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FORWARD BIAS, UNCOVERED INTEREST PARITY AND RELATED PUZZLES*

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Abstract

Uncovered interest parity is widely used in open economy macroeconomics. But the evidence rejects UIP and implies forward bias. There are many suggested explanations for the failure of UIP and forward bias, but none are widely accepted, at least partially because none appear to explain the related puzzles discussed below. This paper shows how sterilized “leaning against the wind” and a combination of inflationary and liquidity effects of open market operations can explain forward bias and the failure of UIP even when expectations are rational. They also appear to be able to explain the related puzzles.

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Key words: risk premiums; rational expectations; uncovered interest parity; intervention, covered interest parity; forward bias; liquidity effects.

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** Author’s Note: Unlike most economists, I am a Logical Positivist. As such I assume that all theories are false, but that some are less false than others. I offer this explanation for forward bias and the failure of UIP not as something that is or could be “true”, but as something that I believe could be less false than any of the current alternatives.

1. Introduction.

As Lothian and Wu (2011) point out, uncovered interest parity (UIP) is one of three key international financial relations used repeatedly in open-economy macroeconomics. But the evidence rejects UIP and implies forward bias. With flexible rates, standard test equations that should produce coefficients of 1.0 routinely produce negative coefficients, some of which are significant. See Sarno (2005) for a discussion of that evidence.¹

But as Section 2.3 points out, those negative coefficients disappear under the gold standard and with pegged exchange rates. This paper shows for the first time how sterilized “leaning against the wind” and/or a combination of liquidity and inflationary effects associated with open market operations due to macro-economic stabilization produce negative coefficients under flexible exchange rates.

The importance of forward bias and the failure of UIP has prompted many attempts to explain them, but none has distinguish between flexible and managed exchange rates. Two of the most widely cited explanations are risk premiums and the failure of Rational Expectations. For a discussion of those two alternatives see Sarno (2005).

Less frequently cited alternatives include the following: using interest rates to stabilize exchange rates [McCallum (1994)], a tradeoff between interest rate and exchange rate stability [Anker (1999)], uncertain monetary policy [Lafuente and Ruiz (2006)], nonlinearities [Sarno et al (2006)], fads and fashion [Sercu and Vinaimont (2006)], perpetual learning [Chakraborty and Evans (2008)], adverse selection [Burnside et al (2009)], career risk [Liu and Sercu (2009)], deep habits [Moore and Roche (2010)], infrequent portfolio decisions [Bacchetta and van Wincoop (2010)], carry and momentum trading [Baillie and Chang (2011)], and over confidence [Burnside et al (2011)]. A recent book, Miller (2014), uses an inter-temporal version of UIP with systematic errors in expectations to explain the apparent failure of UIP. But the puzzle as to why the two theories fail so badly under flexible rates, but not managed rates, remains.

All these explanations, including the one proposed here, were developed to explain forward bias and/or the failure of UIP. As a result, that bias and/or failure does not provide empirical support for any of the explanations. There are, however, several related puzzles. They are (1) the Carry Trade Puzzle, (2) the Commodity Puzzle, (3) the Development Puzzle, (4) the Inflation and Outlier Puzzles, (5) the Maturity Puzzle and (6) the Time Dependency Puzzle. Explaining

¹ Baillie and Osterberg (2000) and Maynard and Phillips (2001) among others claim that this evidence is a statistical artifact. Aggarwal et al (2009) reject that claim.

these puzzles would support explanations for forward bias and the failure of UIP. For one theory to explain all these puzzles would be a major contribution to open-economy macroeconomics.

Section 2 reviews forward bias and the failure of UIP under flexible rates. It then reviews the evidence for managed exchange rates. Section 3 discusses Covered Interest Parity (CIP) because CIP plays an important role in forward bias and the failure of UIP. Section 4 discusses the basic ideas behind the model and some of its important assumptions. Section 5 describes the model and its important implications. Section 6 discusses how well the model, and the ideas behind it, explain the related puzzles. Section 7 is a brief summary.

2. Primary Puzzles.

This section begins with the two primary puzzles: forward bias and the failure of UIP under flexible exchange rates. It then reviews the relevant evidence for managed exchange rates.

2.1. Uncovered Interest Parity.

Discussions of UIP often take the economic theory behind it for granted, but the theory behind UIP is not obvious. There are at least two different approaches.

Eq. (1) describes UIP. The expected change in the exchange rate equals the appropriate interest rate differential.

$$E(\Delta s_{t+k}|I_t) = i_t - i^* \tag{1}$$

Where s_t is the log of the domestic price of foreign exchange, $E(x_{t+k}|I_t)$ is the conditional expectation of x_{t+k} based on the information set I_t available at t . i_t and i^* are risk-free domestic and foreign interest rates with the same maturity as s_{t+k} . Expectations are "rational" in the sense of Muth (1961) when I_t contains all of the current information in the model.

One approach to UIP begins with CIP and *assumes* that speculation eliminates expected speculative returns by eliminating the difference between $E(s_{t+k}|I_t)$ and the log of the appropriate current forward rate denoted f_t .² Together they imply eq. (1). This approach ignores transaction costs and risk premiums, and seems to implicitly assume that expectations are rational.

Given the large body of evidence supporting CIP, when UIP fails, it is natural to question the assumption that $E(s_{t+k}|I_t)$ equals f_t . That question appears to be the source of the idea that risk premiums "cause" UIP to fail. Less than Rational Expectations provides another potential explanation for the failure of this version of UIP.

² This is the approach used in the New Palgrave Dictionary of Economics, Vol. 1 (2008, 451).

A second approach uses the Fisher equation, an expectations version of purchasing power parity and the simplifying assumption that real interest rates are equal.³ When nominal interest rates equal real rates plus expected rates of inflation, $i_t - i^*$ equals the appropriate difference in expected rates of inflation plus the difference in real interest rates. With real differentials zero, the Fisher equation and an expectations version of PPP imply eq. (1) because $E(\Delta s_{t+k}|I_t)$ and $i_t - i^*$ both depend on expected inflation. Like the first approach this one ignores transaction costs and risk premiums, and seems to implicitly assume rational expectations.

Under both approaches, eq. (2) is the standard test equation where expectations are rational, e_{t+k} has a zero mean, is uncorrelated and is orthogonal to $i_t - i^*$.

$$\Delta s_{t+k} = a + b(i_t - i^*) + e_{t+k} \quad (2)$$

UIP implies that estimates of b , denoted \hat{b} , should equal 1.0. With flexible exchange rates, \hat{b} are routinely negative, and often negative and significant. But as the review of the relevant evidence in Section 2.3 shows, \hat{b} are seldom negative, and hardly ever negative and significant, with managed exchange rates.

2.2. Forward-Bias.

The modern forward-bias puzzle begins with Fama (1984) who splits f_t into $E(s_{t+1}|I_t)$ and a "premium" denoted p_t .

$$f_t = E(s_{t+1}|I_t) + p_t \quad (3)$$

Although subsequent literature almost universally calls p_t a risk premium, Fama (1984) does not. He first mentions p_t in his Abstract without any mention of a "risk premium". He then points out that eq. (3) is "no more than a particular definition of the premium component of the forward rate. To give this equation economic content, a model that describes the determination of p_t is required." Eq. 12 provides that economic content.

