FX Interventions and Capital-Constrained Banks: Evidence from USD/ILS Spot, Forward, and Option Markets[1]

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Abstract

Using confidential daily data, we examine the Bank of Israel's foreign exchange interventions from 2013 to 2019. We find that a 1 billion US dollars (USD) purchase leads to a 0.82% depreciation of the Israeli Shekel (ILS) - a strong effect compared to other studies. We show that this effectiveness can partially be attributed to the limited risk-taking capacity of global banks. The interventions also widen the negative deviation from covered interest parity and influence the higher-order moments of risk-neutral expectations derived from options prices. We find that USD purchases shift the USD/ILS distribution upwards and reduce crash risk. Moreover, the options market anticipates and prices in upcoming interventions.

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

Keywords: Foreign exchange intervention, covered interest parity, exchange rate, expectations, financial frictions, limited risk-bearing capacity.

1. INTRODUCTION

The Great Financial Crisis (GFC) profoundly changed the global monetary policy landscape. On the edge of a significant economic downturn, central banks across the globe cut their policy rates to near zero, launching an era of persistently low interest rates. These actions forced central banks to adopt unconventional monetary policy tools - including foreign exchange (FX) interventions in the spot market[1] aimed at stabilizing exchange rates and influencing broader financial conditions.

To explore the effectiveness of these FX interventions (FXI), we use Israel as our empirical laboratory. In March 2008 – after an 11-year hiatus – the Bank of Israel (BOI) resumed its USD spot purchases, ultimately accumulating USD 89.2 billion in reserves by end-2019. Characterized by frequent and fully sterilized[2] USD purchases, these FXIs offer a rich setting for our empirical investigation.

Our paper advances the literature on three fronts. First, we develop a unified empirical framework that traces the BOI's FXIs effects on the spot, forward, and option markets. Second, we show that sterilized FXIs can be highly effective, particularly when global banks face binding capital constraints. Third, we examine the impact of interventions in the FX spot market on option-implied crash risk. This analysis is motivated by the pioneering work of Farhi and Gabaix (2016) who propose a rare disaster model of FX rates, which links the price of insurance against a currency's crash risk to the spot rate; this (positive) correlation between the price of crash risk insurance and the spot rate implies that FXIs in the spot market should also alter tail probabilities in FX option markets.

Our unified empirical framework is particularly valuable for examining derivatives markets. Despite numerous studies on the effectiveness of FXIs in spot markets, the response of derivatives markets to such interventions remains underexplored. This gap is attributable to the early-stage evolution of FX derivatives markets, which historically suffered from low informational efficiency and limited liquidity. The advent of electronic trading networks has drastically transformed these markets, leading to rapid growth[3] and making them informationally efficient and highly liquid.

Given the growing importance of the FX derivatives market, central banks implementing FXI strategies must gain a deeper understanding of how these interventions interact with forward and option markets. For example, elevated trading costs may impede the dynamic replicaton of option contracts in practice (Tian and Wu, 2023), rendering derivatives non-redundant assets. Consequently, by analyzing option markets, central banks extract information beyond what is already reflected in spot markets. To provide a practical toolkit for policymakers, we analyze how sterilized FX spot market interventions affect FX option market expectations and its potential to exacerbate frictions in the FX swap market.

Our laboratory raises the question of external validity. Encouragingly, our empirical findings align with the predictions of a model proposed by Amador, Bianchi, Bocola, and Perri (2020), which shows that a central bank in a small open economy (SOE) can implement a spot-market FXI regime to remain capable of monetary policy action when nominal interest rates are zero by directly affecting financial conditions through the foreign exchange channel. This correspondence suggests that our findings generalize to other SOEs facing persistently low interest rates.

Summary of main results. We find that FXIs of USD 1 billion USD[4] lead to a significant 0.83% (0.82%) depreciation of the ILS against the USD (nominal effective exchange rate (NEER)). This effect is large by both historical and international standards.[5]

We also find that the deviation from covered interest rate parity (CIP) – also known as the cross-currency basis (CCB) and here defined as the difference between the USD borrowing rate and the synthetic USD investment rate implied by CIP – becomes significantly more negative on intervention days. This is because the USD/ILS forward rate increases by less than the spot rate, consistent with one of the predictions of the Amador et al. (2020) model. Specifically, we show that a USD 1 billion FXI widens the CIP deviation by 13 basis points on impact, and that this initial effect persists for at least 90 days.

Analyzing the USD/ILS option market, we find that a higher USD/ILS risk reversal (RR),[6] indicating a more pronounced tilt towards a weaker ILS over this option strategy's lifetime, is associated with higher future FXI volumes. This suggests that the option market partially prices in future FXIs before they occur. This implies that market participants view the BOI's intervention strategy as credible and predictable. We also find that the higher-order moments of the risk-neutral density (RND) – specifically, the variance, skewness and kurtosis, proxied by USD/ILS option price quotes – change significantly on FXI days. Specifically, option market expectations shift towards less volatile and less extreme spot rates (lower kurtosis) in the future, while accounting for the possibility of a large ILS depreciation (higher skewness) due to future FXI.

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

Related literature and our contributions. (i) We contribute to the literature that estimates the impact of FXIs on the FX spot rate,[7] which has primarily focused on FXI episodes in "far less complex" market structures (Chaboud, Rime, and Sushko, 2022). The GFC has led to significant changes in global financial markets, including the historically exceptional prolonged period of low interest rates and the recognition that financial frictions are crucial for the effectiveness of sterilized FXI (Popper, 2024) when CIP breaks down.

(ii) When CIP fails, financial frictions are necessary for sterilized FXI to be effective, as otherwise financial market participants would immediately arbitrage any FX rate misalignments resulting from FXIs. In addition, it is now widely accepted that the effect of sterilized FXI is significantly reduced when nominal interest rates are near zero.[8] We systematically analyze the role of financial frictions and find that the impact of FXI is larger when global banks are more capital-constrained. This finding provides empirical support for recent theoretical research that rationalizes the effectiveness of sterilized FXI in the spirit of the Gabaix and Maggiori (2015) model.[9] To our knowledge, this empirical finding is new in the FXI literature and provides guidance to central banks on the type of financial friction that makes sterilized FXI in the spot market more effective.

(iii) We also contribute to the literature that seeks to explain the CIP deviations observed since the onset of the GFC.[10] To our knowledge, we are the first to empirically quantify the effect that FXIs have on the CCB. Our findings show that FXIs widen it, consistent with one of the predictions of the Amador et al. (2020) model, which suggests that FXIs may lead to systematic CIP violations when the zero lower bound (ZLB) of nominal interest rates binds. Our results support their interpretation, whereby part of the CIP deviations observed after the GFC are due to a conflict between exchange rate policies and the ZLB.

(iv) In contrast to our findings, the few studies that have previously analyzed how FXIs in the spot market affect FX option market expectations, report only a weak effect.[11] Our study contributes to the FXI literature by providing new empirical evidence from a mature option market. Also, unlike previous studies, we do not focus solely on options with a specific maturity, but instead examine options with maturities ranging up to twelve months. This extension is relevant for monetary policymakers, as it provides insights into the longer-term effects of spot market interventions on option market expectations.

(v) To the best of our knowledge, we are the first paper to provide empirical evidence on the effect of FXIs on tail probabilities. We analyze the response of these probabilities over different horizons, providing central banks with insights into the effectiveness of their FX market interventions. As the shape of the RND changes with these probabilities, our contribution allows central banks to understand why market participants' risk perception of extreme events changes on FXI days.

(vi) Finally, we contribute to the literature by providing empirical evidence on secret FXIs, which is scarce and under-researched (Naef and Weber, 2023). The fact that central banks often intervene in the FX spot market secretely (Fratzscher, Gloede, Menkhoff, Sarno, and Stöhr, 2019) implies that the empirical evidence in the FXI literature is biased towards the effectiveness of overt FXIs. We aim to fill this gap.

This paper is structured as follows: Section 2 outlines our methodology and data. Section 3 presents our main findings, including the response of spot and forward markets, and an assessment of the role of financial frictions in explaining the effectiveness of the BOI's FXI activities (Section 3.1), as well as the relationship between FXIs and the option market (Sections 3.3 and 3.4). Section 4 concludes.

2. MAIN DATA AND METHODOLOGY

2.1 A Bird's Eye View on the BOI's FXI Activities

In the empirical section, we analyze the BOI's last FXI regime prior to the COVID-19 pandemic, spanning May 2013 to December 2019. This regime was marked by secret and fully sterilized USD purchases in the spot market.

To provide context, Figure 1 shows monthly FXI volumes (publicly available from the BOI), the NEER,[12] and the USD/ILS spot rate from January 2008 to December 2019.[13,14] Over this period, the shekel appreciated sharply: by about 10% against the USD and nearly 30% in NEER terms.

[Insert Figure 1 here]

In tandem, the BOI intervened in the USD/ILS spot market, particularly in periods of strong ILS appreciation pressure. Its FXI strategy changed several times, with a notable pause in FXI activity from July 2011 to April 2013. For details on the BOI's FXI strategies, see Online Appendix A.

2.2 Data

2.2.1 Foreign Exchange Intervention Volumes

Table **??** presents descriptive statistics for the publicly available monthly FXI data from January 2013 to December 2019. On average, the BOI purchased USD 594 million per month, with volumes ranging from USD 2 million to USD 2.27 billion. The FXI volumes are relatively volatile, as indicated by the high standard deviation. Moreover, in 69 out of 84 months, the BOI intervened in the USD/ILS spot market at least once.

