The Perfect Storm: Bank of Israel's 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 analyse the FXI episode of the Bank of Israel (BOI) from 2013 to 2019. We find that a purchase of US dollar (USD) 1 billion is on average associated with a depreciation of the Israeli new shekel (ILS) by 0.82%–0.83%, which is at the upper bound of the estimated impact in other studies. We show that this effectiveness can partially be explained by global financial intermediaries' limited risk-taking capacity. The (indirect) effect on the forward rate is smaller – the BOI's USD purchases have widened the negative deviation from covered interest parity by 13 basis points. This widening remains significant over 90 days. Contrary to the findings in earlier empirical literature, the higher 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.

JEL classification: E52, E58, E65, F31, G14, G15.

Keywords: Central bank intervention, covered interest parity, exchange rate, expectations, financial frictions, limited risk-bearing capacity, limits of arbitrage.

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1 Introduction

Since the Great Financial Crisis (GFC), many central banks have adopted an intervention regime in the foreign exchange (FX) market as part of their monetary policy toolkit[1] to remain capable of monetary policy action in a low interest environment. While the literature has intensively studied the effect of FX interventions (FXI) on spot FX markets, much less is known about its impact in shaping market expectations as reflected in the FX derivatives markets. The few papers that have researched this topic have found only a weak relation between interventions in spot FX markets and their effect on FX derivatives markets. However, if interventions are associated with a significant spot FX rate response, as the literature suggests,[2] the derivative market's perception of the uncertainty concerning the future spot FX rate[3] may also change, as the price of an option is connected to the price of the underlying FX rate.

The apparent disconnect between the spot and derivative markets may also be at odds with the well-known efficiency of derivative markets in rapidly incorporating news into prices. For example, Hattori, Schrimpf, and Sushko (2016) analyse the response of the tails of the risk-neutral probability density (RND) function extracted from S&P 500 index options to unconventional monetary policy announcements, focusing on quantitative easing (QE) policies.[4] They find that these announcements significantly reduce option-implied equity market crash risk. This finding and the fact that both QE policies and direct FX interventions significantly affect FX rates in theory and empirically[5] suggest that FX interventions may similarly reduce crash risk in FX option markets.

In this paper, we take a comprehensive approach to analyze the effect of FXI, using Israel as a case study. We analyse the effect of the Bank of Israel's (BOI) daily intervention activity – which is confidential data – in the USD/Israeli new shekel (ILS) spot market on the foreign value of the ILS, in the spot, forward and options market. In March 2008, the BOI started intervening in the FX market for the first time since 1997[6] by purchasing USD on a frequent basis and fully sterilising these purchases. As a result of this monetary policy regime switch, the BOI accumulated USD 89.2 billion from March 2008 until December 2019, around 23% of Israeli GDP in 2019.

After more than a decade of USD purchases, the question arises of how effective the intervention activity by the BOI has been to date. We are particularly interested in the response of financial market participants' expectations about the future value of the ILS and its future risk characteristics as reflected in the USD/ILS options market, as the effect of FXI on spot FX rates might be short-lived (e.g. according to the asset pricing

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

[2]For example, in a recent meta-analysis Arango-Lozano, Menkhoff, Rodríguez-Novoa, and Villamizar-Villegas (2020) find that a net purchase of USD 1 billion is associated with a contemporaneous depreciation of the domestic currency by 1%.

[3]As reflected in the higher moments (e.g., the variance, skewness and kurtosis) of the risk-neutral probability density of the underlying exchange rate.

[4]See also Cortes, Gao, Silva, and Song (2022) for a similar finding.

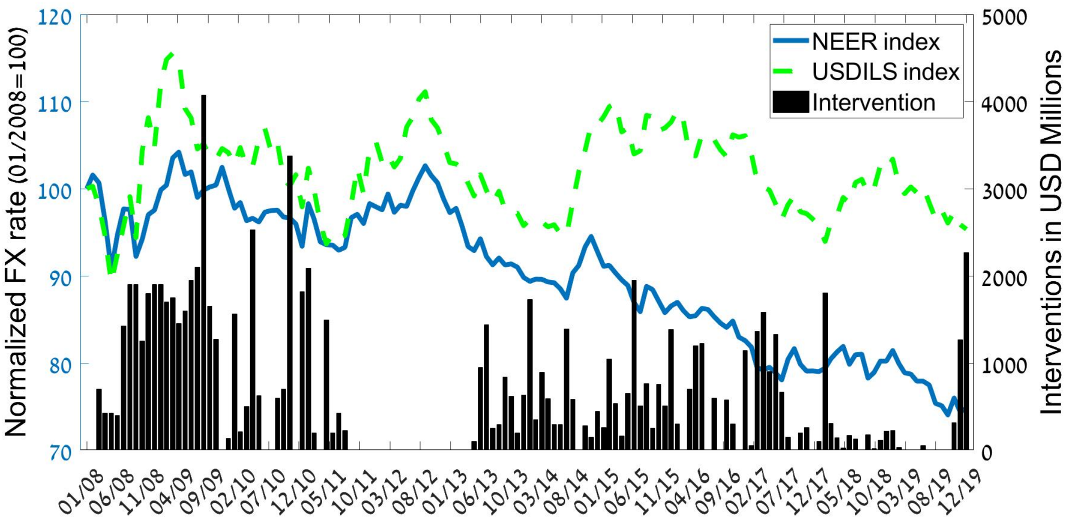
[5]See Jarrow and Li (2015) and Dedola, Georgiadis, Gräb, and Mehl (2021) for evidence on the large and significant impact of QE policies on FX rates.

[6]This intervention activity constitutes the first intervention episode of the BOI since the ILS was allowed to float freely from mid-1997 onwards (Elkayam, 2003).

theory to FX rate determination), if expectations do not change in the intended direction (Miyajima, 2013).[7]

To motivate our paper, Figure 1 displays the monthly volume of FXI, which is public data published by the BOI on a monthly basis, the nominal effective exchange rate (NEER)[8] of the ILS and the USD/ILS spot rate from January 2008 to December 2019.[9] We see a steep appreciation of the ILS by almost 30% from 2008 until the end of our sample according to the NEER and a 10% appreciation vis-à-vis the USD.[10] 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 22 months. For interested readers, we provide an overview of the six different regimes since 2008 in online Appendix A.

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.

In the present paper, we focus on the FXI regime that was in place from January 2013 until January, 14 2021 and was characterized by secret and fully sterilized USD purchases in the USD/ILS spot market. Our sample period ends on December 31, 2019, a few weeks

[7] Dominguez (1986) already emphasized the role of expectations for the determination of FX rates in the aftermath of Bretton Woods. The seminal work of Engel and West (2005) develops an asset pricing formula, where the spot FX rate is a function of both current and expected future fundamentals, which highlights the prominent role of expectations in affecting spot FX rates.

[8] 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`).

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

[10] 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.

before the global COVID-19 pandemic erupted.

Main results. (i) Using the continuously updated generalized method of moments (CU-GMM) estimator, we find that FXI amounting to USD 1 billion[11] are on average associated with a significant 0.83% (0.82%) depreciation of the ILS vis-à-vis the USD (NEER) compared to a trading day without FXI, which is large by both historical and international standards. The initial impact of these FXI remains stable and even rises in the subsequent month, but is statistically significant only for the NEER. (ii) We show that the large contemporaneous effect of the BOI's FXI activity can partially be traced back to the existence of financial frictions (in the form of capital constrained global 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), which 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 finding is new in the FXI strand of literature and provides guidance to central banks about what type of financial friction is desirable to successfully intervene in the spot FX market. (iii) Examining the effect of FXI on the USD/ILS forward rate, the first moment of the RND, we find that FXI increase the price of the USD/ILS forward rate by less than the effect on the spot rate.The lower effect implies that the BOI's FXI activity makes the deviation from covered interest rate parity (CIP) – usually referred to as the cross-currency basis (CCB) – more negative. We show that on impact, a 1 billion FXI increases the CIP deviation by 13 basis points and that the effect persists for at least 90 days. These results are significant in comparison to previous studies that have examined the impact of balance sheet constraints on CIP deviations. Our findings are in line with the theoretical predictions of the Amador, Bianchi, Bocola, and Perri (2020) model, who study the problem of a central bank that pursues an optimal FX rate policy when the zero lower bound binds that systematically leads to a violation of CIP. Our findings are also consistent with the theory of foreign exchange interventions advanced by Fanelli and Straub (2021).[12] (iv) 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,[13] is associated with higher future FXI. This finding suggests that the options market partially prices in future FXI. (v) Contrary to the empirical evidence from other central banks' FXI episodes, the higher-order moments of the RND[14] – proxied by the scaled price quotes of the USD/ILS options – change significantly on days when the BOI intervenes. Specifically,

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

[12]Their framework builds on limited capital mobility in the form of fixed transaction costs and position limits that restricts the ability of financial intermediaries to arbitrage away all return differentials between domestic and foreign bond markets. Changes in the central bank's asset portfolios generates a spread between domestic and foreign bonds, as in Gabaix and Maggiori (2015), which makes FXI effective. Assuming a given exchange rate path without FXI, they also introduce pecuniary externalities in the form of rich households that ignore that their spending decisions negatively affect the purchasing power income of the poor households via the real exchange rate. This externality renders the market equilibrium socially suboptimal. FXI are then used by the central bank to mitigate the distributional effects of adverse real exchange rate movements.

[13]That is, a positive skewness of the RND, as the RR is mostly positive in the period of interest (see Table 4).

[14]That is, its option-implied volatility (IV), skewness, and kurtosis.

we find that the BOI's FXI activities tilt option market expectations towards less volatile (lower at-the-money IV) and less extreme spot rates (lower kurtosis) in the future, while accounting for the possibility of a large ILS depreciation as an aftermath of FXI (higher skewness). (vi) Looking at tail probabilities, we find that the market anticipates a significant effect of the BOI's FXI activity on directional crash risk (i.e., a large depreciation of the ILS), which is consistent with our result (iv). (vii) Consistent with the lower kurtosis documented in (v), the tail probabilities of a large ILS appreciation (i.e., the left tail) decrease dramatically in the weeks following FXI both in the short- and the longer-term for all option maturities that we consider. On the contrary, the tail probabilities of a large ILS depreciation (i.e., the right tail) in general only decrease in the short-term for all option maturities. Consequently, the BOI's FXI had a stronger effect on the left-tail probabilities, i.e., the BOI seems to be more successful in reducing the ILS appreciation pressure than in generating ILS depreciation pressure.

Price discovery in option markets. The question arises as to why part of the information of an upcoming FXI is priced in the options market but not in the spot market,[15] as both markets are connected by put-call parity, unless there are arbitrage opportunities to exploit.[16] Two potential answers come to mind: (1) **limits to arbitrage.** Duffie (2010), Gromb and Vayanos (2010) and Du, Tepper, and Verdelhan (2018) show that balance-sheet constraints may prevent arbitrageurs (e.g., banks) from eliminating arbitrage opportunities. In the case of FX markets, Menkhoff, Sarno, Schmeling, and Schrimpf (2012) argue that limits to arbitrage help explain the profitability of momentum strategies. The argument for constrained arbitrageurs seems particularly relevant in our case, as we find that a one standard deviation increase in the daily change of the RR for all the maturities that we examine is associated with an increase of the expected size of FXI amounting to only USD 3 million (USD).[17] Assuming a USD 1 billion FXI, which is associated with a 0.83% appreciation of the USD/ILS spot rate according to our empirical results, implies that the options market anticipates a mere mUSD $3 \times 0.83\% = 0.0025\%$ depreciation, which is less than 1% of the standard deviation of the daily USD/ILS returns. Therefore, the costs for arbitrageurs may outweigh their expected profits. (2) **Derivative's market sophistication**. Market participants in the derivatives market may be more sophisticated than in the spot market.[18] Empirically, price discovery analyses indeed suggest that FX derivative markets lead spot FX markets in pricing in news.[19]

Related literature and our contributions. We contribute to the strand of literature on FXI in at least five dimensions: (i) there are only few studies that analyze how FXI affect market expectations about the future foreign value of a currency and its risk

[15]The fact that the USD/ILS options market does not significantly adjust its prices when FXI are carried out, while the USD/ILS spot rate significantly changes suggests that the impact of future FXI episodes on the future spot FX rate is priced in the former case.

