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The Immediate Impact and Persistent Effect of FX Purchases on the Exchange Rate*

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ההשפעה המידית והמתמדת של רכישות מטבע חוץ על שער החליפין

איתמר כספי, עמית פרידמן וסיגל ריבון

תקציר

בשנים האחרונות בנק ישראל מתערב בשוק המט״ח, בדומה לבנקים מרכזיים אחרים; ההתערבות משמשת כלי מוניטרי נוסף שמטרתו למתן את מגמת הייסוף של שער החליפין. מחקר זה מנתח כיצד ההתערבות משפיעה על שער החליפין בטווח המיידי ולאורך זמן. על מנת לזהות השפעות אלה אנו מודדים תחילה את ההשפעה המיידית התוך-יומית באמצעות מסד ייחודי של נתונים בתדירות גבוהה – רמת שער החליפין הנמדדת בכל דקה – מהתקופה שבין 2009 ל-2017. בהמשך אנו משתמשים באומדן התוך-יומי על מנת לאמוד במשך כמה ימי מסחר ההשפעה מתמידה. אנו מבססים את הגישה האמפירית שלנו על מסגרת התוצאות הפוטנציאליות ושיטת התחזיות הלוקליות (Local Projections). אנו מוצאים כי ההתערבויות – כלומר רכישות המט״ח הבלתי צפויות – גורמות לפיחות מיידי בשער השקל-דולר ביותר מ-90% מהמקרים, וכי השפעה מיידית זו מתמידה במשך 40—60 ימי מסחר (חודשיים-שלושה קלנדריים). בהתבסס על ממצאים אלו אנו מסיקים שבין 2013 ל-2017 פיחתו ההתערבויות את שער החליפין בכ-2%—3% בממוצע, וכל התערבות השפיעה בהתאם לעוצמתה. יש להדגיש כי תוצאות אלו משקפות אך ורק את התרומה של רכישות המט״ח הבלתי צפויות במסגרת משטר הרכישות המשתנות שהיה בתוקף בכל תקופת החקירה, ולא את השפעת עצם קיומו של המשטר.

The Immediate Impact and Persistent Effect of FX Purchases on the Exchange Rate

Itamar Caspi, Amit Friedman, and Sigal Ribon

Abstract

In recent years, Forex (FX) interventions have been routinely used by the Bank of Israel as well as by other central banks as an additional monetary instrument, with the objective of moderating appreciation trends of the domestic currency. This paper analyzes the immediate effect of the Bank of Israel's FX interventions on the exchange rate and the persistence of this effect over time. To identify this effect, we first measure the intraday impact of FX intervention using a novel high-frequency, minute-by-minute dataset of interventions between 2009 and 2017. Next, we use our intraday measure to estimate the persistence of FX intervention shocks over longer horizons (in trading days), where we base our empirical approach on the potential outcome framework and the Local Projections method. We find that FX intervention shocks – that is, unexpected FX purchases – cause, on impact USDILS exchange rate depreciation in over 90 percent of the cases. We also find that this effect has a persistent impact on the nominal effective exchange rate for about 40–60 trading days, which are equivalent to between 2 and 3 calendar months. Based on this finding we infer that between 2013 and 2017 interventions caused the level of the exchange rate to depreciate by about 2–3 percent on average, where the effect of each intervention varied with its intensity. We stress that these results reflect the contribution of unexpected FX purchases given the fact that the discretionary intervention regime was in place throughout the investigated period, and not the effect of the presence of the regime itself.

Keywords: Sterilized FX interventions, high-frequency data, impulse response, local projections, potential outcome, Bank of Israel.
JEL Classification: C22, E58, F31.

1. Introduction

In recent years, FX interventions have been routinely used as an additional monetary instrument by central banks in developing as well as advanced economies around the world. Discretionary, sterilized purchases of foreign currency, which are often matched by expansionary monetary policy, are carried out to moderate the appreciation trend of the local currency. The Bank of Israel has used FX purchases for similar purposes in recent years as well, and these purchases have tended to intensify during periods of exchange rate appreciation (see Figure 1).

This paper analyzes the effect of FX purchases made by the Bank of Israel (BoI) on the exchange rate, using novel, proprietary, and confidential data that consists of high-frequency, minute-by-minute observations of the exchange rate and FX purchases. The on-impact intraday effects of FX interventions are measured in terms of the change in the USDILS exchange rate during intraday intervention spells. Next, we use the intraday measure to estimate the causal effect of FX intervention shocks, defined as the unanticipated part of interventions, on the nominal effective exchange rate.

Our empirical strategy follows Angrist and Kuersteiner (2011), Angrist, Jordà, and Kuersteiner (2017), and Jordà and Taylor (2016) who combine the potential outcome framework (i.e., the Rubin Causal Model) and the Local Projections method (Jordà, 2005) to estimate the causal effect of a policy treatment (FX interventions in our case) and its persistence in a dynamic setting. The appeal of this empirical strategy is that it makes explicit the conditions needed for the identification of a causal effect. Also, it is rather robust to misspecification in the estimated model.[1]

Theoretically, sterilized FX purchases, such as those carried out by the BoI, can impact the level of the exchange rate through two main channels: the portfolio balance channel and the signaling channel. The former operates under the assumption that domestic and foreign bonds are not perfect substitutes. The latter operates under the assumption that purchases of foreign currency by the central bank send a signal to

[1] In a closely related paper, Kuersteiner et al. (2016) investigate the effectiveness of sterilized foreign exchange interventions by exploiting a discontinuous policy rule used by the Central Bank of Colombia.

markets about future policy moves – either that the central bank is about to pursue an accommodative monetary policy in the future, or that the central bank has an implicit exchange rate floor, a "resistance" level. While the first channel is pertinent whenever a "big" player is active on the market, the second channel is unique to the central bank and hence makes the dollar purchased by the central bank special. The first channel's effects are probably more transitory, at least when markets function normally; but the second channel's effects might have a medium-term effect on the exchange rate. This suggests that a complete assessment of the policy must consider both the immediate impact of FX intervention and the persistence of this impact over time.

Most of the recent literature on the impact of interventions in the FX market by the central bank is empirical and uses daily or intraday data to study the effect of these interventions. A critical issue in this literature is endogeneity, which limits the ability of researchers to treat intervention shocks as exogenous. Put simply, FX interventions tend to be triggered by exchange rate movements generated by other factors, and hence the identification of their impact is difficult. A possible solution is to focus on the "intervention window," i.e., the exact time spell around the FX intervention, based on intraday data. This methodology, however, is limited: while the existence of a short-term impact is a necessary condition for discretionary intervention to be effective, it is insufficient for a macroeconomic analysis of the policy, which also requires an assessment of the persistence of the initial impact of the FX intervention over time. For this reason, in this paper, we apply both methodologies.

Recent surveys (e.g., Engel, 2014; Neely, 2005, 2011; Menkhoff, 2013) conclude that empirical studies that examine high-frequency data usually find an immediate effect on the exchange rate in the right direction, and the results on the effect on volatility are mixed. However, these studies are usually incapable of providing evidence for the persistence of the initial effect in the week, month, or quarter after the intervention (Engel, 2014).

Villamizar-Villegas and Perez-Renya (2015) from Colombia's central bank survey the empirical literature and conclude that the effect of FX interventions is small and very transitory. Menkhoff (2013) reviews studies that examine intervention in developing countries and reports that these studies usually find that intervention affects the level of the exchange rate, while the results on the effect of interventions on volatility are mixed. A small number of studies use lower frequencies: weekly, monthly, or quarterly data. This strand of literature usually employs instrumental variable methods to solve the above mentioned endogeneity problem to identify the "clean" effect of intervention. Adler, Lisack, and Mano (2015), using monthly data and a panel of countries, find strong evidence that intervention has a statistically and economically significant effect on the exchange rate. Adler and Tovar (2011), using a panel of 15 countries for the period 2004–2010, excluding the financial crisis years (2008–09), find that intervention slows the pace of appreciation, but is less efficient when the economy is open to capital flows.

Blanchard, Adler, and de Carvalho Filho (2015) show that intervention can ease the pressure associated with exogenous capital flows on the exchange rate. Basing their study on a cross-country regression analysis and using quarterly data, they find that exchange rate appreciation in response to capital imports is lower in countries identified as "interveners" than in other countries.