[Insert Table **??** here]

To give a better sense of the magnitude of FXI, Table **??** compares the size of FXIs to other metrics:

[Insert Table **??** here]

The table shows that the BOI's average daily FXI volume is large relative to domestic GDP. For instance, Fratzscher et al. (2019) document that countries with free-floating exchange rates typically intervene at a scale of just 0.02% of GDP – about 60% less than the BOI. FXI volumes are also sizable relative to market turnover: the BOI's FXIs average 8.16% of daily USD/ILS spot and forward market turnover. In contrast, the Bank of Japan's (BOJ) FXI volumes from 1999 to 2004 averaged only 1.3% of daily market turnover (Fatum, 2015).

We also see that the BOI intervenes in the USD/ILS spot market on average for only 1.46 trading days per calendar week (1.73 days per trading week), which is short by international standards. For example, Disyatat and Galati (2007) report that the Czech National Banks's (CNB) FXI spells averaged eight trading days.

2.2.2 *Exchange Rates and Financial Variables*

Table 3 presents descriptive statistics for the main variables we use in the empirical section. The data is sourced from Bloomberg with a timestamp of 5 PM EST. The upper panel ("Exchange rates") reports daily log returns (in percent) for the USD/ILS and EUR/USD FX rates, the NEER, and the 3-month USD/ILS forward rate. On average, the ILS appreciated, which is consistent with the trend shown in Figure 1. The lower panel ("Misc") provides descriptive statistics for the 3-month USD/ILS CCB, the 5-year Israeli CDS spread, and the VIX.

[Insert Table 3 here]

2.2.3 *USD/ILS Option Price Quotes*

Table B2 in Online Appendix B reports descriptive statistics for the daily USD/ILS options data, retrieved from Bloomberg with a timestamp of 5 PM EST. The table includes at-the-money implied volatilities (ATMVs) quotes,[15] 10-Δ and 25-Δ[16] butterfly (BF) spreads,[17] and 10-Δ and 25-Δ RRs[18] across six maturities, ranging from one week ("1w") to twelve months ("12m").[19] Following the option markets' quoting convention, all price quotes are measured in implied volatilities and expressed in percent (Reiswich and Wystup, 2010).

Given the high persistence of the option strategy price quotes (see column "AR(1)"), we use their prices in first differences in our empirical estimations. Untabulated results confirm that differencing effectively removes this persistence. Notably, the one-week BF spreads (for both option deltas) show a much lower persistence, suggesting potential stale prices or limited liquidity. This also applies – though to a lesser extent – to the one-week RRs (also for both option deltas) and the one-week ATMV, which motivates the next part of our analysis.

Liquidity. Given the central role of options data in our analysis, we evaluate the liquidity of the Israeli FX options market by international standards. Based on data from the BIS Triennial Central Bank Survey,[20] which covers nearly 1,300 banks and dealers across 54 countries, we find that in April 2019, average daily OTC-traded FX options in Israel accounted for 6.2% of total FX transaction volume.[21] This share is high by international standards – placing Israel among the top five countries in 2019, as well as in all previous triennial surveys since April 2007 (untabulated results).

Figures E2-E4 in Online Appendix E present box plots of the relative bid-ask spreads (BAS) – defined as the BAS divided by the mid-quote[22] – for the three option price quotes used in our paper, covering 28 currency pairs and six maturities. The results show two key patterns: (i) The relative BAS is consistently higher for one-week contracts, which we therefore exclude from the analysis; and (ii) for all three strategies, the relative BAS for USD/ILS lies within the interquartile range. These two findings suggest that liquidity in the Israeli FX option market is comparable to international standards and not a major concern for our analysis.

2.3 Estimation

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

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

where Δs_t is the log return of the USD/ILS spot rate, NEER or three-month USD/ILS forward rate, FXI_t is the size of interventions, and X_t a vector of control variables.

Endogeneity may arise because central banks often use FXIs to 'lean against the wind' – that is, to revert (or dampen) sustained trends in the foreign value of the domestic currency.[23] As a result, FXIs respond to and influence the spot FX rate simultaneously, leading to OLS estimates that understate the true effect of FXI. Using daily data, as in our analysis, can reduce this bias (Rogers and Siklos (2003); Menkhoff, Rieth, and Stöhr (2021)).

Identification strategy. Daily data alone may not fully address endogenity concerns. To account for this, we also run General Method of Moments (GMM) regressions using instruments – a standard approach in the FXI literature.[24] Specifically, we combine Equation (1) with a central bank reaction function for spot market FXIs:

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

where Z_t is a vector of instrumental variables.

We employ the continuously updated GMM (CU-GMM) estimator of Hansen, Heaton, and Yaron (1996), using a heteroskedasticity and autocorrelation (HAC) consistent covariance matrix. This estimator is preferred to the two-step or iterated GMM estimator due to its superior small sample properties.

3. RESULTS

3.1 *Effect of Interventions on the Spot Rate, Forward Rate, and Cross-Currency Basis*

3.1.1 *Informal Event Study*

Figure 2 shows average cumulative USD/ILS spot rate returns from nine days before to eleven days after the initiation of an FXI spell (starting on day t). Returns are weighted by the relative size of FXI[25] to account for the potentially right-skewed distribution of FXI volumes. For comparison, we also report equally weighted cumulative returns, which give more weight to episodes with smaller interventions.

We see that the BOI is successful in reversing the ILS appreciation trend, meeting the commonly used "event" and "direction" criteria for effective FXI episodes.[26] Specifically, the FXIs cause a depreciation by the end of the first intervention day (t). This trend reversal continues on the next day ($t + 1$), possibly reflecting a second FXIs day. Weighting returns by intervention size highlights stronger trends around day t, suggesting the BOI intervenes more aggressively during episodes of more pronounced prior appreciation.

[Insert Figure 2 here]

3.1.2 Instruments and Control Variables in the GMM

Instruments. We use instruments commonly employed in the FXI literature – presumed to be correlated with the FXI data but uncorrelated with the spot FX rate shocks in Equation (1) on intervention days. These include the one-day lagged daily FXI volume to capture the persistence in FXIs during periods of sustained appreciation pressure,[27] 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 NEER return. These instruments are exogenous to the current spot rate but likely influence FXI decisions, given that FXI timing and size typically reflect prior exchange rate dynamics. We use the NEER – a measure of international competitiveness[28] – because preserving competitiveness has been a key motive behind the BOI's FXI regime (Cukierman, 2019).

We select the number of lags based on the specification with the highest adjusted R^2 among those specifications that pass the Montiel Olea and Pflueger (2013) test for weak instruments, which is robust to heteroskedasticity, autocorrelation, and clustering. To assess the joint validity of our instruments, we apply the difference-in-Hansen test (Eichenbaum, Hansen, and Singleton, 1988) to selected subsets of instruments. Both test results strengthen confidence in addressing endogeneity using the CU-GMM estimator. Detailed first-stage and additional robustness checks are provided in Online Appendix F.

Control variables. To ensure our results are not confounded by macroeconomic news, we control for the one-day log return of the EUR/USD spot rate (capturing broad USD movements); the one-week change in the VIX (proxying global financial uncertainty);[29] Israeli monetary policy and CPI surprises (see Table B1 in Online Appendix B), US monetary policy surprises – captured via short-term Federal Funds rate and longer-term policy path surprises over FOMC announcement windows, following Nakamura and Steinsson (2018) – and the CITI US macroeconomic surprise index (see Table B1 in Online Appendix B for construction details).

3.1.3 Regression Results

Effect on the spot rate. Table 4 reports regressions of the daily log return (in percent) for the USD/ILS spot rate (Panel A) and the NEER (Panel B). Each specification includes an intercept, the contemporaneous FXI variable (in billions of USD), and the full

[Insert Table 4 here]

set of control variables, forming our benchmark model. Column 2 presents standard OLS estimates ([1]), column 3 shows the results using the CU-GMM estimator with our instruments ([2]), and column 4 reports results from a two-stage least squares (2SLS) regression ([3]) as a robustness check.

The estimated FXI coefficient is highly significant and similar across both spot rate measures: 0.83% for the USD/ILS rate (Panel A)[30] and 0.82% for the NEER (Panel B). Compared to prior studies that have analyzed the FXI activity of the BOI in the aftermath of the GFC, our estimates are larger. Ribon (2017), using monthly data from 2009–2015, finds that FXI of USD 830 million leads to a depreciation of the NEER that is larger on average by 0.6% compared to a trading day with no FXI activities. After adjusting to our scale, her estimate is approximately 9.8% lower than ours (0.82) – a difference that is economically negligible. This discrepancy may reflect differences in data frequency or the sample period.

Relative to FX interventions by other central banks (see Section 1), the BOI's sterilized FXIs exert an unusually large effect on the USD/ILS rate by both historical and international standards. Such sizable impact implies strong transmission through non-interest rate channels, which is surprising, as sterilization of FXIs typically dampens its impact by neutralizing the interest rate channel.[31] Therefore, Section 3.2 explores factors that may explain this high effectiveness.

Finally, note that the Hansen J-test statistic of over-identifying restrictions is statistically insignificant. These results indicate that the data align with the imposed moment conditions, suggesting our CU-GMM specification is appropriate.

Robustness. Motivated by the work of Fratzscher (2008), who documents that actual FX interventions are often accompanied by verbal interventions, we also demonstrate in Online Appendix H that our results remain robust when including verbal interventions by BOI officials.

Effect on the forward rate and the cross-currency basis. The estimated coefficient for the three-month USD/ILS forward rate equals 0.73% and is statistically significant at the 10% significance level (Panel (A) in Table 5). Assuming constant domestic and foreign interest rates between two consecutive trading days,[32] this result departs from the CIP predictions of a one-to-one relationship between spot and forward rates when interest rates remain unchanged.