[16]See Cox and Hobson (2005) and Heston, Loewenstein, and Willard (2007) who demonstrate that this parity breaks down when the martingale property is lost for the underlying security.

[17]It is calculated as the standard deviation of the average relation between RRs and future interventions.

[18]See Brenner and Schreiber (2013) and Piccotti and Schreiber (2015) for evidence from Israel.

[19]See Tse, Xiang, and Fung (2006) and Rosenberg and Traub (2009).

characteristics as reflected in the options market.[20] These risk characteristics are captured by the option-implied higher-order moments (i.e. volatility, skewness, and kurtosis) of the RND. Most of these papers usually do not find a statistically significant relation between FXI in the spot FX market and these risk-neutral moments (or the quoted prices of the option contracts that price these moments). Contrary to the existing literature, we do not limit ourselves to analyzing options with a specific maturity, but explore options with maturities ranging from one to twelve months. This extension is relevant for monetary policymakers, as they learn about the persistence of the effect that FXI have on market expectations in the options market and therefore (indirectly) on the usefulness of the FX rate as an additional monetary policy tool in a zero interest environment.[21]
(ii) We contribute to the strand of literature that estimates the effect that FXI have on the spot FX market[22] in many ways. First, note that most of these contributions cover the years before the GFC, an event that has triggered major changes in global financial markets that provides a motivation for a fresh analysis on how FXI affect spot FX markets. Given the historically exceptional period of sustained low interest rates in the aftermath of the GFC,[23] the fact that financial frictions were treated in a "stepmotherly" way before (Popper, 2022)[24] and the changes that the FX market has undergone in the past three decades in response to technological innovations (Chaboud, Rime, and Sushko, 2022) and the endorsement of a set of voluntary standards within the "Global Code of Conduct" regulatory framework,[25] it is important to have new empirical evidence on the effect of FXI. Second, most empirical papers use only very coarse proxies (e.g. changes in the stock of a central bank's reserves) for the actual size of FXI[26], because most central banks do not report these operations. Investment income (e.g. interests on existing reserve assets),[27] changes in the market prices of reserve assets and FX fluctuations among

[20] See, for instance, 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).

[21] Characterized by nominal interest rates that have fallen to a level "approximating zero" (McCallum, 2000).

[22] See, for instance, 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 et al. (2020).

[23] When nominal interest rates are zero, FXI only work through the non-interest channels. This reduces the effectiveness of unsterilized FXI. By comparing the impulse response functions of a VAR system for the FXI activity of the Bank of Japan vis-à-vis the USD both in a zero-interest period and in "normal times", Iwata and Wu (2012) show that this is indeed the case. They therefore conclude that the interest rate channel dominates the composite non-interest channels (capturing both the portfolio-balance and the signaling channel; see e.g. Sarno and Taylor (2001) or Villamizar-Villegas and Perez-Reyna (2017) for details). Fatum (2015)) reaches a similar conclusion. All else equal, the more recent empirical evidence on FXI should therefore find a lower effectiveness compared to the studies before the GFC that concentrated on unsterilized FXI.

[24] Note that e.g. CIP held for most currency pairs before the GFC (Akram, Rinne, and Sarno, 2008).

[25] See, for example, McGeever (2017) and Szalay (2020) for details about the global FX rigging scandal that initiated the reforms that have led to the creation of voluntary standards.

[26] See e.g. Neely (2000), Dominguez, Hashimoto, and Ito (2012) and Adler, Chang, Mano, and Shao (2021).

[27] See e.g. Dominguez et al. (2012).

reserve currencies,[28] for instance, may all affect the size of official reserves.[29] their To assess the effectiveness of FXI, it is therefore important to have empirical results using actual FXI data. (iii) We also contribute to the recently revived literature that attempts to rationalize CIP deviations.[30] As shown in Amador et al. (2020), these deviations are a direct proxy for the costs of FXI[31] for a central bank in a small open economy when nominal interest rates are zero. To the best of our knowledge, we are the first to empirically quantify the effect that FXI have on the CCB. We find that FXI widen this metric, as predicted by the Amador et al. (2020) model.[32] Note that previous academic contributions have used deviations from uncovered interest parity (UIP) to proxy for the costs of FXI instead (Amador et al., 2020) or to analyze how FXI affect deviations from UIP (i.e., the forward exchange risk premium),[33] which reinforces our view that our work is the first academic contribution that directly links FXI to the dynamics of the CCB. (iv) The effect of sterilized FXI when nominal interest rates are essentially zero is both theoretically[34] and empirically[35] small. Moreover in a frictionless world, financial market participants should instantaneously arbitrage away any FX rate misalignments (e.g. resulting from FXI). Therefore, for sterilized FXI to be effective, we need some type of market friction. We analyse this systematically and find that more pronounced financial frictions (in the form of more capital-constrained financial intermediaries) go hand in hand with a significantly larger impact of FXI. This finding is novel in the FXI literature that rationalizes the "success" of sterilized FXI in practice and finds that financial frictions are the key prerequisite. (v) To the best of our knowledge, we are the first paper providing empirical evidence on how FXI affect tail probabilities over different horizons. As the shape of the RND changes with these probabilities, our contribution helps to understand why the RND changes when FXI are carried out.

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 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. The final Section 4 concludes.

[28]See Adler et al. (2021) for empirical evidence.

[29]Moreover, in the past, some central bank's (e.g. the Bank of England, according to Naef (2021), may eventually have manipulated their official foreign reserve data.

[30]See Du et al. (2018), Avdjiev, Du, Koch, and Shin (2019) and Du and Schreger (2021), among others.

[31]The costs equal the one-period CIP deviation times the end-of-period market value of the stock of total reserves of the central bank.

[32]In their empirical exercise, Amador et al. (2020) assess the relationship between CIP deviations and monthly foreign reserves as a proxy for the actual size of FXI. As just mentioned, foreign reserves are only a coarse proxy for the latter and may lead to biased empirical results.

[33]For instance, Baillie and Osterberg (1997a) and Baillie and Osterberg (2000). See also Bacchetta, Benhima, and Berthold (2022) for a thorough discussion on CIP vs. UIP deviations, who nevertheless do not model the positive effects of FXI (contrary to e.g. Amador et al. (2020)).

[34]See footnote 23.

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

2 Methodology, estimation strategy and data

2.1 Generalized Method of Moments

To assess the impact of the BOI's FXI activity, we first run simple OLS regressions. We ignore thereby potential endogeneity biases (for the time being) caused, for instance, by the hard to disentangle simultaneity of FXI and the "adverse" trajectory of spot FX rates movements that often trigger them (hint: "leaning against the wind").[36] Note that using daily data already reduces the risk that reverse causality and confounding factors may bias our estimated coefficients.[37] In addition, this exercise will allow us to assess how sizable these endogeneity biases potentially are.

In a second step, we run GMM regressions. This allows us to control for potential endogeneity.[38] The GMM approach has four additional advantages. First, this procedure requires no distributional assumptions. Second, many econometric models can be casted into a GMM approach (e.g. instrumental variable regressions), as they often are special cases of the later (Cochrane, 2005). Third and fourth, the GMM approach is also general in the sense that it allows for heteroskedasticity of unknown form and that it can be used when serial correlation cannot be precluded ex ante. In this case, the effect on the estimated standard errors can be accounted for by using a heteroskedasticity and autocorrelation (HAC) consistent covariance matrix.

Expressing the model of interest as:[39]

$$\mathrm{E}\left[f(w_t, z_t, \theta)\right] = 0, \tag{1}$$

where f represents a vector of R population moment conditions, w_t denotes a vector of observable (endogenous or exogenous) variables, z_t is a vector of predetermined instruments and θ a vector containing the K unknown parameters that we are interested in.

Replacing the expectation operator in Equation (1) with its sample counterpart, we get an expression that allows us to estimate the entries of the parameter vector θ:

$$g_T(\hat{\theta}) \equiv \frac{1}{T}\sum_{t=1}^{T} f(w_t, z_t, \hat{\theta}), \tag{2}$$

with T equal to the number of periods and $g_T(\cdot)$ equal to the sample means of the deviation of the R sample moment conditions from their population counterparts.

When we have less sample moment conditions R than unknown parameters K, the parameter vector $\hat{\theta}$ is unidentified. When the number of sample moment conditions R equals the number of unknown parameters K, the parameter vector $\hat{\theta}$ can be exactly identified by setting the R elements in Equation (2) equal to zero. Finally, when the number of moment conditions exceeds the number of parameters (i.e. $R > K$), the GMM estimator $\hat{\theta}_{GMM}$ is chosen such that it minimizes a quadratic form of $g_T(\hat{\theta}_{GMM})$, weighted

[36] See Neely (2005), Fratzscher (2005) or Tashu (2014) for details.

[37] See e.g. Rogers and Siklos (2003) or Menkhoff, Rieth, and Stöhr (2021) for details.

[38] The empirical literature mainly uses either GMM or instrumental variable-panel regressions to shield against potential biases due to simultaneity (see e.g. Adler and Tovar (2011) and Adler et al. (2019)).

[39] The following exposition follows Chapter 11 in Cochrane (2005) and Chapters 1 and 3 in Hall (2005).

by a symmetric, positive definite weighting matrix W_T:

$$\underset{\hat{\theta}_{GMM}}{\operatorname{argmin}}\, Q_T(\hat{\theta}_{GMM}) = \underset{\hat{\theta}_{GMM}}{\operatorname{argmin}}\, g_T(\hat{\theta}_{GMM})' W_T g_T(\hat{\theta}_{GMM}). \tag{3}$$

It can be shown that the asymptotically efficient GMM estimator of this quadratic form is asymptotically normally distributed:

$$\sqrt{T}\left(\hat{\theta}_{GMM} - \theta\right) \xrightarrow{a} \mathcal{N}(0, V), \tag{4}$$

with V representing the asymptotic covariance matrix.

Continuously updated GMM estimator. When running the GMM regressions, we use the CU-GMM proposed by Hansen, Heaton, and Yaron (1996), as it often exhibits better small sample properties compared to the two-step (or iterated) GMM estimator. This estimator uses a covariance matrix W_T that is updated in each step of the GMM algorithm until it converges.

2.2 Data

2.2.1 Foreign exchange interventions data

Table 1 displays selected descriptive statistics of the publicly available monthly aggregated FXI data from the BOI for the period from January 2013 to December 2019. The descriptive statistics indicate that, on average, the BOI purchased mUSD 594 per month, with a minimum of mUSD 2 and a maximum of USD 2.27 billion. 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 (i.e. exhibit a long tail in the positive direction of the number line), as the mean is larger than the median. In essence, there are a few observations that are large compared to all other FXI data. This is confirmed in an untabulated histogram of the monthly FXI data.

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 and in terms of calendar time, 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 the different FXI episodes:

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, Gloede, Menkhoff, Sarno, and Stöhr (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. Compared to other central banks' FXI episodes, this evidence suggests that FX market participants may partially be able to infer when the BOI is intervening, as the FXI volume is large by international standards. This will later become relevant when interpreting our empirical results.

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 aimed at also affecting market expectations should combine intervention episodes with days of no activity to allow FX derivatives market participants to evaluate the effect of these interventions over longer horizons – the BOI apparently follows this advice.

