first FXI day t.

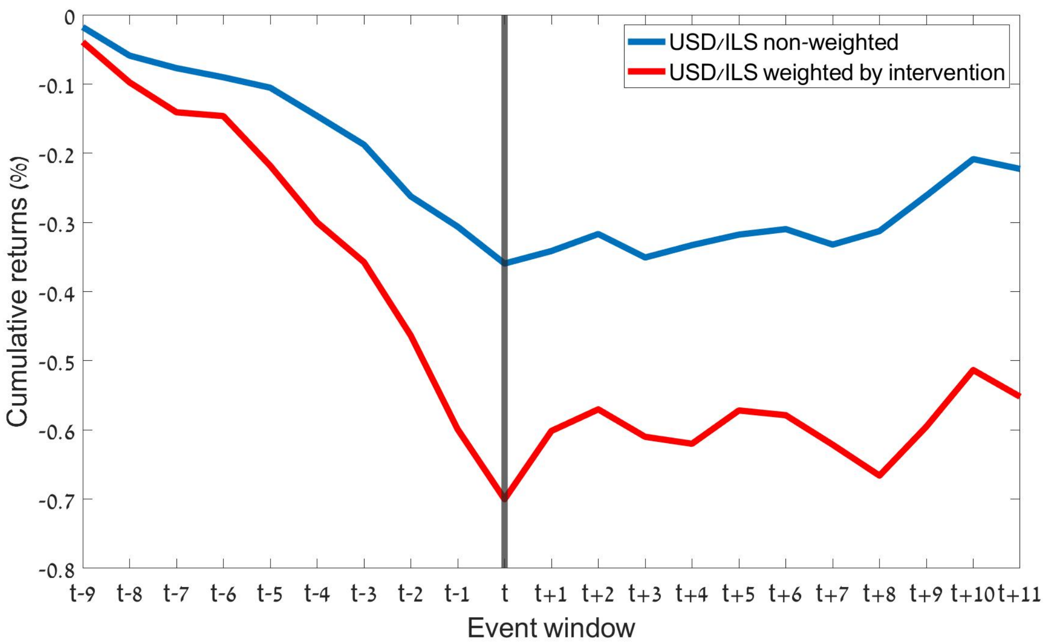
[20] Figure 1 in online Appendix F includes the graphs for the NEER and the three-month USD/ILS forward rate.

[21] The size of FXI on a specific day $t+j$ (with $j \in \{-9, -8 \ldots, 0, \ldots, +10, +11\}$) divided by the total size of FXI in our sample period.

[22] A similar pattern emerges for the NEER and the three-month USD/ILS forward rate.

To summarize, Figure 2 suggests that the BOI is successful in creating a depreciation in the FX market according to the "event" and "direction" criteria that are typically applied in the literature to identify successful FXI episodes.[23]

Figure 2: Cumulative returns of the USD/ILS spot rate surrounding the intervention episodes



Notes: The figure shows the average cumulative returns of the USD/ILS exchange rate (in percent) from time $t-9$ to $t+11$ on a daily basis, where t reflects the beginning of the trading day when the first intervention was carried out. The red line displays the cumulative returns weighted by the relative size of interventions, while the blue line shows this metric using equal weights for each intervention episode.

GMM estimation: instruments. To mitigate the potential simultaneity bias, we use instruments in the GMM regression that are commonly used in the FXI literature and are presumably correlated with the FXI data, but uncorrelated with the spot rate shocks (e.g., other factors affecting the spot rate) on days the BOI intervenes. Our instruments include the one-day lagged daily FXI volume to account for the persistence in FXI in periods of sustained appreciation pressure, following Ito and Yabu (2007), Fatum and Hutchison (2010), Fatum and Yamamoto (2014), and Nedeljkovic and Saborowski (2019). We also add a dummy variable that equals one if the BOI intervened in the previous calendar week, the one-day lagged two-day return of the NEER and the three-

[23]See e.g. Humpage (1999), Fatum and Hutchison (2003), Fratzscher (2005), Fatum and Hutchison (2006), Galati et al. (2007), Fatum (2008), Fratzscher (2008) and Fratzscher et al. (2019).

day lagged two-week return of the NEER, as these are exogenous to the current exchange rate, but presumably correlated with the FXI data, as the decision to intervene and the size of FXI both depend on the trajectory of the spot rate. We choose the NEER, as one motivation of the BOI to start intervening in the FX market was the preservation of competitiveness (Cukierman, 2019), which is reflected in the NEER. Appendix A provides more details.

The number of lags for the instruments are selected based on adjusted R^2 criteria. We select the specifications with the highest adjusted R^2 among the specifications that pass the Montiel Olea and Pflueger (2013) test.

To assess the joint validity of these instruments, we calculate the difference-in-Hansen test proposed by Eichenbaum, Hansen, and Singleton (1988) for specific subsets of instruments. The test results add support to our specification. We also test for weak instruments with the Montiel Olea and Pflueger (2013) test, a test that is robust to heteroskedasticity, autocorrelation, and clustering. The test statistic exceeds the critical value. We therefore reject the null hypothesis that the instruments have insufficient explanatory power and can be confident that we will be able to handily address the endogeneity when using the CU-GMM estimator. For detailed results of the first-stage regression and additional robustness tests for the validity of our instruments, see Appendix A.

Control variables. We include the one-day log return of the EUR/USD spot rate, the one-week change in the VIX[24] and news indicators, to ensure that our results are not contaminated by relevant macro news.[25] For each control variable, we want to discuss now the economic intuition and the expected coefficient.

Euro/Dollar. Following Augustin, Chernov, and Song (2020), we capture a potentially broad devaluation of the USD using its value against the euro, the second most

[24]We have also experimented with the decomposition of the VIX into a risk aversion (i.e., the risk premium component (Carr and Wu, 2009)) and an uncertainty component, following the approach proposed by Bekaert, Hoerova, and Lo Duca (2013). As our results are robust to this decomposition of the VIX, we opted to present the results using the VIX, following e.g. Nedeljkovic and Saborowski (2019). Hence, the risk aversion component seems to be of secondary importance when analyzing the BOI's FXI regime.

[25]See online appendix B for details.

important currency in the world. We expect a broad devaluation of the USD (i.e. ΔEUR/USD > 0) to be associated with an appreciation of the ILS (i.e., H_a: $\delta < 0$).[26]

VIX. Following the literature reviewed in Goldberg and Krogstrup (2023), we expect an increase of uncertainty in global financial markets, proxied by the VIX (i.e. ΔVIX > 0), to be accompanied by safe haven flows (e.g., on a net basis, international capital flows to the US). As an aftermath, we expect the USD to appreciate in such an environment (i.e. H_a: $\delta > 0$).

Local Monetary and Macro shocks. Focusing on monetary shocks, we include a variable that captures the magnitude of monetary policy surprises in Israel ("IL_Monetary_Surprise"). Here, an unexpected tightening (i.e. IL_Monetary_Surprise > 0) is expected to attract international capital, pushing up the foreign value of the ILS. Hence, the coefficient associated with this indicator should be negative (i.e. H_a: $\delta < 0$). Similarly, a surprise in Israeli monthly CPI (i.e. IL_CPI_Surprise > 0) should be followed by a tightening of monetary policy and therefore attract foreign capital. Hence, this coefficient should also be negative (i.e., H_a: $\delta < 0$).

US Monetary and Macro shocks. We also control for both short ("NS_FRR_Surprise") and longer-term monetary surprises in the US ("NS_Policy_Surprise") which are based on high frequency data per the methodology described in Nakamura and Steinsson (2018).[27] For the US monetary policy surprise (e.g., NS_Policy_Surprise), a tightening in the US (i.e. NS_Policy_Surprise > 0) is associated with an appreciation of the USD vis-à-vis the ILS (i.e. H_a: $\delta > 0$).

We also control for macroeconomic surprises in the US, as captured by the CITI US surprise index ("CITI_Surprise_Index").[28] A positive (negative) CITI_Surprise_Index means that macroeconomic US data releases have been better (worse) than expected.

[26] For the statistical significance test, we have to translate our scientific hypothesis to an alternative hypothesis, which we denote by H_a.

[27] The extended series is available from Miguel Acosta's website at https://www.acostamiguel.com/research.html.

[28] The index is measured in basis points of aggregated standard deviations of surprises and has no natural bounds. To get coefficients that are similar in size to the coefficients associated with other explanatory variables, we divide this indicator by a 1000.

Hence, an unexpectedly positive US macroeconomic news should be associated with an appreciation of the USD (i.e., H_a: $\delta > 0$).

Table 5 displays the results of regressing the daily log return (in percent) of the USD/ILS spot rate (Panel A), the NEER (Panel B) and the three-month USD/ILS forward rate (Panel C) on an intercept, the contemporaneous intervention variable (in billions

Table 5: Effect of interventions on the spot rate and the forward rate

(a) Panel A

Dependent variable: Δ ln(USD/ILS$_t$) (in %)			
	[1]: OLS	**[2]: CU-GMM**	**[3]: 2SLS**
Intercept	−0.023***	−0.029**	−0.029**
	(−2.93)	(−2.28)	(−2.27)
FXI$_t$	0.56***	0.83**	0.82**
	(4.91)	(2.06)	(2.01)
ΔEUR/USD$_{t-1,t}$	−0.408***	−0.412***	0.044***
	(−23.04)	(−21.42)	(−21.36)
ΔVIX$_{t-5,t}$	0.011***	0.011***	0.011***
	(4.33)	(4.31)	(4.26)
IL_Monetary_Surprise$_t$	−3.293***	−3.344***	−3.315***
	(−4.84)	(−5.02)	(−4.94)
IL_CPI_Surprise$_t$	−5.947*	−0.537**	−0.535**
	(−1.73)	(−2.04)	(−2.03)
NS_FFR_Surprise$_t$	1.546	−5.853*	−5.834*
	(0.90)	(−1.69)	(−1.68)
NS_Policy_Surprise$_t$	−0.530**	1.411	1.405
	(−2.01)	(0.81)	(0.80)
CITI_Surprise_Index$_t$	−0.067	−0.00010	−0.00009
	(−0.29)	(−0.44)	(−0.37)
Hansen J-statistic		0.213	
Hansen J-statistic p-value		0.975	