A plausible explanation involves balance sheet-constrained banks facing difficulties in obtaining USD funding,[33] making it costly – especially for lower-rated banks (see Rime, Schrimpf, and Syrstad (2022)) – to arbitrage CIP deviations.

[Insert Table 5 here]

Panel B in Table 5 supports this interpretation by showing that FXIs significantly affect the CCB. Here we define the three-month CCB as the difference between the USD borrowing rate and the synthetic USD investment rate implied by CIP – expressed in annualized percentage points – following the market convention of Du, Tepper, and Verdelhan (2018):

$$CCB_t = r_t^{US} - \left[r_t^{IL} - (f_{t,t+90} - s_t) \right], \tag{3}$$

where r_t^{US} is the log of (1 + 3-month USD LIBOR), r_t^{IL} the log of (1 + 3-month TELBOR), $f_{t,t+90}$ the log of the 3-month USD/ILS forward rate, and s_t the log of the 3-month USD/ILS spot rate. We focus on the 3-month money market rates, as these maturities are the most liquid rates and have historically been used to arbitrage CIP deviations (Rime et al., 2022).

Specifically, a regression of the three-month CCB on FXI volumes reveals a striking result: a USD 1 billion FXI is associated with a widening of the (negative[34]) USD basis by more than 13 basis points (bps), compared to a median basis of -17.7 bps. This effect is both statistically and economically meaningful,[35] suggesting that the BOI's FXIs significantly amplify funding stress in the USD/ILS swap market.[36]

Theoretically, however, our findings align with the predictions of the model proposed by Amador et al. (2020). In their framework, the central bank (CB) of a SOE, such as Israel, implements an optimal exchange rate policy under a zero-interest rate environment through FX interventions. These interventions lead to a contemporaneous depreciation of the SOE's currency. However, market participants anticipate that the FXI regime will eventually be abandoned in the future – implying a future appreciation of the domestic currency. This expectation creates arbitrage opportunities, as the anticipated appreciation cannot be offset by a reduction in the nominal risk-free interest rate due to the binding ZLB. Moreover, since financial intermediaries are assumed to face binding balance sheet constraints, they are unable to exploit these arbitrage opportunities – allowing them to persist. As a result, both foreign and domestic investors prefer domestic bonds due to their higher expected returns, which triggers capital inflows. Since domestic bonds strictly dominate foreign bonds, the domestic CB must step in and purchase the latter, financing these purchases by issuing domestic bonds or money.

For completeness, we note that our CCB results also align with the FXI framework of Fanelli and Straub (2021),[37] who explore the role of FXI in mitigating the distributional consequences of adverse real exchange rate movements. In their model, FXIs lead to CIP violations whenever trading in the forward market faces no participation costs or no position limits.

Robustness. As shown in Table I1 in Online Appendix I, our results are robust to the common market practice of using FX swaps instead of separate spot and forward transactions, the incorporation of transaction costs, the inclusion of the marginal funding costs for the arbitrageur, which are approximated by the commercial paper rate, and the Makam yield[38] for the risk-free investment leg of the CIP arbitrage trade.

3.2 Determinants of the Effectiveness of FXI

Recent theoretical contributions in the FXI literature highlight the role of financial frictions – such as capital-constrained financial intermediaries – in explaining the effectiveness of sterilized FXI, as they prevent the elimination of arbitrage opportunities when CIP breaks down (see the reviews in Villamizar-Villegas and Perez-Reyna (2017) and Popper (2024)).

To illustrate the role of frictions, we draw on the two-country model of Gabaix and Maggiori (2015). In this model, households trade goods internationally and borrow/lend in risk-free domestic currency bonds with international financiers. These financiers face financial constraints due to limited risk-bearing capacity and balance sheet risks, resulting in a downward-sloping demand curve for risk-taking. As a consequence, they demand a currency risk premium to absorb imbalances in the global bond market. This leads to imperfect substitution between risk-free bonds in the two countries, and asset returns become dependent on relative asset supplies. Central banks can then affect this risk premium by altering relative asset supplies. For instance, FXIs aimed at depreciating the domestic currency involve the purchase of foreign currency bonds, financed by selling, e.g., domestic currency bonds. These transactions alter the relative supplies in the global bond market and thereby the size and the composition of the financiers' balance sheets. This, in turn, influences the currency risk premium and the spot rate. The effect of FXIs thereby increases with the severity of financial frictions.

To empirically explore the role of financial frictions, we interact FXI size with the weekly difference (due to its non-stationarity) of the squared leverage ratio of primary dealers from He, Kelly, and Manela (2017) (HKM) – a measure of financial intermediaries' risk-bearing capacity. Table 6 shows that FXI effectiveness increases significantly when global banks are more capital-constrained, consistent with Gabaix and Maggiori (2015). Our result also supports the micro-founded model for the International Monetary Fund's (IMF) integrated policy framework, proposed by Adrian, Erceg, Kolasa, Lindé, and Zabczyk (2021), where the "limited risk-bearing capacity of agents" is key for the effectiveness of FXI in SOEs. Consequently, our finding is particularly relevant for central banks in SOEs, where FXIs are a more intensively used monetary policy instrument (International Monetary Fund, 2022). The FX rate is also an important channel for the transmission of monetary policy in these economies (see e.g., Devereux and Engel (2003) and Svensson (2000)), highlighting the relevance of our finding.

Finally, our results also align with the view that the tighter banking regulation in the aftermath of the GFC – e.g., the higher capital requirements under the new banking regulatory framework Basel III[39] – may have amplified the effectiveness of sterilized FXI. This is because the HKM metric, which is a function of the leverage ratio, is a key determinant of the effecctiveness of the BOI's FXI activities. The increased use of FXIs, as reported by the International Monetary Fund (2022), may be partially attributed to this regulatory change.

Robustness. To assess the robustness of our findings, we calculate the composite squared leverage ratio of the banks that are most actively trading in the USD/ILS spot market, following the He et al. (2017) approach. Using this indicator (displayed in Figure J1 in Online Appendix J) does not alter our results (compare Table 6 with Table J1 in Online Appendix J). Additionally, the HKM indicator is strongly correlated with an alternative risk-bearing capacity indicator that is constructed with the leverage ratios of FX primary dealers as the input, as shown in Cerutti and Zhou (2023). These two findings suggests that the specific choice of the indicator is of secondary importance.

[Insert Table 6 here]

3.3 Interventions and the Higher-Order Moments of the RND

We examine how option markets' expectations change in response to the BOI's spot market interventions. Specifically, we analyze the price quotes of ATMVs, scaled RRs, and scaled BF spreads,[40] which serve as proxies for the higher-order moments of the RND.[41] We assess how these price quotes respond to FXI activities both contemporaneously and over longer horizons (Section 3.3.2), focusing on option contracts with maturities ranging from one month ("1 M") to twelve months ("12 M"). This granularity allows us to understand the option market participants' view about the long-term effect of FXI, which is relevant for policymakers.

3.3.1 *Foreign Exchange Interventions and the Information Contained in the Higher-Order Moments of the Risk-Neutral Distribution*

We investigate whether the lagged higher-order moments of the RND are positively associated with the size of FXIs. To this end, we regress FXI data on the one-day lagged two-week change of the equally weighted mean of the scaled 10- and 25-Δ RR ("$\Delta\overline{\text{RR}}_{t-11,t-1}$"), scaled BF spreads ("$\Delta\overline{\text{BF}}_{t-11,t-1}$"), and ATMV ("$\Delta\text{ATMV}_{t-11,t-1}$"), using in addition our benchmark controls $\mathbf{X}_t$ from Table 4:

$$\text{FXI}_t = \alpha + \beta_{\text{RR}}\ \Delta\overline{\text{RR}}_{t-11,t-1} + \beta_{\text{BF}}\ \Delta\overline{\text{BF}}_{t-11,t-1} + \beta_V\ \Delta\text{ATMV}_{t-11,t-1} + \mathbf{X}_t^T\boldsymbol{\gamma} + \varepsilon_t,$$

All RND-moment measures (or scaled option price quotes) are computed over $t-11$ to $t-1$ and entered with a one-day lag to reduce simultaneity concerns.

We control for the contemporaneous change in the spot rate to account for the systematic positive correlation between changes in the USD/ILS spot rate and changes in the quoted prices of the RRs and BF spreads. This correlation is observed in practice[42] and may impact our results if not properly controlled for. In other words, we aim to assess how the options market responds to new information, independent of the contemporaneous spot rate movements. The results are presented in Table 7.

The results indicate that only the coefficients associated with $\Delta\overline{\text{RR}}$, a measure of the skewness of the RND, are significant. This suggests that option market participants primarily price in crash risks related to a large future ILS depreciation, as the coefficients associated with the $\Delta\overline{\text{BF}}$ spreads are insignificant. Consequently, by intervening in the spot market, the BOI is able to affect option market expectations in the intended direction (i.e., towards an expected ILS appreciation).

In terms of the size of this effect, we see that a one percentage point increase of the RR is associated with a larger FXI volume of between USD 153 million ("1 M") and USD 226 million ("6 M"). The upward adjustment of the RRs occurs across all maturities, suggesting that option market participants expect the upcoming FXI activities to have a lasting effect on the future spot rate, persisting for at least twelve months.

[Insert Table 7 here]

3.3.2 *Econometric Assessment of the Longer-Term Effect of FXI*

We employ the local projection-instrumental variable (LP-IV) approach, as used in Ramey and Zubairy (2018), to examine the impact of the BOI's FXIs on the higher-order moments of the RND function (Figure 3). This approach allows us to assess how the expected higher moments of the future spot rate distribution respond to FXIs over

[Insert Figure 3 here]

longer periods. We control again for the contemporaneous correlation between option price quotes and the spot rate.