2.2.2 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. The data contain a maximum of 1826 trading days.[40]

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. The statistics indicate that the ILS appreciated vis-à-vis the USD and the currencies of its major trading partners by 0.004% and 0.014% on

[40]There are some missing observations in the volume data, which we linearly interpolate.

average, which is qualitatively in line with the time series displayed in Figure 1. These time series suggest – all else being equal – that the ILS appreciated more vis-à-vis the currencies of Israel's major trading partners ex USA, than against the USD itself. Similarly, the USD on average appreciated against the EUR by 0.009% per trading day.

Focusing on the USD/ILS FX market, the second upper panel of the table ("USD/ILS transaction volume") provides information on the daily FX market transaction volume in mUSD. The data indicate that the volume of over-the-counter (OTC) traded USD/ILS options exhibits a market share of approximately 6.4% on average.[41] Although this number seems small at first sight, it is large when compared to the corresponding metric in other countries (see the discussion in the next Section 2.2.3).

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
$\Delta \ln$(3M forward)	−0.005	−0.02	0.37	−2.29	1.59	0.05	1826
USD/ILS transaction volume (in mUSD):							
Spot and forward	1660.34	1643.89	875.37	0.04	6399.10	0.10	1769
Swap	4109.50	4118.74	1853.63	0.00	11623.51	0.18	1749
OTC options	395.39	277.84	419.14	0.00	5354.98	0.23	1744
Misc (in %):							
5-year Israeli CDS	0.80	0.74	0.20	0.48	1.52	0.9952	1826
VIX	14.86	13.89	3.81	9.14	40.74	0.9281	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 daily transaction volume in the USD/ILS spot, forward, swap and OTC options market are compiled by the BOI and denominated in millions of USD ("mUSD"). 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 table also displays descriptive statistics in the lower panel ("Misc") for the 5-year Israeli CDS spread. On average, the CDS spread equaled 80 basis points (bps) in the period of interest, which is low by international standards and in line with Israel's high (investment grade) credit rating.[42] The last row displays the descriptive statistics for the VIX as a proxy measure of global uncertainty.

2.2.3 The USD/ILS options market

Table 4 displays descriptive statistics of the USD/ILS options data that we use in the empirical section. The data that we retrieve from Bloomberg is recorded on a daily basis

[41] Measured as the average total transaction volume of OTC USD/ILS options (i.e. mUSD 395.39) divided by the average total USD/ILS transaction volume (i.e. USD 6.17 billion).

[42] Israel's credit rating was last set at A1 by Moody's with a stable outlook on April 24, 2020 (as of the date of writing the paper). This credit rating has remained unchanged since May 6, 2006.

and spans the period from January 1, 2013, to December 31, 2019. The data include at-the-money implied volatilities (ATMV) (upper panel), 10-Δ and 25-Δ[43] butterfly (BF) spreads (middle panel) and 10-Δ and 25-Δ RRs[44] (lower panel) for six maturities, ranging from one week ("1w") to twelve months ("12m").[45] The price quotes are measured in implied volatilities and 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. 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 compared to 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. The lower persistence of the price quotes with the shortest maturities might indicate stale prices and a lack of liquidity, which brings us to our next topic.

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 data from the BIS triennial central bank survey that covers 54 countries and includes data collected from close to 1300 banks and other dealers on FX turnover, amongst others. The survey begins in April 2007.[46] Our calculations (see Table E.1 in online Appendix E) reveal that the ratio of OTC-traded FX option volume to the total FX transaction volume[47] 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 terms of the ratio of total FX options transaction volume to total FX transaction volume in all the surveys that have been conducted 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.[48] We note two things: (i) The relative BAS is generally higher for the one-week contracts. We therefore omit these contracts in the following. (ii) The results show that the relative BAS for the three option strategies are all ranked in the interquartile range, which makes us confident that our option market data is not significantly affected by low liquidity.

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

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

[45]Tables D.2, D.3 and D.4 in online Appendix D displays the coefficients of the cross-correlation between the log returns of these options data. The cross-correlations indicate that the price quotes of the USD/ILS options 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 exchange rate, reflecting a kind of momentum. This contemporaneous relationship was documented in McCauley and Melick (1996), Malz (1997) and Campa, Chang, and Reider (1998) for RRs and implies that investors assign a more pronounced tilt towards a further depreciation of the ILS vis-à-vis the USD (i.e. a higher RR), when the ILS has already weakened (i.e. a higher USD/ILS exchange rate).

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

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

[48]As the IV 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 used 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.

3 Results

As described in Section 1, the empirical evidence to date indicates that FXI significantly affect the targeted FX spot rate in the desired direction. We hypothesize that FXI also affect the market's perception of the uncertainty associated with the future FX spot rate, as reflected in the FX options market. Before we assess to what extent FXI in the

USD/ILS spot market affect USD/ILS option prices (and the herewith associated option-implied higher moments of the extracted RND), we first confirm that FXI indeed lead to a depreciation of the foreign value of the ILS in the period under review.

3.1 Effect of interventions on the foreign value of the ILS

3.1.1 Informal event study

We begin with an informal event study: Figure 2 displays the average cumulative returns of the USD/ILS spot rate (Panel (a)), the NEER (Panel (b)), and the three-month USD/ILS forward rate (Panel (c)), starting 9 days prior to a FXI episode (starting at the beginning of day t) and ending 11 days after the first FXI day. The average cumulative returns are weighted using the relative size of FXI,[49] as we have learned from Table 1 (and the herewith associated following discussion) 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, irrespective of the actual size of USD purchases. Equally weighting the FXI episodes tilts the results in favour of those episodes where the size of FXI was relatively small.[50]

We see that the BOI's FXI contain the appreciation trend of the foreign value of the ILS both in the FX spot and the FX forward market and create a depreciation of the ILS by the end of the first FXI. There is also a slight continuation of this "trend reversal" on day $t+1$, which may reflect a second FXI day in some cases. 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. To summarize this section, these figures imply that the BOI is successful in creating a lasting depreciation in the USD/ILS FX market according to the success "event" and "direction" criterion in the FXI literature.[51] In the next sections, we examine the effect of the BOI's FXI activity more rigorously.

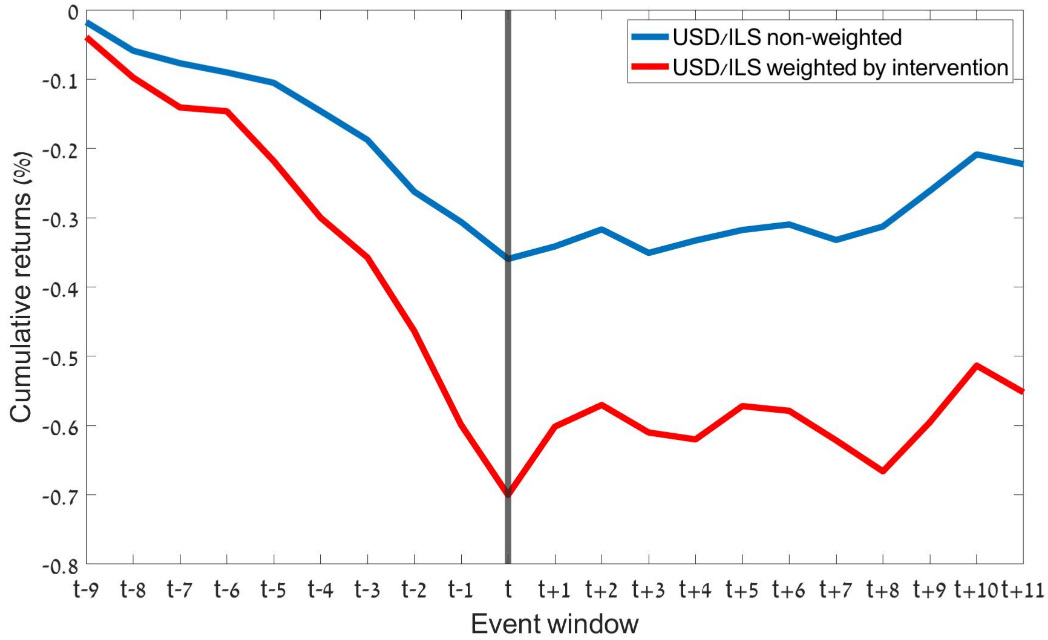
[49]The size of FXI at a specific day $t+j$ (with $j \in \{-9, -8 \ldots, 0, \ldots, +10, +11\}$) divided by the total size of FXI in our sample period.

[50]As a by-product, this "graphical exercise" allows us to learn about the reaction function of the BOI.

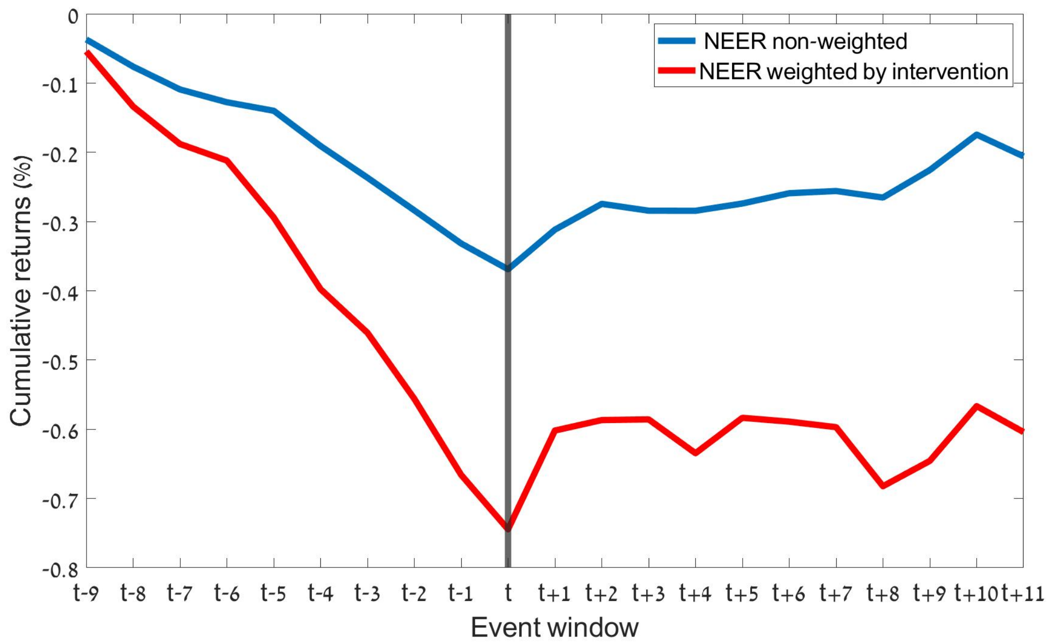
[51]See Humpage (1999), Fatum and Hutchison (2003), Fratzscher (2005), Fatum and Hutchison (2006), Galati et al. (2007), Fatum (2008), Fratzscher (2008) and Fratzscher et al. (2019).