Although almost all the relevant literature refers to p_t as a risk premium, from this point on, p_t is the expected return to speculation. If $E(s_{t+1}|I_t)$ is less than f_t , a speculator expects to make a profit by selling the currency forward at f_t , and then buying the currency in the future to cover the forward sale at the lower $E(s_{t+1}|I_t)$.

As Sarno (2005, 678) points out, it is unlikely that p_t is a risk premium.

The message that emerges from the empirical analysis of risk-premium models, in general or partial equilibrium, is that it is hard to explain excess returns in forward

³ This appears to be the approach used in Engel (2016).

foreign exchange by an appeal to risk premia alone; either φ , the coefficient of relative risk aversion, must be incredibly large, or else the conditional covariance of consumption must be incredibly high.

Rather than concentrating on risk premiums in the equilibrium condition that risk premiums equal expected speculative returns, Section 4 concentrates on showing how sterilized intervention and a combination of inflationary and liquidity effects produce expected speculative returns. Those expected returns produce forward bias and risk premiums even when expectations are rational.⁴

Whatever the interpretation of p_t , eq. (3) implies eq. (4).

$$f_t - s_t = E(\Delta s_{t+1}|I_t) + p_t \quad (4)$$

Assuming Rational Expectations and rearranging eq. (4) produces eq. (5).

$$\Delta s_{t+1} = (f_t - s_t) - p_t + \varepsilon_{t+1} \quad (5)$$

Omitting p_t produces the "Fama equation".

$$\Delta s_{t+1} = \alpha + \beta(f_t - s_t) + \zeta_{t+1} \quad (6)$$

Where $\hat{\beta}$ is the estimated β .

$\hat{\beta}$ between countries with flexible rates are routinely negative and often significant. For some recent evidence see Table 2 in Copeland and Lu (2016). As the next subsection shows, when rates are not flexible, that is not the case.

2.3. Flexible versus Managed.

Most discussions of forward bias and the failure of UIP refer to the negative and often significant estimates of $\hat{\beta}$ and $\hat{\beta}$ under the current float. But there also are estimates under the gold standard, when rates were flexible during the early 1920s and under pegged exchange rates, all between developed countries. In addition there are estimates between developed and emerging countries under both "managed" and flexible rates.⁵

Coleman (2012) estimates $\hat{\beta}$ between the U.S. and U.K. from 1888 to 1905, the classical gold standard. His $\hat{\beta}$ are about 0.5. Paya et al (2010) estimate $\hat{\beta}$ between the U.K. and U.S. from December 1921 to May 1925 when rates were flexible. Their $\hat{\beta}$ is negative and significant.⁶

⁴ The combination of forward bias and rational expectations raises an interesting question about the meaning of an "efficient" market.

⁵ "Managed" covers a wide range of regimes from currency boards to crawling pegs. Particularly with emerging countries, currencies can be flexible *de Jure* but not necessarily *de facto* because of trade and/or capital controls.

⁶ This interval is a bit unusual because the U.K. was deliberately deflating in order to restore the pre WWI value of sterling versus the U.S. dollar, which had maintained the pre WWI gold content of the dollar.

Flood and Rose (1996) pool their daily data and use SUR to estimate b under both pegged and flexible exchange rates. Their pegged rates are from the Exchange Rate Mechanism of the European Monetary System from March 1979 to March 1994 where Germany is the home country. Their flexible rates use Australia, Canada, France, Germany, Japan, Switzerland and the U.K. from 1981 to October 1994 where the U.S. is the home country. Using flexible rates, a common intercept and a three month interval their $\hat{\alpha}$ is -0.04 . With specific intercepts it is -0.88 . Both $\hat{\alpha}$ are significantly less than zero.

Using pegged rates, a common intercept and a three month interval their $\hat{\alpha}$ is 0.54 . With specific intercepts it is 0.60 . Both $\hat{\alpha}$ are significantly greater than zero but significantly less than one. Using one month rather than three month intervals produces similar results. These estimates are designed to avoid the peso problem. When uncorrected for peso problems estimates are close to, but still significantly greater than, zero

Lothian and Wu (2011) estimate b using annual data for France and the U.K. versus the U.S. for about the 200 years before 1999. Their rolling regressions tell an interesting story. The $\hat{\alpha}$ are generally positive up to the general adoption of flexible rates in the 1970s. They then turn negative until the 1990s where they begin to turn positive again. But this turn to positive appears to be only temporary. Using data from 1987 to 2006, Aslan and Korap (2010) find that all four of their flexible currencies versus the U.S. dollar have negative $\hat{\alpha}$ and that two are significant.

Bansal and Dahlquist (2000) and Frankel and Poonawala (2010) provide $\hat{\alpha}$ between developed countries during the current float with the U.S. the home country and between the U.S. and emerging countries with both flexible and managed rates. Whether country pairs are developed or developed and emerging, when rates are flexible their $\hat{\alpha}$ are usually negative and at times significant. When rates are managed, $\hat{\alpha}$ are generally positive and not significantly different from zero. (Note that these estimates are not corrected for peso problems.)

This overview of the relevant evidence suggests the following: systematically negative and occasionally negative and significant $\hat{\alpha}$ and/or $\hat{\alpha}$ are restricted almost exclusively to flexible exchange rates. Whether country pairs are developed or developed versus emerging does not seem to make a difference.⁷

3.0. CIP.

⁷ This result suggests that the Development Puzzle discussed below is not really about development, but rather about managed versus flexible rates with developing countries usually having managed rates and developed countries usually having flexible.

Covered Interest Parity is based on effective arbitrage and is one of the few theories in open economy macroeconomics for which there is convincing empirical support.⁸ Akram et al (2008) probably provide the best available analysis of Covered Interest Parity.⁹ They say that one can safely assume that CIP holds for daily and lower frequency data. Given that strong support, any explanation for the failure of UIP or forward bias that is not consistent with CIP is suspect. Section 4 assumes CIP.

Since, as is typical, Akram et al (2008) use maturities of one year or less from developed countries with flexible rates, strictly speaking their conclusions only hold under those conditions. Whether or not CIP holds under other conditions is an issue that needs to be resolved.¹⁰

Eq. (7) describes the *theory* of Covered Interest Parity.

$$f_t - s_t - (i_t - i^*) = \mathbf{d}_t \quad (7)$$

Where forward premiums and interest rate differentials have the same maturity.

For good data deviations \mathbf{d}_t should reflect primarily transaction costs, particularly bid-ask spreads. To simplify the discussion, it ignores \mathbf{d}_t and assumes that CIP holds exactly.

CIP implies that the failure of UIP and forward bias are two sides of the same coin. With \mathbf{d}_t zero, eq. (7) implies (8).

$$f_t = s_t + (i_t - i^*) \quad (8)$$

Subtracting an appropriate $E(s_{t+1}|I_t)$ from both sides of eq. (8) produces eq. (9).

$$f_t - E(s_{t+1}|I_t) = (i_t - i^*) - [E(s_{t+1}|I_t) - s_t] \quad (9)$$

The forward bias $f_t - E(s_{t+1}|I_t)$ equals the deviation from UIP $(i_t - i^*) - [E(s_{t+1}|I_t) - s_t]$.

