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EXPLAINING FORWARD
EXCHANGE BIAS...INTRADAY

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ABSTRACT

Intraday interest rates are zero. Consequently, a foreign exchange dealer can short a vulnerable currency in the morning, close this position in the afternoon, and never face an interest cost. This tactic might seem especially attractive in times of crisis, since it suggests an immunity to the central bank's interest rate defense. In equilibrium, however, buyers of the vulnerable currency must be compensated on average with an intraday capital gain as long as no devaluation occurs. That is, currencies under attack should typically *appreciate* intraday. Using data on intraday exchange rate changes within the EMS, we find this prediction is borne out.

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Explaining Forward Exchange Bias . . . Intraday

This paper examines implications of the fact that interest rates are zero intraday.[1] In particular, we focus on the foreign exchange (FX) market, and ask whether trading strategies might be affected. The answer to this question is of greater import than might first appear. For example, in times of crisis central banks typically employ an interest rate defense, raising domestic rates to attract a capital inflow and punish short-sellers. But, if dealers are immune to this defense — at least on an intraday basis — then perhaps the viability of fixed rate regimes is undermined. (Goldstein et al (1993) provide an overview of how central banks defended their currencies during the 1992 currency crisis.)

A simple example helps. With intraday interest rates of zero, a dealer can short a high interest rate currency in the morning, close her position in the afternoon, and never face an interest cost. If there is any likelihood of an intraday devaluation, this appears to be an attractive strategy, other things equal, since the dealer is immune to the interest cost of an overnight short position.

Other things should not be equal in equilibrium, however. Buyers of the vulnerable currency must be compensated on average with an intraday capital gain, as long as no devaluation occurs. That is, devaluation risk is offset by systematic *appreciation*. Further, the greater the probability and size of the devaluation, the greater the implied appreciation. Thus, the absence of a role for the interest differential in equating expected returns across currencies implies that the exchange rate itself takes up the slack.

In a regression of intraday exchange rate changes on interest differentials we find this prediction is borne out: the higher the weak currency's interest rate, the

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[1] For details regarding settlement, see Stigum (1990), particularly pages 893–901.

more that currency *appreciates* intraday. The same finding elsewhere in the literature is referred to as "forward rate bias". Though the longer–horizon findings — that high interest rate currencies tend to appreciate — remain unexplained, our's does not: intraday, the expected cost of shorting a currency in crisis offsets the expected gains from devaluation.

The paper is organized as follows: Section 2 presents a model of intraday trading in times of crisis; Section 3 describes the data; Section 4 presents our results; and Section 5 concludes.

I. A Model of Intraday Trading

Consider a single asset that is tradable in a single market at any time over a span divided into n periods, each of length T. In order to abstract from portfolio balance issues, we assume the asset is in zero net supply (we discuss risk premia in our comments on intervention below). Let S_t denote the price of the asset at time t. For concreteness, we associate S_t with the nominal exchange rate in French Francs per Deutschemark, or FF/DM. Further, let R_t^{FF} and R_t^{DM} denote the per–period nominal interest rates, in FF and DM respectively, applying to open positions. Our core assumptions are the following:

(A1) Settlement–FX: all FX trades effected within a period are settled at period close.

(A2) Settlement–Interest: open positions in FX involve interest on a per–period basis, but only if open positions are carried across period close. If carried across a period close and offset in the subsequent period, open positions accrue a full period of interest, regardless of how far into the subsequent period the position is maintained.

(A3) Uncovered interest parity (UIP) holds.