Figure 2: Cumulative returns of the USD/ILS spot rate, the NEER and the 3-month USD/ILS forward rate surrounding the intervention episodes

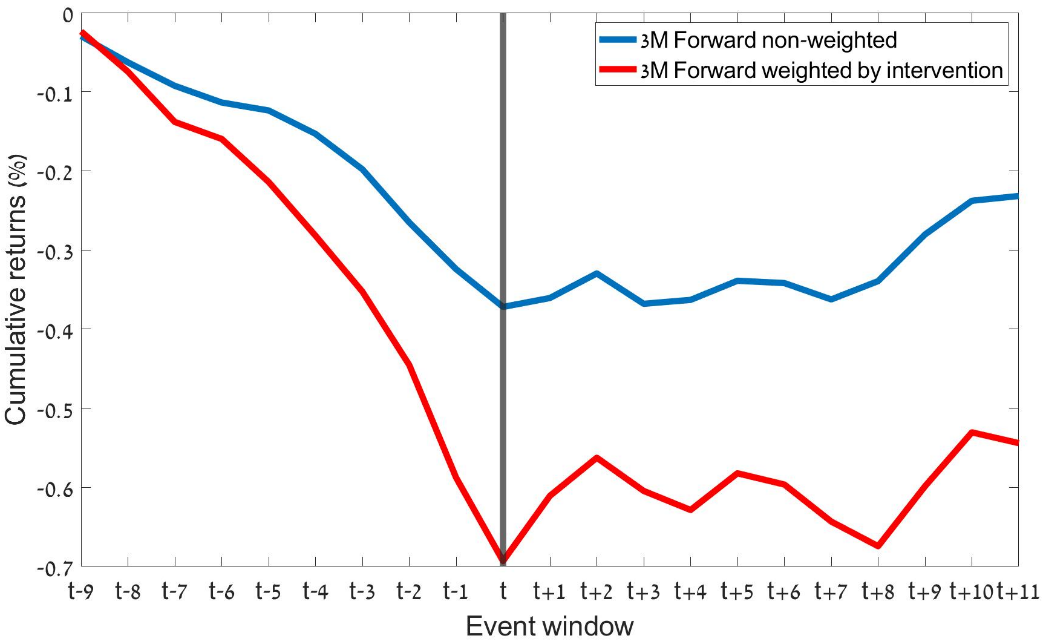
(a) Cumulative returns of the USD/ILS spot rate



(b) Cumulative returns of the NEER



(c) Cumulative returns of the 3-month USD/ILS forward rate



Notes: The figure shows the average cumulative returns of the USD/ILS exchange rate, the NEER (both in percent) and the three-month USD/ILS forward 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.

3.1.2 Econometric assessment of the contemporaneous effect

Estimating the causal effect of FXI on the FX spot rate using OLS usually results in downward-biased estimates. The bias is caused by the stylized fact that central banks typically intervene to respond to adverse spot rate fluctuations (thereby "leaning against the wind"), while the current spot rate simultaneously[52] responds to these FXI activities.

First-stage regression. To mitigate the potential bias caused by this endogeneity, we follow the standard approach in the literature and use instruments in the GMM framework that are correlated with the FXI data but not with the shocks that affect the FX spot rate on the days when the BOI intervenes. We use instruments that are commonly used in the FXI literature and are defined in online Appendix B. Our instruments include the one-day lagged daily FXI volume,[53] 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-day lagged two-week return of the NEER. We have also experimented with additional instruments, e.g. the deviation of the USD/ILS spot rate from an implicit target level,

[52]This bias would not arise if central banks "responded only slowly to fluctuations in the exchange rate, or if the data sampling interval were sufficiently fine" (Chen, Watanabe, and Yabu, 2012), i.e. using intraday data as in Caspi et al. (2022).

[53]Following, e.g., Nedeljkovic and Saborowski (2019) to account for the persistence in FXI in periods of sustained appreciation pressure. To assess the validity of this instrument, we have calculated the difference-in-Hansen test proposed by Eichenbaum, Hansen, and Singleton (1988). The results add support to our specification.

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, following the FXI strand of literature.[54,55] As these instruments were not significant, we opted to exclude them.

As controls, we use contemporaneous explanatory variables: The one-day log return of the EUR/USD spot rate, the one-week change in the VIX,[56,57] a variable that captures the magnitude of the monetary surprise in Israel ("IL_Monetary_Surprise")[58] and a variable that captures the surprise in Israeli monthly CPI ("IL_CPI_Surprise").[59] We also control for both short- and longer-term monetary surprises ("NS_FFR_Surprise", "NS_Policy_Surprise")[60] and for global macroeconomic surprises as captured by the CITI US surprise index ("CITI_Surprise_Index").[61] A positive (negative) CITI_Surprise_Index means that macroeconomic US data releases have been better (worse) than expected. The index is measured in basis points of aggregated standard deviations of surprises and has no natural bounds.[62] We choose the lags of the instruments based on adjusted R^2 criteria, i.e. selecting the specifications with the highest adjusted R^2 among the specifications that pass the Montiel Olea and Pflueger (2013) test.

The result of the first-stage regression are displayed in Table 5. Most estimated coefficients have the expected sign, pointing to a "leaning against the wind" FXI activity. Our results are also in line with the results in Ribon (2017), although her results are for monthly data.

Because we use all the instruments of this first-stage regression specification as instruments for our CU-GMM estimation, we also 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

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

[55]Following the approach in e.g. Galati et al. (2005), we have also experimented with the one-month ATMV and the one-month 25-Δ RR using the deviation (i.e. a multiple of its standard deviation) from different historical means as an indicator that triggers FXI.

[56]Motivated by Cerutti, Obstfeld, and Zhou (2021), among others, who document that the CIP deviation tends to widen in periods of increased uncertainty, which they model using the VIX.

[57]We have also experimented with the decomposition of the VIX into a risk aversion (i.e. a risk premium (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 using the VIX instead of the estimated uncertainty component, 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 FX intervention regime.

[58]Defined as the difference between the actual IL monetary interest rate and the average of interest rate forecasts by professional forecasters (about 12) the day before the interest rate decision.

[59]Defined as the difference between the annualized actual change in the IL CPI and the average annual change in the CPI forecasted by professional forecasters the day before the announcement of the CPI.

[60]Defined as the unanticipated change of the federal funds rate target (using federal funds futures) and the unanticipated change in the path of future interest rates within a 30-minute window surrounding scheduled FOMC meetings. This data is an updated version of Nakamura and Steinsson (2018) and can be downloaded from `https://www.acostamiguel.com/replication/MPshocksAcosta.xlsx` and has recently been used by, e.g., Miranda-Agrippino and Ricco (2021).

[61]The news indicators are included to ensure that our results are not contaminated by relevant macro news.

[62]To get coefficients that are similar in size to the coefficients associated with other explanatory variables, we divide this indicator by a 1000.

instruments have insufficient explanatory power. We 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.[63]

Table 5: First-stage regression

	Dependent variable: FXI_t (in USD billion)
Controls	
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.

In Appendix A, we compare the estimated coefficients and the statistical significance across several first-stage regression specifications, e.g. including additional controls[64] and

[63] See Hahn, Hausman, and Kuersteiner (2004) and Donald and Newey (2000).

[64] We have also experimented with e.g. 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 GMM regression, we decided not to include this variable to have a parsimonious specification.

instruments. From that "sensitivity analysis" we learn 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.[65] As the first-stage regression 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.

Contemporaneous effect. Table 6 displays the results of regressing the daily log return (in percent) of the USD/ILS exchange rate (Panel A), the NEER (Panel B) and the three-month USD/ILS forward rate[66] (Panel C) on an intercept and the contemporaneous intervention variable (in billions of USD). Column 2 presents the results when running a standard OLS regression, while column 3 displays the results when using the CU-GMM estimator. As a robustness check, we also report the results of a two-stage least squares (2SLS) regression in the fourth column. The control variables and instruments are the same as in Table 5.

Before considering the effect of FXI, we want to briefly discuss the estimated coefficients of the other explanatory variables, focusing on the results when running the CU-GMM. A weaker USD (i.e. ΔEUR/USD > 0) is associated with an appreciation of the foreign value of the ILS (i.e., H_0: $\beta < 0$). An increase in global uncertainty (i.e. ΔVIX > 0) leads to safe haven flows (e.g., on a net basis, foreign capital flows to the US). As an aftermath, the USD tends to appreciate in such an environment (i.e. H_0: $\beta > 0$).

Focusing on the news indicators, we note that in most cases the sign of the news indicators is also consistent with prior expectations. For instance, an unexpected tightening of monetary policy in Israel (i.e. IL_Monetary_Surprise > 0) is expected to attract foreign capital, thereby pushing up the foreign value of the ILS. Hence, the coefficient associated with this indicator should be negative (i.e. H_0: $\beta < 0$). Similarly, a positive inflation surprise (i.e. IL_CPI_Surprise > 0) should be followed by a tightening of monetary conditions. Hence, the coefficient should be negative (i.e., H_0: $\beta < 0$). The surprise component of the change in the federal funds rate target (i.e. NS_FFR_Surprise) "is not necessarily in the same direction as the federal funds rate action itself" as emphasized in Gürkaynak, Sack, and Swanson (2005). Hence, a positive surprise can be associated either with the expectation of a tightening (i.e. H_0: $\beta > 0$) or an easing (i.e. H_0: $\beta < 0$) of monetary policy in the US. Hence, the sign of the corresponding coefficient cannot be pinned down on theoretical grounds. For the US monetary policy surprise (i.e. NS_Policy_Surprise), the estimated coefficient is consistent with what we expect: A tightening in the US (i.e. NS_Policy_Surprise > 0) pushes the USD/ILS spot rate up (i.e. H_0: $\beta > 0$). This indicator is, nevertheless, statistically insignificant. For the CITI_Surprise_Index, the coefficient has the opposite sign to what we expect, whereby good US macroeconomic news should lead to an appreciation of the USD (i.e., H_0: $\beta > 0$). The estimated coefficient is, nevertheless,

[65] 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; 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.

[66] The results using USD/ILS forward contracts with other maturities are similar, so we omit them for the sake of brevity.

Table 6: Contemporaneous relation between the exchange rate and interventions

(a) Panel A

Dependent variable: $\Delta \ln(USD/ILS_t)$ (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)
$\Delta EUR/USD_{t-1,t}$	−0.408***	−0.412***	0.044***
	(−23.04)	(−21.42)	(−21.36)
$\Delta VIX_{t-5,t}$	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)
$\text{IL\_Monetary\_Surprise}_t$	−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)
$\text{NS\_Policy\_Surprise}_t$	−7.76***	−8.51***	−7.882***
	(−3.11)	(−3.38)	(−3.09)
$\text{CITI\_Surprise\_Index}_t$	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 5. 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.

both economically and statistically insignificant.

The effect of FXI. The coefficient associated with the FXI variable is highly statistically significant in all regressions, even when ignoring the potential bias caused by simultaneity and simply using standard OLS. Focusing on the results obtained using the CU-GMM estimator, we see that the estimated coefficients are also 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 finding is consistent with our prior – in an efficient market, a depreciation of the ILS vis-à-vis the USD, all else equal, should depreciate the ILS vis-à-vis all other currencies via cross-rates and assuming no-arbitrage. In Appendix C we show that these results are not driven by verbal interventions by officials at the BOI.

When comparing the estimated coefficients when using OLS versus CU-GMM, we see that these are larger in the latter case which suggests that the inclusion of instruments is important to mitigate the endogeneity caused by simultaneity. As explained in Fratzscher (2005) and similar to our findings in Table 5, central banks usually intervene to "lean against the wind," that is, to revert or contain a sustained trend of the foreign value of the domestic currency vis-à-vis a specific foreign currency.[67] Under these circumstances, endogeneity causes a downward (i.e., a negative) bias in the estimated coefficients. As a consequence, OLS regressions tend to underestimate the actual effect of FXI.

Finally, note that the Hansen J-test statistic of over-identifying restrictions is statistically insignificant. This indicates that our GMM model is well specified. Said differently, the data that we use seems to be consistent with the imposed moment conditions.