4. Background.

Subsection 4.1 shows, for the first time, how a combination of liquidity and inflationary effects can produce negative \wedge and \wedge . Subsection 4.2 shows, for the first time, how sterilized foreign exchange intervention can produce negative \wedge and \wedge . Both sections assume that central banks have the freedom to try to stabilize the macro economy provided by flexible exchange rates. These ideas are not model specific. They should hold in a wide range of reasonable

⁸ Several papers claim that CIP fails after 2008. For a review of that work and an evaluation of CIP after the Great Recession see Rime et al (2017).

⁹ For additional work on CIP see Fong et al (2010) and the work cited there.

¹⁰ Fletcher and Taylor (1996) find unexploited deviations from long-term CIP. Skinner and Mason (2011) find violations of long-term CIP, but only for emerging markets. Suh and Kim (2016) seem to suggest substantial deviations from CIP for emerging markets.

models. One objective of the model described in Table 1 is to show that the failure of UIP and forward bias can be consistent with rational expectations.

Subsection 4.3 takes up the issue of sticky versus flexible prices. Subsection 4.4 takes up the issue of how to model foreign exchange markets.

4.1. Liquidity and Inflationary Effects.

Keynesian models generally ignore the inflationary effects of expansionary monetary policies. Many non-Keynesian models ignore the liquidity effect of those policies. Combining liquidity and inflationary effect produces an explanation for forward bias and the failure of UIP.

Inflationary effects of expansionary monetary policies produce depreciation. Liquidity effects can produce negative interest rate differentials. The resulting positive $\Delta s(t)$ and negative $i_t - i^*$ imply negative \hat{s} and \hat{i} . This reasoning is consistent with a wide range of macro models.

There is substantial evidence that monetary policy is a source of forward bias and the failure of UIP. A large literature uses vector auto-regression to analyze how shocks to monetary policy affect UIP. It includes Eichenbaum and Evans (1995), Grilli and Roubini (1996), Cushman and Zha (1997), Kim and Roubini (2000), Faust and Rogers (2003), Scholl and Uhlig (2008), Bjørnland (2009), Bouakez and Normandin (2010) and Heinlein and Krolzig (2012). Most articles claim that policy shocks create at least temporary deviations from UIP.

4.2. Leaning against the Wind.

Central banks lean against the wind when they buy a foreign currency as the price falls and sell as the price rises. They do so to reduce the short-run volatility in exchange rates while at the same time allowing fundamental forces determine exchange rates in the long-run.

Central banks sterilize to prevent their intervention from affecting the monetary base in ways that would conflict with other policy objectives. They sterilize their intervention by acquiring short-term securities as they sell foreign exchange, which leaves the monetary base unchanged. Referring to the era of flexible exchange rates, Neely (2001, 4-6) reports that almost 90% percent of central banks sometimes or always lean against the wind and that 40% fully sterilize while only 30% never sterilize.

When two plausible conditions hold, sterilized leaning against the wind produces negative \hat{s} and \hat{i} . First “leaning against the wind” introduces inertia into changes in exchange rates and second that sterilized and unsterilized intervention affect nominal interest rate differentials differently.

There is empirical support for the first assumption. Phillips and Pippenger (1993) find that sterilized intervention introduces inertia into changes in exchange rates. Although she attributes it to a signaling effect, in her review of the early literature Edison (1993, 54) refers to a similar temporary effect. In their review of the later literature, Beine et al (2003, 892) also mention a similar temporary effect. More recently Fatum (2008) finds evidence of inertia. Pippenger and Phillips (1973) probably provide the best evidence because they are able to avoid simultaneity by assuming that, in the absence of intervention, exchange rates are random walks; an assumption that Pippenger (2008) supports.

The second assumption holds when domestic and foreign assets are not perfect substitutes and central banks have a desired level of foreign exchange that they want to hold at the foreign central bank. In that case, fully sterilized intervention leaves both the domestic and the foreign monetary base unchanged. But the change in the relative stock of short-term assets alters relative interest rates.¹¹

There is evidence that intervention produces negative Δ . Baillie and Osterberg (1997) and (2000) and Mark and Moh (2007) both find that intervening in foreign exchange markets causes UIP to fail.

4.3. Sticky Prices.

One key issue in macroeconomics is sticky versus flexible commodity prices. This paper assumes that commodity prices are both sticky and flexible. It depends on the commodity market: auction versus wholesale and retail. It also depends on the monetary regime: stable versus unstable.

4.3.1. Market. Under stable monetary regimes, as is widely recognized, information and transaction costs produce sticky wholesale and retail prices. Similar information and transaction costs make arbitrage difficult in wholesale markets and impossible in retail markets. One cannot

¹¹ Suppose the Fed buys pound sterling and sells an equivalent amount of U.S. Treasury bills. The stock of T bills held by the public increases, tending to increase U.S. T bill rates. To maintain the desired level of sterling deposits at the Bank of England, the Bank, acting on instructions from the Fed, buys an equivalent amount of U.K. bills. The stock of U.K. bills held by the public declines, tending to lower U.K. T bill rates. The net result is a rise in U.S. minus U.K. T bill rates.

buy grapes a 99 cents per pound at one grocery store and walk across the street and sell them for \$2.00 a pound at another grocery store. At the wholesale level if, after accounting for the exchange rate, Kleenex prices are much higher in Japan than the United States, marketing contracts prevent one from buying Kleenex wholesale in the U.S. and selling them in Japan.

On the other hand, prices in auction markets like those for many agricultural products, metals and petroleum products are highly flexible because the cost per dollar traded is much lower when trading a “homogenous” product by the truck or shipload rather than by the ounce or pound.

Recognizing both “sticky” and “flexible” commodity prices raises issues widely ignored in the debate over purchasing power parity or PPP. Almost all empirical work uses retail prices where arbitrage is impossible and the law of one price or LOP does not apply.¹² But as Rogoff (1996, 649) points out, arbitrage and the LOP are the basic building blocks of PPP. As a result, there is a disconnect between testing and theory. Testing PPP uses primarily retail prices where arbitrage is not possible, while theory assumes effective arbitrage.

This paper assumes that arbitrage is effective in all *auction* markets and that expectations are rational in those markets.¹³ Of course neither assumption holds in wholesale and retail markets. That assumption affects the way this paper treats PPP.

4.3.2. Regime: There should be no disagreement over the issue of “sticky” wholesale and retail prices under stable monetary regimes. Sticky prices are an implication of basic microeconomics. See for example Alchian (1969). Holding prices constant has benefits. For example it increases demand by reducing price uncertainty. It also has costs, e.g., larger inventories. In general the solution to this optimization problem will be neither perfectly rigid nor perfectly flexible prices. That is sticky prices.

The same reasoning implies that wholesale and retail prices should be more flexible under both inflation and deflation because both impose additional costs. Inflation increases the cost of holding prices constant by further increasing the need for inventories. Holding prices constant with deflation reduces quantity demanded.