Fratzscher et al. (2015) examine the effectiveness of intervention using a unique database containing daily data from 33 countries between 1995 and 2011 (including Israel). In general, they find that intervention usually "succeeds"; that is, it achieves the exchange rate movement in the desired direction, and hence can be an effective policy instrument, especially when applied in high dosages and when consistent with moving the exchange rate toward its fundamental equilibrium. However, they estimate only the short-term impact of interventions.

A few studies examine the effectiveness of intervention by the BoI since 2008. Sorezcky (2010) addresses this question, somewhat indirectly, for the period when the Bank of Israel intervened mostly with fixed, preannounced quantities. He tests whether the intervention in the foreign currency market is reflected in an exchange rate that deviates from the one predicted by a VAR system that includes an exchange rate equation without intervention. He finds that most of the effect was obtained when the Bank announced a change in the intervention regime, in particular, a movement from the fixed purchase of $25 million per day to $100 million per day, and later during the transition to variable, discretionary purchases. Ribon (2017), using the instrumental variable approach, finds that the Bank of Israel's purchases contributed to the devaluation of the shekel. Purchases equal to the monthly average in the period examined, $830 million, contributed to devaluation in the effective exchange rate by about 0.6 percent, compared to a month with no intervention. However, she does not test the persistence of an intervention shock.

In the context of the existing literature, the contribution of this paper is twofold: first, we measure the impact of FX purchases directly, using proprietary, confidential, high-frequency Israeli data. Second, we estimate the persistence of the initial shock, using a robust and simple "model-free" methodology, which was originally suggested by Jorda (2005), that requires only a parsimonious and economically clear set of identifying assumptions. Technically, it requires only single-equation regression analysis.

Our main results are as follows: (a) FX intervention has a high "success rate" on impact. In over 90% of intervention cases, the exchange rate moved in the desirable direction (i.e., that of depreciation, as all the interventions we analyze are purchases). (b) An intervention shock persists for about 40 to 60 trading days (between 2 and 3 calendar months) before it attenuates or becomes statistically insignificant. This result means that the exchange rate returns during the 40 to 60 days are still affected by the initial intervention shock on day 1. These results, coupled with the actual intervention pattern of the BoI in recent years, allow us, at least in principle, to quantify the aggregate effect of FX intervention over time. The result is that since 2013, FX purchases have led to an average depreciation of between 2 and 3 percent. It is important to emphasize, that this result reflects only the impact of the intervention shocks - i.e. the effect of the unexpected purchases, given that the regime was in place, and not the possible effect of the regime itself on the level of the exchange rate, which we cannot estimate .2

[2] In analogy to the monetary shocks literature, our focus is on the unsystematic part of the rule under which monetary policy makers act and not on the effect of operating according to a given rule.

The paper is organized as follows. Section 2 provides some details and stylized facts on FX interventions made by the Bank of Israel since March 2008. Section 3 briefly discusses the economic theory behind FX interventions. In particular, it presents the channels through which sterilized interventions might affect the spot exchange rate. Section 4 describes the measurement of the short-term impact of intervention on the exchange rate. Section 5 describes the methodology that is applied to estimate the persistence of the short-term intervention shock over time. Sections 6 and 7 present our main results and a robustness analysis, and Section 8 concludes.

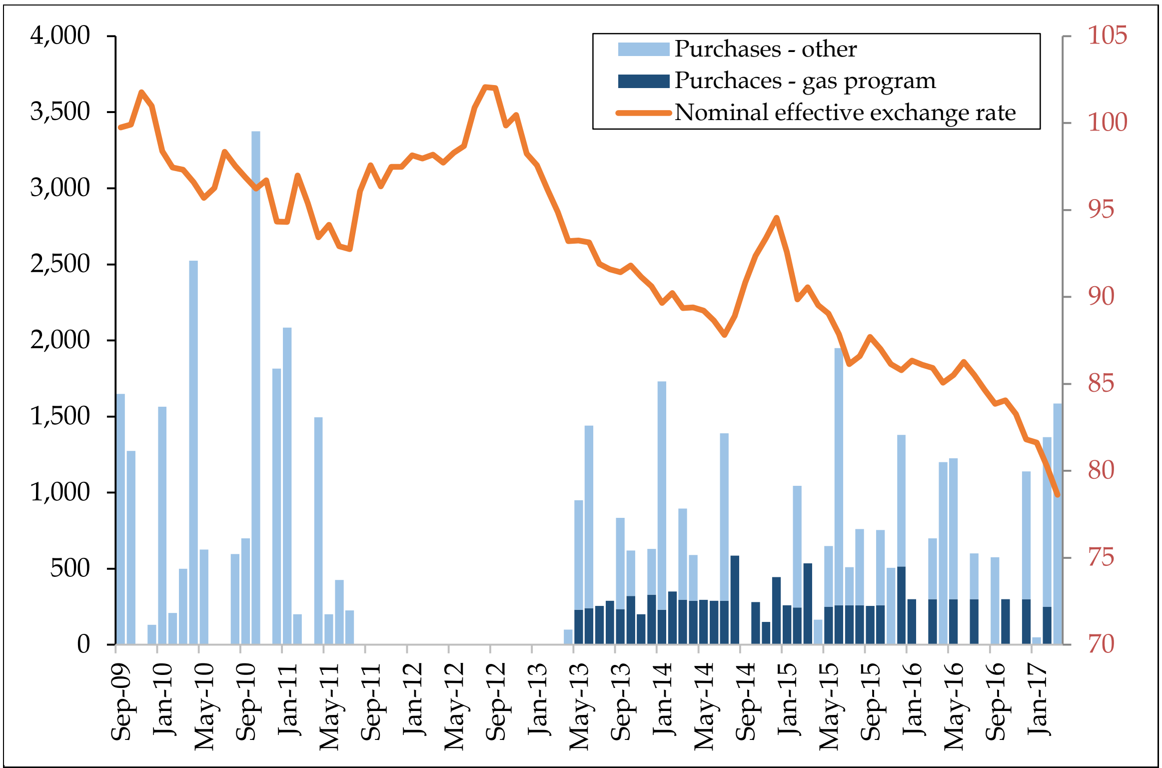
2. FX interventions by the Bank of Israel

In March 2008, for the first time in a decade, the Bank of Israel intervened in the FX market. The decision to purchase FX was made on the backdrop of a sharp and rapid appreciation of the shekel, which real fundamental factors could not account for in full. This provided an opportunity to replenish international reserves, which as a share of GDP had declined steadily over a decade and had reached an uncomfortably low level. Initially, purchases were carried out daily, in fixed, preannounced amounts of $US25 million, which were later augmented to $US100 million. In August 2009, when reserves reached a level that was deemed at the time adequate, the BoI moved to a discretionary intervention regime under which the timing and volume of FX purchases were not communicated to the public in advance. On May 2013, the BoI announced that on top of the above-mentioned discretionary policy, a preannounced quantity would be purchased to offset the appreciation pressures arising from the commencement of the production of natural gas.[3] Since that announcement, the two-tier regime has remained in effect. Although the annual gas purchase volume is communicated to the market before every calendar year, the accurate timing and daily quantities are unknown to the market in advance. Thus, while daily FX purchases were anticipated up to August 2009, since that date they have been unanticipated, and therefore can be used to construct proxies for intervention shocks.

[3] On April 30, 2013, natural gas from the Tamar reservoir started to flow and to partially substitute imported fossil fuels. A few days later the BoI announced that $US 2.1 billion would be purchased by the end of 2013. The gas purchases serve as a temporary substitute for the lack of a sovereign wealth fund.

Like other modern central banks, the BoI operates under a dual lexicographic mandate that includes price stability and economic activity, in that order. The rationale behind FX purchases is to maintain the competitiveness of the tradable sector under transitory global conditions that result in an overvalued exchange rate, relative to its fundamentals.[4] Also, since 2013, inflation has been persistently lower than the midpoint of the inflation target (between 1 and 3 percent). FX purchases, which aim at curbing appreciation pressures, are in accordance with the price stability target of the BoI. Hence, FX purchases brought about a double-margin operation that has enabled the BoI to remain active even after the interest rate was reduced to an unprecedented near-zero low level.[5]

Figure 1: FX purchases by the Bank of Israel and the nominal effective exchange rate



Notes: Purchases are specified in millions of USD per month. September 2009 – April 2017.
Source: Bank of Israel.