The estimated coefficient that captures the effect of FXI on the three-month USD/ILS forward rate equals 0.73% and is only statistically significant at the 10% significance level. The value is 11%–12% smaller in size than the coefficient for the two spot rates: FXI seem to reduce the so-called forward premium (i.e. the difference between the forward and the spot rate and a proxy for the CCB when nominal interest rates are essentially zero). Assuming constant domestic and foreign interest rates,[68] our result is at odds with the CIP condition that dictates that the spot and forward rates should move one-to-one. A possible explanation for this arbitrage opportunity might be the existence of balance sheet-constrained banks and the associated difficulty in obtaining dollar funding in the aftermath of the GFC[69,70] that makes it costly for low-rated banks to arbitrage the CCB.[71]

In Table 7, we confirm that the effect on the forward premium (or CCB) is indeed negative and statistically highly significant by regressing the three-month CCB on the FXI.[72] The results are striking – a 1 USD billion FXI is associated with an increase in the dollar basis of about 13 basis point which is statistically and economically significant.[73] To the best of our knowledge, we are the first ones to empirically document a relation between FXI and the dollar basis (and the CCB in general).[74]

Our results are also in line with the predictions of the model proposed by Amador et al. (2020). In their model the central bank of a small open economy (like Israel) can choose an optimal FX rate policy in a zero-interest environment (e.g., to stimulate labor demand by a depreciation of the domestic currency), in addition to the size of its balance sheet. As a by-product, this policy leads to a violation of interest parity when the zero lower bound binds. In such a situation, they show that a central bank optimally sets interest rates to zero and carry out FXI in the spot FX market. All else equal, the implementation of this policy then generates the expectation of an appreciation of the domestic currency

[67] And sometimes also to stabilize the targeted spot rate by dampening its volatility.

[68] 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 rather small. More details follow on page 30.

[69] The recent empirical literature detects a negative CCB vis-à-vis the USD in FX markets since the onset of the GFC (for instance, Du et al. (2018) and Du and Schreger (2021)). In this case, hedged synthetic USD funding via cross-currency swap markets is more expensive than borrowing USD directly in the US cash market.

[70] As highlighted in Cerutti et al. (2021), post-GFC developments have amplified the financial frictions that create these arbitrage opportunities.

[71] See e.g. Rime, Schrimpf, and Syrstad (2022) for empirical evidence.

[72] The results are larger when we use the one-month CCB that show a 30 basis points increase.

[73] For instance, Avdjiev et al. (2019) document that a daily 1 percent appreciation of the broad dollar is related to a 2 basis point decrease in the cross-currency basis which they interpret as economically large.

[74] A possible explanation for the apparent non-existence of previous papers analyzing how FXI affect the CCB may be that the empirical papers surveyed in Osterberg (1989) have found that relative bond supplies â which is the metric that underlies the portfolio-balance mechanism for FXI - had no significant explanatory power for CIP variations, suggesting that FXI are unlikely to have a large effect on CIP.

Table 7: Effect of intervention 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 5. 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.

in the future (i.e. $f_t < s_t$). To see why this is the case and following Du et al. (2018), we include the market convention of the CCB for the USD/ILS currency pair:

$$CCB_t = r_t^{US} - \left[r_t^{IL} - (f_t - s_t)\right], \tag{5}$$

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.

According to the asset market approach to exchange rate determination, sterilized FXI imply that both interest rates r_t^{US} and r_t^{IL} remain unchanged (Villamizar-Villegas and Perez-Reyna, 2017), when these FXI are carried out.[75] Therefore, the CCB can be expressed as

$$CCB_t \approx f_t - s_t. \tag{6}$$

[75] This assumption is especially true when using data sampled on a daily frequency.

As postulated by the Amador et al. (2020) model, the BOI's FXI will dampen the initial (and subsequent) appreciation pressure (i.e. raise s_t), but generate the expectation of a reversal of the contemporaneous depreciation of the ILS (i.e. a lower increase of f_t), as market participants know that the probability that the FXI regime will be abandoned in the future is positive. As a consequence, the cross-currency basis becomes more negative (positive in Amador et al. (2020), as they use the CCB with the opposite sign[76]). Our empirical result, showing that the BOI's intervention activity widens the CCB, is therefore consistent with their model's predictions concerning the CCB.

Before concluding this section, a natural question that arises is how our estimated coefficients that quantify the effect of FXI on the spot rate compare to the estimates in other recent papers? Ribon (2017) has also analyzed the BOI's most recent FXI regime. Using monthly FXI data, she 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 corresponds to an estimated coefficient of 0.74, which is approximately 9.8% lower than our estimate of 0.82 for the case of the NEER in Table 6. We note, however, that she examined a different period (2009–2015) than we did.
Compared to other papers that have analyzed the FXI activity of other central banks (see Section 1 for details), we find that our estimates of 0.82% and 0.83% are at the upper bound of other papers, 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, whereby FXI can affect FX rates only through the non-interest channels, which are empirically dominated by the interest-rate channel (Iwata and Wu, 2012), the magnitude of our estimated coefficients is surprisingly large. In the following section, we therefore try to identify indicators that explain the strong impact of the BOI's FXI activity.

3.1.3 Determinants of the contemporaneous effectiveness of the BOI's FXI

Financial frictions. The current theoretical contributions that rationalize the effect of sterilized FXI highlight the role of financial frictions (e.g., in the form of capital-constrained financial intermediaries) in preventing the elimination of arbitrage opportunities as an explanation for the effectiveness of sterilized FX interventions.[77] To exemplify the role of frictions, we follow the line of reasoning in Gabaix and Maggiori (2015).[78] In their basic two-country model, households trade goods internationally and invest via international financiers (e.g. global banks) in risk-free domestic currency[79] bonds. The financiers are, however, subject to financial (e.g. capital) constraints, which limits their risk-bearing capacity. This results in a downward-sloping demand curve for risk-taking. The households' investment decisions therefore result in capital flows in different currencies that are only partially intermediated by these financiers. To motivate financiers to restore equilibrium, they must therefore be compensated by a risk premium. Both bonds thereby become imperfect substitutes and asset returns then depend on the relative asset

[76] Other papers that also use this alternative definition are Du and Schreger (2016), Du, Im, and Schreger (2018) and Dedola et al. (2021), amongst others.

[77] See the reviews in Villamizar-Villegas and Perez-Reyna (2017) and Popper (2022).

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

[79] That is, denominated in the households' corresponding home currency.

supplies. By altering the relative supplies, central banks can affect this risk premium. For instance, interventions by e.g. the domestic central bank to depreciate its currency are carried out by purchasing foreign currency risk-free bonds financed by selling domestic currency risk-free bonds. These interventions alter thereby the relative supplies in the global bond market and therefore the size and the composition of the financiers' balance sheets. As an aftermath, the risk premium changes and thereby the FX rate. The effect of FXI is thereby increasing in the severity of the friction.

To explore the role of financial frictions, we extend our regression in Table 6 by including the squared leverage ratio[80] of primary dealers (i.e., major global banks) proposed by He, Kelly, and Manela (2017),[81] abbreviated by "HKM" in the following, and additionally by interacting this ratio with the size of FXI. This ratio is a direct indicator of intermediaries balance-sheet capacity and is strongly countercyclical, i.e., high when risk aversion is high (e.g., during a recession). The results are displayed in Table 8.

The results suggest that the more limited the risk-bearing capacity of these dealers are (i.e. the more severe the financial frictions are), the more effective are the BOI's FXI (with a highly significant coefficient) for a given size of FXI. Our finding is consistent with the Gabaix and Maggiori (2015) model and the 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 proposed by Adrian et al. (2021) for the International Monetary Fund. In their framework the "limited risk-bearing capacity of agents" plays a key role for FXI to be effective in small open economies. Therefore, our finding is especially relevant for central banks in small open economies, because FXI are more common in these countries. 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 analyze this issue by comparing the impulse response function (IRF) associated with FXI in a period when CIP held with the IRF when CIP was violated. We think that the indicator that we use captures these frictions in a more consistent manner. In addition, the indicator that we use strongly comoves with an alternative FX dealer leverage ratio indicator, as shown in Cerutti and Zhou (2023). Their finding therefore reinforces our empirical results, as it implies that the risk-bearing capacity indicator that only uses the leverage ratios of primary dealers by He et al. (2017) leads to a time series that is very similar to the time series that only uses the leverage ratios of FX primary dealers.

Size of interventions relative to market turnover. We hypothesize that the BOI's effectiveness may be due to the large size of the USD purchases in the period of interest. A comparison of the average size of FXI relative to domestic GDP indicates that this ratio is large by international standards. For instance, Table 2 in Fratzscher et al. (2019) indicates that countries that de jure have a free floating regime in place intervene by 0.02% of GDP on average per event day vs. 0.05% of GDP in the case of the BOI (see Table 2). The number increases to 0.03% and 0.05% for countries with pegs and broad or narrow

[80] I.e. the squared inverse of the capital ratio.

[81] See also Atkeson, Eisfeldt, and Weill (2015) for an OTC market model where risk-sharing is only imperfect due trade size limits that ultimately leads to a socially suboptimal equilibrium.

bands, respectively. Our conjecture is further supported by the stylized facts about FXI and the determinants that explain their effectiveness, as identified by e.g. Fratzscher et al. (2019). Using a sample of daily data covering 33 countries from 1995 to 2011, they find that a key determinant of success is a large size of FXI (e.g. in terms of domestic GDP).

Table 8: Contemporaneous relation between the exchange rate and interventions when accounting for financial frictions

Controls	**Dependent variable: $\Delta \log(\mathbf{USD/ILS}_t)$ (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)
$\text{IL\_Monetary\_Surprise}_t$	−3.02***
	(−4.57)
IL_CPI_Surprise_t	−0.59**
	(−2.06)
NS_FFR_Surprise_t	−2.67
	(−0.78)
$\text{NS\_Policy\_Surprise}_t$	3.13
	(1.28)
$\text{CITI\_Surprise\_Index}_t$	−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 ("$\text{EUR/USD}_{t-1,t}$"; 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"), using the continuously updated GMM estimator (CU-GMM). For details about the set of instruments that are included in the CU-GMM, see Table 5. 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.

To empirically assess to what extent the effectiveness of the BOI's FXI is related to the large size of the USD purchases in the period of interest, we therefore add the ratio that relates the size of the BOI's USD purchases to the daily USD/ILS spot market turnover (after subtracting the size of the BOI's FXI). The interaction of this ratio with the FXI variable results, however, in non-significant coefficients (untabulated results). Therefore, we conclude this section by highlighting that the effectiveness of the BOI's FXI activity seems to partially be attributable to financial frictions. In view of supranational institutions (e.g. the Bank for International Settlements[82] and the International Monetary Fund[83]) recommending small open economies to mitigate the inflationary pressure in the aftermath of the Ukraine invasion that has fueled energy costs (usually invoiced in USD) by temporarily intervening in the FX market - especially vis-à-vis the USD, the global premier invoicing currency - central banks in these countries may assess to what extent financial frictions exist to decide whether or not to start buying USDs to mitigate the impact of imported inflation on domestic inflation.

3.1.4 Econometric assessment of the longer-term effect of FXI

The empirical evidence on effectiveness of FXI in general shows that their effect on FX spot rates is rather short-lived.[84,85] To check whether this is also true for the BOI's FXI activities, we now assess how persistent the effect of the BOI's FXI activity on the foreign value of the ILS is.

To this end, we analyze the relation between the size of the USD purchases and following FX rate returns using the local projection-instrumental variable (LP-IV) approach (used in e.g., Ramey and Zubairy (2018)) for the USD/ILS spot rate (panel (a)), the NEER (panel (b)), and the three-month USD/ILS forward rate (panel (c)).[86] Specifically, we regress their log returns from $t-1$ to $t+h$ on the intervention 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 cross-currency basis, h ranges from zero to 100. The instruments that we use are the same than in Table 5.

As we have overlapping data, we have experimented with the correction suggested by Hjalmarsson (2011)[87] and divided the standard t-statistic by the square root of the corresponding forecast horizon. We also corrected for the potential bias in the estimated coefficients when running long-horizon predictive regressions, as suggested in Boudoukh et al. (2021). As our results were robust to this specification, we opted for the standard LP-IV approach instead. As controls, we use the variables that we used in Table 5, but adjust the changes in the controls for the different lengths of the forecast horizon. The results are shown in Figure 3.