As far as I am aware, there is no convincing evidence one way or the other as to whether prices are more flexible with inflation than with comparable deflation. But there is impressive evidence that prices become very flexible under very unstable monetary regimes, i.e.,

¹² Like PPP, the LOP is based on effective arbitrage. The mistaken belief that commodity arbitrage and the LOP fail is based on articles like Engel and Rogers (1996), Asplund and Friberg (2001) and Parsley and Wei (2001). But they do not really test either commodity arbitrage or the LOP because they all use prices from retail markets where arbitrage is impossible.

¹³ For some evidence that arbitrage is effective in commodity markets, see Pippenger and Phillips (2008) and Pippenger (2016).

hyperinflation. See for example the German hyperinflation described by Graham (1930) and the Austrian hyperinflation described by van Walré de Bordes (1924), both in the early 1920s.

The French experience in the early 1920s is more interesting because it contains moderate inflation *and* deflation. See Tsiang (1959). There are only wholesale price indexes for the experience because it was before the development of consumer price indexes. But it is clear that prices were flexible in both directions. To the best of my knowledge, no one has analyzed that experience to determine whether or not prices were more flexible upward than downward.

The model described in Table 1 assumes a stable monetary regime because almost all the evidence for forward bias and the failure of UIP comes from stable monetary regimes. That assumption does not mean that the model would not apply to less stable regimes.

4.4. Stock versus Flow: Since the late 1970s most open economy macro models have assumed an asset approach to exchange rates in which asset market equilibrium determines exchange rates.¹⁴ That approach has been a total failure.¹⁵ I know of no one who claims that we can predict, or even “postdict”, the behavior of exchange rates, particularly the short-run behavior, any better today than we could before the asset approach. For that reason, the model in Table 1 assumes a “flow” model in which a flow demand for imports, supply of exports, international investments and portfolio adjustment interact to determine the exchange rate.

Table 1
The Model

$f_t - s_t = i_t - i^* = (\lambda - 1)s_t + (1 - \lambda)(i_t - i^*) + z_t$	Covered Interest Parity.	(I)
$s_t = (\lambda - 1)s_t + (1 - \lambda)(i_t - i^*) + z_t$	Flexible spot rate.	(II)
$f_t = \lambda(i_t - i^*) + (1 - \lambda)(f_t - s_t) + z_t$	Flexible forward rate.	(III)
$e_t = Du_t - FX\Delta s_t + v_t$	Changes in the monetary base.	(IV)
$(i_t - i^*) = E(\Delta_{(t+1)} I_t) + (i_t - i^*) - \lambda e_t - HX\Delta s_t$	Interest rate differential.	(V)
$E(\Delta_{(t+1)} I_t) = C(Du_t - FX\Delta s_t + v_t)$	Expected inflation.	(VI)
$\Delta_{(t+1)} = C(Du_t - FX\Delta s_t + v_t) + x_{t+1}$	Actual inflation.	(VII)
Definitions:		
$(i_t - i^*)$	Price level differential in logs.	

¹⁴ Almost any market can be modeled in terms of stocks or flows. For example the market for cars is usually modeled as the daily, weekly or monthly flow demand for and supply of cars. But it also can be modeled as an existing stock of cars and a demand for that stock with the resulting stock equilibrium determining the price and that price determining the rate of output.

¹⁵ Pippenger (2003) tests the two approaches and concludes that the evidence on balance rejects an asset approach.

$(r_t$	Real interest rate differential.
$(n_t$	Nominal interest rate differential.
u_t	Actual minus natural rate of unemployment.

Shocks and restrictions:

$v_t = Vv_{t-1} + v_t$, $u_t = Uu_{t-1} + w_t$, $(r_t = R(r_{t-1} + y_t$, $z_t = z_{t-1} + \varepsilon_t$. C, D, Λ, α and h are all ≥ 0 while V, U and R are all ≥ 0 but less than 1.0. Random variables w_t, x_t, y_t, v_t and ε_t have zero means, zero initial values, are uncorrelated and orthogonal. $1 \geq F \geq 0$, $Z = \alpha(1+F)X$ and $H = h(1-F)$.

5. Model.

The formal model begins with eq. (I) in Table 1 that describes CIP. Like the rest of the model it ignores transaction costs. Eq. (II) describes a flow market for spot foreign exchange, *e.g.*, the dollar price of sterling, where exchange rates are flexible. Eq. (III) describes the corresponding forward market. As required by CIP, subtracting (II) from (III) produces the short-term nominal interest rate differential $(r_t$ on the right-hand side. With the log of the exchange rate $s(t)$ exogenous in Eq. (I), which is often an implicit assumption in the relevant literature, $\lambda - 1$ is zero in eq. (II).

The primary role of eq. (III) is to show that the model is consistent with CIP. Assuming that $\lambda - 1$ is zero simplifies the later derivations of $\hat{\Delta}$ and makes them more consistent with the relevant literature without distorting the main implications of the model.

With $\lambda - 1$ zero, three factors determine spot exchange rates: central bank intervention captured by $ZX\Delta s_t$, exogenous shocks captured by z_t and relative price levels captured by $(r_t$. For simplicity, the foreign price level is assumed to be constant, which implies that foreign expected inflation is zero.

$ZX\Delta s_t$ describes the most common form of intervention when exchange rates are flexible, leaning against the wind. Central banks lean against the wind by selling a currency as its price rises and buying as its price falls.

X describes the Fed's response to a given Δs_t . The larger X the more the Fed leans against the wind. Z describes how that intervention affects Δs_t . A positive Z introduces positive autocorrelation in Δs_t .

Both Z and the resulting change in the monetary base depend on sterilization. The Fed sterilizes its intervention by selling (buying) assets like U.S. T bills as it buys (sells) sterling. With complete sterilization, intervention does not affect the monetary base and F in eq. (IV) is

zero. With no sterilization, F is one and each dollar's worth of sterling that the Fed sells reduces the domestic monetary base by one dollar. There is a general consensus that sterilization reduces Z . There is a less general consensus that Z is positive even when sterilization is complete. For the reasons discussed in Section 4.2, Z is positive even when F is zero.

Selling spot sterling reduces the Fed's holdings of sterling deposits at the Bank of England. To restore those deposits to their desired level, at the direction of the Fed, the Bank of England sells U.K. assets like T bills that it holds in the Fed's account at the Bank. Those sales prevent the intervention from affecting the monetary base in the U.K. Buying sterling as its price falls does the opposite.

As a result, when a central bank fully sterilizes, intervention does not affect either the domestic or the foreign monetary base. But purchases (sales) of domestic short-term assets tend to lower (raise) domestic short-term interest rates while sales (purchases) of foreign short-term assets tend to raise (lower) foreign interest rates. As a result, when leaning against the wind causes the domestic central bank to sell foreign exchange, full sterilization causes i_t to fall.

If a central bank does not sterilize, then the same sale of foreign exchange reduces the domestic monetary base, which tends to restrict domestic short-term credit and increase domestic short-term interest rates. That sale also increases the foreign monetary base, which tends to increase foreign short-term credit and lower foreign short-term interest rates. As a result, unsterilized intervention tends to increase i_t .

i_t in eq. II captures Purchasing Power Parity. i_t uses a ratio of auction prices where the weights are identical. It does not use retail prices because arbitrage is not possible in retail markets. There are other reasons for using auction rather than retail prices. First, at the retail level the distinction between traded and non-traded goods is an illusion. At the retail level *all* goods are effectively non-traded. No one buys shoes at Marks & Spencer in London and sells them to Macy's in New York. On the other hand, all goods with auction markets are traded. Second, it does not seem appropriate to use retail prices, which are not driven by expectations, to explain auction exchange rates, which are driven by expectations.