Assumption (A1) is realistic since spot FX is traded over periods within which settlement time is unchanging (in reality, settlement typically occurs two days forward rather than at the day's "close"). Assumption (A2) captures the fact that daily interest is a discrete variable: if one opens a position and closes it five minutes later, but settlement of the second trade is one day later than that of the first trade, then one full day's interest will accrue. Assumption (A3) — though rejected empirically over monthly and quarterly horizons — allows us to focus attention on the expected return consequences of intraday trading. To our knowledge, UIP has not been tested at this horizon (Hodrick (1987)). Henceforth, we work with with a log–linear approximation of UIP (the negligible size of intraday cross terms is demonstrated below).[2]

The above assumptions imply that:

$$E[s_{t+\tau} - s_t | \Omega_t] = D_{t+\tau}(R_t^{FF} - R_t^{DM}), \qquad \tau < T. \tag{1}$$

Here, $s_t = \log(S_t)$ and Ω_t denotes the representative agent's information set at time t. $D_{t+\tau}$ is an indicator variable equal to 1 if $t+\tau$ is in the period subsequent to that containing t, and equal to 0 if $t+\tau$ is in the same period as containing t. Thus, when $D_{t+\tau} = 0$, the expected change in the log of the exchange rate must also be zero.

The expected dynamics implied by equation (1) are presented in Figure 1. Implicit in the figure is the assumption that R_t^{FF} and R_t^{DM} are constant, with $R^{FF} > R^{DM}$. The most distinctive feature is that this model generates expected discontinuities in the exchange rate at the settlement points.[3]

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[2] We note that any terms arising from Jensen's inequality are absorbed into the constant of our estimating equation as long as second moments are time–invariant.

[3] In reality, spot FX is settled the second business day after the transaction, so there is a distinction between the time the settlement date (value date) advances one day, and the time payments are actually made on the day of settlement. For our

Figure 1

Expected Exchange Rate Behavior Over Time
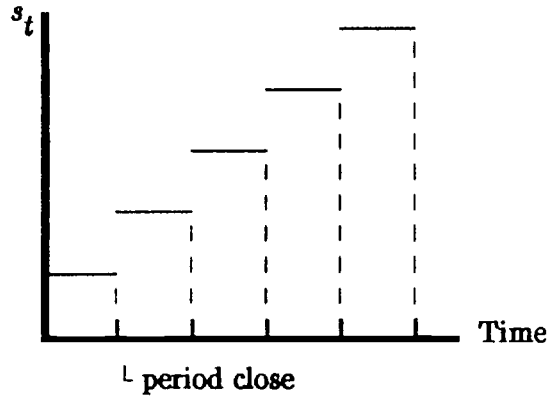
Times of Crisis

We turn to implications of the model in times of crisis. Times of crisis are interesting because interest differentials become first-order relevant even at horizons of one day. For example, during March, 1983 the value of $R^{FF}-R^{DM}$ topped 80% on an annual basis (30-day eurorates). It is within this extreme context that policy-makers must evaluate the effectiveness of the interest rate defense.

In order to gauge the size of interest rate differentials on a daily basis, Table I presents some statistics. The numbers in the columns on the right represent the size of the periodic exchange rate discontinuities illustrated in Figure 1. (Note that the columns are the same up to the precision reported. Hence, the cross terms that distinguish the linear version of uncovered interest parity from the exact version are quite small at this horizon.)

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purposes, what matters is the time the value date advances one day. For the currencies we consider below, the worldwide standard for advancing the value date has varied between 9 PM and 10:30 PM London time (GMT) over the EMS period (sources: bank dealers and Reuters).

<div align="center">

Table I

Annual Interest Differentials on a Daily Basis[*]

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Quoted $R^{FF}-R^{DM}$ Annual Basis	$(R^{FF}-R^{DM})/360$ Daily Basis Points	$(1+R^{FF}/360)/(1+R^{DM}/360) - 1$ Daily Basis Points
10%	2.8	2.8
15%	4.2	4.2
20%	5.6	5.6

[*] Daily–basis values are expressed in 0.01%, or basis points. Eurorates (other than Sterling) are quoted on a 360–day basis so that gross yield over t days equals $1+R(t/360)$ where R is the quoted rate [see Stigum (1981), pages 175–178]. The DM rate used is the median quote in our sample.