Our results reveal that FXI are associated with three key shifts in the option-implied RND: (i) a pronounced decline in ATMV at the intervention date that remains significantly lower for the six-, nine-, and twelve-month maturities, (ii) an increase in skewness for short-dated options, reflecting a greater likelihood of ILS depreciation than appreciation,[43] and a (iii) reduction in excess kurtosis[44] for longer-dated contracts, implying that extreme spot rate moves are deemed less likely.[45]
Although the statistical significance is mixed – some estimates are only significant over a short period – the directional effects are robust: FXIs consistently tilt option-implied expectations toward future ILS depreciation and lower implied volatility in the months that follow. Economically, a USD 1 billion purchase – associated with an average 0.83% ILS depreciation against the USD – yields approximately a 5 pps decline in ATMV, a 0.10 pps increase in BF spreads, and a 0.3 pps rise in RRs.

The effect on the higher-order moments unfolds slowly. This slow adjustment could simply reflect sampling error. However, the gradual build-up in option price quotes also aligns with the notion that sophisticated arbitrageurs face binding capital constraints and risk limits, preventing an immediate full adjustment to intervention news. Given the well-documented clustering of FX interventions (see footnote 7 and Table **??**), market participants may anticipate additional interventions once a FXI shock occurs, which – due to aforementioned "limits to arbitrage" – delays full option price adjustment. This interpretation is particularly compelling for longer-maturity ATMV options, where margin requirements are highest because of high potential future exposure.[46]

The pattern we document aligns with models of slow-moving capital (see Duffie (2010) and the references within) where price discovery occurs gradually as constrained arbitrageurs slowly incorporate new information about intervention policy into option valuations. In particular, Roussanov and Wang (2023) demonstrate that even in the highly liquid USD market, a U.S. monetary policy shock leads to a gradual, week-long appreciation of the USD, an effect they attribute to constrained arbitrageurs. Therefore, our results are in line with this literature.

Relationship to Table 7. A complementary explanation for the slow option price adjustment is that FX option writers may misestimate the size of FXIs ex ante. The dynamism in the option price quotes then aligns with the idea that option writers ex ante only priced in a fraction of the actual FXI volumes – and, as demonstrated in Table 7, also only for RRs – and recalibrate their expectations concerning the higher-order moments of the RND after an FXI episode accordingly. This gradual adjustment highlights the role of spot market FXIs in shaping evolving option market expectations.

Last but not least, the market also needs time to learn and agree on the effectiveness of the intervention spell, especially since the BOI's FXIs are secret.

3.4 *Interventions and Tail Probabilities*

We now analyze how the tail probabilities of the RND change in anticipation of future FXIs over the lifetime of the underlying option contracts (Section 3.4.1). We also assess how these probabilities respond to FXI in the spot market, both contemporaneously and over longer horizons (Section 3.4.2).

3.4.1 *Relationship Between the Lagged Tail Probabilities and Interventions*

This section analyzes the relationship between lagged option-implied tail (or crash) probabilities and the size of future FXIs, serving three purposes: (i) it builds on our prior finding (Section 3.3.1) showing that lagged changes in the scaled RR are positively associated with the size of FXIs, after controlling for their effect on the USD/ILS spot rate. As RRs reflect the risk-neutral probabilities of a large ILS depreciation versus a large ILS appreciation, their positive correlation with FXIs suggests higher concern over downside than upside risks. Disentangling the probabilities of an extreme ILS depreciation from those of an extreme ILS appreciation therefore allows us to better understand how option markets recalibrate expectations in anticipation of forthcoming FXIs. (ii) The interest in understanding how FXIs affect tail risks is also motivated by the BOI's past success in mitigating these risks via spot market FXIs,[47] suggesting that the BOI may consider tail risks in their monetary policy decision-making process. (iii) Framing results in terms of probabilities rather than option-implied higher moments (or option prices), enhances interpretability, facilitates monetary policy-making under a FXI regime, and supports central bank communication with the public.

Methodology. For each trading day and across five maturities, we fit a second-order polynomial to describe the implied volatility-moneyness curve, following the approach of Zhang and Xiang (2008):[48]

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

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

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

with K denoting the strike price, F_t the forward rate implied by put-call parity for ATM options, $\bar{\sigma}$ representing the average volatility of the underling exchange rate[49] – an industry convention for stocks to facilitate cross-asset comparability – and $\tau = T - t$ the time to maturity, where T is the expiration date of the underlying option contracts.[50]

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

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

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

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

We proceed in a similar way to obtain the probabilities of a sharp ILS depreciation.

In our paper, the risk-neutral tail probabilities reflect an expected change in the USD/ILS spot rate by ± 2 percent[51] 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 are adapted from Hattori, Schrimpf, and Sushko (2016), who evaluate equity market tail risks over a three-month horizon using the S&P 500 index. Given the lower volatility of FX markets relative to equities, we scale these thresholds down accordingly.

The results are presented in Table 8. While all estimated coefficients carry the expected sign, statistical significance emerges only for the probabilities of a sharp ILS depreciation. Specifically, a one percentage point increase in the right-tail probability – i.e., a higher risk-neutral likelihood of a large ILS depreciation – is associated with an expected increase in the size of FXIs ranging from USD 315 million ("1 M") to USD 928 million ("12 M"), relative to trading days when right-tail probabilities remain constant. This result suggests that market participants anticipate larger FXI volumes when the perception of downside risks increases.

[Insert Table 8 here]

3.4.2 *Econometric Assessment of the Longer-Term Effect of FXI*

Figure 4 depicts the dynamic response of the option-implied left-tail and right-tail probabilities to an unexpected FXI shock at time zero.[52] The shock corresponds to an anticipated ILS appreciation or depreciation by at least 2%, 3%, 6%, 9% and 10% across maturities of one, three, six, nine, and twelve months, respectively. The plot shows that shifts in the RND are primarily driven by a reduction in the probability of a sharp ILS appreciation (i.e., the left tail). For the right tail, the null hypothesis of no significant persistent effect cannot be rejected, except for a short-lived impact on the nine-month options at the beginning of the time horizon. This finding indicates that the BOI's spot market FXIs also affect option market expectations in the intended direction, specifically by mitigating appreciation pressures on the ILS.

4. CONCLUSION

Since early 2008 – after policy rates hit the zero lower bound and conventional ammunition was exhausted – the Bank of Israel (BOI) frequently intervened in the USD/ILS spot market by purchasing USDs to counteract ILS appreciation pressure. Focusing on the FXI regime from 2013 through the onset of the COVID-19 pandemic, we find that these sterilized interventions resulted in a sharp depreciation of the ILS. Our paper thereby adds recent empirical evidence to the FXI literature that often analyzed FXI markets that were much less developed and often used coarse and imprecise proxies for the undisclosed actual FXI volumes. We also add empirical evidence on secret FXIs, which is still scarce and underresearched (Naef and Weber, 2023).

We show that capital constraints on global financial intermediaries help explain this effectiveness, lending empirical support to models such as Gabaix and Maggiori (2015), which attribute the effectiveness of sterilized FXIs to intermediary constraints. This insight offers operational guidance to central banks by identifying the structural conditions under which the effect of sterilized FXIs is amplified. Additionally, we show that the BOI's FXIs widen the deviations from covered interest rate parity (CIP) – as captured by the cross-currency basis (CCB) – consistent with the predictions of Amador et al. (2020), who study the optimal FX rate policy in a small open economy when

[Insert Figure 4 here]

policy rates are zero. This framework suggests FXI regimes in a zero interest rate environment lead to systematic CIP violations – supporting the external validity of our empirical results.[53]

Moreover, our findings highlight the rich informational content of FX option markets for evaluating the effectiveness of spot market FXIs. By monitoring how option market expectations – reflected in the higher-order moments of the risk-neutral density (or the corresponding ATMV, scaled BF spreads, and scaled RRs) and tail risk probabilities – adjust in response to FXIs in the spot market, central banks can assess whether interventions steer market expectations in the intended direction. Such insights enhance the sustainability of intervention strategies and underscore the need for FXI-operating central banks to implement a systematic framework that integrates option market data into the assessment and design of FXI policy.