(b) Panel B

Dependent variable: $\Delta \ln(NEER_t)$ (in %)			
	[1]: OLS	**[2]: CU-GMM**	**[3]: 2SLS**
Intercept	−0.03***	−0.03	−0.03
	(−3.60)	−2.65	−2.52
FXI_t	0.56***	0.82*	0.66*
	(4.70)	(1.92)	(1.71)
$\Delta EUR/USD_{t-1,t}$	0.01	0.00	0.01
	(0.66)	(0.14)	(0.54)
$\Delta VIX_{t-5,t}$	0.007***	0.01***	0.01***
	(2.53)	(2.50)	(2.52)
IL_Monetary_Surprise$_t$	−3.29***	−3.35***	−3.30***
	(−5.07)	(−5.03)	(−5.12)
IL_CPI_Surprise$_t$	−0.54**	−0.56**	−0.54**
	(−2.11)	(−2.15)	(−2.11)
NS_FFR_Surprise$_t$	−4.69*	−4.79	−4.65
	(−1.57)	(−1.46)	(−1.55)
NS_Policy_Surprise$_t$	0.04	−0.21	−0.02
	(0.03)	(−0.13)	(−0.01)
CITI_Surprise_Index$_t$	0.00004	0.00003	0.00003
	(0.17)	(0.12)	(0.13)
Hansen J-statistic		0.27	
Hansen J-statistic p-value		0.97	

(c) Panel C

Dependent variable: $\Delta \ln(\text{3M forward}_t)$ (in %)			
	[1]: OLS	**[2]: CU-GMM**	**[3]: 2SLS**
Intercept	−0.02***	−0.03***	−0.025**
	(−2.56)	(−2.02)	(−1.96)
FXI_t	0.47***	0.73*	0.705*
	(4.14)	(1.77)	(1.69)
$\Delta\text{EUR/USD}_{t-1,t}$	−0.33***	−0.33***	−0.337***
	(−19.32)	(−18.35)	(−18.48)
$\Delta\text{VIX}_{t-5,t}$	0.01***	0.01***	0.011***
	(4.42)	(4.42)	(4.40)
IL_Monetary_Surprise$_t$	−3.31***	−3.28***	−3.332***
	(−5.76)	(−5.81)	(−5.86)
IL_CPI_Surprise$_t$	−0.61**	−0.62**	−0.609**
	(−2.06)	(−2.11)	(−2.08)
NS_FFR_Surprise$_t$	−3.75	−3.33	−3.653
	(−1.48)	(−1.23)	(−1.41)
NS_Policy_Surprise$_t$	−7.76***	−8.51***	−7.882***
	(−3.11)	(−3.38)	(−3.09)
CITI_Surprise_Index$_t$	0.000021	0.000082	0.000002
	(0.09)	(0.34)	0.008
Hansen J-statistic		2.22	
Hansen J-statistic p-value		0.53	

Notes: The daily log return of the USD/ILS spot rate (in percent), the nominal effective exchange rate ("NEER"; panel B), and the three-month USD/ILS forward rate ("3M Forward"; panel C) is regressed on an intercept, the size of interventions ("FXI_t"; in USD billions), the daily log return of the EUR/USD spot rate ("$\text{EUR/USD}_{t-1,t}$"; in percent), the one-week change in the VIX ("$\Delta\text{VIX}_{t-5,t}$"; in percentage points) and the five news indicators (variable names ending with "Surprise$_t$"). In specification [1] and [2] standard OLS and the continuously updated GMM estimator (CU-GMM) are used. In specification [3], we report the two-stage least squares estimator (2SLS). For details about the set of instruments that are included in the CU-GMM, see Table A.1. To assess whether the data in the CU-GMM is consistent with the imposed moment conditions, the Hansen J-test statistic of over-identifying restrictions is included. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. The sample spans the period from January 1, 2013, to December 31, 2019.

of USD) and the control variables, which is our benchmark specification. Column 2 presents the results when running a standard OLS regression, while column 3 displays the results when using the CU-GMM estimator with the instruments. As a robustness check, we also report the results of a two-stage least squares (2SLS) regression in column 4 (specification [3]).

Before considering the effect of FXI on the spot and the forward rate, we want to briefly look at the estimated coefficients associated with the control variables. Focusing on the GMM results, we see that most control variables exhibit statistically significant and economically relevant coefficients, all also with the predicted sign, except for the CITI_Surprise_Index which is statistically and economically insignificant.

Effect on the spot rate. The estimated coefficient associated with the FXI variable is highly significant and comparable in size for the two spot rates, equaling 0.83% for the USD/ILS rate (panel A) and 0.82% for the NEER (panel B). This similarity in the magnitude is consistent with our prior that a depreciation of the ILS vis-à-vis the USD should lead to a depreciation of the ILS vis-à-vis other currencies via cross-rates in an informationally efficient, frictionless capital market. In Appendix C we show the longer-term effect of FXI on the spot rates. Figure C.1 adds further support to our perception of informationally highly efficient FX markets, as the initial effect of the FXI is contemporaneously reflected in both spot rates, with no observable differences after the FXI episode.

How do our estimated coefficients compare to the estimates in other papers that have analyzed the same FXI regime? Ribon (2017) using monthly FXI data finds that FXI amounting to mUSD 830 contribute to a depreciation of the NEER that is larger on average by 0.6% compared to a trading day with no FXI activities. Re-scaling the size of FXI to make her results comparable to ours, her estimated coefficient is approximately 9.8% lower than our estimate of 0.82 for the NEER. We note, however, that she examined a different period (2009–2015) than we did.

Compared to the spot market response documented in other papers that have analyzed the FXI activity of other central banks (see Section 1 for details), our estimates are at the upper bound, reflecting a high effectiveness of the BOI's FXI by both historical and international standards. Having in mind that the BOI sterilized its USD purchases, which should reduce the effectiveness of FXI in general, as sterilized FXI work only through the non-interest channels,[29] the magnitude of our estimated coefficients is surprisingly large. Therefore, in Section 3.1.1 we will identify indicators that help explain why the BOI's FXI have been so effective.

Finally, note that the Hansen J-test statistic of over-identifying restrictions is statistically insignificant. Hence, the data that we use is consistent with the imposed moment conditions, indicating that our GMM model is well specified. In Appendix B we show that our results are robust to the inclusion of verbal interventions by officials at the BOI, motivated by the work of Fratzscher (2008) who documents that actual FXI are

[29] Which are empirically also dominated by the interest-rate channel (Iwata and Wu, 2012).

often accompanied by verbal interventions.

Effect on the forward rate and the cross-currency basis. The estimated coefficient associated with the three-month USD/ILS forward rate equals 0.73% and is statistically significant only at the 10% significance level. Assuming constant domestic and foreign interest rates between two subsequent trading days,[30] our result is at odds with the CIP condition that dictates that the spot and forward rates should move one-to-one, unless, e.g., balance sheet-constrained banks face difficulties in obtaining dollar funding[31] that makes it costly for lower-rated banks to arbitrage the CCB (see Rime, Schrimpf, and Syrstad (2022) for empirical evidence).

In Table 6, we regress the three-month CCB on the FXI.[32] The results are striking – a 1 billion USD FXI is associated with a further widening of the (negative) dollar basis by more than 13 basis points (bps), which is statistically and economically[33] significant. What is even more salient, is that the effect persists for 100 days as seen in Appendix Figure C.1c.

Theoretically, however, our results are not surprising, as they are predicted by the model proposed by Amador et al. (2020). In their model, the central bank (CB) of a small open economy (SOE, like Israel) enforces an optimal FX rate policy in a zero-interest environment that leads to a contemporaneous depreciation of its currency. Market participants, however, anticipate that the FXI regime will be abandoned in the future. Hence, a future reversal of the depreciation of the domestic currency is expected (i.e. $f_t < s_t$). As interest rates in the SOE cannot adjust due to the binding ZLB and as in their model financial intermediaries are subject to binding financial constraints that prevents them from exploiting arbitrage opportunities, the expected appreciation of the domestic currency is not offset. As a consequence, foreign (and

[30] Note that the USD purchases are sterilized by the BOI. Furthermore, as we use daily data, the daily change of the US risk-free interest rate is small.

[31] The recent empirical literature detects a negative CCB for many currencies vis-à-vis the USD since the onset of the GFC (e.g. Du et al. (2018) and Du and Schreger (2021)). Hedged synthetic USD funding via cross-currency swap markets is then more expensive than borrowing USD directly in the US cash market.

[32] The results are even larger when using the one-month CCB, where FXI lead to a 30 bps increase.

[33] For instance, Avdjiev et al. (2019) document that a daily 1 percent appreciation of the broad dollar is related to a 2 bps decrease in the CCB which, they interpret as economically large. It is however comparable in size to the results documented in Aldunate, Da, Larrain, and Sialm (2023) who study the effect of Chilean pension funds on the exchange rate.

Table 6: Effect of interventions on the three-month cross-currency basis

Dependent variable: Δ 3M Basis$_t$ (in %)			
	[1]: OLS	**[2]: CU-GMM**	**[3]: 2SLS**
Intercept	0.10	0.32*	0.32*
	(1.02)	(1.83)	(1.78)
FXI$_t$	−3.35**	−13.56***	−13.10**
	(−2.06)	(−2.33)	(−2.14)
ΔEUR/USD$_{t-1,t}$	0.19	0.29	0.31
	(0.79)	(1.15)	(1.19)
ΔVIX$_{t-5,t}$	−0.09	−0.07	−0.09
	(−1.36)	(−1.17)	(−1.30)
IL_Monetary_Surprise$_t$	37.32***	38.07***	38.14***
	(3.15)	(3.24)	(3.24)
IL_CPI_Surprise$_t$	3.13	3.384	3.29***
	(1.14)	(1.22)	(1.18)
NS_FFR_Surprise$_t$	11.89	5.899	7.69
	(0.50)	(0.23)	(0.30)
NS_Policy_Surprise$_t$	58.75	68.97*	64.00
	(1.52)	(1.78)	(1.63)
CITI_Surprise_Index$_t$	0.001	0.001	0.002
	(0.46)	(0.63)	(0.76)
Hansen J-statistic		1.87	
Hansen J-statistic p-value		0.60	

Notes: The daily change of the three-month USD/ILS basis (in percentage points, annualized) is regressed on an intercept, the size of interventions ("FXI$_t$"; in USD billions), the daily log return of the EUR/USD spot rate ("EUR/USD$_{t-1,t}$"; in percent), the one-week change in the VIX ("ΔVIX$_{t-5,t}$"; in percentage points) and the five news indicators (variable names ending with "Surprise$_t$"). In specification [1] and [2] standard OLS and the continuously updated GMM estimator (CU-GMM) are used. In specification [3], we report the two-stage least squares estimator (2SLS). For details about the set of instruments that are included in the CU-GMM, see Table A.1. To assess whether the data in the CU-GMM is consistent with the imposed moment conditions, the Hansen J-test statistic of over-identifying restrictions is included. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. The sample spans the period from January 1, 2013, to December 31, 2019.

domestic) investors prefer domestic to foreign bonds, triggering capital inflows. The domestic CB has then to step in and purchase the foreign bonds, financed by issuing domestic bonds and money.