The question we want to answer is this: does the lack of intraday interest rates provide agents with a costless means of speculating against vulnerable currencies? Our analysis follows directly from equation (1), as before, except that now we must determine the implications of our assumptions under a positive probability of devaluation. Clearly, the *total* expected change in the exchange rate must still be zero. Accordingly, for intra–period open positions we can write:

$$E[s_{t+\tau}-s_t|\Omega_t] = pE[s_{t+\tau}-s_t|\text{deval.}] + (1-p)E[s_{t+\tau}-s_t|\text{no deval.}] = 0 \qquad (2)$$

where p denotes the exogenous probability that a devaluation will occur between t and $t+\tau$. With $E[s_{t+\tau}-s_t|\text{deval.}]>0$, this implies that $E[s_{t+\tau}-s_t|\text{no deval.}]<0$. That is, *conditional on no devaluation, the weak currency should appreciate* on average within the period. Figure 2 provides a qualitative illustration:

Figure 2

Ex–Post Exchange Rate Behavior Conditional on No Devaluation
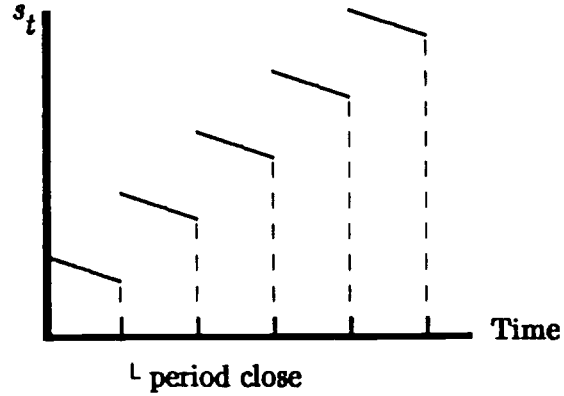
A testable implication of our model as applied to crises is presented in the following proposition:

Proposition 1: Intraday, if a higher weak–currency interest rate reflects greater expected devaluation then — conditional on no devaluation — a higher weak–currency interest rate implies greater expected appreciation, ceteris paribus.

Proof: We know from equation (2) that intra-period $E[s_{t+\tau}-s_t|\Omega_t] = pE[s_{t+\tau}-s_t|\text{deval.}] + (1-p)E[s_{t+\tau}-s_t|\text{no deval.}] = 0$. But, if an increase in $(R_t^{FF}-R_t^{DM}) => $ an increase in $pE[s_{t+\tau}-s_t|\text{deval.}]$, then $pE[s_{t+\tau}-s_t|\text{no deval.}]$ must be lower.

This is the implication we test in the data. That is, we estimate the following regression:

$$\Delta s_{t+\tau} = \beta_0 + \beta_1(R_t^{FF}-R_t^{DM}) + \epsilon_{t+\tau} \tag{3}$$

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where: $\Delta s_{t+\tau}$ in the intra–day change in the log of the spot rate; $R_t^{FF}-R_t^{DM}$ is the interest differential (daily basis); and $\epsilon_{t+\tau}$ is a stationary expectational error. (Since $\epsilon_{t+\tau}$ represents news it is orthogonal to available information such as interest rates; hence, least squares is a consistent estimator for (3).) Proposition 1 implies that if a higher interest differential reflects higher expected devaluation, then β_1 should be negative *so long as there are no intraday devaluations in the sample.* (In the sample we consider, none occurred. That said, it is important that devaluation *can* occur intraday. Sweden provides an example: the November 19, 1992 devaluation occurred during business hours. Further, the devaluation was news: the Prime Minister was apprised just ten minutes before flotation (see the *Financial Times*, 11/20/92)).[4]

Note that under covered interest parity our regression is exactly the canonical regression of $\Delta s_{t+\tau}$ on the forward discount. The estimated coefficients in the literature are consistently negative for intermediate horizons, in violation of uncovered interest parity (see Hodrick (1987) for a comprehensive discussion of forward discount bias). In contrast, our model, derived from UIP, *predicts* a negative coefficient — for intraday horizons.