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NOTES

1. As an alternative, FX interventions through the FX derivatives market have become more popular in recent years, as summarized in Domanski, Kohlscheen, and Moreno (2016). Examples include Brazil, with FX interventions in the FX forward and FX swap market (Chamon, Garcia, and Souza, 2017; Nedeljkovic and Saborowski, 2019; Ferreira, Mullen, Ricco, Viswanath-Natraj, and Wang, 2025), Colombia with FX interventions through the FX option market (Keefe and Rengifo, 2015; Kuersteiner, Phillips, and Villamizar-Villegas, 2018), and Chile with FX interventions via FX swaps and FX forwards (Kohlscheen and Andrade, 2014; Arenas and Griffith-Jones, 2023; Jara and Piña, 2023).
2. Each USD purchase is offset by open market operations of equal size, leaving domestic liquidity – and therefore policy rates – unchanged.
3. See, e.g., King, Osler, and Rime (2012, 2013) and the "2022 Triennial Survey of turnover in OTC FX markets" (Bank for International Settlements, 2022). The survey reports a 648% and 1101% increase in FX options and outright forwards turnover since 1995, compared to a 326% increase in spot FX volumes.
4. We evaluate the impact of FXIs by assuming a size of USD purchases of USD 1 billion, a common amount used in the FXI literature and unrelated to the BOI's actual FXI volumes.
5. For instance, in a meta-analysis covering 74 empirical studies that have analyzed FX interventions in 19 countries across five decades, Arango-Lozano, Menkhoff, Rodríguez-Novoa, and Villamizar-Villegas (2020) document that a net purchase of USD 1 billion is associated with a depreciation of the domestic currency by 1%. The authors report evidence of a weak positive publication bias and find that the effects are smaller in advanced economies. Focusing on specific countries, Menkhoff et al. (2021) document that the USD/JPY exchange rate depreciates on impact by 0.2% to a USD 1 billion purchase by the Bank of Japan. Fatum (2015) finds a smaller effect ranging from a 0.01% to a 0.12% JPY depreciation.
6. A RR is a widely used option strategy that involves buying a call and selling a put option on the same underlying at a pre-specified purchase price, called the strike price. In our context, a RR allows investors to buy USD in exchange for ILS (a USD call ILS put option) and obligates them to sell ILS in exchange for USDs (an ILS call USD put option) at a pre-specified USD/ILS exchange rate. A positive RR is observed when the call option price exceeds the put option price, indicating that investors are willing to pay more for an USD call than for an ILS call. This implies that investors expect the USD to appreciate rather than to depreciate against the ILS.
7. See Sarno and Taylor (2001); Neely (2005); Fratzscher (2005); Égert and Komárek (2006); Disyatat and Galati (2007); Fatum (2015); Ribon (2017); Caspi, Friedman, and Ribon (2022); Adler, Lisack, and Mano (2019); Nedeljkovic and Saborowski (2019); Arango-Lozano et al. (2020).
8. Evidence from Japan suggests that FXIs lose nearly half of their effectiveness when the ZLB binds (Iwata and Wu, 2012).
9. This model has revitalized the theoretical FXI literature, which had been dormant since the pioneering work of Backus and Kehoe (1989).
10. Du et al. (2018); Avdjiev, Du, Koch, and Shin (2019); Du and Schreger (2021).
11. See, e.g., Bonser-Neal and Tanner (1996); Castrén (2004); Fratzscher (2005); Galati, Melick, and Micu (2005); Galati, Higgins, Humpage, and Melick (2007); Disyatat and Galati (2007); Morel and Teïletche (2008); Marins, Araujo, and Vicente (2017).
12. This exchange rate is calculated as the geometric average of the foreign value of the ILS FX vis-à-vis 24 currencies, representing 31 of Israel's major trading partners, weighted by trade share (Friedman and Galo (2015) and `https://www.boi.org.il/en/Markets/ExchangeRates/Pages/efectinf.aspx`).
13. Both FX rates are presented as indices to facilitate comparison.

14. Both FX rates are quoted in American terms, i.e., as the price of one unit of foreign currency (or a currency basket) in domestic currency units. An increase then reflects a depreciation of the shekel.
15. These are the price quotes of USD/ILS (put/call) option contracts with a strike price equal to the current forward rate – called at-the-money-forward options – expressed as option-implied volatilities.
16. By market convention, FX options are quoted using the Garman and Kohlhagen (1983) (GK) model. A 10-Δ call (put), for instance, corresponds to a GK option delta of 0.1 (-0.1). The option spot delta measures the sensitivity of the option price to small changes in the underlying.
17. These option price quotes are the result of, e.g., buying a call below the spot rate, selling two at the spot rate, and buying one above it. As a BF spread buyer you profit most when the FX rate at maturity is close to the "middle strike" (the one where you sold two options). Hence, these option strategy is typically used by investors that expect only modest exchange rate volatility over the option contract's maturity.
18. For details on risk reversals and butterfly spreads, see Online Appendix C.
19. Tables D2–D4 in Online Appendix D report cross-correlations between the log returns of the option contracts. The results show high correlations among option prices, especially at longer maturities.
20. Source: `https://www.bis.org/statistics/rpfx19.htm`.
21. Including FX spot, forward, option, and swap transactions; see Figure E1 in Online Appendix E
22. Since ATMV levels differ across currencies, we divide the BAS by the mid-quote to ensure comparability across currency pairs.
23. See, e.g., Neely (2005); Fratzscher (2005); Naef (2024).
24. See Adler and Tovar (2014); Adler et al. (2019).
25. The size of FXI on day $t + j$ (where $j \in \{-9, -8 \ldots, 0, \ldots, +10, +11\}$) is expressed as a share of the total FXI volume over the entire sample period.
26. See, e.g., Humpage (1999); Fatum and Hutchison (2003); Fratzscher (2005); Fatum and Hutchison (2006); Galati et al. (2007); Fatum (2008); Fratzscher (2008); Fratzscher et al. (2019).
27. Following Ito and Yabu (2007); Fatum and Hutchison (2010); Fatum and Yamamoto (2014); Nedeljkovic and Saborowski (2019).
28. See `https://data.bis.org/topics/EER`.
29. We also experimented with the decomposition of the VIX into a risk aversion (i.e., the risk premium (Carr and Wu, 2009)) and an uncertainty component, following Bekaert, Hoerova, and Lo Duca (2013). As our results remained robust, we chose to report findings based on the overall VIX, aligning with Nedeljkovic and Saborowski (2019). This suggests that risk aversion plays a secondary role in the context of the BOI's FXI regime.
30. Panel a of Figure G1 in Online Appendix G confirms that the effect is both immediate and persistent, with no statistically significant reversal following the start of an FXI episode.
31. See, e.g., Iwata and Wu (2012) who provide empirical evidence from Japan in a zero-interest rate environment.
32. Note that the BOI's USD purchases are sterilized, which – according to the asset market approach to exchange rate determination – implies that FXI do not systematically affect the domestic interest rate (see, e.g., Villamizar-Villegas and Perez-Reyna (2017)). Moreover, since we use daily data, changes in the U.S. risk-free interest rate from one day to the next are negligible.
33. Recent empirical studies document a persistently negative CCB for many currencies vis-à-vis the USD since the GFC (Du et al. (2018); Du and Schreger (2021)). In such cases, hedged synthetic USD funding via FX swaps is more expensive than borrowing USD directly in the US cash market.
34. Figure I1 in Appendix I illustrates this by showing that the CCB for the USD/ILS FX rate falls within the region where arbitrage was profitable for global banks.
35. The standard deviation of the three-month CCB over the sample period is 16.5 bps. Hence, the BOI's FXI activities widen the CCB by around 0.82 standard deviations.
36. The effect persists for up to 90 days, as shown in panel c of Figure G1 in Online Appendix G.
37. This correspondence is unsurprising: Amador et al. (2020) build on the intermediary frictions of Gabaix and Maggiori (2015), and Yakhin (2021) demonstrates that the Gabaix and Maggiori (2015) and Fanelli and Straub (2021) models are equivalent to a first-order approximation.

38. Makam is a zero-coupon, risk-free short-term security (up to one year) issued by the Bank of Israel.
39. Note that under Basel III, a higher leverage ratio indicates lower leverage (i.e., a higher capital ratio), which is the opposite of the usual leverage interpretation.
40. We scale the price quotes of the RR and the BF option contracts to remove their dependence on the prevailing level of the option-implied volatility curve (Jurek, 2014).
41. After dividing the price quotes of the RR and the BF option contracts by the ATMV with equivalent maturity, the scaled price quotes directly reflect the option-implied skewness and excess kurtosis of the USD/ILS RND (see Online Appendix K3).
42. Tables D2, D3, and D4 in Online Appendix D report positive correlations between the log returns of the option price quotes and the daily USD/ILS spot rate changes. This contemporaneous relationship - documented in McCauley and Melick (1996); Malz (1997) and Campa, Chang, and Reider (1998) for RRs - suggests that investors assign a larger weight to a continued depreciation (appreciation) of the ILS following recent ILS weakness (strength), indicating momentum. The rare-disaster model of FX rates proposed by Farhi and Gabaix (2016) offers a compelling alternative explanation for this pattern.
43. The scaled RR rises significantly around the intervention for one-month tenors only.
44. The BF spread increases significantly over longer horizons for the six-, nine- and twelve-month options, consistent with a drop in implied excess kurtosis.
45. The patterns (ii) and (iii) are consistent with the empirical evidence in Chen, Hsieh, and Huang (2018), who document that skew risk predominates at short horizons while tail risk emerges over longer horizons in EUR/USD options.
46. ATMV sit at the peak of the vega curve – that is, they're most sensitive to changes in implied volatility – so as implied volatility decays over the life of the contract, their values erode most sharply. By contrast, RRs carry (in theory) zero vega, and BF spreads exhibit a small negative vega. Hence, when implied volatility falls, ATMV are expected to drop significantly, RR quotes should remain essentially unchanged, and BF-spread prices should increase only marginally – by far less than the decline in the ATM options (see Online Appendix C3 for details).
47. From July 2008 to 2010, according to an interview of the former Governor of the BOI Stanley Fisher in Maggiori (2021).
48. This curve was initially proposed by Backus, Foresi, and Wu (2004) for FX options, albeit with a different definition of moneyness ξ.
49. Calculated as the daily average of the five implied volatilities across call, put, and ATM options.
50. We opted for this approach instead of jump-diffusion models as in, e.g., Olijslagers, Petersen, de Vette, and van Wijnbergen (2020), as it is implausible to expect a complete depreciation (i.e., a crash) of either the ILS or the USD during the sample period.
51. Hence, $E(S_T) = 0.98S_t$ (or $E(S_T) = 1.02S_t$) for the probability of a sharp ILS appreciation (depreciation), where $E(\star)$ denotes the expectations operator.
52. For tractability, we interpret the linear projections directly as tail probabilities - rather than, e.g., transforming them via a logistic or probit link - thus enabling a straightforward estimation of FXI effects.
53. In the meantime, many more papers propose models that predict persistent and systematic CIP deviations after FXIs, see, e.g., Bacchetta, Benhima, and Berthold (2023); Bacchetta, Davis, and van Wincoop (2024); Ferreira et al. (2025).