[4] The Israeli economy emerged from the 2008 global financial crisis relatively unscathed. Its relative robustness led to massive capital inflows already before the crisis, a phenomenon that only intensified after the outbreak of the crisis (Eckstein and Friedman, 2010).

[5] The interest rate rose to 0.5 percent in 2009 and after a hiking cycle fell again to 0.1 percent in March 2015, where it has remained since.

3. Theoretical background

Theoretically, sterilized FX purchases can impact the level of the exchange rate through two main channels. The first, the portfolio balance channel, is at work when the local currency is not a perfect substitute for foreign currency. The second, the signaling channel, is at work when the purchases send a signal to markets either that the central bank is about to pursue an accommodative monetary policy in the future, or that the central bank has an implicit exchange rate floor, a "resistance" level below which it will act. In the current jargon, FX purchases made through the signaling channel can also be interpreted as a form of "forward guidance." In addition to these mechanisms, FX purchases may have a different type of impact when implemented at the zero lower bound, where the distinction between sterilized and unsterilized intervention is blurred.

While the portfolio channel is pertinent whenever a big player is active on the market, the signaling channel is unique to the central bank and hence makes the FX purchased by the central bank special. One can argue that the first channel's effect tend to be more transitory, at least when markets function normally; but the second channel's effect can have a medium-term effect on the exchange rate. A sizable and persistent effect on the exchange rate can naturally have a macroeconomic effect – on output, prices and the interest rate.

We now turn to a theoretical discussion of the effects of FX interventions. A good starting point is the asset-pricing model of the spot exchange rate (Engel and West, 2005). Following the notation in Engel (2014), let S_t denote the spot exchange rate at time t and let $s_t = \log(S_t)$. Next, denote by λ_t the risk premium associated with an investment in the domestic currency that is defined as the deviation from the uncovered interest rate parity,

$$\lambda_t \equiv E_t s_{t+1} - s_t - (i_t - i_t^*), \quad (1)$$

where i_t and i_t^* denote the domestic and foreign interest rates, respectively, and E_t denotes the expectation operator conditioned on all information available at time t.

Rearranging Equation (1) yields a definition of the (log) spot rate:

$$s_t = -(i_t - i_t^*) - \lambda_t + E_t s_{t+1}. \tag{2}$$

Solving (2) by forward iterations yields

$$s_t = -\sum_{j=0}^{\infty} E_t\left(i_{t+j} - i_{t+j}^*\right) - \sum_{j=0}^{\infty} E_t \lambda_{t+j} + \lim_{j\to\infty} E_t s_{t+j+1}. \tag{3}$$

Equation (3) relates the spot exchange rate to current and expected interest spreads (note that index j runs from zero to infinity), current and expected risk premiums, and the expected exchange rate in the long-run, $\lim_{j\to\infty} E_t s_{t+j+1}$.

The right-hand side of Equation (3) show the channels through which sterilized FX interventions, i.e., interventions that keep the interest rate fixed, might affect the spot exchange rate. First, a policy announcement that raises (lowers) the expected interest spread might causes the spot rate to depreciate (appreciate) today. Second, a policy action that changes the current or expected risk premiums might change the spot rate today. Finally, a policy that changes the beliefs on the long- run exchange rate might affect the spot rate today.

The literature focuses on two channels through which the monetary authority might affect the exchange rate: (1) changes in expectations regarding the future path of the interest rate spread (the *signaling* channel) and (2) changes in the current or expected risk premium (the *portfolio* channel). Hence our definition of a structural intervention shock is broad in the sense that it accounts for unanticipated shocks as well as news shocks. The definition includes, for example, what is currently referred to as "forward guidance shock," which is a type of news shock, since the signaling channel works by changing market expectations about the future path of the short-term interest rate. The presence of such "news shocks" might cause an identification problem in cases where the central bank applies explicit forward guidance as well as FX interventions since forward guidance is essentially signaling about future rates. However, we argue that this issue is of lesser importance in the Israeli case since official forward guidance was not introduced by the Bank of Israel until recently (November 2015) and excluding the period where it was used does not affect our results.

4. Measuring the on-impact effect of FX intervention

To measure the immediate impact of FX purchases, and circumvent the endogeneity/simultaneity problem, we use high-frequency, intraday, data. The approach follows an event-study methodology: we measure the return to intervention, defined as the on-impact shock that is manifested in the exchange rate market once the BoI intervenes and during the intervention window. These shocks to the exchange rate allow us to construct various measures of intervention success and efficacy over time.

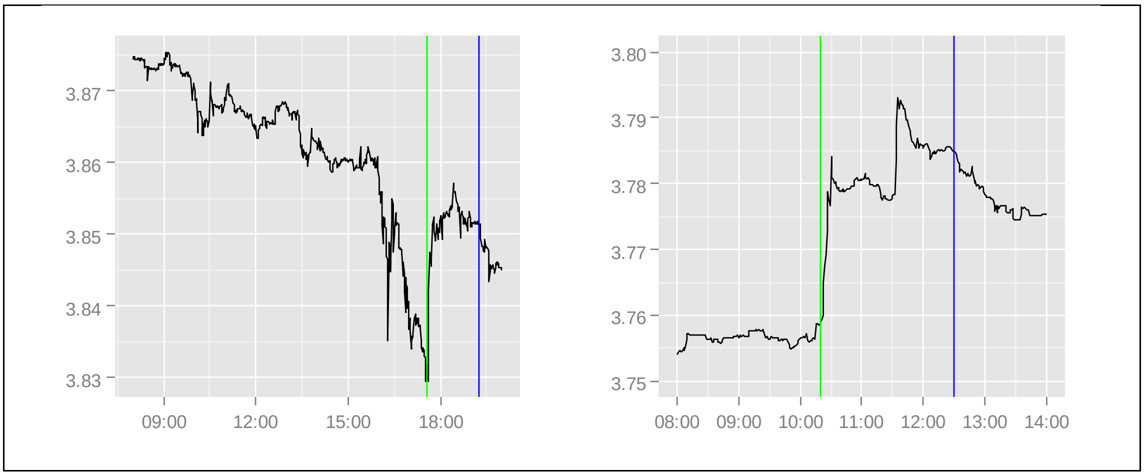
Our dataset includes minute-by-minute USDILS quotes collected by Reuters from several contributors' quotes (Reuters ticker: ILS=RR). This data is merged with records of the BoI's dealing-room FX transactions operational system, which contains records on the timestamp, the sum, the counterparty, and the price of each FX transaction. The result is a unique proprietary dataset, which is confidential due to market sensitivities. We use this dataset to measure the total effect of the intervention during the intervention window, which typically lasts several hours. The total effect of intervention during an intervention day is based on the exchange rate change during an intervention window, that is, just before the intervention starts and immediately after the last intervention transaction on that day:

$$daily\ effect \equiv ER_{after\ intervention} - ER_{before\ intervention}$$

$$daily\ return \equiv \log(ER_{after\ intervention}) - \log(ER_{before\ intervention})$$

The implicit assumption behind these computations is that the stochastic generating process of the exchange rate is a random walk and that the change in the short intervention spell can be fully attributed to the intervention. The shocks and returns are measured both in USDILS terms and in a synthetic currency, which serves as a proxy for the nominal effective exchange rate.

Figure 2: The impact of FX intervention: Two typical examples



Notes*:* The two snapshots above show the USDILS rate on two trading days during which the Bank of Israel intervened in the FX market**.** The green line indicates the entry point of the BoI into the market and the blue line indicates the exit point. The impulse of intervention is measured by the exchange rate returns between the exit and entry points. The snapshot on the left points to the importance of using high-frequency data to identify the impact of intervention. The impact of intervention cannot be detected based on daily data due to intraday endogeneity.