II. Data and Related Issues

Our empirical implementation uses two currencies within the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS): the French Franc and the Italian Lira, both relative to the German DM, anchor of the ERM. A number of factors are relevant for our choice of data. First, we need fixed exchange rates to get the devaluation possibility that drives the model. Second, we need high

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[4] Note that if a large sample were available — i.e., one that includes a representative number of intraday devaluations — one would expect a value of zero for β_1 under UIP.

expected devaluation — proxied by high interest differentials — otherwise the implied intraday drift is too small to detect. Third, the ERM dominates both Bretton Woods and developing–country possibilities: more crises were defended with high interest rates than under Bretton Woods, and institutional issues are not the problem they would be in the developing–country context (e.g., capital controls, thin markets, etc.). Finally, within the ERM, the French Franc and Italian Lira account for the lion's share of high interest differential observations. Indeed, there are still relatively few attacks of the magnitude we require; hence, we pool our data across countries. (See also Svensson (1993) for further evidence regarding the intrinsic appeal of the ERM as a target of analysis.)

Our sample runs from 3/13/79 to 10/26/92, which includes a total of 3555 weekdays. We construct FF/DM and IL/DM rates (IL denotes Italian Lira) using dollar quotes, i.e., the FF/DM rate equals (FF/$)($/DM). Our end–of–period rates are the daily London close quotes (midpoints) from the *Financial Times*, which over this period were recorded at 5 PM London time. Our beginning–of–period rates are European Currency Unit (ECU) fix rates recorded at 2:15 Swiss time (1:15 London time) by the Bank of International Settlements (BIS). There is no spread for the ECU fix series, since fixings are auctions. Finally, these fix series are the earliest consistent series available for London trading hours, to our knowledge.

Our interest rate data for the FF, IL, and DM are the 30–day euro–currency rates recorded at 10AM Swiss time (9 AM London time) by the BIS. As euro–rates, they are virtually free of political risk. The 30–day market is deeply traded; we also use 2–day rates for a robustness check.[5]

We need to determine a definition of a crisis in terms of interest differentials

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[5] Note that the interest cost of an *overnight* short position is tied to a *forward* interest rate, from $t+2$ days to $t+3$ days, since spot deliveries are typically two days forward. This has no bearing, however, on the fact that the interest cost of an intraday short position is zero.

since our model's non–zero drift prediction is only relevant during times of crisis. The larger the cutoff interest differential, the larger the implied drift, but the cost is lower statistical power since the available sample shrinks rapidly. Our preferred cutoff is a ten percent interest differential (annual basis), $R^{FF}-R^{DM}$ or $R^{IL}-R^{DM}$, although we present results for different thresholds. This preference is based on three factors. First, a ten percent differential is large enough to be a strong signal of crisis. Second, on a daily basis, a ten percent differential is large enough to imply a drift that is not dominated by typical spreads (Lyons (1993b) finds a 2 basis point median spread in DM/$ transactions data; note that Reuters' indicative quotes overstate inter–dealer spreads by a factor of 2 or 3). Third, ten percent is not so large as to limit severely our sample size.

Parenthetically, though intervention often takes place during crises, this does not vitiate our results. Unsterilized intervention — the more important for the FX market — has effects that are captured by the interest rates in our model. One could argue that *intraday* unsterilized intervention is not reflected in the morning interest rates, and creates bias in our regression since it systematically goes in the support direction. This argument is flawed, however: it neglects the fact that only innovations in intervention should impact the exchange rate; what matters is departures from expected intervention, not just the direction. In addition, we view the case for sizeable portfolio–balance effects from sterilized intervention as weak, especially given the point about innovations above (see Edison (1992)). Irrespective of these arguments, though, if the data generate a significant negative β_1 in equation (3) then there is a cost to shorting vulnerable currencies intraday, whether the source is intervention or not. Of course, if central banks are the only buyers earlier in the day, then perhaps they do not require the expected appreciation that maintains UIP. This possibility makes a finding of a significant negative β_1 all the more striking.