TABLES

TABLE 1
DESCRIPTIVE STATISTICS FOR THE MONTHLY PUBLIC 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 reports descriptive statistics for monthly aggregated FX intervention volumes (USD billions) in columns 2–6, and the number of months with at least one intervention day in column 7. The data cover the period from January 2013 to December 2019.

TABLE 2
DESCRIPTIVE STATISTICS FOR THE DAILY CONFIDENTIAL 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 presents descriptive statistics of the daily intervention data from January 1, 2013 to December 31, 2019. Row 1 shows Israel's GDP in USD, compiled by the Israeli Central Bureau of Statistics. Row 2 reports the daily traded volume in the USD/ILS market, as provided by the BOI. Row 3 displays the average duration of an intervention spell within a rolling weekly window (e.g., from Monday to Monday, Tuesday to Tuesday). Row 4 shows the average number of consecutive intervention days within a calendar week.

TABLE 3
DESCRIPTIVE STATISTICS FOR THE MAIN VARIABLES

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

Notes: The table reports descriptive statistics for the main variables, based on daily data from January 1, 2013 to December 31, 2019, covering up to 1,826 trading days. Exchange rates (USD/ILS and EUR/USD; both expressed as daily log changes in percent) and the 5-year Israeli CDS spread are sourced from Bloomberg with a timestamp of 5 PM EST. The NEER is adjusted to match the USD/ILS trading hours (see Table B1 in Online Appendix B for details). The 3-month USD/ILS forward rate is retrieved from Bloomberg. The USD/ILS cross-currency basis (CCB) is the 3-month CCB calculated based on Equation (3). The VIX, obtained from the CBOE, reflects implied volatility from S&P 500 options at U.S. closing time and has fewer observations due to U.S. holidays.

TABLE 4
EFFECT OF FOREIGN EXCHANGE INTERVENTIONS ON THE SPOT EXCHANGE RATE

(a) PANEL A

Dependent variable: $\mathbf{\Delta\,ln}(\text{USD/ILS}_t)$ (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)
$\Delta\text{EUR/USD}_{t-1,t}$	−0.408***	−0.412***	0.044***
	(−23.04)	(−21.42)	(−21.36)
$\Delta\text{VIX}_{t-5,t}$	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: $\boldsymbol{\Delta}$ **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	

Notes: The dependent variable is the daily log return (in percent) of the USD/ILS spot rate (Panel A) and the nominal effective exchange rate ("NEER"; Panel B). Regressors include an intercept, the size of foreign exchange interventions ("FXI_t"; in USD billions), the daily log return of the EUR/USD spot rate ("$EUR/USD_{t-1,t}$"; in percent), the one-week change in the VIX ("$\Delta VIX_{t-5,t}$"; in percentage points), and five news indicators (variables ending with "Surprise$_t$"). Specification [1] employs standard OLS, [2] applies the continuously updated GMM estimator (CU-GMM), and [3] reports two-stage least squares (2SLS) estimates. For details on the CU-GMM instrument set, see Table F1 in Online Appendix F. The Hansen J-test statistic evaluates the validity of the over-identifying restrictions in the GMM. The t-statistics (in parentheses) are Newey-West HAC corrected. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The sample spans the period from January 1, 2013, to December 31, 2019.

TABLE 5
EFFECT OF INTERVENTIONS ON THE FORWARD RATE AND CROSS-CURRENCY BASIS

(a) PANEL A	Dependent variable: Δ **ln**(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)
$\Delta EUR/USD_{t-1,t}$	−0.33***	−0.33***	−0.337***
	(−19.32)	(−18.35)	(−18.48)
$\Delta VIX_{t-5,t}$	0.01***	0.01***	0.011***
	(4.42)	(4.42)	(4.40)
IL_Monetary_Surprise$_t$	−3.31***	−3.28***	−3.332***
	(−5.76)	(−5.81)	(−5.86)
IL_CPI_Surprise$_t$	−0.61**	−0.62**	−0.609**
	(−2.06)	(−2.11)	(−2.08)
NS_FFR_Surprise$_t$	−3.75	−3.33	−3.653
	(−1.48)	(−1.23)	(−1.41)
NS_Policy_Surprise$_t$	−7.76***	−8.51***	−7.882***
	(−3.11)	(−3.38)	(−3.09)
CITI_Surprise_Index$_t$	0.000021	0.000082	0.000002
	(0.09)	(0.34)	0.008
Hansen J-statistic		2.22	
Hansen J-statistic p-value		0.53	

(b) PANEL B	Dependent variable: $\boldsymbol{\Delta}$ 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 log return (in percent) of the three-month USD/ILS forward rate ("3M Forward"; Panel A) and the daily change of the three-month USD/ILS basis (in percentage points p.a.; "Δ3M Basis$_t$"; Panel B) are regressed on an intercept, the size of interventions ("FXI$_t$"; in USD billions), the daily log return (in percent) of the EUR/USD spot rate ("EUR/USD$_{t-1,t}$"), the one-week change in the VIX ("ΔVIX$_{t-5,t}$"; in percentage points), and five news indicators (variables ending with "Surprise$_t$"). Specification [1] uses standard OLS, [2] the continuously updated GMM estimator (CU-GMM), and [3] two-stage least squares (2SLS). For details on the CU-GMM instrument set, see Table F1 in Online Appendix F. The Hansen J-test assesses the validity of the over-identifying restrictions in the GMM specification. t-statistics (in parentheses) are Newey-West HAC robust. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The sample period is January 1, 2013, to December 31, 2019.

TABLE 6
DETERMINANTS OF THE EFFECTIVENESS OF INTERVENTIONS

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

Notes: The daily log return of the USD/ILS spot rate (in percent) is regressed on an intercept, the size of interventions ("FXI_t"; in USD billions), the one-week change in the HKM indicator ("$\Delta HKM_{t-5,t}$"), the interaction between FXI_t and $\Delta HKM_{t-5,t}$, the daily log return of the EUR/USD spot rate ("$EUR/USD_{t-1,t}$"; in percent), the one-week change in the VIX ("$\Delta VIX_{t-5,t}$"; in percentage points) and the five news indicators (variable names ending with "Surprise$_t$"), using the continuously updated GMM estimator (CU-GMM). The set of instruments used in the CU-GMM is detailed in Table F1 in Online Appendix F. We report the Hansen J-test statistic of over-identifying restrictions to assess the consistency of the data with the imposed moment conditions. The t-statistics are Newey-West HAC corrected and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. The sample period is January 1, 2013, to December 31, 2019.

TABLE 7
RELATIONSHIP BETWEEN LAGGED SCALED RISK REVERSALS, BUTTERFLY SPREADS, AT-THE-MONEY IMPLIED VOLATILITIES, AND FOREIGN EXCHANGE INTERVENTIONS

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

Notes: The size of daily FX interventions ("FXI_t", in USD billion) is regressed on the one-day lagged two-week change of the equally weighted mean of the scaled 10- and 25-delta USD/ILS risk reversals ($\Delta\overline{RR}_{t-11,t-1}$), the scaled 10- and 25-delta USD/ILS butterfly spreads ($\Delta\overline{BF}_{t-11,t-1}$) and the at-the-money USD/ILS options ($\Delta ATM_{t-11,t-1}$). We consider five option maturities in total, ranging from one month ("1 M") to twelve months ("12 M"). As additional controls, we use controls of our benchmark specification in Table 4. The t-statistics are Newey-West HAC corrected and reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. The sample period is January 1, 2013 to December 31, 2019.

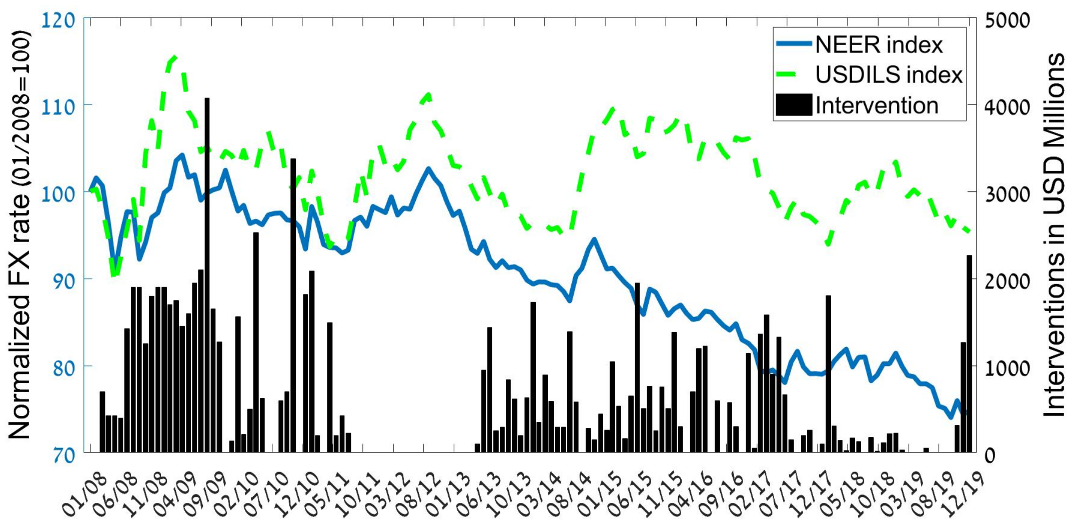
TABLE 8
RELATIONSHIP BETWEEN LAGGED TAIL PROBABILITIES AND INTERVENTIONS

	Dependent variable: FXI_t				
	1M	3M	6M	9M	12M
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 reports regression results of daily intervention volume ("FXI_t", in USD billion) on the one-day lagged two-week changes in the probability of a sharp ILS appreciation ("ΔProb. of appreciation$_{t-11,t-1}$", in percentage points) and depreciation ("ΔProb. of depreciation$_{t-11,t-1}$", in percentage points) across five contract maturities, ranging from one month ("1 M") to twelve months ("12 M"). All specifications include control variables: the one-day lagged log returns of the NEER over one-week and one-month horizons, and the one-day lagged one-day change in the VIX. The t-statistics (in parentheses below the coefficients) are Newey-West HAC corrected. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Sample period: January 1, 2013 to December 31, 2019.