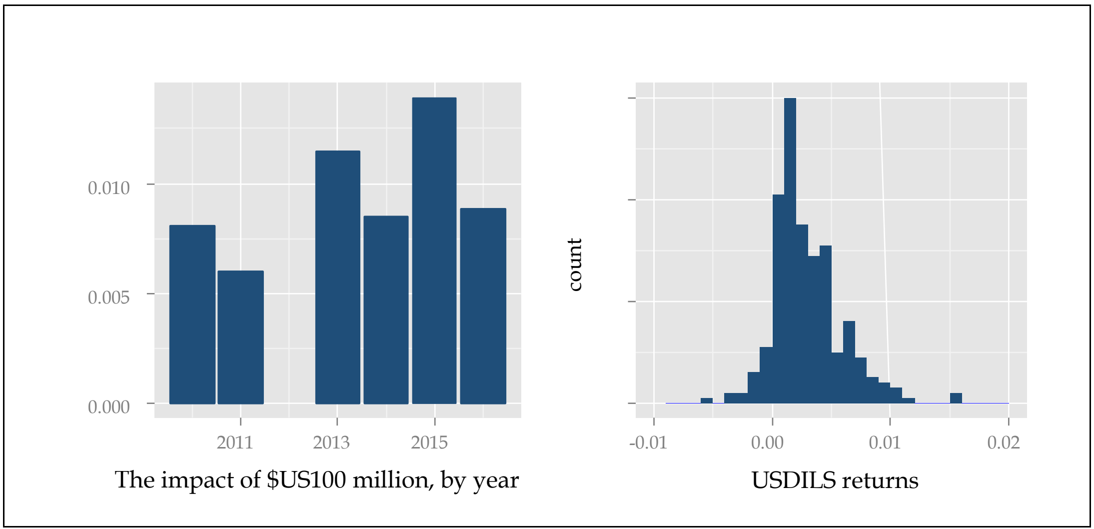
Figure 2 presents two typical intervention spells and the intraday effect on the exchange rate. Figure 3 shows the efficiency of interventions and the distribution of returns between 2009 and 2016.

In addition to the full intervention spell effect described above, we also measure the approximated initial impulse of intervention, based on a fixed length 30-minute window around the first intervention. This measure is "cleaner" in the sense that it does not contain traces of intraday endogeneity, but rather captures only a fraction of the full daily effect. We will refer to this alternative measure in the robustness tests presented in Section 6.

5. Estimating the persistence of FX intervention shocks

This section describes the method and assumptions used to assess the persistence of our intraday measure of the effect of FX interventions on the nominal effective exchange rate. First, we put our empirical challenge in the potential outcomes framework (Rubin, 1974, 1977). Second, we define a structural intervention shock and explicitly state the assumptions behind our identification strategy. Finally, we describe the econometric model used to trace out the dynamic response of the exchange rate to FX intervention shocks.

Figure 3: The average efficiency of intervention between 2009 and 2016 and the distribution of the returns to intervention under the discretionary purchase regime



Notes: The figure on the left presents the average effect of purchases of $US100 million on the USDILS rate (the daily effect mentioned above), by year, based on unweighted observations. For example, in 2015, purchases of this amount resulted in a depreciation of slightly more than 1.2 shekel cents. The figure on the right presents the distribution of the returns to each intervention episode during the discretionary period (08/11/2009 and on). Overall, FX purchases succeeded in generating USDILS depreciation in 91 percent of the cases. The histogram is based on hundreds of observations.

We start by letting y_t denote the outcome variable, which in our case is the log of the nominal effective end-of-day exchange rate (NEER). Let FXI_t denote the intraday measure of change in the USDILS exchange rate during an intervention spell within day t, where $FXI_t = 0$ when no intervention takes place.

Next, denote by $\boldsymbol{W}_t$ a vector of variables that potentially serve as good predictors of y_t. Finally, let $\boldsymbol{\mathcal{X}}_t$ denote the information set available in period t that includes lagged values of both y_t and FXI_t, as well as $\boldsymbol{W}_t$. We further assume that the central bank's intervention decision function, denoted by $FXI_t(\boldsymbol{\mathcal{X}}_t, \varepsilon_t, \theta)$, is linear, where ε_t is a random FX intervention policy shock that is uncorrelated with $\boldsymbol{\mathcal{X}}_t$, and $\theta \in \Theta$ is a set of parameters.

In the SVAR and local projections literature (see Jordà 2005), it is common to analyze the causal effect of a certain shock on the endogenous variable through the lens of an impulse response function (IRF) for an unanticipated shock of size one, defined as

$$IRF(h) \equiv E_t(y_{t+h}|\, \varepsilon_t = 1) - E_t(y_{t+h}|\, \varepsilon_t = 0) \qquad (4)$$

where h denotes the horizon and E_t denotes the expectation operator, conditioned on information available until period t. Another useful exposition of the IRF can be made couched in terms of *potential outcomes*.

Borrowing from Definition 1 in Angrist and Kuersteiner (2011), a potential outcome $y_{t+h}^{\theta}(f)$ is the value that the realization of y_{t+h} would be equal to if $FXI_t(\boldsymbol{\mathcal{X}}_t, \varepsilon_t, \theta) = f$, for all $f \in F$ and $\theta \in \Theta$. Less formally, for a fixed θ, the vector of potential outcomes $\boldsymbol{\mathcal{Y}}_{t+h}^{\theta} = [y_{t+h}^{\theta}(f^0), y_{t+h}^{\theta}(f^1), \dots]'$, $f^j \in F$, holds all possible realizations of y at horizon $t+h$, where each realization corresponds to a different response set by the central bank at period t, i.e., to different realizations of $FXI_t(\boldsymbol{\mathcal{X}}_t, \varepsilon_t, \theta)$. Thus, in the jargon of the potential outcomes framework, the IRF traces out the difference between two potential outcomes of the dependent variable – one with an initiated single-period shock of a given size δ, and the other with no initiated shock at any horizon.

Given ε_t, we can estimate its IRF using the local projections method of Jordà (2005), which is based on estimating the following set of h-steps-ahead predictive regressions.

$$y_{t-1+h} - y_{t-1} = \alpha_{(h)} + \beta_{(h)}\varepsilon_t + u_{(h),t-1+h}, \qquad (5)$$

for $h = 1, \dots H$, where $y_{t-1+h} - y_{t-1}$ denotes the cumulative change from time $t-1$ to time $t-1+h$ in the log of the NEER times 100, i.e., the cumulative percentage change in the exchange rate with respect to its level at the end of day $t-1$.[6]

The series of estimated coefficients $\hat{\beta}_{(1)}, \dots, \hat{\beta}_{(H)}$ from Equation (2) provides a consistent estimate of the *cumulative* impulse response function of an unexpected FX intervention shock of size one. In other words, $\hat{\beta}_{(h)}$ is the estimate of the cumulative percentage change in the NEER due to a change of size one in ε_t after h periods.

[6] A similar approach is used in papers that study the effect of monetary policy shocks, where a shock is defined as the change in the futures funds rate during a tight window around FOMC (or other central bank) statements (e.g., Swanson, 2017; Gertler & Karadi, 2015).

Unfortunately, estimating Equation (5) is impossible since the vector of potential outcomes $\boldsymbol{\mathcal{Y}}_{t+h}^{\theta}$ and the shock of interest ε_t are unobservable. Nonetheless, under certain conditions, it is possible to recover the causal effect of ε_t on y_{t+h}, using an endogenous variable and a proper set of controls (Angrist and Kuersteiner, 2011; Angrist, Jordà, and Kuersteiner, 2017; Jordà and Taylor, 2016). Specifically, we use FXI_t as the endogenous variable and make the following identifying assumption:

Assumption 1 *(structural FX intervention shocks) Let ε_t denote the residual from a linear projection of FXI_t* on $\boldsymbol{\mathcal{X}}_t$, i.e., $\varepsilon_t = FXI_t - E(FXI_t|\boldsymbol{\mathcal{X}}_t)$. *The following conditions hold for ε_t:*

(i) independence of potential outcomes;

(ii) contemporaneous uncorrelatedness of ε_t with other structural shocks.

Part (*i*) of Assumption 1 states that FXI_t is as good as a randomly assigned shock once we control for the variables[7] in $\boldsymbol{\mathcal{X}}_t$. Under the assumption that the response of the central bank is linear, the residual (or innovation) from a linear projection of FXI_t on $\boldsymbol{\mathcal{X}}_t$ represents an idiosyncratic source of random variation that is independent of potential outcomes. This includes situations where our intraday measure of FX interventions is not completely unexpected, and hence not randomly assigned, but can still be randomized by a proper set of predictors (control variables).