If both central banks target price levels, they stabilize i_t and the exchange rate. In that case exchange rates would be stationary as they were under the true gold standard where gold flows stabilized relative price levels.

If either central bank targets inflation, price ratios tend to have unit roots because at least one central bank allows changes in its price level to accumulate. Since Taylor rules target inflation, not price levels, they would imply that (π_t) have unit roots. Here exchange rates are flexible and (π_t) is roughly a random walk.

e_t in eq. (IV) describes changes in the domestic monetary base.¹⁶ Most central banks use a short-term interest rate like the Fed funds rate as their primary policy tool. With a positive D , when unemployment is above the natural rate and u_t is positive, the Fed lowers the Fed funds rate. To make that lower rate effective the Fed acquires short-term assets, which increases the reserves of commercial banks and the monetary base. When u_t is negative, it does the opposite. The question is whether or not other short-term interest rates fully respond to changes in the Fed funds rate.

In Table 1 responses to u_t are symmetric, but only for simplicity. I know of no central bank that responds symmetrically to high and low unemployment.

For simplicity, the model uses unemployment to illustrate how macro-stabilization produces the inflationary and liquidity effects that produce negative $\Delta \pi$ and $\Delta \pi$. Stabilizing prices has similar effects. Suppose the Fed raises the Fed funds rate to dampen inflation. To make the higher rate effective, it reduces its portfolio, which reduces the domestic monetary base and the legal reserves of depository institutions. Liquidity effects raise other short-term interest rates relative to what they would have been. Deflationary effects lower them and the exchange rate relative to what they would have been. UIP fails because (π_t) is larger than Δs_t .

A positive X implies intervention. With full sterilization, intervention does not affect the monetary base. With less than full sterilization, selling sterling reduces the monetary base and buying increases it. v_t captures random changes in the base due to things like bad weather.

Eq. (V) describes the nominal interest rate differential (π_t) for short-term financial assets like three month Treasury bills. The Fed responds to a positive u_t by lowering the Fed funds rate. How lowering the Fed funds rate affects (π_t) depends on the inflationary and liquidity effects of the expansionary open market operation used to reduce the Fed funds rate. C describes the inflationary effects and A describes the liquidity effects. If $C - A$ is negative expansionary open market operations lower (π_t) and there is a *net* liquidity effect.

¹⁶ The precise nature of e_t is not critical. It could be some other appropriate monetary aggregate.

When Λ is zero and there is no intervention, the Fisher equation holds. In that case, the model implies that increasing the monetary base by $x\%$ percent per year increases prices by $x\%$ per year. With foreign prices constant for simplicity, the exchange rate rises by $x\%$ per year. With foreign expected inflation zero for simplicity, ζ_t would be positive. With ζ_t and Δs_t both positive, $\hat{\pi}$ is positive. If ζ_t is constant, $\hat{\pi}$ is one. This link between expansionary open market operations, inflation, interest rate differentials and depreciation seems to be the basic idea behind UIP.

Liquidity effects weaken that link. Even with ζ_t constant, a liquidity effect, *i.e.*, a positive Λ , implies that ζ_t is less than $x\%$, which implies that UIP fails in the sense that $\hat{\pi}$ is less than one. If there is a net liquidity effect, then ζ_t and $\hat{\pi}$ are negative.

A combination of liquidity and inflationary effects help explain negative $\hat{\pi}$ under flexible rates, but not other regimes, because central banks have more freedom to engage in the kind of open market operations that produce liquidity effects under flexible rates than under other regimes. Sterilized leaning against the wind also helps explain negative $\hat{\pi}$ under flexible rates, but not other regimes. Under gold and pegged rates central banks are committed to defending the official exchange rate, not moderating short-run movements in the rate. They also have little interest in sterilization because it weakens the effects of their intervention.

Eq. (VI) describes expected inflation. How strongly $E(\Delta_{t+1}|I_t)$ responds to changes in the monetary base depends on the inflationary effects of open market operations denoted C . C depends on the time horizon and monetary regime. The shorter the time horizon the smaller is C . A substantial increase in the monetary base today would not cause much of a price increase tomorrow, but it should within a year. In a highly stable monetary regime like most of post WWII Germany, one would expect C to be relatively small. With hyperinflation as in Germany during the early 1920s or the moderately unstable monetary conditions in France at about the same time, one would expect C to be larger.

Eq. (VII) describes actual inflation Δ_{t+1} . It equals expected inflation plus x_{t+1} , as required by the assumption of Rational Expectations.

5.1. $\hat{\pi}$

Appendix I shows the solution for $\hat{\pi}$ using the full model. It is complex. Part of that complexity is the result of three things that most other explanations for the failure of UIP ignore: (1) that $(\lambda-1)$ might not be zero, (2) that several different kinds of shocks affect $\hat{\pi}$ and (3) the

possibility that those “shocks” might not be white noise. But most of the complexity is the result of including intervention.

5.1.1. No Intervention: Eq. (10) shows the solution for $\hat{\lambda}$ in a “stripped down” version of the model where $(\lambda-1)$, V , U and R are all zero and there is no intervention. That is when spot rates are “exogenous” in the CIP equation, all shocks except z_t are white noise and there is no intervention. These are common implicit assumptions in most of the relevant models and simplify comparing this model to others.

$$\hat{\lambda}_1 = \{C(C-\Lambda)[D^2\sigma^2 + \sigma^2]\} / \{(C-\Lambda)^2[D^2\sigma^2 + \sigma^2] + \sigma\} \quad (10)$$

If C is zero, $\hat{\lambda}_1$ is zero. If Λ is zero, $\hat{\lambda}_1$ goes to one as σ goes to zero. If $C-\Lambda$ is negative and C is positive, $\hat{\lambda}_1$ is negative. A negative $\hat{\lambda}_1$ requires both an inflationary and net liquidity effect.

The idea behind eq. (10) is simple and does not depend on the specifics of this model. Consider an expansionary open market operation. With no liquidity effect, let it produce actual inflation, expected inflation, a positive interest rate differential and depreciation. $\hat{\lambda}_1$ is positive. As long as they are equal, $\hat{\lambda}_1$ goes to one as σ goes to zero because the Fisher equation holds. If liquidity effects partially offset expected inflation, the nominal differential is smaller than the depreciation and UIP fails in the sense that $\hat{\lambda}_1$ is less than one. If there is a *net* liquidity effect, $\hat{\lambda}_1$ is negative because there is depreciation and the interest differential is negative.

5.1.2. Intervention: Central banks in developed countries with flexible rates routinely lean against the wind and sterilize their intervention. Countries with managed rates have less incentive to do so because they are usually more concerned with longer run movements in their exchange rate. Even if they did lean against the wind, countries with managed rates would have little incentive to sterilize.