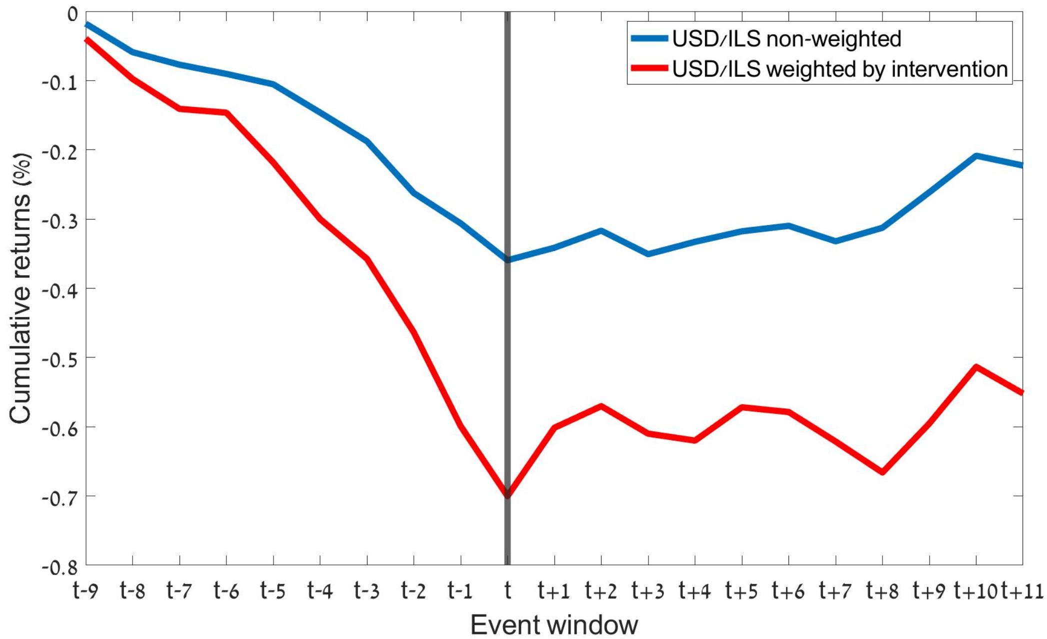
FIGURES

FIGURE 1
FOREIGN VALUE OF THE ILS AND THE SIZE OF FOREIGN EXCHANGE INTERVENTIONS



Notes: The figure shows monthly averages of the nominal effective exchange rate (NEER) and the USD/ILS spot rate (both on the left axis), along with total monthly FX intervention volumes in USD millions (right axis). The NEER and the USD/ILS are indexed to 100 in January 2008 and expressed in units of the domestic currency per unit of foreign currency, so a decline in the index indicates an appreciation of the shekel. The data span the period from January 2008 to December 2019.

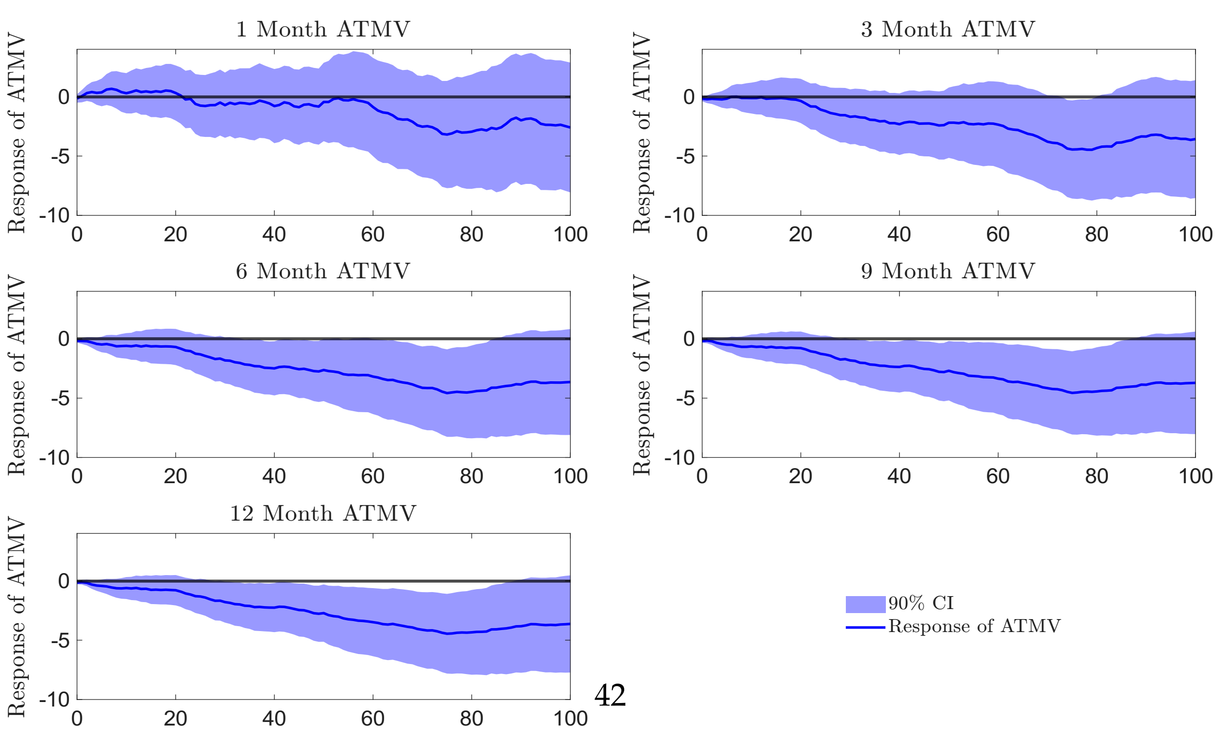
FIGURE 2
CUMULATIVE USD/ILS SPOT RATE RETURNS AROUND THE INITIATION OF AN INTERVENTION SPELL



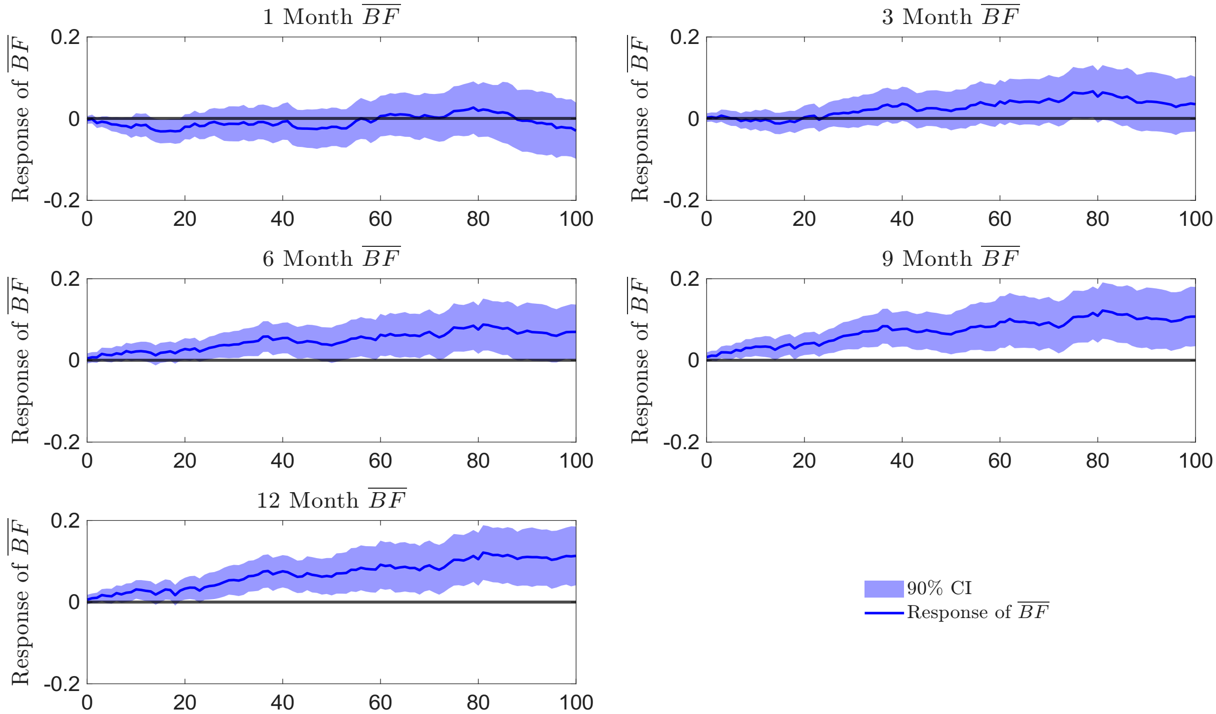
Notes: The figure displays average cumulative USD/ILS exchange rate returns (in percent) from $t-9$ to $t+11$, where t marks the start of the first intervention day. The red line represents returns weighted by the relative size of each intervention; the blue line shows equally weighted returns across episodes.