Part (*ii*) of Assumption 1 states that this residual is "structural" in the sense that it is contemporaneously unrelated to other primitive shocks that might affect the economy and the exchange rate simultaneously (e.g., monetary policy shocks). This part of the assumption states that the randomness that is left after conditioning on $\boldsymbol{\mathcal{X}}_t$, is related solely to the random element of the central bank's reaction function and not to other primitive and unanticipated shocks. We argue that this assumption is plausible in cases where FXI_t is estimated within a tight window around an intervention spell, during which it is known that most of the variance of the exchange rate is due to actions taken by the central bank.

[7] In the treatment effect literature, this assumption is usually referred to as the *selection-on-variables* assumption.

Equipped with Assumption 1, we are now able to estimate the persistence of FX intervention shocks, using the following set of h-step-ahead predictive regressions for $h = 1, \dots, H$:

$$y_{t-1+h} - y_{t-1} = \alpha_{(h)} + \beta_{(h)} FXI_t + \gamma_{(h)} \boldsymbol{\mathcal{X}}_t + u_{(h),t-1+h}, \tag{6}$$

, where $y_{t-1+h} - y_{t-1}$ denotes the cumulative change from time $t-1$ to time $t-1+h$ in the log of the NEER.

If Assumption 1 indeed holds, Equation (6) provides a consistent estimate of the cumulative impulse response function of an unexpected FX intervention shock of size one.[8] In turn, statistical inference regarding the direction and magnitude of $\beta_{(h)}$ is done using Newey−West HAC robust standard errors, due to the dependent and potentially heteroskedastic structure of the regression error[9], $u_{(h),t-1+h}$.

At this point, it is important to note that in Equation (4) we implicitly assume that the data-generating process for y_t is approximately linear in both FXI_t and $\boldsymbol{\mathcal{X}}_t$. The same assumption is inherent in most SVAR and local projections applications. This assumption is also supported by the approximately linear relation between the purchased quantity and the change in the exchange rate within the intervention window. Nonetheless, we recognize that this type of assumption is quite strong and we will address this issue in the robustness section. Another implicit assumption we make using Equation (1) is that the regression is saturated, i.e., that the distribution of the control variables that are appear in $\boldsymbol{\mathcal{X}}_t$ is the same for both the treatment (intervention days) and control (days without intervention) groups. We will also address this issue in our robustness analysis.

[8] Formally, for consistency, we need to impose additional conditions that relate to stationarity and mixing properties of the process (y_t, FXI_t, X_t). For details, see Angrist and Kuersteiner (2011).
[9] Specifically, HAC standard errors are estimated using the Bartlett kernel where the bandwidth is set to h.

6. Results

We estimate the impulse response function of the nominal effective exchange rate to an FX intervention shock identified using the methodology described in the previous section. We use daily data for the period starting from September 2009 through May 2017 – a total of 1,857 trading days. The sequence of h coefficients is the cumulative effect on day $t + h$ (relative to the level of the exchange rate on $t - 1$) of an intervention shock to the exchange that occurred on day t.

Figure 4 shows the estimated impulse response for our baseline specification where we do not include any $\boldsymbol{X}_t$ control variables. The first point in the graph is the immediate same-day estimated response of the exchange rate to the intervention. Theoretically, this point should have a unit value, but because the exchange rate that is used to measure the first-day effect is not identical to the one used to identify the shock using intraday data[10] it may represent the diminishing effect of the intervention on the same day, or an appreciation just before the start of the intervention. Another explanation is the fact that we use the representative NEER and not the end-of-day rate. This might cause a downward bias in the estimated first-day effect because at least some interventions were conducted *after* the NEER level was set.[11] For this specification, the effect accumulates to around 1 (as a proportion of the size of the intervention) after about 15 trading days, and the cumulative change in the exchange rate becomes insignificant after about 40 trading days (about two calendar months). As expected, the uncertainty around the point estimate increases over time, as other economic and financial factors (including further intervention shocks) affect the development of the exchange rate in this time span. Our baseline specification, as portrayed in Equation (6), allows a drift term to the exchange rate, represented by $\alpha_{(h)}$. An underlying appreciation trend of the shekel will show up as an increasing (in absolute value) negative coefficient. The estimated intercept coefficient points to a trend appreciation of about 1.2% for 100 trading days (about 140 calendar days, which amounts to about 6 months) or about 3% annually.

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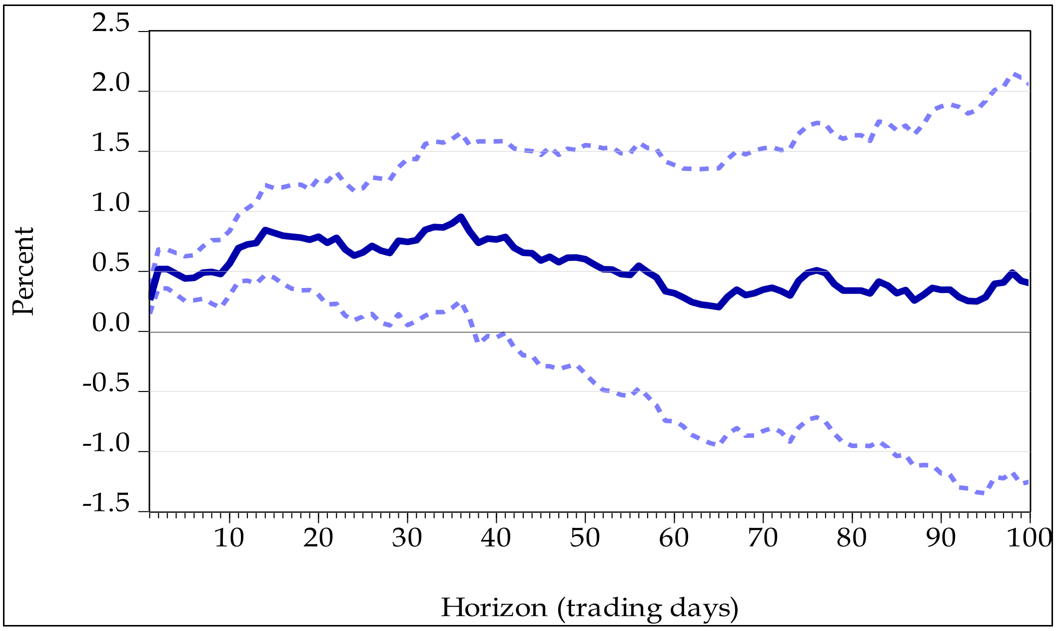
[10] Measured by the change in the representative daily NEER exchange rate instead of the change in the USDILS exchange rate during the intervention window.

[11] Indeed, using end-of-day rates (not presented) points to a larger first-day effect.

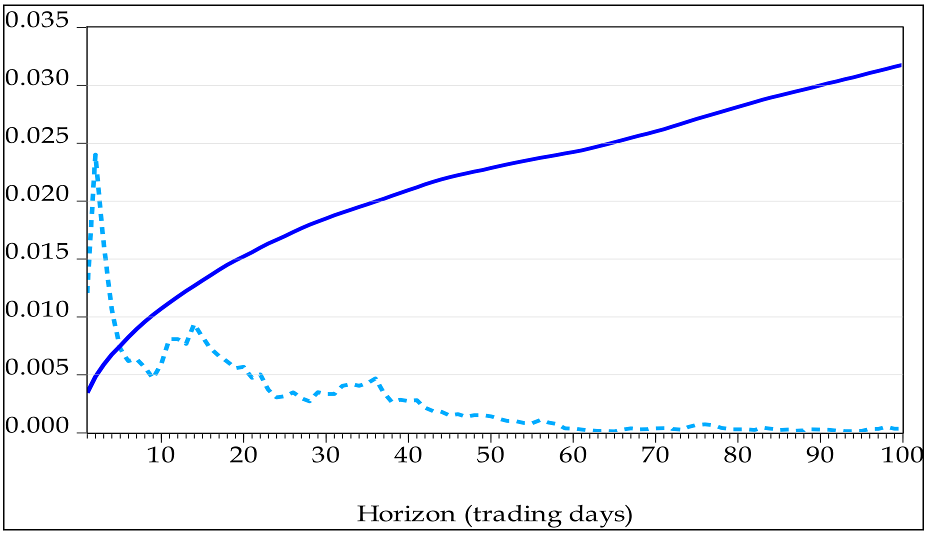
Figure 4: The cumulative effect of an FX intervention shock of size one percent



Notes: This figure presents the cumulative IRF of an FX intervention shock of size one in the log of the nominal effective exchange rate times 100 (solid blue line) ± 1.65 × HAC standard errors (dashed light blue lines that represent a 90% confidence interval). Results are based on Equation (6) without control variables.