Sterilized leaning against the wind with flexible exchange rates can reinforce the combination of liquidity and inflationary effects that explain why $\hat{\lambda}$ are negative when rates are flexible.

Eq. (11) adds intervention to eq. (10).

$$\hat{\lambda}_2 = \frac{\{[\Pi C(C-\Lambda) + (\Pi C)^2 \Omega \{\Phi / (1-\Phi^2)\}][D^2\sigma^2 + \sigma^2] + \Pi^2 \Omega \{\Phi / (1-\Phi^2)\}[\sigma^2 + \sigma^2]\}}{[\{(C-\Lambda)^2 + (\Omega \Pi C)^2 \{1 / (1-\Phi^2)\}][D^2\sigma^2 + \sigma^2] + (\Omega \Pi)^2 \{1 / (1-\Phi^2)\}[\sigma^2 + \sigma^2] + \sigma} \quad (11)$$

Where Π equals $1 / (1+ZX)$, Ω equals $[(\Lambda-C)F-H]X$, and Φ equals $[ZX-CFX] / [1+ZX]$.

Π is positive and probably close to one because Z and X are both positive and probably much less than one. As a result, the contribution of intervention to the sign of $\hat{\lambda}$ depends primarily on

the signs of Ω and $\Phi/(1-\Phi^2)$. When they have the same sign, leaning against the wind contributes to a positive Δ . With opposite signs it contributes to a negative Δ . If sterilization is incomplete, their signs are difficult to determine. But if sterilization is complete and F is zero, they have opposite signs and leaning against the wind contributes to a negative Δ .

To see how sterilized intervention reduces Δ , consider how a central bank responds to a positive ε_t . It sells foreign exchange to moderate the rise in the exchange rate. To sterilize that sale it acquires domestic short-term assets. To rebuild its holdings of foreign exchange, it sells foreign T bills.

Sterilized leaning against the wind contributes to negative Δ when two things happen:¹⁷ First sterilization produces negative ε_t . Second leaning against the wind produces positive Δ_{t+1} .

5.2. Risk Premiums.

There are no risk premiums in Table 1. Ignoring transaction costs, *equilibrium* implies that expected speculative returns equal risk premiums. That equilibrium implies that exogenous increases in risk premiums increase equilibrium expected returns by reducing the incentive to speculate. It also implies that exogenous increases in those expected returns increase risk premiums by increasing the incentive to speculate. But that equilibrium condition says nothing about “causation”; it only says that the two must be numerically equal. As far as I am aware, no one has explained how risk premiums create expected speculative returns. On the other hand it is easy to see how expected speculative returns create risk premiums.

Consider the following mental experiment: Start with both sides of that equilibrium condition equal to zero with no one speculating in either currency. First consider the effects of an exogenous reduction in perceived risk. There may be indirect effects, but there are no direct effects. No one buys speculative assets because of the reduced perceived risks because there is no expected return.

Now, starting with the same initial equilibrium, consider the effects of an open market operation whose liquidity and inflationary effects create expected speculative returns. Those returns induce speculators to take uncovered positions. Those uncovered positions create risk premiums.

This paper concentrates on explaining expected speculative returns. Risk premiums are important, but for simplicity this paper ignores them. Modeling the dynamic *adjustment* process

¹⁷The following discussion assumes an initial equilibrium where both Δ s and ε are zero.

between risk premiums and expected speculative returns that produces negative Δ and Δ is beyond the objectives of this paper, which are to show how sterilized leaning against the wind and a combination of inflationary and liquidity effects can produce the expected speculative returns that cause UIP to fail and produce forward bias.

5.3. Forward bias.

CIP implies that Δ and Δ are two sides of the same coin. So eq. 10 describes how a combination of liquidity and inflationary effects produces negative Δ while eq. (11) describes how sterilized leaning against the wind contributes to negative Δ . They do not provide the economic content that Fama's p_t requires.

The model in Table 1 provides that content. Eq. (12) describes Fama's premium when there is no intervention, $(\lambda-1)$ and σ are zero and "shocks" are white noise.¹⁸

$$f_t = E(s_{t+1}|I_t) - \Lambda(Du_t + v_t) \quad (12)$$

This p_t is not a risk premium because there are no risk premiums in this model. It represents an expected speculative return. In spite of Rational Expectations, liquidity effects drive a rational wedge between forward rates and expected future spot rates. That wedge creates a rational expected speculative return.

To see the economics behind eq. (12) start with all actual and expected changes zero. Then a positive v_t creates one percent actual inflation, expected inflation and depreciation. First consider the case where Λ is zero and the Fisher equation holds. With σ zero, $E(\Delta s_{t+1}|I_t)$, Δs_{t+1} , i_t and $f_t - s_t$ are all one percent. There is no forward bias, $E(s_{t+1}|I_t)$ equals f_t .

Now consider the same case where Λ is positive. A positive Λ violates the Fisher equation and reduces both i_t and $f_t - s_t$, but it does not directly affect $E(\Delta s_{t+1}|I_t)$ or Δs_{t+1} . As a result, even though expectations are rational, f_t is less than $E(s_{t+1}|I_t)$ and there is forward bias.

6. Related puzzles.

Explaining many different phenomena with a single theory is a major objective of science. A Unified Field Theory is the holy grail in physics.

¹⁸ Appendix II describes the full solution for p_t .

This paper and all of the other explanations listed in the introduction were designed to explain forward bias and/or the failure of UIP. As a result, that evidence does not provide empirical support for any of the explanations. Support requires something new; something that the theory was not designed to explain.

Neither this paper nor any of the other explanations in the Introduction were developed to explain the related puzzles listed in the Introduction. If any of these explanations, including this one, could solve those related puzzles it would provide strong support for that explanation and also be a major contribution to open economy macroeconomics.

This section shows that leaning against the wind and/or a combination of inflationary and liquidity effects can explain the related puzzles. Whether or not other explanations can do as well I leave up to the supporters of those explanations.

Discussions of the related puzzles are brief because a thorough discussion of each puzzle would be as long as this paper.

5.1. Carry Trade.

The "Carry Trade" refers to borrowing where international interest rates are "low" and lending where they are "high" without cover, which appears to produce profit with little risk. Those profits suggest that, for at least some trades, expected speculative returns exceed risk premiums. For some recent articles on the carry trade, see Burnside et al (2008), Hochradl and Wagner (2010) and Copeland and Lu (2016).

Burnside et al (2008) show how diversification increases the returns to the Carry Trade. Hochradl and Wagner (2010) stress the problems associated with trying to explain this puzzle with risk premiums and conclude that the related limits to speculation explanation does not provide a complete explanation. Copeland and Lu (2016) attribute carry-trade profits to "low volatility" and claim that they decline or disappear with "high volatility".

Sterilized leaning against the wind and a combination of liquidity and inflationary effects create the expected speculative returns that drive the Carry Trade. Banks and other institutions with relatively low transaction costs take risky positions based on rational expected returns. Those risky positions require risk premiums.

5.2. Commodities.

One would expect Fama's premium to be as valid for commodity markets as for foreign exchange markets. His premium can refer to the price of wool as well as the price of foreign

exchange. Eq. (5) would appear to be as relevant for wool, or any other commodity with forward markets, as it is for foreign-exchange markets.