The point estimates suggest that the contemporaneously strong and positive effect of FXI on the foreign value of the ILS in the spot markets is not reverted in the subsequent

82 See Hofmann, Mehrotra, and Sandri (2022).

83 See the IMF blog by Gita Gopinath and Pierre-Olivier Gourinchas from October 14, 2022 `https://www.imf.org/en/Blogs/Articles/2022/10/14/how-countries-should-respond-to-the-strong-dollar`.

84 See Galati et al. (2005) and the survey in Villamizar-Villegas and Perez-Reyna (2015).

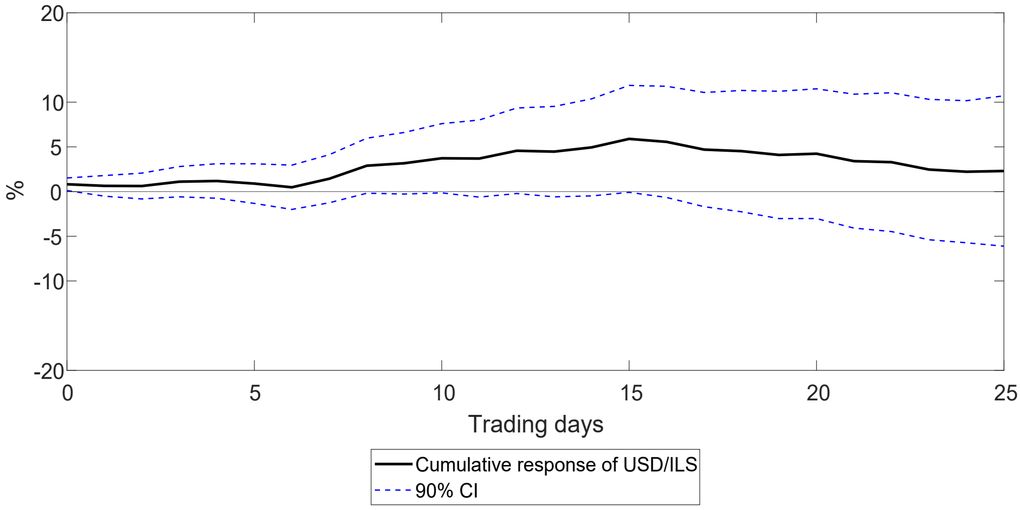
85 From the previously cited discussion in Miyajima (2013) we know that a possible explanation for this short-lived effect may be that central banks intervene too often, thereby not allowing financial market participants to effectively learn about the intervention activity (e.g. the intensity and size of FXI).

86 Note that when running LP-IV regressions, we treat FXI as unexpected, similar to e.g. Caspi et al. (2022). To motivate this, note that the effectiveness of secret vs. non-secret (or detected or public) FXI becomes irrelevant in practice when interest rates are essentially zero, as empirically shown in Fatum (2015).

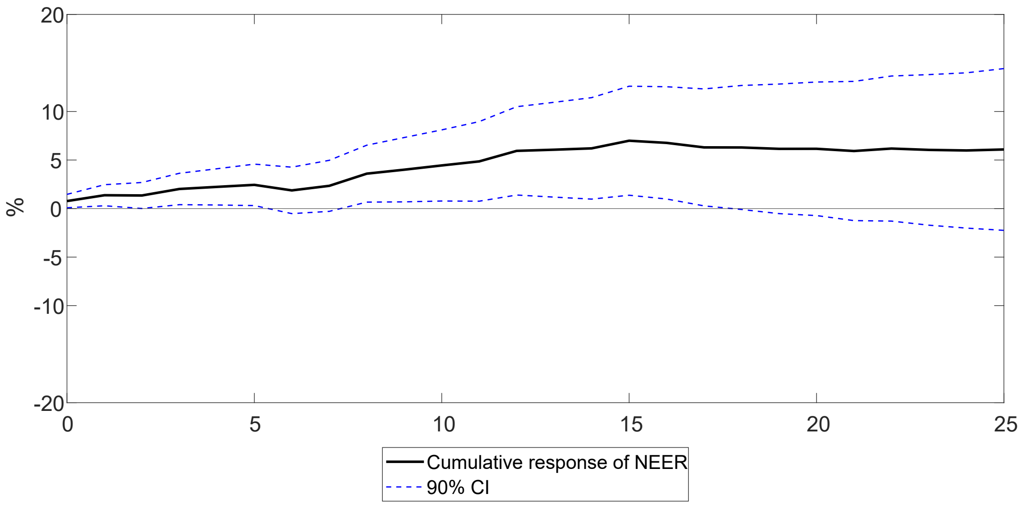
87 Also recommended by Boudoukh, Israel, and Richardson (2021) due its superior finite sample properties compared to alternative adjustments. For instance, the widely used Newey-West HAC standard errors inflate the t-statistics. Our results are thus more conservative than papers that use these type of adjustments.

Figure 3: Cumulative returns of the USD/ILS spot rate, the NEER and the 3-month USD/ILS cross-currency basis in the aftermath of intervention episodes

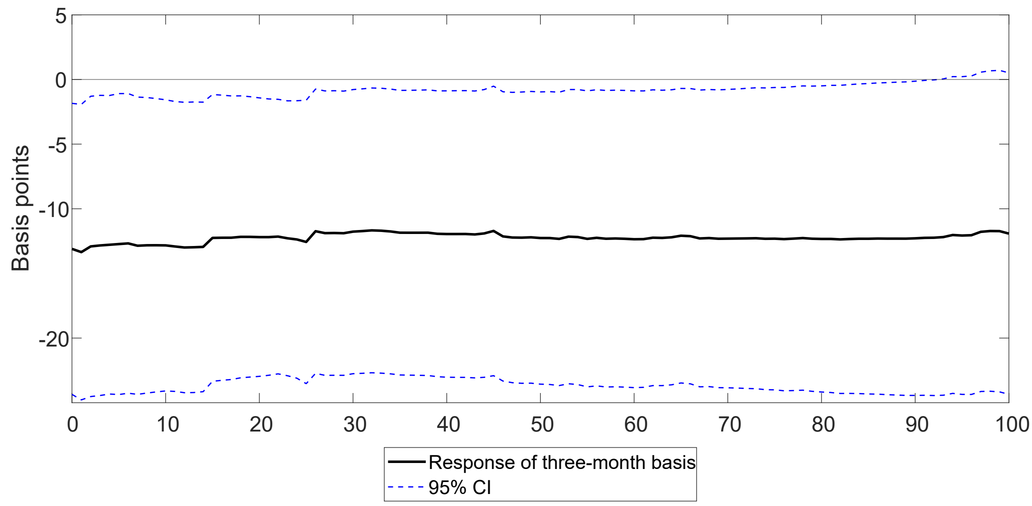
(a) Cumulative returns of the USD/ILS spot rate



(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.

month (panels (a) and (b)). The results are, however, only marginally significant and only for the NEER for up to 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 suggestive of a more efficient USD/ILS spot market.

Regarding the results of 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 intervention activity indeed makes the CCB more negative over longer 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)), speculates that the FXI may have exacerbated the CCB.

3.2 Interventions and the higher-order moments

To understand how option markets' expectations are affected by FXI, we extend in Section 3.2.2 our analysis and assess to what extent option markets price in future FXI, as reflected in the price quotes of the ATMVs, RRs, and BF spreads - remember that these price quotes as proxies for the higher-order moments of the RND. We also assess how these price quotes respond to the BOI's FXI activities both contemporaneously and over longer horizons (Section 3.2.3). We focus hereby on option contracts with maturities ranging from one month ("1 M") to twelve months ("12 M"). This granularity helps us analyze how option market participants view the long-term effect of FXI, which is relevant for policymakers. Before running these analyses, however, we discuss in Section 3.2.1 the role of option markets in providing information beyond what is already reflected in spot markets.

3.2.1 The role of informational externalities and market imperfections

Informational externalities. The spot FX rate is equal to the discounted value of its future fundamental value according to the asset pricing model of FX rate determination (Engel and West, 2005). This implies that the spot rate is forward-looking, similar to option contracts. Ruling out arbitrage opportunities means that the information content of FX options is then equal to the information content of the underlying FX rate, as a riskless hedging portfolio of the latter replicates the former. In this case, what information do we gain by analyzing options data beyond the information that is already priced in the spot rate? The seminal work of Grossman (1988), when applying his insights for the equity option market to the FX option market, shows that option prices reveal information about the share of financial market participants that would potentially sell (or buy) a specific currency in the case of unexpected large spot FX rate movements (i.e., when crash risks materialize). These risks can be insured by entering a RR or a BF spread[88] contract. Therefore, from a theoretical perspective, we know that looking at option markets allows us to learn about the financial market's perceived uncertainty concerning the future spot exchange rate and how this uncertainty changes when FXI are carried out.

Market imperfections. With limits to arbitrage such as balance-sheet constrained banks, derivatives are no longer redundant assets and help complete the market (Figlewski, 2018). Another source that may lead to market incompleteness is due to practical limitations (e.g., the existence of trading costs) that impede option writers to fully remove their risk exposures (e.g., delta exposures when delta hedging these risks). For instance, as shown by Tian and Wu (2021), option writers cannot fully hedge their risk exposures in practice and therefore demand a premium for bearing these risks. These authors then identify three relevant risk components, where one is the premium demanded for bearing random jump risk (i.e. crash risk).

To conclude this section, we discussed the several mechanisms in which looking at option markets may provide a better understanding of the determinants that underlie changes in the RND and, thereby, of the source of changes in the USD/ILS spot rate due to changes in the higher-order moments of the RND. Questions that we can answer by looking at the USD/ILS options market include, for instance: on the days the BOI intervenes (and, as we showed, causes a depreciation), does it also affect the price of insurance against FX crash risk (i.e., the quoted prices of the RRs and the BF spreads)? Did the RND become more left-skewed over time due to the BOI's prolonged intervention activity? Are the tail probabilities significantly affected by FXI? These are questions that can only be answered by examining the options market.

[88] To rationalize the use of RRs, note that in the lottery-preference literature, ex ante skewness is used as a proxy for the "lottery-like characteristics of options", see e.g. Boyer and Vorkink (2014). The (scaled) RR - that is a direct proxy of the ex ante skewness - can therefore be used to shield against jump risks.

3.2.2 Relationship between the higher-order moments and future interventions

We assess to what extent the price quotes of the ATMVs, the RRs and the BF spreads account for the effect of FXI over their lifetime. Formally, we regress the FXI data on the one-day lagged[89] two-week change of the equally weighted mean of the scaled[90] 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 control for the contemporaneous change in the spot rate to control for the aforementioned "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.[91] 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 FX rate. The results are displayed in Table 9. In all the specifications, we use the variables described in Table 5 as controls and instruments.

Table 9: Relationship between FXI and lagged scaled risk reversals, butterfly spreads and at-the-money implied volatilities

	Dependent variable: 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)
$\Delta\overline{\text{RR}}_{t-11,t-1}$	0.153**	0.205**	0.226*	0.187*	0.204*
	(2.03)	(2.12)	(1.87)	(1.66)	(1.68)
$\Delta\overline{\text{BF}}_{t-11,t-1}$	0.122	−0.078	−0.133	−0.266	−0.361
	(0.39)	(−0.28)	(−0.49)	(−1.04)	(−1.21)
$\Delta\text{ATMV}_{t-11,t-1}$	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 ($\Delta\overline{\text{RR}}_{t-11,t-1}$), the scaled 10- and 25-delta USD/ILS butterfly spreads ($\Delta\overline{\text{BF}}_{t-11,t-1}$) and the at-the-money USD/ILS options ($\Delta\text{ATM}_{t-11,t-1}$). 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 Table 5. 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 most coefficients reflecting the relationship between FXI and prior changes in the quoted option prices are not significant. An exception are those coefficients associated with the weighted RRs, a measure of the skewness of the RND. Most of the

[89] We lag the regressors to remove the contemporaneous effect that the BOI's USD purchases have on the USD/ILS spot rate.