Returning to our empirical exercise, note that according to the asset market approach to exchange rate determination, sterilized FXI imply that the domestic interest rate r_t^{IL} remains unchanged (Villamizar-Villegas and Perez-Reyna, 2017), when FXI are carried out. Moreover, the interest differential between Israel and the US was quite stable and close to zero in the period that we consider. It can then easily be seen from the market convention of the CCB (Du et al., 2018) that FXI lead to a violation of interest parity:

$$CCB_t = r_t^{US} - \left[r_t^{IL} - (f_t - s_t) \right] \approx f_t - s_t, \tag{3}$$

where r_t^{US} denotes the log of (1 + 3-month USD LIBOR), r_t^{IL} the log of (1 + 3-month TELBOR), f_t the log of the 3-month USD/ILS forward rate and s_t the log of the 3-month USD/ILS spot rate. We focus on the 3-month money market rates, as these maturities are the most liquid rates and typically used to arbitrage away CIP deviations in money markets (Rime et al., 2022).

To the best of our knowledge, we are the first paper that documents a direct relation between daily FXI and the dollar basis, thereby providing for the first time empirical evidence for a novel (and alternative) explanation for the observed CIP deviation between the ILS and the USD since the GFC.

For the ease of completeness, note that our finding concerning the CCB is also consistent with the theory of FXI advanced by Fanelli and Straub (2021) who study the usefulness of FXI as an instrument to mitigate the distributional effects of adverse real exchange rate movements. In their model FXI also lead to CIP violations when trading in the forward market is neither subject to participation costs nor to position limits.

3.1.1 Determinants of the effectiveness of interventions

he most recent theoretical contributions in the FXI strand of literature highlight the role of financial frictions (e.g., in the form of capital-constrained financial intermediaries) as a key explanation for the effectiveness of sterilized FXI, as they prevent the elimination of arbitrage opportunities (see the reviews in Villamizar-Villegas and Perez-Reyna (2017) and Popper (2022)),

To exemplify the role of frictions in this context, we follow the line of reasoning in Gabaix and Maggiori (2015).[34] In their two-country model, households in both countries trade goods internationally and invest via international financiers (e.g., global banks) in risk-free domestic currency bonds. These financiers are, however, subject to financial constraints due to limits in their risk-bearing capacity and existing balance sheet risks, resulting in a downward-sloping demand curve for risk-taking. As a consequence, the global capital flows in both currencies induced by the households'

[34] See also Blanchard, Adler, and de Carvalho Filho (2015).

investment decisions are only partially intermediated by these financiers. To restore equilibrium, financiers must therefore be compensated by a risk premium. Both bonds thereby become imperfect substitutes and asset returns then depend on relative asset supplies.

By altering relative supplies, central banks can then affect this risk premium. For instance, FXI with the goal of depreciating the domestic currency involve the purchase of risk-free foreign currency bonds, financed by selling risk-free domestic currency bonds. These transactions alter the relative supplies in the global bond market and thereby the size and the composition of the financiers' balance sheets. As an aftermath, the risk premium changes and so does the spot rate. The effect of FXI is thereby increasing in the severity of the friction.

To explore the role of financial frictions in explaining the effectiveness of the BOI's FXI in the spot market, we extend our regression from Table 5 and include the squared leverage ratio of primary dealers (i.e., major global banks[35]) proposed by He, Kelly, and Manela (2017), abbreviated by "HKM" in the following. The HKM – equalling the squared inverse of the capital ratio – is a direct indicator of the balance-sheet capacity of financial intermediaries. We also interact the HKM with the size of FXI.[36] The results are displayed in Table 7 and suggest that the more limited the risk-bearing capacity of these dealers is, the more effective are the BOI's FXI for a given size of FXI (with a highly significant coefficient).[37]

Our finding is qualitatively consistent with the Gabaix and Maggiori (2015) model and other aforementioned theoretical models on sterilized FXI that highlight the role of financial frictions for the effectiveness of sterilized FXI. Our finding also adds strong support to the micro-founded model for the integrated policy framework of the International Monetary Fund (IMF) proposed by Adrian et al. (2021). In their framework, the "limited risk-bearing capacity of agents" plays a key role for the effectiveness of FXI in SOEs. Therefore, our finding seems to be especially relevant for central banks

[35]Note that global banks are indeed the relevant arbitrageurs in international money markets (Rime et al., 2022).

[36]Note that the global banks in HKM also broadly coincide with the global banks that trade in the Israeli FX measure.

[37]We use the first difference of the HKM measure in the past week to capture the contemporaneous effect of the HKM on the effectiveness of the FXI. The results remain quantitavley similar when using other horizons.

in small open economies, because FXI are a more intensively used monetary policy instrument in these countries (International Monetary Fund, 2022). Moreover, it is now widely accepted that the FX rate is an important channel for the transmission of monetary policy in small open economies (see e.g., Devereux and Engel (2003) and Svensson (2000)), highlighting the relevance of our finding. We are only aware of the work of Kuersteiner, Phillips, and Villamizar-Villegas (2018) who compare the impulse response function (IRF) associated with FXI in a period when CIP held with the IRF that results in periods when CIP was violated. Compared to their approach, we think that the HKM indicator in a GMM framework captures these frictions in a more consistent manner. In addition, as shown in Cerutti and Zhou (2023), the HKM indicator strongly comoves with an alternative risk-bearing capacity indicator that uses the leverage ratios of FX primary dealers, which suggests that the specific choice of the indicator is of secondary importance.

Table 7: Determinants of the effectiveness of interventions

Controls	Dependent variable: $\Delta \log$(USD/ILS$_t$) (in %)
Intercept	−0.03*
	(−1.87)
FXI_t	0.83*
	(1.74)
$\Delta\text{HKM}_{t-5,t}$	0.005**
	(2.09)
$\Delta\text{HKM}_{t-5,t} \times \text{FXI}_t$	0.32***
	(2.60)
$\Delta\text{EUR/USD}_{t-1,t}$	−0.39***
	(−22.05)
$\Delta\text{VIX}_{t-5,t}$	0.005
	(1.62)
IL_Monetary_Surprise$_t$	−3.02***
	(−4.57)
IL_CPI_Surprise$_t$	−0.59**
	(−2.06)
NS_FFR_Surprise$_t$	−2.67
	(−0.78)
NS_Policy_Surprise$_t$	3.13
	(1.28)
CITI_Surprise_Index$_t$	−0.00002
	(−0.08)
Hansen J-statistic	13.48
Hansen J-statistic p-value	0.14

Notes: The daily log return of the USD/ILS spot rate (in percent) is regressed on an intercept, the size of interventions ("FXI$_t$"; in USD billions), the change in HKM indicator ("HKM$_t$"), the interaction between FXI$_t$ and the one-week change in the HKM indicator ("$\Delta\text{HKM}_{t-5,t}$"), the daily log return of the EUR/USD spot rate ("EUR/USD$_{t-1,t}$"; in percent), the one-week change in the VIX ("$\Delta\text{VIX}_{t-5,t}$"; in percentage points) and the five news indicators (variable names ending with "Surprise$_t$"), using the continuously updated GMM estimator (CU-GMM). For details about the set of instruments that are included in the CU-GMM, see Table A.1. To assess whether the data in the CU-GMM is consistent with the imposed moment conditions, the Hansen J-test statistic of over-identifying restrictions is included. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. The sample spans the period from January 1, 2013, to December 31, 2019.

Before concluding, note that as the HKM metric is a function of the leverage ratio, a ratio that has become a key instrument of the global banking regulatory framework Basel III, our results are consistent with the view that the stricter banking regulation in the aftermath of the GFC (e.g., by requiring lower leverage ratios) may have rendered sterilized FXI more effective, which may partially explain the steadily increasing use of FXI according to the International Monetary Fund (2022) report.

3.2 Interventions and the higher-order moments of the RND

To understand how option markets' expectations change when the BOI intervenes in the spot market, we extend now our analysis and assess to what extent option markets price in future FXI, as reflected in the price quotes of the ATMVs, the scaled RRs, and the scaled BF spreads.[38] These price quotes are proxies for the higher-order moments of the RND (see online Appendix F.3 for details). Hence, any changes in these prices quotes reflect a change in the higher-order moments of the RND.

We assess how these price quotes respond to the BOI's FXI activities both contemporaneously and over longer horizons (Section 3.2.2). We focus on option contracts with maturities ranging from one month ("1 M") to twelve months ("12 M"). This granularity allows us to understand the option market participants view about the long-term effect of FXI, which is relevant for policymakers.

3.2.1 Relationship between the lagged higher-order moments of the RND and interventions

In this section, we assess to what extent the price quotes of the ATMVs, the RRs and the BF spreads account for the effect of future FXI over their lifetime. Formally, we regress the FXI data on the one-day lagged two-week change of the equally weighted mean of the scaled 10- and 25-Δ RR ("$\Delta\overline{\text{RR}}_{t-11,t-1}$"), the scaled BF spreads ("$\Delta\overline{\text{BF}}_{t-11,t-1}$") and the ATMV ("$\Delta\text{ATMV}_{t-11,t-1}$") as controls. We scale the price quotes of the RR and the BF options, so that these prices no longer depend on the prevailing level of the option-implied volatility curve (Jurek, 2014). Depending on the specific definition of the IV smile curve, the scaled price quotes then directly reflect the option-implied skewness and excess kurtosis of the USD/ILS RND.