Given the importance of the bias in foreign-exchange markets, looking for the same bias in commodity markets would seem an obvious and important thing to do. To the best of my knowledge there have been only two attempts to do so: Fama and French (1987) and Kearns (2007). Using futures indexes, Kearns finds positive α for commodities. Using individual futures prices, Fama and French find mostly positive α for commodities. Mostly negative α for flexible exchange rates and mostly positive α for commodities is the Commodity Puzzle.

Sterilized leaning against the wind and a combination of liquidity and inflationary effects produce forward bias in foreign exchange markets. However neither directly affects auction commodity markets.¹⁹ As a result, there is no systematic forward bias in auction commodity markets because there is nothing in those markets that drives a rational wedge between forward prices and expected future prices.

5.3 Development.

Bansal and Dahlquist (2000) were the first to suggest that the forward-bias puzzle is confined largely to developed countries. Later Frankel and Poonawala (2010) estimated β between the U.S. and 21 developed countries and 14 emerging countries. The average α between developed countries and the U.S. is -4.3 . The average α between emerging countries and the U.S. is 0.003 . That difference illustrates what has been called the Development Puzzle.

Section 2.3 points out that, whether countries are developed or emerging, α tend to be negative when exchange rates are flexible and zero or positive when managed. The “Development Puzzle” therefore appears to be due to the fact that most emerging countries have managed rates while almost all developed countries have flexible rates.

By explaining why α tend to be negative when exchange rates are flexible, sterilized leaning against the wind and a combination of inflationary and liquidity effects explains this puzzle.

5.4: Inflation and Outliers.

The Inflation Puzzle is that α increases with inflation. The Outlier Puzzle is that there are positive (negative) α or α with outlier (non-outlier) interest rate differentials and/or forward

¹⁹ Even developed countries intervene directly or indirectly in basic commodities. Agricultural price supports and export subsidies are examples. But that is not the same as leaning against the wind in the international auction markets where those products are bought and sold.

premiums. See for example Sarno et al (2006) and Baillie and Chang (2011). Both puzzles are probably the result of outlier inflation.

Miller (2014, 13) does not suggest an explanation for the Outlier Puzzle. He concludes his discussion by saying “Therefore, the reason why non-outlier IDs yield negative estimates of β appears to be a key toward solving the UIP puzzle.” (Note that his β is my b .) Regarding the Inflation Puzzle, Miller (2014, 9) says the following: “No one, however, has developed a UIP framework that generates a positive relation between estimates of β and the inflation rate.”

A combination of liquidity and inflationary effects provides a framework for inflation and outliers. With low inflation, liquidity effects tend to dominate inflationary effects. The resulting negative $C-\lambda$ produces negative \hat{C} and $\hat{\lambda}$. As inflation increases and produces outliers $C-\lambda$ increases, which increases \hat{C} and $\hat{\lambda}$.

5.5. Maturity.

Using developed countries with flexible exchange rates, Alexius (2001), Chinn and Meredith (2004) and Chinn (2006) find that \hat{C} are usually negative for maturities of one year or less but that \hat{C} are usually positive for over one year. More recently Lothian and Wu (2011) find a similar pattern using about 200 years of annual data. Negative \hat{C} for short maturities and positive \hat{C} for long maturities is the conventional Maturity Puzzle.²⁰

Alexius (2001) does not suggest any solution for this puzzle. Chinn and Meredith (2004, 419) point out that “None of the standard explanations for the UIP puzzle – risk premiums, expectational errors, or peso problems – appear at first glance to offer an explanation for why the result should be so different.....” They then go on to develop an extension of McCallum (1994) to explain this puzzle. Chinn (2006) refers to several possible solutions including the extension of McCallum, a “preferred habitat” explanation and differing expectations similar to those in Miller (2014).

Sterilized leaning against the wind and a combination of liquidity and inflationary effects explain this puzzle. As the maturity of (t) increases $C-\lambda$ increases as liquidity effects fade and inflationary effects increase. An open market operation or intervention that would produce a positive Δs_{t+1} and negative (t) at short maturities produces a positive Δs_{t+1} and a positive (t) at long maturities.

²⁰ Using pound sterling and the euro as home currencies, Grossman et al (2014) still find negative \hat{C} at 12 month maturities.

Miller (2014, 11) suggests an alternative maturity puzzle: UIP holds when regressing long and short maturity changes in exchange rates against long-maturity interest rate differentials.²¹

The model also explains Miller's version of the Maturity Puzzle. Let a positive v_t or u_t produce a positive Δs_{t+1} and negative $(i_t$ at short maturities. As maturity increases, $C-\Lambda$ increases until $(i_t$ is positive. The result is a positive Δs_{t+1} and negative $(i_t$ at short maturities with a positive $(i_t$ for long maturities. Λ is negative for short maturities, but the short-maturity Δs_{t+1} and long maturity $(i_t$ are both positive.²²

5.6. Time Dependency.

Between developed countries under the current float, Λ and Λ vary widely over time. For examples of this time dependency for $(i_t$, see Han (2004). For examples of this dependency for Λ , see Baillie (2011).

Using rolling regressions Lothian and Wu (2011) estimate Λ using over two hundred years of data. Before the early 1970s when most rates were managed, Λ are relatively stable, usually positive and often not significantly different from zero. After almost all rates for developed countries become flexible in the early 1970s, Λ become unstable, consistently negative and at times negative and significant. The Time Dependency Puzzle therefore is Why are Λ and Λ so time dependent when rates are flexible but not when they are managed?

Sterilized leaning against the wind and a combination of liquidity and inflationary effects explain why Λ and Λ are negative when rates are flexible. Variations in sterilization, intervention and the open market operations that produce inflation and liquidity effects can explain why Λ and Λ are so time dependent under flexible exchange rates.

For simplicity, the model in Table 1 assumes that sterilization (F) and the intensity of intervention (X) and how intervention affects exchange rates (Z) are all constant, but they are not. For some central banks there will be times when it is convenient not to sterilize or to sterilize only partially. Foreign exchange markets have periods of stability and volatility. Central banks are likely to intervene more when rates are volatile than when they are stable. Z is likely to change as market conditions including volatility change. For all these reasons the extent of sterilization and intervention are likely to change over time, causing Λ and Λ to vary over time. Since leaning against the wind with full sterilization is a characteristic of flexible rather than

²¹ See Miller (2014, 11) for the relevant references.

²² Larger deviations from CIP at longer maturities also can help explain the Maturity Puzzles. For some evidence of such deviations see Fletcher and Taylor (1996)

managed rates, it will cause \hat{r} and \hat{u} to vary more over time when rates are flexible than when they are managed.

For simplicity the model assumes that central banks respond symmetrically to macroeconomic shocks like unemployment. But central banks do not respond as aggressively to low inflation as to high inflation or to low unemployment as to high unemployment. As inflation and unemployment vary over the business cycle, the kind of open market operations that produce liquidity and inflationary effects will vary. These variations, and the variations in the inflationary and liquidity effects themselves can cause \hat{r} and \hat{u} to vary over time when rates are flexible. When exchange rates are managed, central banks do not have the kind of freedom to macro-stabilize that they have under flexible rates.