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III. Estimation Results

Table II presents our OLS results. To get a sense of the sensitivity of our sample size and results to the interest differential, we provide estimates for three different cutoffs: 10%, 15%, and 20% on an annual basis. To provide more interpretable coefficients, we translate the annualized interest differentials to a daily basis [using the Table 1 formula $(R_t-R_t^{DM})/360$, where R_t and R_t^{DM} are annual basis quotes, and R_t denotes either R_t^{FF} or R_t^{IL} as appropriate.].

Table II

The Intraday Returns Relationship

$$\Delta s_{t+\tau} = \beta_0 + \beta_1(R_t-R_t^{DM}) + \epsilon_{t+\tau}$$

	$\hat{\beta}_0$	$\hat{\beta}_1$	OBS
30–Day Interest Diff. (annualized)			
$\geq$10%	0.0002 (1.05)	−0.90 (−2.36)	842
$\geq$15%	0.0007 (1.91)	−1.48 (−2.71)	261
$\geq$20%	0.0009 (1.43)	−1.74 (−2.30)	105

* $\Delta s_{t+\tau}$ is the change in the log of the exchange rate over the intraday holding period, in FF/DM or IL/DM as appropriate. $R_t-R_t^{DM}$ is the nominal interest differential, daily basis, where R_t denotes either R_t^{FF} or R_t^{IL} as appropriate. OBS denotes number of observations meeting the interest differential cutoff criterion. The criterion $\geq$10% denotes observations for which the own–currency interest rate is at least 10% higher than the DM interest rate on an annual basis. Similarly for the other criteria. Estimated using OLS. Sample: 3/13/79 to 10/26/92. T–statistics in parentheses.

The results are clear: the greater the interest differential, the more the vulnerable currency appreciates intraday.[6] The implications of our model are apparently borne out in the data.

We can go further and interpret the β_1 magnitudes, but this introduces the knotty problem of translating trading hours into trading days. With some simplifying assumptions, it is easy to show that UIP predicts $\beta_1 = -1$.[7] Again, the prediction works well: while $\beta_1 = 0$ can be rejected at conventional levels of statistical significance, the hypothesis that $\beta_1 = -1$ cannot.

IV. Conclusions

Our first result derives from analysis of our model: intraday interest rates of zero do not imply that agents have a costless means of speculating against vulnerable currencies within the day. On the contrary, if the interest differential cannot do its work then exchange rate dynamics have to take up the slack. Further, if expected returns are to be equated, then the larger the expected devaluation, the more the vulnerable currency is expected to *appreciate* within any day in which a devaluation does not occur.

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[6] We conduct three types of sensitivity analysis: (1) we use 2–day interest rates instead of 30–day rates, (2) we split the data by country, and (3) we bootstrap the standard errors. The 2–day interest rates produce a negative and highly significant β_1. The country results are weaker for Italy: though France alone still generates a significantly negative β_1, Italy does not. Finally, bootstrapped standard errors are roughly twice as large as conventionally–calculated standard errors, but are conditional on independence of the residuals over time, a strong assumption in this context. The reported t–statistics use conventionally–calculated standard errors.

[7] The assumptions are: (i) per proposition 1, the daily–basis $R_t - R_t^{DM} = p\mathrm{E}[s_{t+\tau} - s_t | \text{deval.}]$ where τ is the length of a trading day, (ii) our empirical measure of $s_{t+\tau} - s_t$ corresponds to one trading day, and (iii) p is small, so that $(1-p)$ is close to 1. To see that UIP predicts $\beta_1 = -1$, note that equation (2) implies $\mathrm{E}[s_{t+\tau} - s_t | \text{no deval.}] = -(1-p)^{-1}(p\mathrm{E}[s_{t+\tau} - s_t | \text{deval.}]) \approx -(R_t - R_t^{DM})$.

Our second result is empirical: our analytical results are borne out in the data. The larger the expected devaluation — proxied by the interest differential— the more the *vulnerable* currency *appreciates* intraday. Hence, dealers are not immune to the central bank's interest rate defense within the day. That said, the implied intraday drifts are not large. This kind of an effect is irrelevant for all but the lowest transaction-cost participants at times of substantial devaluation risk.

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