We control for the contemporaneous change in the spot rate to control for the systematic positive correlation between changes in the USD/ILS spot rate and changes in the quoted prices of the RRs and BF spreads that is observed in practice. In other words, we want to assess to what extent the options market reacts to new information beyond the contemporaneous reaction that is due to changes of the spot rate induced by the BOI's FXI. The results are displayed in Table 8. In all the specifications, we use

[38] We divide the price quotes of both the RR and the BF option contracts by the ATMV with equivalent maturity.

the same controls as in our benchmark specification in Table 5.

Table 8: Relationship between lagged scaled risk reversals, butterfly spreads, at-the-money implied volatilities and interventions

	Dependent variable: $\mathbf{FXI_t}$				
	1 M	**3 M**	**6 M**	**9 M**	**12 M**
Intercept	0.01***	0.01***	0.01***	0.01***	0.01***
	(6.86)	(6.90)	(6.85)	(6.82)	(6.74)
$\Delta\overline{RR}_{t-11,t-1}$	0.153**	0.205**	0.226*	0.187*	0.204*
	(2.03)	(2.12)	(1.87)	(1.66)	(1.68)
$\Delta\overline{BF}_{t-11,t-1}$	0.122	−0.078	−0.133	−0.266	−0.361
	(0.39)	(−0.28)	(−0.49)	(−1.04)	(−1.21)
$\Delta ATMV_{t-11,t-1}$	0.0016	0.0042	0.0037	0.0019	−0.0008
	(0.30)	(0.64)	(0.50)	(0.25)	(−0.09)
Controls	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	6.34	6.40	6.39	6.34	6.38

Notes: The size of daily FX interventions ("FXI_t", in USD billion) is regressed on the one-day lagged two-week change of the equally weighted mean of the scaled 10- and 25-delta USD/ILS risk reversals ($\Delta\overline{RR}_{t-11,t-1}$), the scaled 10- and 25-delta USD/ILS butterfly spreads ($\Delta\overline{BF}_{t-11,t-1}$) and the at-the-money USD/ILS options ($\Delta ATM_{t-11,t-1}$). We consider five option maturities in total, ranging from one month ("1 M") to twelve months ("12 M"). As additional controls, we use the variables described in Appendix Table A.1. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% levels respectively. The sample spans the period from January 1, 2013 to December 31, 2019.

The results show that only the coefficients associated with $\Delta\overline{RR}$, a measure of the skewness of the RND, are significant. As the coefficients associated with the $\Delta\overline{BF}$ spreads are insignificant, option market participants seem to price in only crash risks related to a large ILS depreciation. Hence, by intervening in the spot market, the BOI can also affect the higher-order moments of the RND (reflecting option market expectations) in the intended direction.

Regarding the size of the effect, we see that an increase of the RR by one percentage point is associated with a FXI volume which is larger by between mUSD 153 ("1 M") and mUSD 226 ("6 M"). The upward adjustment of the RRs in anticipation of higher future FXI happens across all maturities. This implies that option market participants perceive the upcoming FXI activity as having a large effect on the future spot rate that is expected to last for at least twelve months. Said differently, they price an upcoming intervention before it occurs.

3.2.2 Econometric assessment of the longer-term effect of FXI

In this section, using the local projection-instrumental variable (LP-IV) approach (used in e.g., Ramey and Zubairy (2018)), we examine to what extent the BOI's FXI in the USD/ILS spot market affect the scaled price quotes of these option strategies both contemporaneously and with a lag. This allows us to understand to what extent the expected higher moments of the distribution of future spot rates respond to FXI in the spot market over longer periods. We control again for the contemporaneous correlation between the option price quotes and the spot rate

We begin by analyzing the effect of FXI on the higher-order moments of the RND function (Figure 3). We see that FXI are: (i) Associated with a lower ATMV,[39] (ii) Higher skewness due to an increase in the thickness of the right tail relative to the thickness of the left tail (i.e., a more pronounced tilt towards an ILS depreciation)[40] and (iii) Lower kurtosis (i.e. extreme movements are deemed to be less likely).[41,42] We also note – even though the statistical significance is mixed – that they all point to the same directional effect: FXI tilt the RND towards a future ILS depreciation and lower the implied volatility in the months following the FXI. The results are also economically significant. For instance, a purchase of 1 billion USD - associated with an average depreciation of the ILS by 0.83% vis-à-vis the USD - is associated with a decrease of the ATMV by 5 percentage points (pps).

Our finding (ii), suggesting that the impact of FXI on skewness is significant only for the short option maturities, is consistent with the empirical evidence in Chen, Hsieh, and Huang (2018) for EUR/USD options, who document that "skew risk" is rather a short-term phenomenon,[43] as the significance of the skewness for the exchange rate risk premium decreases with option maturities. Similarly, the finding that the impact of FXI on kurtosis is significant only for the longer option maturities is in line

[39] The ATMV contemporaneously significantly decreases and remains significantly lower over longer periods for the six-, nine- and twelve-month options.

[40] The scaled RR significantly increases over longer periods for one-month options.

[41] Note that the BF spread is negatively related to the excess kurtosis of the distribution of the log return of the USD/ILS spot rate at the maturity date of the underlying options.

[42] The scaled BF spread significantly increases over longer horizons for the six-, nine- and twelve-months options.

[43] Their explanation for this phenomenon is the observation documented in Galai and Schreiber (2013), whereby financial firms trade more short-term than longer-term contracts, as their main motive is to make speculative profits by taking advantage of market uncertainty.

with their observation that "tail risk" is a longer-term phenomenon,[44] as the relevance of the kurtosis relative to the skewness for the exchange rate risk premium increases with option maturities. Our results are consistent in the sense that the significance of the coefficients associated with the skewness and the kurtosis changes with option maturities in a way that is qualitatively identical to the pattern in Chen et al. (2018).

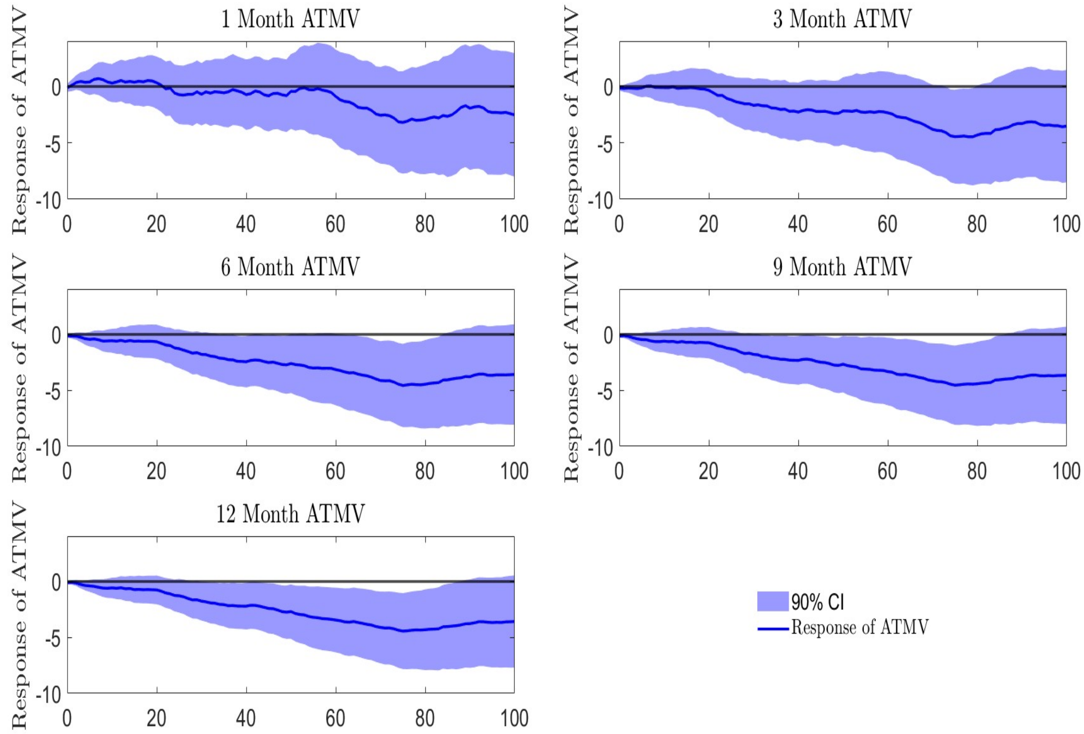
Considering the results from the previous section, which showed that the options market accounts for the FXI in RRs, the additional changes in the higher moments observed after an FXI indicate that only a portion of the FXI was expected. Additionally, the results reveal that the options market did neither anticipate the lower implied volatility nor the lower kurtosis as a response to the BOI's FXI in the spot market.

Last, we note that the effect on the higher moments is slow-moving with an initial impact that keeps on growing and reaches its peak after 100 days. This could be because it takes time for the market to learn and agree on the effectiveness of the intervention spell. Recall that FXI are secret, and as we show in section 3.2.1, only part of the interventions are priced in.