FIGURE 3
LONGER-TERM EFFECT OF A FX INTERVENTION SHOCK OF SIZE USD 1 BILLION

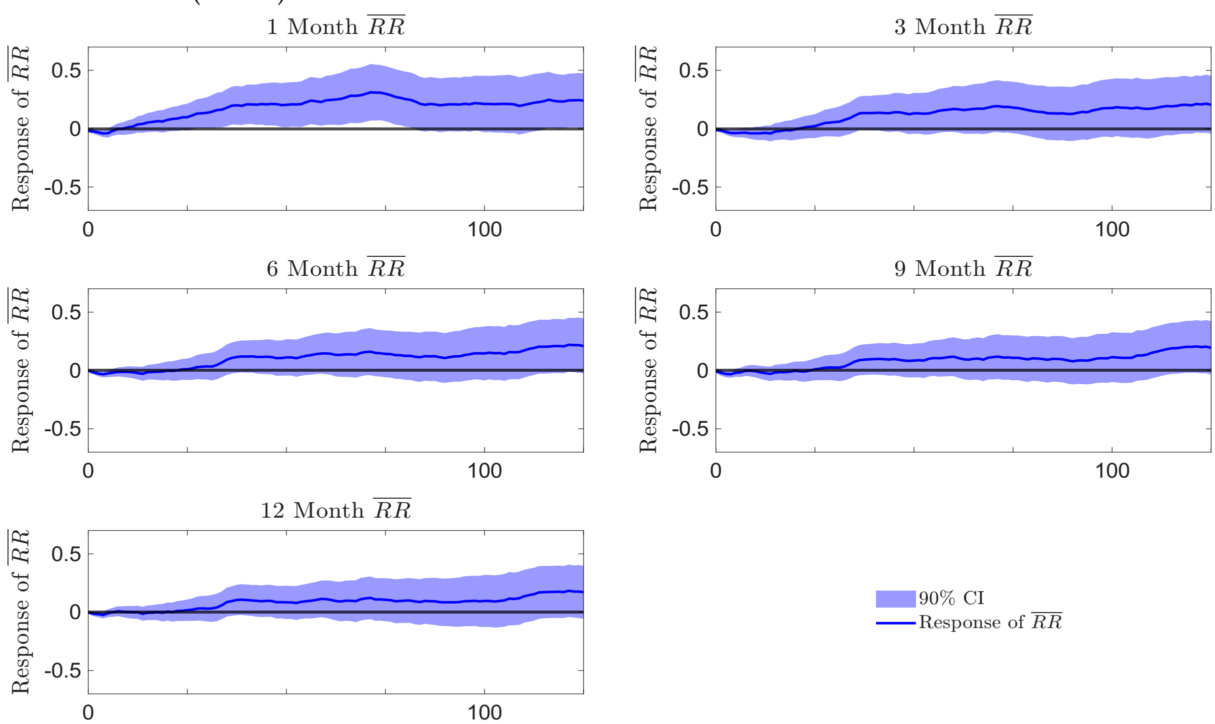
(a) CUMULATIVE CHANGE OF THE AT-THE-MONEY IMPLIED VOLATILITY ACROSS FIVE MATURITIES (IN PP)



(b) CUMULATIVE CHANGE OF THE SCALED BUTTERFLY SPREADS ACROSS FIVE MATURITIES (IN PP)



(c) CUMULATIVE CHANGE OF THE SCALED RISK REVERSALS ACROSS FIVE MATURITIES (IN PP)

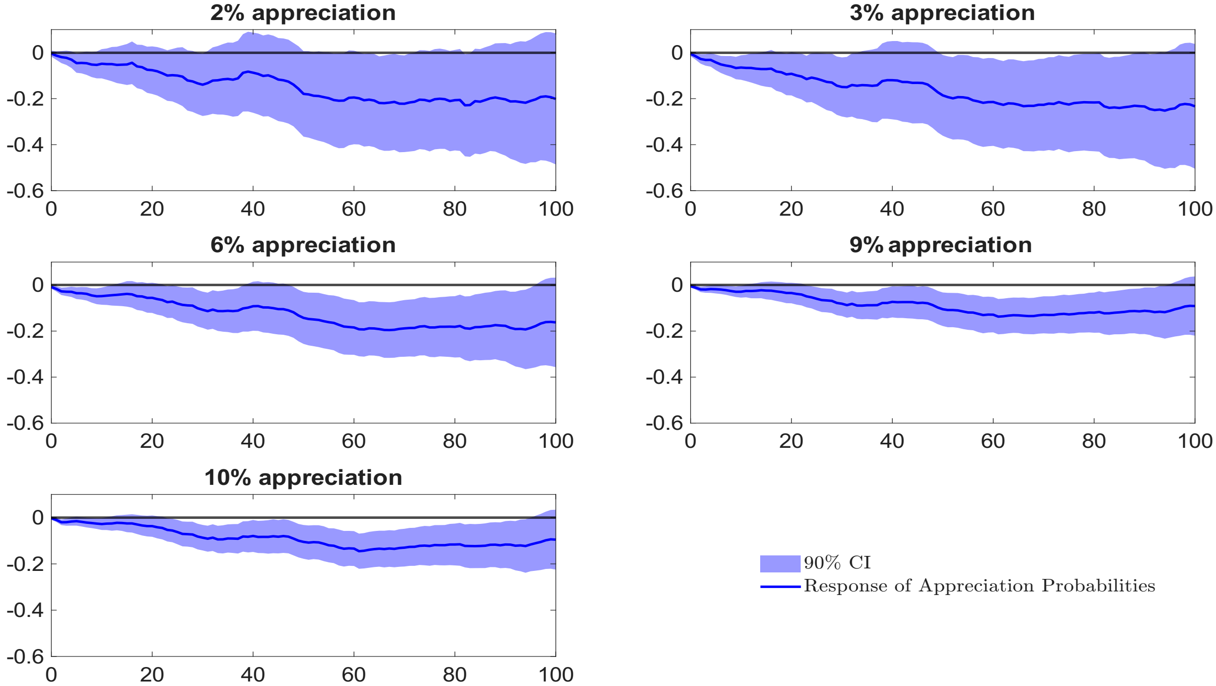


Notes: The figure shows the average cumulative change of the USD/ILS at-the-money volatility (Panel (a)), Butterfly spreads (Panel (b)), and risk reversals (Panel (c)) across five maturities from day 0, . . . , to 100, where day 0 marks the start of the trading day when the first intervention occurred. Solid lines indicate the cumulative response, while shaded areas represent 90% confidence intervals.

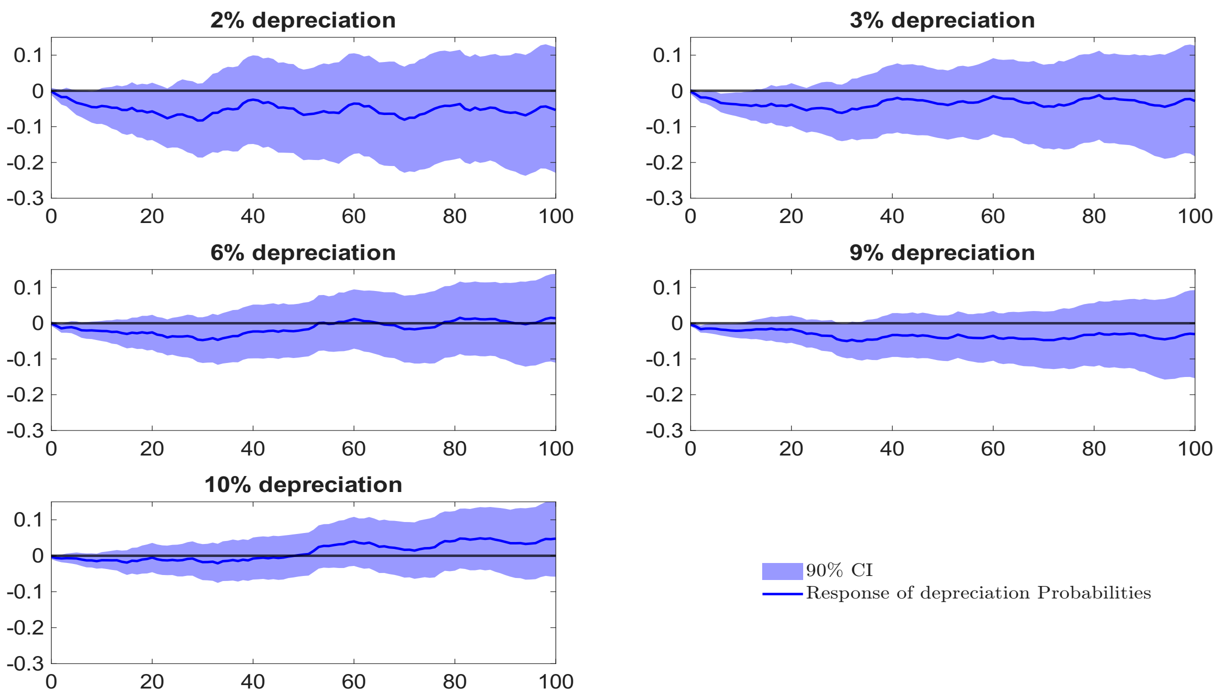
FIGURE 4

THE LONGER-TERM EFFECT OF A $1 BILLION FX INTERVENTION SHOCK

(a) CUMULATIVE CHANGE OF LEFT-TAIL PROBABILITIES ACROSS FIVE MATURITIES (IN PP)



(b) CUMULATIVE CHANGE OF RIGHT-TAIL PROBABILITIES ACROSS FIVE MATURITIES (IN PP)



Notes: The figure illustrates the average cumulative change in the option-implied tail probabilities (in pps) over a 100-day horizon across five maturities. Panel (a) shows left-tail probabilities (reflecting ILS appreciation), while panel (b) displays the right-tail probabilities (reflecting ILS depreciation) probabilities. Day 0 marks the start of the trading day during which FXI activity commenced. The solid lines represent cumulative responses, and shaded areas display the 90% confidence intervals.