[90] We scale the RR and BF option contracts based on the ATMV with equivalent maturity. By scaling, the quoted prices of these two option strategies no longer depend on the prevailing level of the option-implied volatility curve (Jurek, 2014) and – depending on the definition of the IV smile curve – directly reflect the option-implied skewness and excess kurtosis of the USD/ILS RND (see online Appendix F.3).

[91] See footnote 43.

coefficients of the RR are significant (although some are only marginally significant – however, in a pooled regression, the effect is both positive and significant) and positive. Hence, a more pronounced tilt of the expected future USD/ILS spot rate towards large USD appreciation surprises in the two weeks prior to an intervention episode is associated with higher subsequent FXI. The upward adjustment of the price quotes of the RRs in anticipation of higher future FXI happens across all five maturities. It is significant for all maturities, except for the one-year RR. This implies that options market participants perceive the upcoming FXI activity as having an effect lasting for at least twelve months.

We could alternatively interpret this finding in the sense that the BOI seems to "lean with the wind" in the USD/ILS options market, intervening when the implied skewness increases, which could indicate a more comprehensive FXI strategy that also triggers FXI based on option market information. However, we find this interpretation less convincing, as such a strategy would be hard to implement: note that the coefficient on the RR reflects the marginal increase of the RR after controlling for changes in the USD/ILS spot rate. That is, we'd need to believe that the BOI monitors the prices of RRs in the OTC market controlling for the contemporaneous effect that FXI have on the USD/ILS spot rate. Moreover, it would go against their "leaning against the wind" strategy in the spot market.

Regarding the magnitude of the effect, 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").

To conclude this section: while the coefficients associated with the RRs are significant, this is not true for the BF spreads and the ATMV. Therefore, option market participants seem to only price in crash risks related to a large ILS depreciation ("unidirectional crash risk"). It is in this sense that the BOI succeeds in affecting the higher-order moments (i.e. reflecting market expectations) in the intended direction.

3.2.3 Relationship between the higher-order moments and contemporaneous and future interventions

In the previous section, we have analyzed the relationship between the price quotes of the scaled USD/ILS option strategies and future FXI. This section now examines how the BOI's FXI affect the scaled price quotes of these option strategies contemporaneously and with a lag, using the LP-IV-approach. These calculations allow us to understand how the expected higher moments of the distribution of future USD/ILS spot rates adjust over longer periods as a response to the BOI's FXI activity.

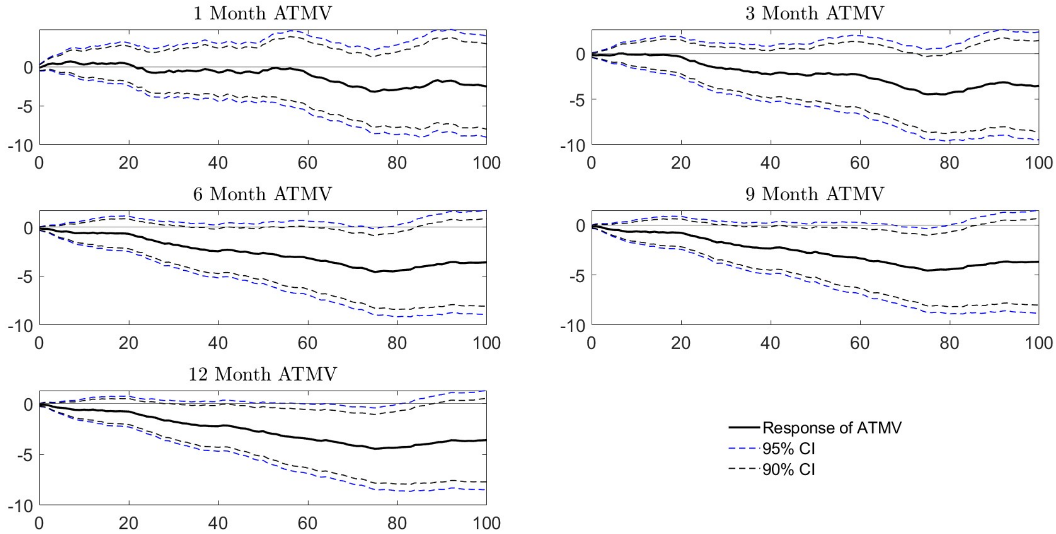
The results are for the higher moments are presented in Figure 4, where we control again for the contemporaneous correlation between the option price quotes and the spot exchange rate (see footnote 43 for the motivation). Otherwise, our results might be affected by this correlation, which is unrelated to FXI.

We begin with analyzing the effect of FXI on the higher-order moments of the RND distribution (Figure 4.) We see that interventions are: (i) Associated with lower option-implied volatility,[92] (ii) Higher skewness due to an increase in the thickness of the right

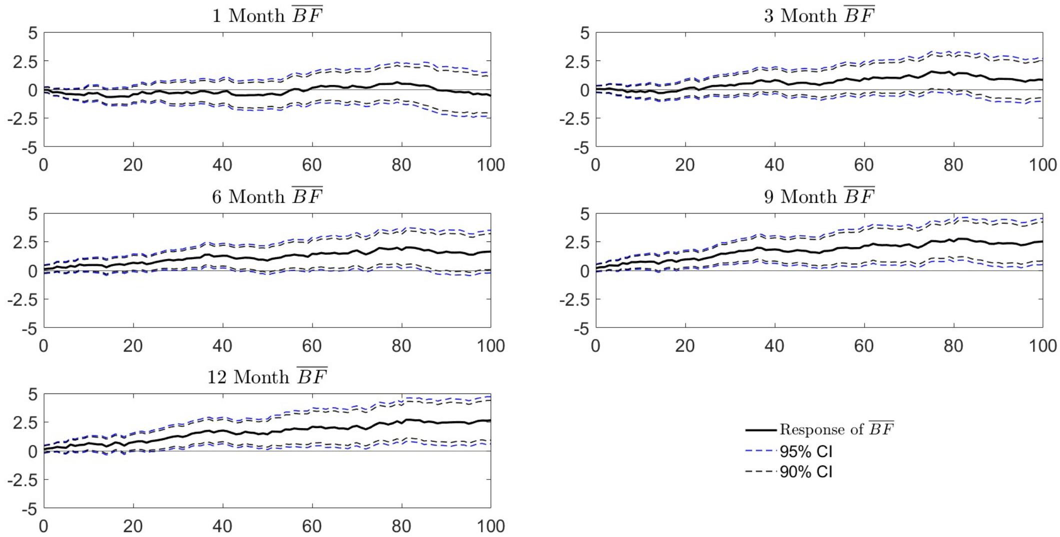
[92]ATMV contemporaneously significantly decreases and remains significantly lower over longer periods for the six-, nine- and twelve-month options.

Figure 4: Cumulative effect of an FX intervention shock of size \$1 billion

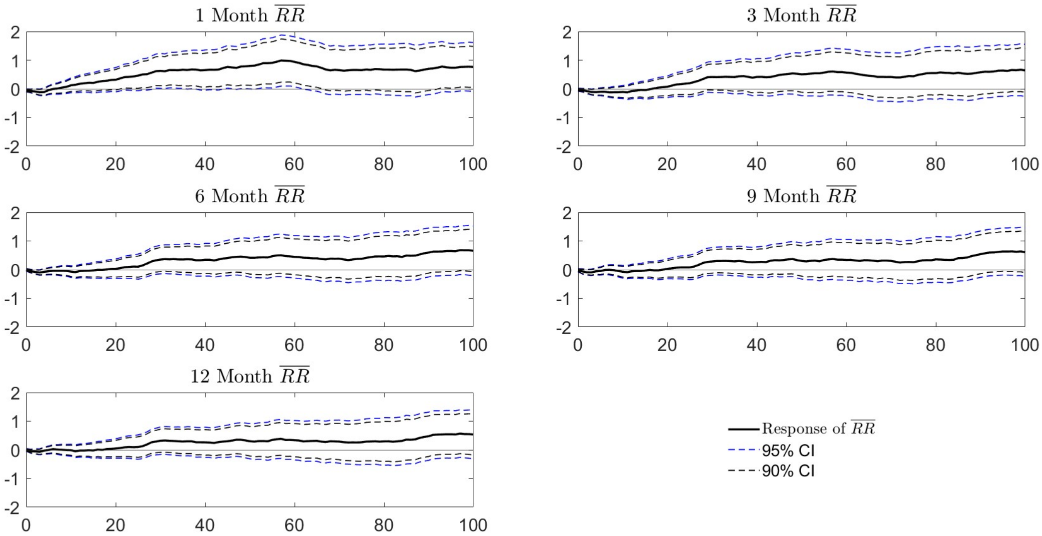
(a) Cumulative change of the at-the-money implied volatility options across five maturities



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



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



Notes: The figure shows the average cumulative change of the USD/ILS at-the-money volatility contracts (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.

tail relative to the left tail (i.e. a more pronounced tilt towards an ILS depreciation)[93] (i.e. a more pronounced tilt towards an ILS depreciation) and (iii) Lower kurtosis (i.e. extreme movements deemed to be less likely).[94,95] We also note that – even though the statistical significance is mixed (i.e., some of the results are only marginally significant) – they all point out to the same directional effect: interventions tilt the RND to the right (i.e. towards an ILS depreciation) and lower the implied volatility in the months following the interventions. The results are also economically significant. For instance, a $1 billion intervention - associated with an average depreciation of the ILS by 0.83% vis-à-vis the USD - is associated with a reduction of 5 percentage points (pps) in the ATMV.

Considering the results from the previous section, which showed that the options market accounts for the intervention in RRs, the additional changes in the higher moments observed after an FXI indicate that only a portion of the intervention was expected. Additionally, the results reveal that the options market did not anticipate the lower implied volatility or the lower kurtosis as a response to the BOI's FXI activities.

3.3 Interventions and the risk-neutral tail probabilities

In the following, we want to analyze to what extent tail probabilities of the RND extracted from the price quotes of USD/ILS options change in anticipation of future FXI over the lifetime of the underlying options(Section 3.3.1). We also want to assess how these

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

[94]Note that the BF spread is negatively related to the excess kurtosis of the log return of the USD/ILS spot rate.

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

probabilities respond to FXI both contemporaneously and over longer horizons (Section 3.3.2).

3.3.1 Tail probabilities and future interventions

This section analyzes the relation between option-implied tail (or crash) probabilities of the USD/ILS RND and future FXI. Analyzing this relation serves three purposes: (i) In the previous section, we found a positive relation between the option-implied skewness of the RND and subsequent FXI, after controlling for the effect of these FXI on the USD/ILS spot rate. The RR[96] can also be considered as the difference between the RND of a large depreciation minus the risk-neutral probability of a large appreciation, where both probabilities are weighted by the corresponding intrinsic values that compose this option strategy. Therefore, disentangling the RND components helps us to understand the source of the relation between changes in the RRs and future FXI. (ii) The interest in understanding to what extent FXI affect tail risks is also motivated by the observation[97] that the BOI in the past (July 2008 to 2010) succeeded in reducing these risks, which suggests that the BOI may have taken tail risks into account as part of their policy decision-making process also in the period that we analyze. (iii) Probabilities are more intuitive to understand than changes in option prices or option-implied higher moments. Our approach therefore simplifies policymaking.