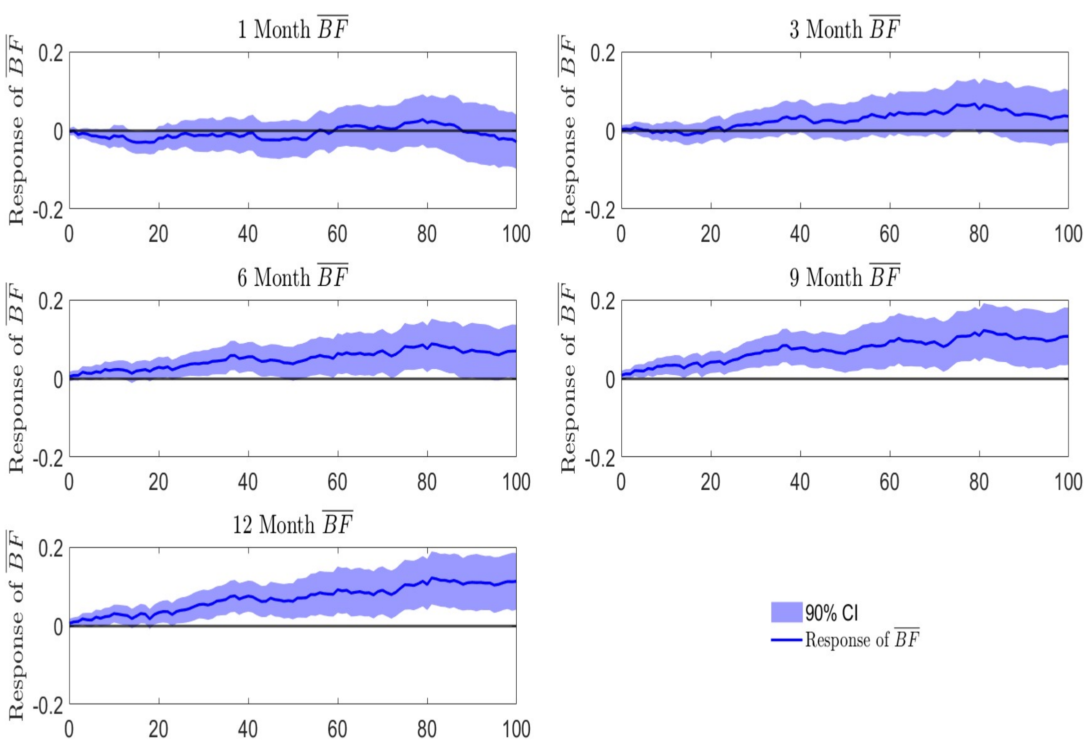
[44] Their explanation for this phenomenon is the observation documented in Galai and Schreiber (2013), whereby industrial firms hedging their currency exposures dominate financial firms for longer option maturities.

Figure 3: Longer-term effect of a FX intervention shock of size $1 billion

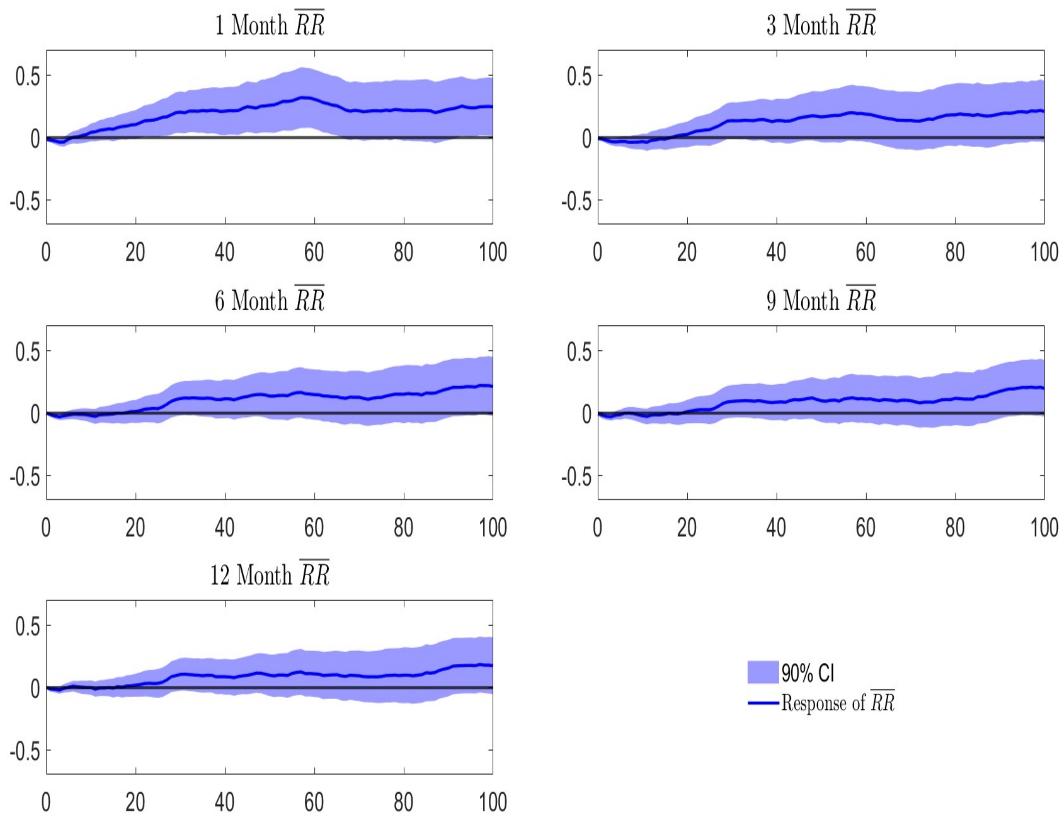
(a) Cumulative change of the at-the-money implied volatility across five maturities



(b) Cumulative change of the scaled butterfly spreads across five maturities



(c) Cumulative change of the scaled risk reversals across five maturities



Notes: The figure shows the average cumulative change of the USD/ILS at-the-money volatility (panel (a)), butterfly spreads (panel (b)) and risk reversals (panel (c)) across five maturities at day $0, 1, \ldots, 100$, where 0 reflects the beginning of the trading day when the first intervention was carried out. The black lines show the cumulative response, while the dotted blue lines display the 90% and 95% confidence intervals, respectively.

3.3 Interventions and tail probabilities

In the following, we want to analyze to what extent the tail probabilities of the RND change in anticipation of future FXI over the lifetime of the underlying options (Section 3.3.1). We also want to assess how these probabilities respond to FXI in the spot market, both contemporaneously and over longer horizons (Section 3.3.2). This expansion is the natural response to the rare disaster model of FX rates proposed by Farhi and Gabaix (2016) that links a currency's crash risk to its spot rate, as this (positive) correlation implies that FXI in the spot market must also alter tail probabilities.

3.3.1 Relationship between the lagged tail probabilities and interventions

This section analyzes the relation between option-implied tail (or crash) probabilities and the size of future FXI. Analyzing this relation serves three purposes: (i) In the previous section, we found a positive relation between the lagged changes in the scaled RR and the contemporaneous size of FXI, after controlling for their effect on the USD/ILS spot rate. Note that the RR reflects the risk-neutral probabilities that option markets attach to a sizeable depreciation of the ILS relative to the probabilities attached to a sizable appreciation of the ILS. Disentangling the former probabilities from the latter probabilities therefore allows us to better understand why the relation between RRs and future FXI changes. (ii) The interest in understanding to what extent FXI affect tail risks is also motivated by the observation[45] that the BOI successfully reduced these risks with spot market FXI in the past (July 2008 to 2010), which suggests that the BOI may consider tail risks in monetary policy decision-making process. (iii) Probabilities are more intuitive to understand than changes in option prices or option-implied higher moments. The empirical results of our approach therefore facilitates policy-making and central banks' communication with the public (e.g. when explaining their monetary policy decisions).

To estimate these probabilities, we fit each trading day and for each of the five maturities that we examine a second-order polynomial to describe the implied volatility-moneyness curve, following the approach proposed by Zhang and Xiang (2008):[46,47]

$$IV(\xi) = \gamma_0 \left(1 + \gamma_1 \xi + \gamma_2 \xi^2\right), \tag{4}$$

with γ_0, γ_1 and γ_2 capturing the level, the slope and the curvature of the IV smile curve and ξ being defined as

$$\xi \equiv \frac{\ln(K/F_t)}{\bar{\sigma}\sqrt{\tau}}, \tag{5}$$

with K denoting the strike price, F_t the forward rate implied by put-call parity for ATM

[45] Based on an interview of the former Governor of the BOI Stanley Fisher in Maggiori (2021).

[46] This curve was proposed by Backus, Foresi, and Wu (2004) for FX options using a slightly different definition for the moneyness *xi*.

[47] See also Cortes, Gao, Silva, and Song (2022) for a similar approach to estimate option-implied tail probabilities.

options,[48] $\bar{\sigma}$ a measure of the average volatility of the underling exchange rate,[49] the latter being an industry convention for stocks to allow comparisons across stocks (in our case: currencies) and $\tau = T - t$ the time to maturity, with the T the date when the underlying option contracts expire.

We opted for this approach instead of using a jump-diffusion model as in e.g. Olijslagers, Petersen, de Vette, and van Wijnbergen (2020), as it is not plausible to expect a complete devaluation (i.e., a crash) of either the ILS or the USD in the period of interest.

After fitting the IV smile curve, we calculate the risk-neutral tail probabilities attached to a strong appreciation of the ILS, using a closed-form formula proposed by Zhang and Xiang (2008):

$$F(S_T, \tau, S_t, 0) = \Phi(-d) + \phi(d)\frac{\gamma_0}{\bar{\sigma}}\left[\gamma_1 + 2\gamma_2\frac{\ln(S_T/F_t)}{\bar{\sigma}\sqrt{\tau}}\right], \tag{6}$$

where S_T is the underlying exchange rate and $\phi(*)$ and $\Phi(*)$ are the standard normal density function and the cumulative standard normal distribution function, respectively. Furthermore,

$$\begin{aligned} d &= \frac{\ln(F_t/S_T) - 0.5V^2\tau}{V\sqrt{\tau}}, \\ V &= \gamma_0\left(1 + \gamma_1\frac{\ln(S_T/F_t)}{\bar{\sigma}\sqrt{\tau}} + \gamma_2\left[\frac{\ln(S_T/F_t)}{\bar{\sigma}\sqrt{\tau}}\right]^2\right). \end{aligned}$$

We proceed in a similar way to obtain the probabilities of a strong depreciation of the ILS. In the present paper, the estimated risk-neutral tail probabilities reflect a change of the USD/ILS spot rate by $\pm$ 2 percent[50] for the one-month maturity, $\pm$ 3 percent for the three-months maturity, $\pm$ 6 percent for the six-months maturity, $\pm$ 9 percent for the nine-months maturity, and $\pm$ 10 percent for the twelve-months maturity. These "thresholds" were chosen in accordance with the thresholds in Hattori, Schrimpf, and Sushko (2016) who analyze equity market tail risks for the S&P 500 index over a three-month horizon. As stock markets are more volatile than FX markets, we scale these thresholds down accordingly.

[48]Which we replace by the corresponding forward rate.

[49]Which we replace by the average of the five implied volatilities of the call, put and ATM options, updated on a daily basis.

[50]Hence, $S_T = 0.98S_t$ ($S_T = 1.02S_t$) for the probability of an appreciation (depreciation) of the ILS.