Figure 5 shows the standard error of the estimated regression alongside the R^2 for each horizon. As expected, the share of the variation in the change in the exchange rate over h horizons explained by the initial shock at time t declines and the standard error of the regression rises as h increases.

Figure 5: R^2 and standard error of estimated equation



Notes: This figure presents the standard error of the regression (solid blue line) and the R-squared (dashed light blue line) at different horizons. Results are based on Equation (6).

6.1. *Additional controls*

As noted above, the on-impact response on the day of the intervention is smaller than unity. This phenomenon may reflect the existence of some endogeneity in the measurement of the daily change in the exchange rate, partly due to the difference in the specification of the time window for the construction of the measured return and the full business day, which also reflects the additional change in the exchange rate before and after intervention took place during the day. Because the Bank of Israel sometimes intervenes in days characterized by appreciation, the net daily change measured in the exchange rate on those days is smaller than the intraday return.

Therefore, we include in alternative specifications of the regression an exogenous variable that may account for this effect and therefore improve the ability to identify the true effect of the intervention. We choose to add to the baseline specification lagged values of FXI_t, lagged first difference of log NEER, and the lagged interest rate differential between the Bank of Israel interest rate and the Fed interest rate (which was fixed for most of the period). The domestic interest rate is set according to a monthly cycle and, for most trading days, it is exogenous to the decision to intervene on a specific date.

The results, reported in Table 1, show that the effect of intervention shocks, including the on-impact estimated effect, remains qualitatively similar to that in the baseline specification, although its persistence is somewhat stronger when the interest rate spread is added (see column 4 in the table), with the effect remaining significant for roughly 60 trading days without showing a diminishing trend to zero as earlier (see also Figure 6).

Interestingly, the coefficient of the interest rate differential increases from about zero on the first day to about unity after a hundred trading days, demonstrating that interest rate differentials have a statistically significant medium-term forward effect on the exchange rate (Figure 6). Correspondingly, the R^2 of the equation declines modestly on the first days, but then increases substantially up to about 10% as the horizon lengthens. The phenomenon of the increasing effect during the first days after the intervention, which occurred in the benchmark specification, holds for this specification as well.

Table 1: The cumulative response of the nominal effective exchange rate of the shekel to FX interventions

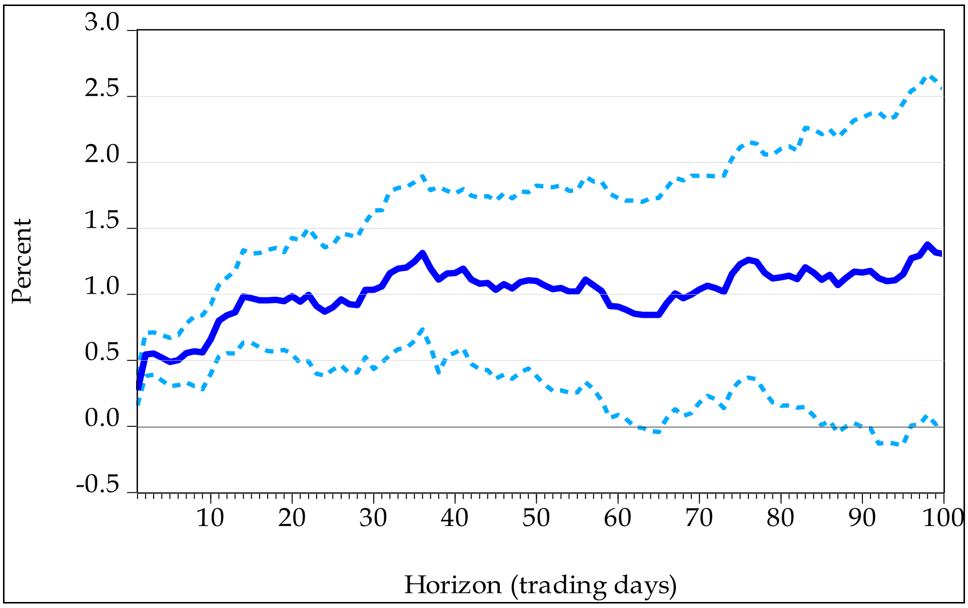
Horizon	Model					
	(1)	(2)	(3)	(4)	(5)	(6)
1	0.26	0.24	0.23	0.25	0.14	0.32
	(0.07)	(0.07)	(0.07)	(0.07)	(0.19)	(0.08)
5	0.44	0.42	0.43	0.47	0.13	0.58
	(0.11)	(0.10)	(0.11)	(0.10)	(0.25)	(0.12)
10	0.57	0.52	0.52	0.60	0.28	0.70
	(0.16)	(0.15)	(0.15)	(0.15)	(0.30)	(0.18)
25	0.66	0.62	0.61	0.84	1.26	0.47
	(0.32)	(0.29)	(0.29)	(0.26)	(0.72)	(0.26)
50	0.60	0.58	0.55	1.00	0.81	0.61
	(0.57)	(0.52)	(0.52)	(0.41)	(1.19)	(0.35)
100	0.40	0.39	0.38	1.21	0.17	0.42
	(1.00)	(0.93)	(0.93)	(0.71)	(1.49)	(0.63)
Control Variables						
FXI_{t-1}	×	✓	✓	✓	×	×
Δy_{t-1}	×	×	✓	✓	×	×
interest rate spread	×	×	×	✓	×	×
Sample	full sample	full sample	full sample	full sample	1st period	2nd period

Notes: The dependent variable is the h-period cumulative change in log of the nominal effective exchange rate of the shekel times 100. Newey–West robust standard errors that allow for correlated and heteroskedastic residuals are shown in parentheses. Estimation sample covers September 8th, 2009 –April 28th, 2017 and includes 1,855 observations (trading days) and hundreds of intervention episodes. An increase in the NEER indicates depreciation, contrary to the common convention. Thus, positive betas suggest that a positive FXI_t leads to depreciation.

We also experimented with adding the rate of change in the exchange rate on the day, 10 days, or 30 days before an intervention to account for possible predictability of the decision to intervene, but the effect was not significant and did not alter the results qualitatively. This result provides additional reassurance that the shock we identify is approximately unanticipated.

It may be that the persistence of the effect of interventions on the exchange rate depends on the market perception of the tendency of the Bank to intervene. Put simply, FX interventions themselves may exhibit some level of persistence; thus, excluding lags of FXI_t might be restrictive. To control for this possibility, we added to our baseline specification the moving average over different horizons of a dummy variable in order to indicate whether any intervention occurred in the previous period. For the dummy for a one-day lag, as well as for dummies for the last 20 or 30 business days, the contribution of this variable was insignificant. We saw some contribution at short horizons – the average dummy for the last 3 trading days. This variable was marginally significant for short and medium horizons. Thus, our main finding on the persistence of the intervention effect remains unchanged (see Figure 7).

Figure 6: The impulse response function including interest rate differentials

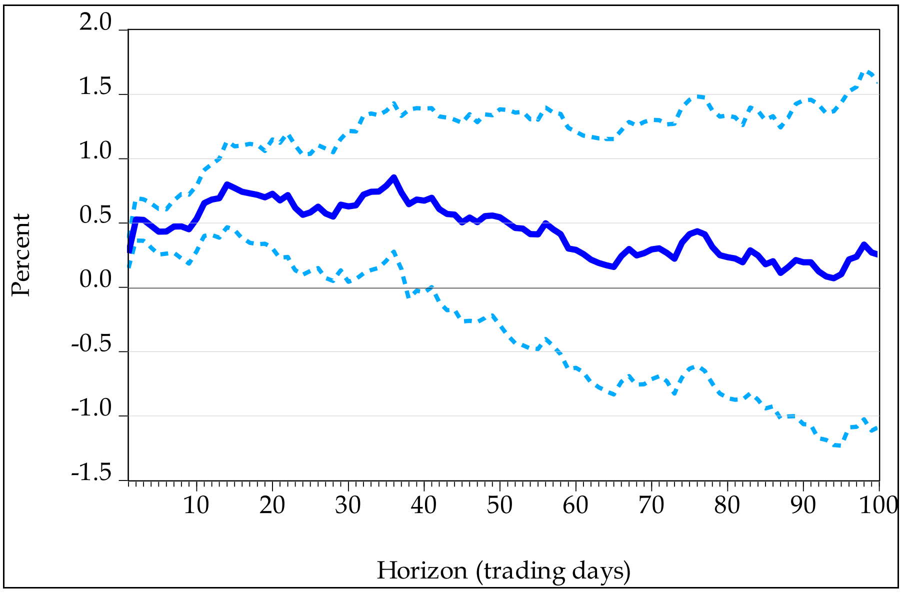


Notes: This figure presents the cumulative IRF of an FX intervention shock of size one in the log of the nominal effective exchange rate times 100 (solid blue line) ± 1.65 × HAC standard errors (dashed light blue lines). Results are based on Equation (6), where we add the interest rate differential as an additional control variable.