To estimate these probabilities, we use the implied volatility-moneyness curve proposed by Zhang and Xiang (2008) that fits the observed volatility "smile" using a second-order polynomial.[98,99]

After estimating the parameters that describe this curve for each trading day and for each of the five maturities that we examine, we calculate risk-neutral tail probabilities for a drop of the USD/ILS spot rate (in our paper: a strong appreciation of the ILS), using a closed-form formula. 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 ± 2 percent for the one-month maturity, ± 3 percent for the three-months maturity, ± 6 percent for the six-months maturity, ± 9 percent for the nine-months maturity, and ± 10 percent for the twelve-months maturity. These "thresholds" were chosen in accordance with the thresholds in Hattori et al. (2016) who analyze US equity market tail risks for the S&P 500 index over a three-month horizon. As stock markets are much more volatile than FX markets, we scale these thresholds down accordingly.

The results are presented in Table 10. The estimated coefficients have all 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 an

[96] After subtracting its time value.

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

[98] The curve was advanced by Backus, Foresi, and Wu (2004) for FX options and later modified by Zhang and Xiang (2008) to be used with equity options.

[99] Cortes et al. (2022) follow a similar approach to estimate option-implied tail probabilities. 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.

anticipated FXI that is on average mUSD 315 ("1 M") to mUSD 928 higher ("12 M"). The results suggest that market participants in part correctly anticipate the size of future FXI that will be carried out to reduce the foreign value of the ILS (i.e., a depreciation).

Table 10: Relationship between lagged RND tail probabilities and future foreign exchange 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

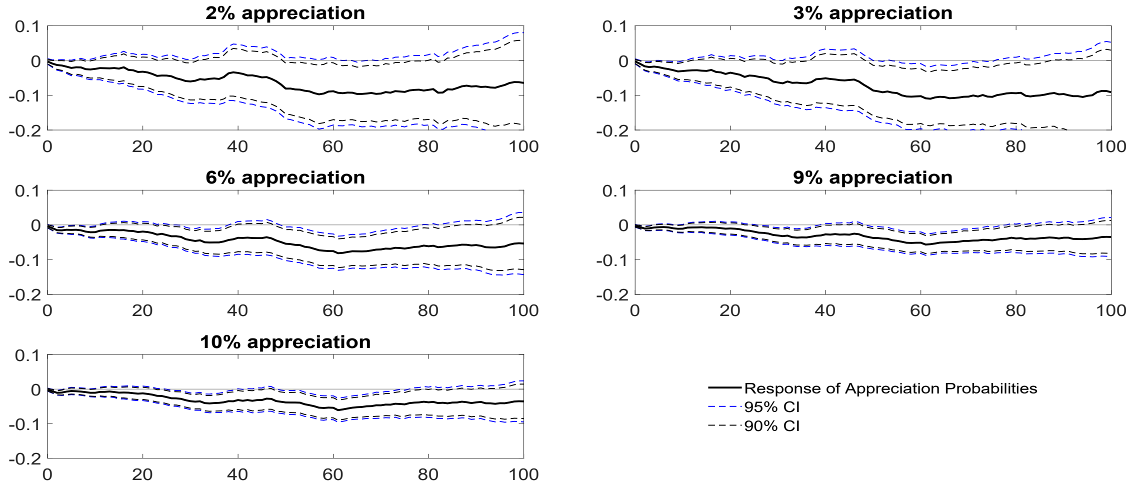
Notes: The table presents the results of regressing the daily intervention volume ("FXI_t", in USD billion) on the one-day lagged two-week change of the probability of a strong appreciation of the ILS ("ΔProb. of appreciation$_{t-11,t-1}$", in percentage points) and of a strong depreciation of the ILS ("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 Relationship between the tail probabilities and contemporaneous and future interventions

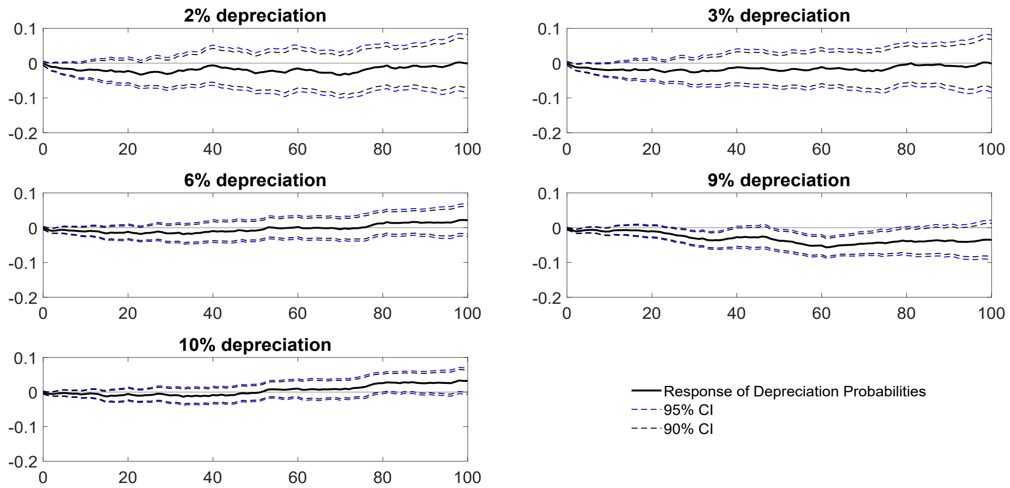
In Figure 5, we show the response of the right- and the left-tail probabilities to an FXI shock at time zero. Specifically, these panels exhibit from the left to the right and from the top to the bottom the responses for the one-month, three-months, six-months, nine-months and one-year contracts to a FXI shock that leads to an appreciation of the ILS vis-à-vis the USD (panel (a)) or a depreciation (panel (b)) of at least 2%, 3%, 6%, 9% and 12%, respectively. The results show that the change of the distribution is mostly driven by the left tail – the probability of a large ILS appreciation goes down by a substantial amount, thereby dampening the appreciation pressure for the ILS. For the right tail, we can't reject the null that there is no significant enduring effect, except for the nine-month options. These findings again support the view that the BOI's FXI activities indeed successfully affect market expectations.

Figure 5: Cumulative effect of an FX intervention shock of size \$1 billion

(a) Cumulative change of left-tail probabilities across five maturities



(b) Cumulative change of right-tail probabilities across five maturities



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 intervened in the USD/ILS spot market to weaken the foreign value of the ILS vis-à-vis the USD. Focusing on the BOI's foreign exchange intervention (FXI) regime from 2013 until the COVID-19 pandemic erupted, we analyze the effectiveness of this relatively long FXI episode. We find that the BOI's FXI have caused a strong – both by historical and international standards – depreciation of the ILS vis-à-vis the USD (and also vis-à-vis a broad composite basket of other major currencies). We show that financial frictions – in the form of capital constrained major financial intermediaries – partially explain why the BOI's intervention activities have been so effective, thereby providing empirical support to the recent theoretical research that rationalizes the effectiveness of sterilized FXI in the spirit of Gabaix and Maggiori (2015). Our findings thereby provide 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. In light of the recent recommendations from supranational institutions (e.g. the Bank for International Settlements and the International Monetary Fund) for small open economies to intervene in the FX market vis-à-vis the USD, the global premier invoicing currency, our finding suggests that the indicator we use to capture the extent of financial frictions may become a yardstick for policymakers in the future when confronted with the decision to intervene in the FX market or not.

We also examine the effect that FXI have on the USD/ILS forward rate. We find that FXI increase the USD/ILS forward rate by less than is the case for the spot rate. The lower effect suggests that the FXI activity widens the deviation from covered interest rate parity (CIP) – usually referred to as the cross-currency basis (CCB). We confirm this finding by regressing the CCB on the size of actual FXI - and are herewith the first paper to empirically show that FXI indeed widen the CCB. In addition, we show that the contemporaneous impact of FXI persists over 90 trading days. This finding is consistent with the implications of theoretical models in the FXI literature that study e.g. 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 to a CIP violation (e.g. as in Amador et al. (2020)).[100]

With regard to how the BOI's FXI have affected the USD/ILS option market, our findings suggest that monitoring the response of option-implied risk-neutral expectations adds valuable information about the effect of FXI. Specifically, our paper finds that (i) the price quotes of the USD/ILS risk reversals – an option strategy that provides insurance against currency crash risk (Jurek, 2014) and reflects a more pronounced tilt towards a stronger USD when it increases – adjust in the expected direction (i.e. increase) in anticipation of higher future FXI. The options market therefore seems to partially price in future FXI. (ii) In line herewith, we find that option market participants increase the risk-neutral probabilities associated with a large depreciation of the ILS in anticipation of higher subsequent FXI during the lifetime of the option contracts that we consider. (iii) Focusing on the effect of FXI on the higher-order moments (volatility, skewness, and kurtosis) of the risk-neutral density (RND) – proxied by the scaled price quotes of USD/ILS

[100] See also Fanelli and Straub (2021) for an alternative framework that also implies a widening of the CCB.

options – we find that the BOI's FXI activities significantly tilt option market expectations towards less volatile and less extreme spot rates in the future, while accounting for the possibility of a large ILS depreciation as an aftermath of FXI. This finding contrasts with the insignificant empirical evidence to date from other central banks' FXI episodes. (iv) Looking at the response of the option-implied tail probabilities, we find that the market anticipates a significant effect of the BOI's FXI activity on directional crash risk (i.e., a large depreciation of the ILS). (v) Consistent with the lower kurtosis documented in (iii), the tail probabilities of a large ILS appreciation (i.e., the left tail) decrease dramatically for all option maturities. The tail probabilities of a large ILS depreciation (i.e., the right tail), on the contrary, are hardly affected. The BOI therefore seems to be more successful in dampening the ILS appreciation pressure than in generating ILS depreciation pressure.

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Appendix

A Specification analysis of first-stage regression

This appendix shows the results of the first-stage regression with different specifications in Table A.1. 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 that equals one whenever the BOI intervened in the previous week. We also add the log 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 spot rate exhibits levels that are deemed to be inconsistent with its long-term moving average as a proxy for the unobserved fundamental USD/ILS value $\Delta\text{MA}(\text{USD/ILS})_{t-1}$, which is defined as the difference between the USD/ILS rate and its one-year moving average.[101] The results reveal that the latter 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] confirm the relevance of the lagged NEER data.

[101]For the motivation, see footnote 53.

Table A.1: 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 Effect of interventions on the cross-currency basis

Table B.1: Contemporaneous exchange rate regressions

	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)
$\Delta\text{EUR/USD}_{t-1,t}$	0.19	0.29	0.31
	(0.79)	(1.15)	(1.19)
$\Delta\text{VIX}_{t-5,t}$	−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 ("$\text{EUR/USD}_{t-1,t}$"; in percent), the one-week change in the VIX ("$\Delta\text{VIX}_{t-5,t}$"; in percentage points) and the one-week change of the USD LIBOR rate ("$\Delta\text{LIBOR}_{t-5,t}$"; 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 5. 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.

C Verbal intervention

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 C.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.

Next, we want to examine how the results of Table 6 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 C.2. They show that intervention continues

Table C.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.

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

	Dependent variable: $\Delta\ln(\text{USD/ILS}_t)$ (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)
$\Delta\text{EUR/USD}_{t-1,t}$	−0.41	−0.41	−0.41
	(−22.98)	(−21.16)	(−21.10)
$\Delta\text{VIX}_{t-5,t}$	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 ("$\text{EUR/USD}_{t-1,t}$"; in percent), the one-week change in the VIX ("$\Delta\text{VIX}_{t-5,t}$"; in percentage points) and the one-week change of the USD LIBOR rate ("$\Delta\text{LIBOR}_{t-5,t}$"; 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 5. 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 C.1.