The results are presented in Table 9. The estimated coefficients all have the expected sign, although they are statistically significant only for the probabilities of a strong depreciation of the ILS. The results show that a 1 percentage point increase in the right tail (that is, a larger probability of a large depreciation of the ILS) is associated with the expectation that the size of FXI will on average be mUSD 315 ("1 M") to mUSD 928 higher ("12 M") compared to the expected size on trading days the right-tail probabilities remain unchanged. This result suggests that market participants anticipate that the size of future FXI will be higher, the higher the probabilities option markets attach to a sizable depreciation of the ILS.

Table 9: Relationship between lagged tail probabilities and interventions

	Dependent variable: FXI_t				
	1 M	**3 M**	**6 M**	**9 M**	**12 M**
Intercept	0.013***	0.014***	0.013***	0.013***	0.013***
	(5.49)	(5.31)	(6.17)	(5.50)	(5.96)
ΔProb. of appreciation$_{t-11,t-1}$	−0.208	−0.370	−0.432	−0.446	−0.503
	(−0.79)	(−1.37)	(−1.51)	(−1.06)	(−1.46)
ΔProb. of depreciation$_{t-11,t-1}$	0.315	0.730*	0.774***	0.641	0.928**
	(1.06)	(1.96)	(2.37)	(1.52)	(2.08)
Controls	Yes	Yes	Yes	Yes	Yes

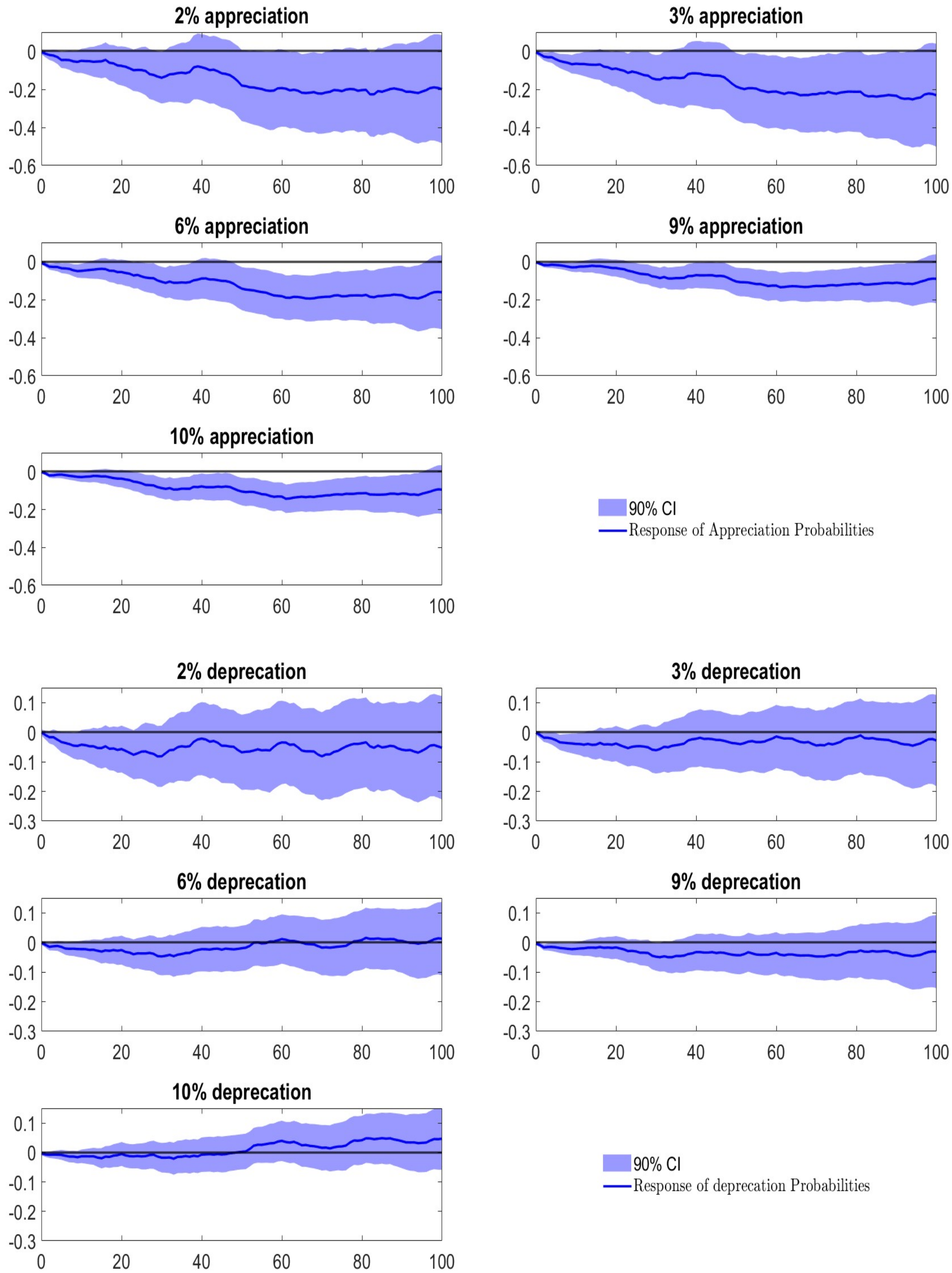
Notes: The table presents the results of regressing the daily intervention volume ("FXI_t", in USD billion) on the one-day lagged two-week change of the probability of a strong appreciation of the ILS ("ΔProb. of appreciation$_{t-11,t-1}$", in percentage points) and of a strong depreciation of the ILS ("ΔProb. of depreciation$_{t-11,t-1}$", in percentage points) for five contract maturities, ranging from one month ("1 M") to twelve months ("12 M"). In all the specifications, we also use both the one-day lagged one-week log return and the one-day lagged one-month log return of the NEER and the one-day lagged one-day change of the VIX as control variables. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% levels respectively. The sample spans the period from January 1, 2013 to December 31, 2019.

3.3.2 Econometric assessment of the longer-term effect of FXI

In Figure 4, we show the response of the right-tail and the left-tail probabilities to an unexpected FXI episode at time zero. The panels exhibit from the left to the right and from the top to the bottom the responses for the one-month, the three-months, the six-months, the nine-months and the one-year contracts to a FXI shock that leads to an expected appreciation (depreciation) of the ILS vis-à-vis the USD of at least 2%, 3%, 6%, 9% and 10%, respectively.

These plots reveal that the change of the RND is driven by a decrease in the probability of a large ILS appreciation (i.e. the left tail), thereby dampening the appreciation pressure for the ILS. For the right tail, we can't reject the null hypothesis that there is no significant enduring effect, except for the nine-month options. This finding supports the view that the BOI's FXI activities in the spot market also affect market expectations in the USD/ILS options market in the intended direction.

Figure 4: Longer-term effect of a FX intervention shock of size $1 billion



Notes: The figure shows the average cumulative change of the left (panel (a); i.e. an ILS appreciation) and the right tail (panel (b); i.e. an ILS depreciation) across five maturities at day $0, 1, \ldots, 100$, where 0 reflects the beginning of the trading day when the first intervention was carried out. The black lines show the cumulative response, while the dotted blue lines display the 90% and 95% confidence intervals.

4 Conclusion

Since early 2008, the Bank of Israel (BOI) has periodically purchased USDs to weaken the foreign value of the ILS vis-à-vis the USD in the spot market. Focusing on the BOI's foreign exchange intervention (FXI) regime from 2013 until the COVID-19 pandemic erupted, we find that these FXI have caused a strong depreciation of the ILS. We show that the high effectiveness of the BOI's FXI can partially be explained by the existence of financial frictions – in the form of capital constrained major financial intermediaries – thereby providing empirical support to the recent theoretical research that rationalizes the effectiveness of sterilized FXI in the spirit of Gabaix and Maggiori (2015). As a by-product, this finding provides guidance to central banks about what type of financial friction (i.e., capital constrained global financial intermediaries) is associated with more effective sterilized FXI in the spot FX market.

We also find that FXI widens the deviation from covered interest rate parity (CIP) – referred to as the cross-currency basis (CCB). This widening is predicted by a model proposed by Amador et al. (2020), who study the problem of a central bank in a small open economy that pursues an optimal FX rate policy in a zero interest rate environment that ultimately leads systematically to a CIP violation, indicating that our findings may be externally valid.

Moreover, our results suggest that monitoring the option markets allows central banks to extract valuable information about how market expectations – reflecting e.g. the higher-order moments of the RND, the price of insurance against crash risk or tail risk probabilities – respond to FXI in the spot market. This suggests that central banks with a FXI regime should implement a comprehensive analytical framework to monitor the effectiveness of their FXI activities in the spot market.

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Appendix

A Specification analysis of first-stage regression

We have experimented with additional instruments such as the deviation of the USD/ILS spot rate from an implicit target level,[51] thereby assuming that the BOI intervenes when the value of the ILS vis-à-vis the USD is deemed to be too high compared to its historical average. We have also experimented with the one-month ATMV and the one-month 25-Δ RR using the deviation from different historical means as an indicator triggering FXI (Galati et al., 2005). As all these instruments were not significant in the first-stage regression, we decided to exclude them.

We have also experimented with the controls, e.g. using the change in the 5-year Israeli CDS spread as an additional explanatory variable, following Nedeljkovic and Saborowski (2019). As this control did neither improve the explanatory power of our first-stage regression nor the statistical characteristics of our CU-GMM regression, we decided not to include this variable to have a parsimonious specification.

The result of the final first-stage regression are displayed in Table A.1. Most estimated coefficients have the expected sign, pointing to a "leaning against the wind" FXI activity. Because all the instruments of this specification are used as instruments in our CU-GMM regression, we include the Montiel Olea and Pflueger (2013) statistic which is robust to heteroskedasticity, autocorrelation, and clustering. The test statistic exceeds the critical value. We therefore reject the null hypothesis that the instruments have insufficient explanatory power and can be confident that we will be able to handily address the endogeneity when using the CU-GMM estimator. The result is important, as this estimator may exhibit poorly-defined finite sample moments when using weak instruments (see Hahn, Hausman, and Kuersteiner (2004) and Donald and Newey (2000)).