6.2. *An alternative measure of the intervention shock*

The main indicator we use as the identified intraday intervention shock is the change in the exchange rate within the daily intervention spell, starting with the first intervention during the day and ending with the last one, in the case where the central bank intervened more than once during that day. The advantage of this measurement is that it considers the full spell of intervention. Nonetheless, the drawback of this measurement is the possibility that it contains endogenous reactions of the central bank during the day to intraday developments in the exchange rate that may be due to or independent of the bank's intervention.

Figure 7: The impulse response function including intervention dummy



Notes: This figure presents the cumulative IRF of an FX intervention shock of size one in the log of the nominal effective exchange rate times 100 (solid blue line) $\pm$ 1.65 $\times$ HAC standard errors (dashed light blue line). Results are based on Equation (6), where we add the moving average of a dummy variable over three days in order to indicate whether any intervention occurred on a certain day.

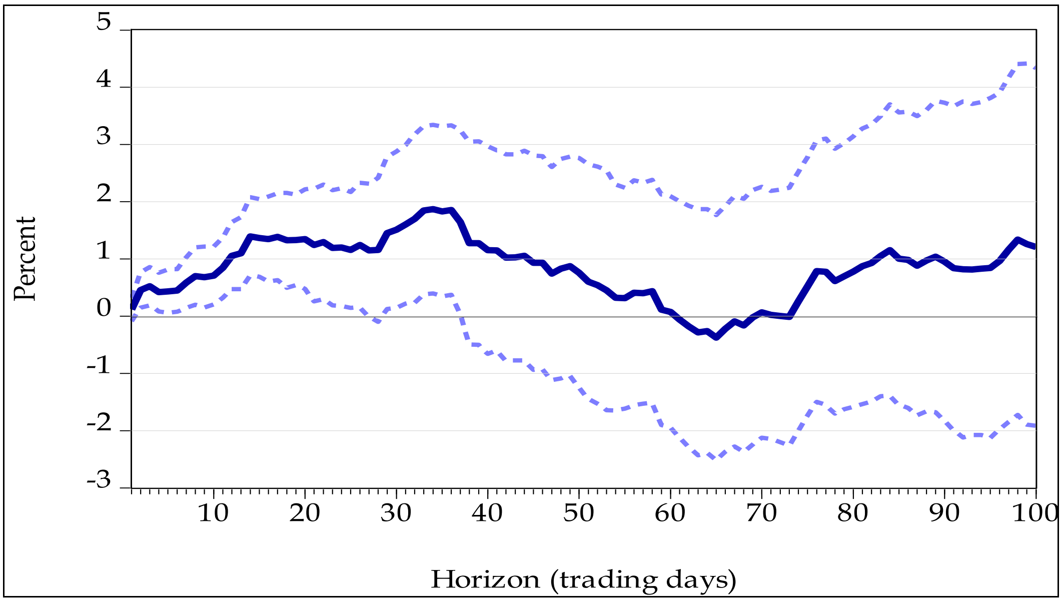
We therefore test an alternative proxy that measures the change in the dollar-shekel exchange rate within a fixed window of 30 minutes around the first intervention on days when interventions occurred. This measure may underestimate the effect of interventions when there were several spells of them during the day, but the advantage is that the "fixed" and "tight" features of the window size minimize the endogeneity concern.

We estimate Equation (6) using this alternative measure, and find that qualitative results remain unchanged (Figure 8). The initial effect is somewhat smaller but significant, and it remains greater than zero for about 30–40 trading days, as was found to be the case in the baseline specification.

6.3. Subsamples

Figure 9 shows the volume of interventions alongside the Bank of Israel interest rate, which is the main monetary instrument. We may distinguish between two periods of intervention. In the first period, starting in August 2009 and ending in April 2011, interest rate hikes accompanied the interventions. The second period, from April 2013 to April 2017, following a period of about a year and a half during which the bank was out of the market (although the policy framework did not change), is characterized by an accommodative monetary policy with interest rate cuts, reaching a minimum of 0.1%.

Figure 8: The impulse response function using a 30-Minute window

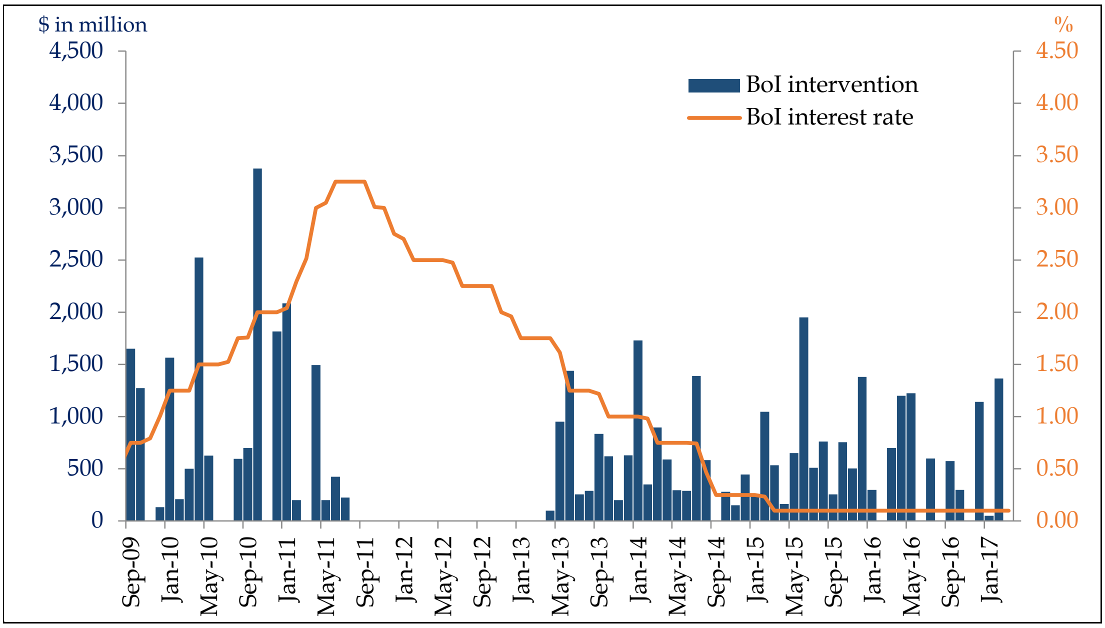


Notes: This figure presents the cumulative IRF of an FX intervention shock of size one in the log of the nominal effective exchange rate times 100 (solid blue line) ± 1.65 × HAC standard errors (dashed light blue line). Results are based on Equation (6), where FXI_t is defined as the change in the USDILS during the first 30 minutes of an intervention spell.

As we have some theoretical reasons to believe that the impact of FX purchases might be a function of the overall monetary stance, we estimate the persistence of the effect of intervention separately for these two subperiods.

We find, for our baseline specification, that intervention had a weaker and marginally significant effect on the exchange rate during the first period, while in the second period the effect was statistically significant (Table 1). We also find that the intercept in the estimated equation, standing for the underlying drift in the exchange rate, was close to zero in the first period as opposed to the negative slope in the second (Figure 10). These two findings together support the notion that although the effect of the intervention was stronger in the second period, the actual rate of appreciation during this time was faster due to other underlying forces (Figure 1).