7. Summary.

This paper shows how sterilized leaning against the wind and a combination of liquidity and inflationary effects of open market operations responding to macroeconomic stabilization policies can cause forward bias and the failure of UIP under flexible exchange rates. It also raises the possibility that they can explain several related puzzles. If they do explain forward bias, the failure of UIP and the related puzzles, it would be a major contribution to macroeconomics

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APPENDIX I

$$\begin{aligned}
\Delta = & \left\{ \left[\Pi C(C-\Lambda) \left\{ \frac{1}{(1-\Phi U)} \right\} + (\lambda-1)(C-\Lambda)^2 \Pi \left\{ U + \frac{(\Phi-1)}{(1-\Phi U)} \right\} \right] \right. \\
& + \Pi^2 C^2 \Omega \left\{ \frac{(U+\Phi)}{(1-\Phi U)(1-\Phi^2)} \right\} + (\lambda-1)(C-\Lambda) \Pi^2 \Omega C \left\{ \frac{[U^2(1+\Phi) - U - \Phi]}{(1-\Phi U)(1+\Phi)} \right\} \\
& + \Omega C \Pi^2 (\lambda-1)(C-\Lambda) \left\{ \frac{(1-U)}{(1-\Phi U)(1+\Phi)} \right\} \\
& + \Pi^2 \Omega (\lambda-1)^2 (C-\Lambda)^2 \left\{ \frac{[(1-U)(\Phi-1-U-\Phi U)]}{(1-\Phi U)(1+\Phi)} \right\} \Big] D^2 \sigma^2 \\
& + \left[(\lambda-1) \Pi \left\{ R + \frac{(\Phi-1)}{(1-\Phi R)} \right\} + \Pi^2 \Omega (\lambda-1)^2 \left\{ \frac{[(1-R)(\Phi-1-R-R\Phi)]}{(1-\Phi R)(1+\Phi)} \right\} \right] \sigma \\
& + \left[\Pi C(C-\Lambda) \left\{ \frac{1}{(1-\Phi V)} \right\} + (\lambda-1)(C-\Lambda)^2 \Pi \left\{ V + \frac{(\Phi-1)}{(1-\Phi V)} \right\} + (\Pi C)^2 \Omega \left\{ \frac{(V+\Phi)}{(1-\Phi V)} \right. \right. \\
& \left. \left. (1-\Phi^2) \right\} + (\lambda-1)(C-\Lambda) \Pi^2 \Omega C \left\{ \frac{[V^2(1+\Phi) - V - \Phi]}{(1-\Phi V)(1+\Phi)} \right\} + \Pi^2 C \Omega (\lambda-1)(C-\Lambda) \left\{ \frac{(1-V)}{(1-\Phi V)(1+\Phi)} \right\} \right. \\
& \left. + (\lambda-1)^2 (C-\Lambda)^2 \Pi^2 \Omega \left\{ \frac{[(1-V)(\Phi-1-V-V\Phi)]}{(1-\Phi V)(1+\Phi)} \right\} \right] \sigma^2 + \Pi^2 \Omega \left\{ \frac{\Phi}{(1-\Phi^2)} \right\} [\sigma^2 + \sigma^2] \\
& / \left\{ \left[1 + 2\Omega \Pi (\lambda-1) \left\{ \frac{(1-R)}{(1-\Phi R)} \right\} + 2[\Omega \Pi (\lambda-1)]^2 \left\{ \frac{(1+\Phi R - \Phi - R)}{(1-\Phi R)(1-\Phi^2)} \right\} \right] \right\} \sigma \\
& + \left[(C-\Lambda)^2 + 2\Omega \Pi C(C-\Lambda) \left\{ \frac{U}{(1-\Phi U)} \right\} + 2\Omega \Pi (\lambda-1)(C-\Lambda)^2 \left\{ \frac{(1-U)}{(1-\Phi U)} \right\} \right. \\
& \left. + (\Omega \Pi C)^2 \left\{ \frac{(1+\Phi U)}{(1-\Phi U)(1-\Phi^2)} \right\} + 2\Omega^2 \Pi^2 C (\lambda-1)(C-\Lambda) \left\{ \frac{(\Phi+U-\Phi U-1)}{(1-\Phi U)(1-\Phi^2)} \right\} \right.
\end{aligned}$$

$$\begin{aligned}
& +2(\Omega\Pi)^2(\lambda-1)^2(C-\Lambda)^2\{(1+\Phi U-\Phi-U)/[(1-\Phi U)(1-\Phi^2)]\} \Big] D^2\sigma^2 \\
& + \left[(C-\Lambda)^2+2\Omega\Pi C(C-\Lambda)\{V/(1-\Phi V)\} + 2\Omega\Pi(\lambda-1)(C-\Lambda)^2\{(1-V)/(1-\Phi V)\} \right. \\
& + (\Omega\Pi C)^2\{(1+\Phi V)/[(1-\Phi V)(1-\Phi^2)]\} + 2\Omega^2\Pi^2 C(\lambda-1)(C-\Lambda)\{(\Phi+V-\Phi V-1)/[(1-\Phi V)(1-\Phi^2)]\} \\
& \left. + 2\Omega^2\Pi^2(\lambda-1)^2(C-\Lambda)^2\{(1+\Phi V-\Phi-V)/[(1-\Phi V)(1-\Phi^2)]\} \right] \sigma^2 + (\Omega\Pi)^2\{1/(1-\Phi^2)\}[\sigma^2 + \sigma^2]
\end{aligned}$$

Where Π equals $1/(1+ZX-(\lambda-1)\Omega)$, Ω equals $[(\Lambda-C)F-H]X$, and Φ equals $[ZX-CFX-(\lambda-1)\Omega]/[1+ZX-(\lambda-1)\Omega]$.

Appendix II

$$\begin{aligned}
p_t = & ({}_t - (\lambda-1)\Pi\mathbf{E}(\Phi^i\Delta_{(t+1-i)} + \Omega\Pi(\lambda-1)\Phi^i\Delta_{(t-i)} - \Pi C D \mathbf{E}(\Phi^i u_{t-i}) + (C-\Lambda)D u_t \\
& + \Omega\Pi C D \Phi^i u_{t-1-i} - (\lambda-1)(C-\Lambda)\Pi D \mathbf{E}(\Phi^i \Delta u_{t+1-i}) + \Omega(\lambda-1)(C-\Lambda)\Pi D \Phi^i \Delta u_{t-i} \\
& - \Pi C \mathbf{E}(\Phi^i v_{t-i}) + \Omega\Pi C \Phi^i v_{t-1-i} + (C-\Lambda)v_t - (\lambda-1)(C-\Lambda)\Pi\mathbf{E}(\Phi^i \Delta v_{t+1-i}) \\
& + \Omega(\lambda-1)(C-\Lambda)\Pi\Phi^i \Delta v_{t-1} - \Pi\mathbf{E}(\Phi^i x_{t+1-i}) + \Omega\Pi\Phi^i x_{t-i} - \Pi\mathbf{E}(\Phi^i \varepsilon_{t+1-i}) + \Omega\Pi\Phi^i \varepsilon_{t-i}
\end{aligned}$$