To assess the robustness of our benchmark specification, we run variants of our first-stage regression in Table A.2. Specification [1] shows that the one-day lagged daily FXI is significant, but not the two-day lag. In specification [2], we add a dummy

[51] Following e.g. Baillie and Osterberg (1997), Galati et al. (2005), Disyatat and Galati (2007), Galati et al. (2007), Ito (2007), Ito and Yabu (2007), Nedeljkovic and Saborowski (2019) and Naef and Weber (2023) that were inspired by the findings in Goodhart and Hesse (1993) and Lewis (1995).

that equals one whenever the BOI intervened in the previous week. We also add the log of the two-day, two-weeks, and three-months returns of the USD/ILS spot rate with different lag structures and an indicator that is assumed to trigger FXI whenever the deviation of the spot rate from its long-term moving average $\Delta MA(USD/ILS)_{t-1}$ – as a proxy for the unobserved fundamental USD/ILS value – is too large. We use the one-year moving average. The results reveal that this deviation doesn't have any explanatory power, unlike the log return series of the USD/ILS spot rate. Specification [3], however, shows that a model with the lagged NEER in addition to the USD/ILS spot rate leads to insignificant instruments. In specification [4], we add the change in the 5-year Israeli CDS and the VIX, after removing the USD/ILS spot rate data. With regards to the CDS and the VIX, only the former is highly significant, but economically insignificant. Specification [5] confirms the relevance of the lagged NEER data.

Table A.1: First-stage regression

Controls	Dependent variable: FXI_t (in USD billion)
Intercept	0.014***
	(7.15)
$\Delta EUR/USD_{t-1,t}$	0.012***
	(2.83)
$\Delta VIX_{t-5,t}$	0.00027
	(0.52)
$IL\_Monetary\_Surprise_t$	0.089
	(0.69)
$IL\_CPI\_Surprise_t$	0.006
	(0.24)
$NS\_FFR\_Surprise_t$	−0.285
	(−0.77)
$NS\_Policy\_Surprise_t$	0.475
	(1.18)
$CITI\_Surprise\_Index_t$	0.067
	(1.23)
Instruments	
FXI_{t-1}	0.174***
	(3.97)
$\mathbb{1}_{\{FXI_{t-6,t-1}>0\}}$	0.008**
	(1.97)
$\Delta NEER_{t-3,t-1}$	−0.016***
	(−3.76)
$\Delta NEER_{t-13,t-3}$	−0.006***
	(−3.63)
Adjusted R^2	6.2
Effective F Statistic	15.99
Critical Value	15.65

Notes: The dependent variable is the size of interventions ("FXI_t") in USD billions, which we obtained from the BOI and is available on a daily basis from January 1, 2013 to December 31, 2019. Summary statistics for the explanatory variables are reported in Tables 3 and 4. The VIX is expressed in percent. Detailed information on the other controls and instruments can be found in online Appendix B. To assess whether the instruments in the GMM have sufficient explanatory power, the Montiel Olea and Pflueger (2013) test statistic is included using the Newey-West variance estimator. The critical value is also presented with a bias tolerance of 0.10. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

To conclude the discussion about our final specification, note that the aforementioned "sensitivity analysis" in Appendix A suggests that the estimated coefficients are both qualitatively and quantitatively similar across all the different specifications. We therefore feel confident about the robustness of our first-stage regression specification. The adjusted coefficient of determination $\bar{R}^2$ is nevertheless lower than in previous studies that have estimated comparable first-stage regressions.[52] As the first-stage regression

[52] See Table 2 in Galati et al. (2005) who obtain an $\bar{R}^2$ of 0.1 and 0.09 for the case of the BOJ and the Federal Reserve, respectively; Table 2 in Disyatat and Galati (2007) with an $\bar{R}^2$ of 0.18 for the CNB;

is only estimated to shield our empirical results against simultaneity bias and not in order to get a specification with a high explanatory power, the low $\bar{R}^2$ is a minor issue.

Tables 6 and 9 in Galati et al. (2007) who report an $\bar{R}^2$ of 0.19 for the JPY sales activity of the BOJ. Ito and Yabu (2007) estimate a reaction function for the BOJ that even explains 30.9% of the variation, using an indicator of interventions instead of the actual size of interventions.

Table A.2: First-stage regression specification analysis

	[1]	[2]	[3]	[4]	[5]
Controls					
Intercept	0.016***	−0.006	−0.005	0.013***	0.013***
	(7.43)	(−0.23)	(−0.22)	(6.65)	(6.81)
ΔEUR/USD$_{t-1,t}$	0.012***	0.012***	0.012***	0.012***	0.012***
	(2.72)	(2.88)	(2.86)	(2.81)	(2.81)
ΔVIX$_{t-5,t}$	−0.00001	0.00024	0.00027	−0.00001	0.00021
	(−0.02)	(0.47)	(0.51)	(−0.02)	(0.40)
IL_Monetary_Surprise$_t$	0.075	0.086	0.086	0.089	0.095
	(0.57)	(0.64)	(0.66)	(0.71)	(0.75)
IL_CPI_Surprise$_t$	0.012	−0.005	−0.002	0.009	0.004
	(0.53)	(−0.21)	(−0.08)	(0.39)	(0.17)
NS_FFR_Surprise$_t$	−0.396	−0.311	−0.293	−0.331	−0.317
	(−1.07)	(−0.86)	(−0.80)	(−0.89)	(−0.86)
NS_Policy_Surprise$_t$	0.526	0.442	0.447	0.490	0.497
	(1.30)	(1.14)	(1.14)	(1.21)	(1.24)
CITI_Surprise_Index$_t$	0.058	0.088	0.087	0.078	0.077
	(1.04)	(1.62)	(1.59)	(1.46)	(1.41)
Instruments					
FXI$_{t-1}$	0.18***	0.17***	0.17***	0.17***	0.17***
	(4.17)	(3.97)	(3.89)	(3.95)	(3.95)
FXI$_{t-2}$	0.02				
	0.40				
$\mathbb{1}_{\{\text{FXI}_{t-6,t-1}>0\}}$	0.01	0.01	0.01*	0.01*	0.01*
	(1.53)	(1.41)	(1.66)	(1.85)	(1.93)
ΔUSD/ILS$_{t-3,t-1}$		−0.01***	−0.01		
		(−2.56)	(−1.19)		
ΔUSD/ILS$_{t-13,t-3}$		−0.0042***	−0.0003		
		(−2.48)	(−0.09)		
ΔUSD/ILS$_{t-61,t-1}$		−0.0013**	−0.0016		
		(−2.20)	(−1.47)		
ΔMA(USD/ILS)$_{t-1}$		0.01	−0.01		
		(0.90)	(−0.84)		
ΔNEER$_{t-3,t-1}$			−0.01	−0.02***	−0.02***
			(−0.85)	(−3.66)	(−3.64)
ΔNEER$_{t-13,t-3}$			−0.01	−0.01***	−0.01***
			(−1.61)	(−2.90)	(−2.98)
ΔNEER$_{t-61,t-1}$			0.0002	−0.0017***	−0.0016***
			(0.15)	(−2.57)	(−2.42)
ΔCDS$_{t-21,t-1}$				−0.0004**	
				(−1.99)	
ΔVIX$_{t-11,t-1}$				0.0005	
				(1.12)	
Adjusted R^2	4.32	6.43	6.49	6.36	6.27
Effective F Statistic	13.43	13.19	10.32	12.48	14.69
Critical Value	15.02	16.51	16.86	17.44	17.37

Notes: The dependent variable is the size of interventions ("FXI_t") in USD billions, available on a daily basis from January 1, 2013 to December 31, 2019. To assess whether the instruments in the GMM have sufficient explanatory power, the Montiel Olea and Pflueger (2013) test statistic is included using the Newey-West variance estimator. The corresponding critical value is presented with a bias tolerance of 0.10. Summary statistics for the explanatory variables are reported in Tables 3 and 4. Foreign and institutional flows are in USD millions. The CDS spread is in basis points. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

B Verbal interventions

In this section, we explore to what extent the results we find in the paper are due to "verbal" interventions and only to a lesser degree to actual interventions, as we claim in our paper. To test this, we hand-collect from Bloomberg all news articles where a high-ranking official (i.e., the governor or the deputy governor) from the BOI mentions FXI. We find 12 such articles which we display in Table B.1. In untabulated results, we show that days in which the articles were published are associated with high USD/ILS volatility, indicating that they do reflect valuable news to the FX market.

Table B.1: Verbal interventions by the BOI

Date	Verbal intervention
4/8/2013	Bank of Israel confirms intervention in forex market Monday
5/13/2013	Bank of Israel unexpectedy cut rates and reveals shekel plan
3/24/2014	HSBC says central bank may impose shekel floor
3/1/2017	BOI says forex intervention still on table
3/2/2017	BOI says reserves can exceed $100b limit
7/6/2017	Israeli govt' to put aside $1.5b for fx intervention
9/29/2017	BOI's Flug: FX intervention in small banks' version of QE
1/31/2018	Bank of Israel official urges patience on shekel strength
12/25/2018	Yaron doesn't rule out intervention in forex market
4/18/2019	Israeli central bank might resume intervening in the forex
11/26/2019	Bank of Israel holds base rate at 0.25%, intervenes in forex market
11/30/2019	Bank of Israel prefers Forex buys to interest cuts for now, says official

Notes: Data is hand-collected from Bloomberg's news terminal. The sample spans the period from January 1, 2013, to December 31, 2019.

Next, we want to examine how the results of Table 5 change, when we exclude the dates in which the BOI verbally intervened. Note that adding verbal interventions as a dummy variable would possibly introduce an endogenity bias – therefore we don't pursue that strategy. The results are shown in Table B.2. They show that intervention continues to be highly effective even on days with no verbal intervention and is quantitatively similar to the results we find for the overall sample.