Figure 9: The volume of interventions and the Bank of Israel interest rate



Source: Bank of Israel.

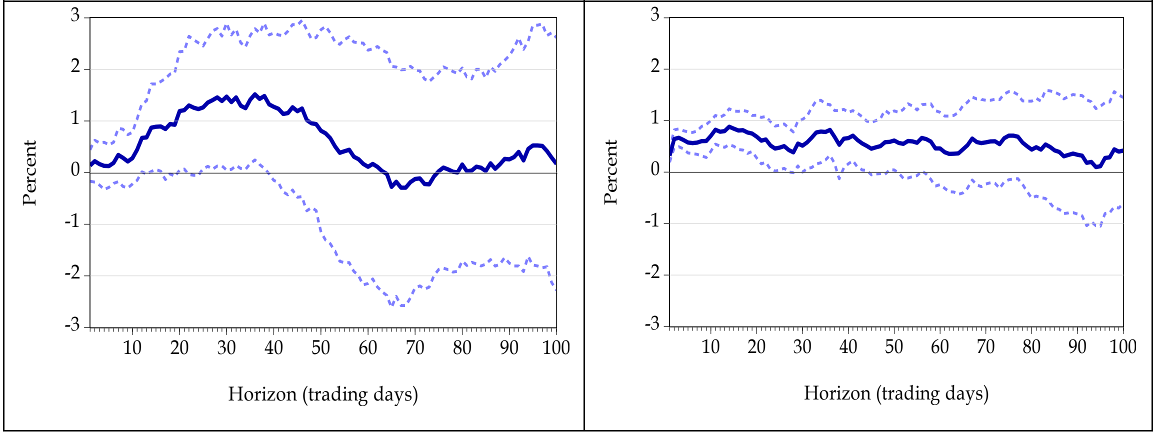
6.4. Historical evaluation of the effect of interventions

Based on the estimated impulse response functions, we may estimate, with caution, the aggregate depreciation of the exchange rate, at any point in time that is due to the sequence of actual interventions in the period examined. This exercise is a crude approximation to the ex-post effectiveness of the intervention in the medium term. It assumes linearity and additivity of the daily effect on the exchange rate and does not consider the uncertainty of our estimates. Also, this exercise measures the contribution of the unexpected FX interventions, while the expected interventions, that are embedded in the regime itself, might also have affected the prevailing exchange rate.

The results of the estimation provide us with a ratio of the initial intervention shock (identified with the intraday data) lasting after h trading days. Therefore, for a given day, the total effect of interventions in the past is the summation over H periods backward of the product of the size of the shock h days ago and the proportion of the shock that lasts after h days, where H is the maximum horizon with a significant effect.

Figure 10: The impulse response function for subsamples

(a) first period | **(b)** second period



Notes: These figures present the cumulative IRF of an FX intervention shock of size one in the log of the nominal effective exchange rate times 100 (solid blue lines) $\pm$ 1.65 $\times$ HAC standard errors (dashed light blue lines). Results are based on Equation (6). Panel (a) present results for the first period of interventions (September 2009–April 2011) and Panel (b) is for the second period (April 2013–April 2017).

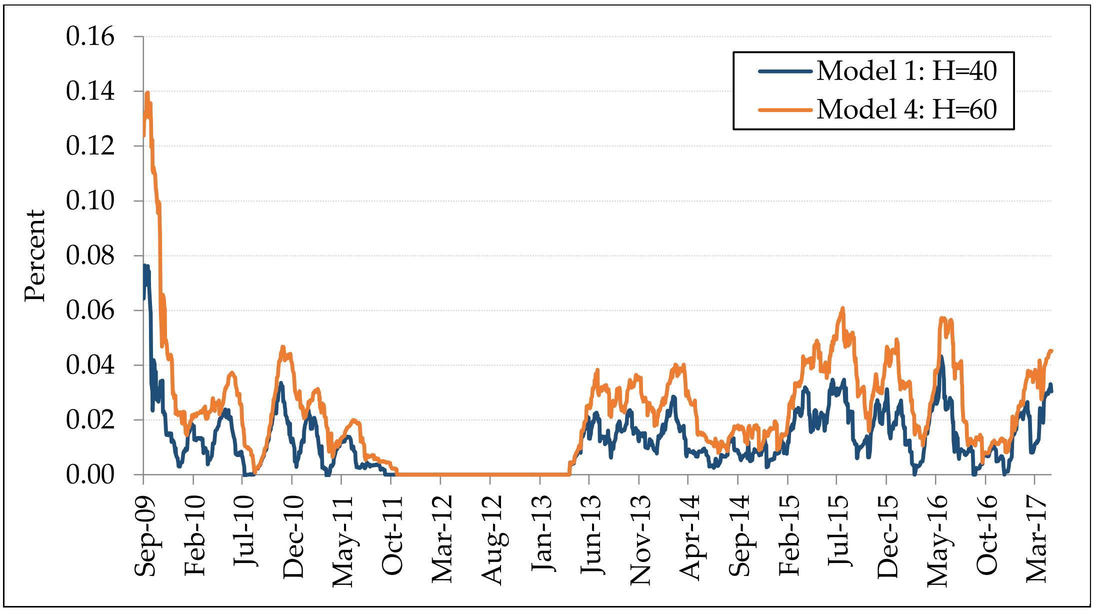
We compute this cumulative effect for the baseline specification and choose H=40 based on the results according to model 1 in Table 1, shown in Figure 4. Alternatively we choose H=60 according to the specification that includes the interest rate differentials (model 4 un Table 1 and Figure 6), where the impulse response shows a larger effect for the first 40 days of trading and lasts longer than in the baseline specification. The mean cumulative effect for this model is somewhat stronger than that in the baseline specification.

Figure 11 shows that during the whole sample period the nominal effective exchange rate depreciated on average by about 1–2%, according to the two alternative models, relative to its level had there not been any interventions. Looking at the subperiod when the Bank of Israel intervened in the market, we conclude that the average nominal effective exchange rate depreciated by 1.5–3% more than it would have done in the absence of intervention.

7. Conclusions

Like several other central banks in developing as well as advanced economies around the world, the Bank of Israel has used in recent years FX interventions as an additional monetary policy instrument in an environment characterized by an accommodative monetary policy with close-to-zero interest rates. In the present paper we analyze the effect of FX purchases by the Bank of Israel on the exchange rate using a unique proprietary dataset that consists of high-frequency, minute-by-minute observations of the exchange rate and the timing and volume of FX purchases. The on-impact intraday effects of FX intervention are measured in terms of the change in the USDILS exchange rate during intraday intervention spells. Next, we use this measure to estimate the causal effect of FX intervention shocks (i.e., the unanticipated interventions) on the nominal effective exchange rate.

Figure 11: The cumulative effect of interventions, September 2009–May 2017



Our empirical strategy follows Angrist and Kuersteiner (2011), Angrist, Jordà, and Kuersteiner (2017), and Jordà and Taylor (2016). In particular, we combine the potential outcome framework (the Rubin causal model) and the local projections method (Jordà, 2005) to estimate the causal effect of a policy treatment (FX interventions in our case) and its persistence in a dynamic setting. We find that FX intervention shocks – that is, unexpected FX purchases – cause, on impact, USDILS depreciation in over 90 percent of the cases and that this effect has a persistent impact on the nominal effective exchange rate for about 40–60 trading days. These results are robust to the inclusion of several control variables and an alternative measure of the short-term impact of FX intervention. We find, however, some evidence of the instability of this effect throughout the sample period.

Based on this finding and the timing and volume of actual interventions, we infer that the level of the exchange rate depreciated by about 2–3 percent on average between 2013 and 2017, a period when FX intervention was frequently applied. It is important to emphasize, that this result reflects the marginal contribution of unexpected FX purchases given that the discretionary intervention regime was in place throughout the investigated period and not the possible impact of the regime itself on the level of the exchange rate.

One obvious drawback of our research is that we remain silent about the medium-term macroeconomic effect of interventions. We do not estimate the effects of interventions on macroeconomic variables such as output, exports, and inflation, which are the final target of interventions in the eyes of policymakers. Hence, any linkage between our results and such macroeconomic effects can only be done indirectly. Accordingly, linking intraday measures of the effect of FX interventions to lower frequency economic variables remains a major challenge to this literature, and we believe it is an important topic for further research.

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