Table B.2: Contemporaneous relation between the exchange rate and interventions on days without verbal interventions

	Dependent variable: $\Delta \ln(USD/ILS_t)$ (in %)		
	[1]: OLS	**[2]: CU-GMM**	**[3]: 2SLS**
Intercept	−0.02***	−0.03**	−0.03**
	(−2.81)	(−2.27)	(−2.26)
FXI_t	0.54***	0.93**	0.91**
	(4.67)	(2.03)	(1.97)
$\Delta EUR/USD_{t-1,t}$	−0.41	−0.41	−0.41
	(−22.98)	(−21.16)	(−21.10)
$\Delta VIX_{t-5,t}$	0.011***	0.01***	0.01***
	(4.32)	(4.28)	(4.24)
IL_Monetary_Shock$_t$	−3.35***	−3.45***	−3.42***
	(−4.70)	(−4.83)	(−4.75)
IL_CPI_Shock$_t$	−0.53**	−0.54**	−0.54**
	(−2.00)	(−2.04)	(−2.03)
NS_FFR_Shock$_t$	−5.95*	−5.80	−5.79
	(−1.73)	(−1.68)	(−1.67)
NS_Policy_Shock$_t$	1.55	1.35	1.35
	(0.90)	(0.78)	(0.77)
CITI_Surprise_Index$_t$	−0.00006	−0.00010	−0.00009
	(−0.25)	(−0.42)	(−0.35)
Hansen J-statistic		0.23	
Hansen J-statistic p-value		0.97	

Notes: The daily change of the three-month USD/ILS basis (in percentage points, annualized) is regressed on an intercept, the size of interventions ("FXI_t"; in USD billions), the daily log return of the EUR/USD spot rate ("$EUR/USD_{t-1,t}$"; in percent), the one-week change in the VIX ("$\Delta VIX_{t-5,t}$"; in percentage points) and the one-week change of the USD LIBOR rate ("$\Delta LIBOR_{t-5,t}$"; in percentage points). In specification [1] and [2] standard OLS and the continuously updated GMM estimator (CU-GMM) are used. In specification [3], we report the two-stage least squares estimator (2SLS). For details about the set of instruments that are included in the CU-GMM, see Table A.1. To assess whether the data in the CU-GMM is consistent with the imposed moment conditions, the Hansen J-test statistic of over-identifying restrictions is included. The t-statistics (in parentheses below the coefficients) are the Newey-West HAC corrected t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. The sample spans the period from January 1, 2013, to December 31, 2019 excluding the days of verbal intervention as shown in Table B.1.

C Econometric assessment of the longer-term effect of interventions

The empirical evidence on the effectiveness of FXI shows in its majority that their effect on spot rates is rather short-lived (see Galati et al. (2005) and the survey in Villamizar-Villegas and Perez-Reyna (2015)). To check whether this is also true for the BOI's FXI activities, we will now assess the persistence of the initial effect of the BOI's FXI activity.

To this end, we analyze the relation between the size of the USD purchases and future spot rate returns using the local projection-instrumental variable (LP-IV) approach (used in e.g., Ramey and Zubairy (2018)). Specifically, we regress separately the log returns from $t-1$ to $t+h$ of the USD/ILS spot rate (panel (a)), the NEER (panel (b)) and the three-month USD/ILS CCB (panel (c)) on the size of FXI on day t, where h – the length of the forecast horizon – ranges from zero up to 25 trading days for the USD/ILS spot and forward rate. For the CCB, h ranges from zero to 100. As controls, we use the variables that we used in Table A.1, but adjust the changes in the controls for the different lengths of the forecast horizon. The instruments that we use are the same than in Appendix Table A.1. We show in Figure C.1 the results for the standard LP-IV approach, as our results were robust to alternative specifications.[53]

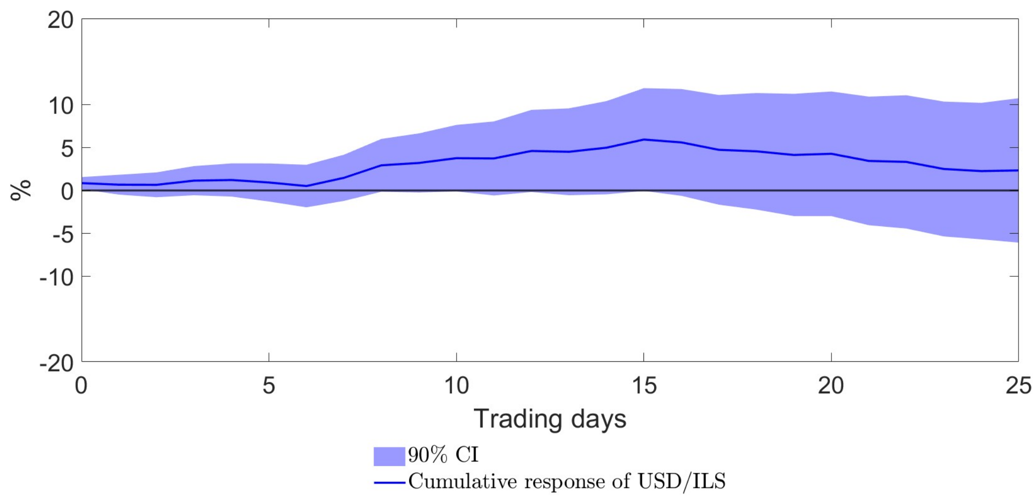
The point estimates suggest that the contemporaneously strong and positive effect of FXI on the foreign value of the ILS in the spot market is not reverted in the subsequent 25 trading days (panels (a) and (b)). The results are significant only for the NEER and only in the first 17 trading days. Having in mind that the NEER includes currencies that are traded less frequently (see our online Appendix E for details), these results are, all else equal, suggestive of an informationally more efficient USD/ILS spot market.

Regarding the results for the CCB (panel (c)), our results are striking. We see that the cumulative returns remain significantly negative up to 90 trading days after the first FXI were carried out. Therefore, the BOI's FXI activity indeed makes the CCB more negative over prolonged periods, which is consistent with the predictions of the Amador et al. (2020) and the Fanelli and Straub (2021) model. It's worth mentioning that Andrew Abir, the deputy governor of BOI, in his analysis of the FX market in 2020 (as per Abir (2020)), speculated that their FXI may have exacerbated the CCB.

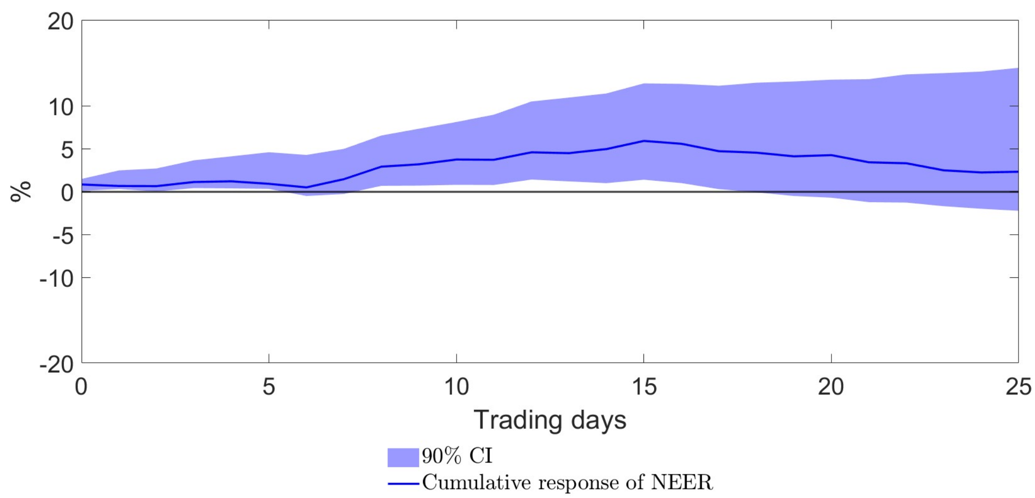
[53] E.g., correcting for potential biases in the estimated coefficients and standard errors, applying the approaches proposed by Hjalmarsson (2011) and Boudoukh, Israel, and Richardson (2021)

Figure C.1: Longer-term effect of a FX intervention shock of size $1 billion

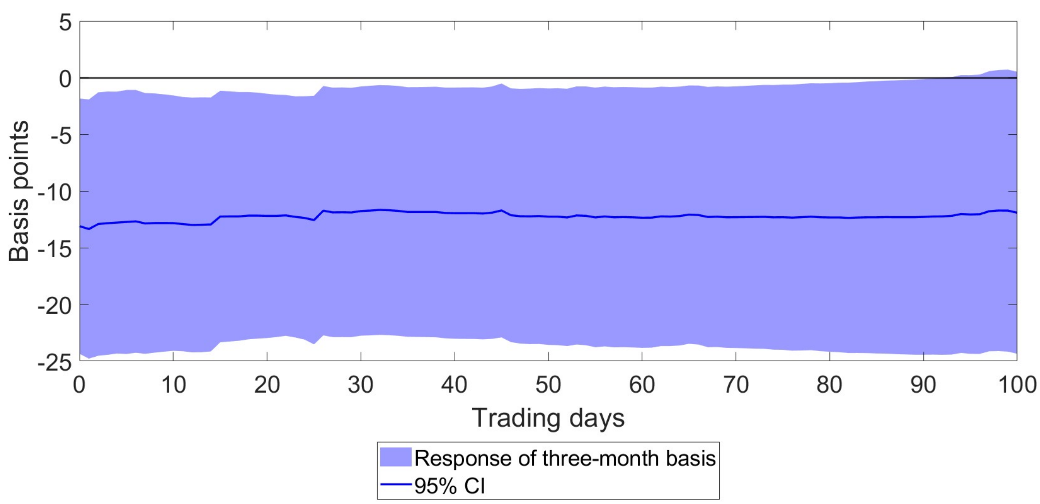
(a) Cumulative returns of the USD/ILS spot rate



(b) Cumulative returns of the NEER



(c) Cumulative returns of the 3-month USD/ILS cross-currency basis



Notes: The figure shows the average cumulative returns of the USD/ILS spot rate (panel (a)) and the NEER (panel (b)) both in percent) at trading day $0, 1, \ldots, 25$. Panel (c) shows the three-month USD/ILS cross-currency basis at trading day $0, 1, \ldots, 100$. Day 0 refers to the trading date when the first interventions (i.e. USD purchases by the BOI) of a given intervention episode was carried out. For panel (a) and (b), the black lines show the cumulative response, while the dotted blue lines display the 90% confidence intervals. For panel (c) the black lines show the currency basis, while the dotted blue lines display the 95% confidence intervals. The estimator is calculated via the LP-IV methodology (e.g., Ramey and Zubairy (2018)) with HAC standard errors.