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General equilibrium pricing of currency and currency options ☆

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ABSTRACT

This paper presents a consumption-based general equilibrium model for valuing foreign exchange contingent claims. The model identifies a novel economic mechanism by exploiting highly but imperfectly shared consumption disaster with variable intensities which are the concerns to the representative investor under recursive utility. When applied to the data, the model simultaneously replicates (i) the moderate option-implied volatilities; (ii) substantial variations in the risk-neutral skewness of currency returns; (iii) the uncovered interest rate parity puzzle; and (iv) the first two moments of carry trade returns. Furthermore, the model rationalizes salient features of the aggregate stock, government bonds, and equity index options.

1. Introduction

The foreign exchange market is the largest financial market in the world, yet the pricing of currencies and their derivatives poses challenges for modeling. In particular, several pricing regularities persist that defy easy explanations. First, the implied volatility of at-the-money (ATM) option contracts is fairly low, usually at around 8–12% (e.g., Carr and Wu, 2007). Second, the implied volatility of currency option quotes is, on average, a U-shaped function of moneyness, and the slope, which measures the risk-neutral skewness, exhibits substantial time variations suggesting that currency return skewness is strongly stochastic. Third, while the uncovered interest parity (UIP) implies that a regression of exchange rate changes on the interest rate differentials should produce a unit slope coefficient, empirical work since Fama (1984) consistently reveals negative slopes implying that high-interest currencies tend to appreciate. Fourth, the traditional carry trade strategy of buying high-interest currencies funded by selling low-interest currencies on average yields sizable, albeit significantly volatile, returns.

This paper proposes a consumption-based general equilibrium model for foreign exchange contingent claims. The central ingredients are the highly but imperfectly shared economic disasters with variable intensities, and the recursive preference (e.g., Epstein and Zin, 1989) that allows for a separation between elasticity of intertemporal substitution (EIS) and risk aversion. Following Barro

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(2006) and Wachter (2013), a disaster is modeled as a peso component in the consumption process. Under the recursive preference, investors care not only about the contemporaneous consumption shocks but also about the prospects of future consumption growth. When EIS is greater than one, they demand extra compensation for the increase of disaster rate out of fear of the substantial drop of consumption in the future. The results in this paper show that risks related to country-specific disaster components with variable intensities can simultaneously replicate many observed features in currency and currency option pricing in a quantitative manner.

The mechanism of the model is as follows. First, since disaster risks are highly shared across borders, the exchange rate needs to fluctuate less to prevent international arbitrage opportunities, which gives rise to the low ATM implied volatility. Second, with imperfect risk sharing, disaster rate at home can either rise above or fall below its foreign counterpart generating, respectively, the negative and the positive skewness in currency returns. Stochastic skewness emerges when the two country-specific components evolve stochastically over time. Third, when disaster is more likely to strike at home than abroad such that the foreign currency pays the lower interest rate, the exchange rate is closely tied to the home-specific disaster intensity whose variations induce a negative correlation between the home pricing kernel and the exchange rate. Home investors thus demand a positive premium for holding the risky foreign currency, which drives up its valuation. Fourth, traditional carry trade strategy exploits the aforementioned risk compensation and at the same time is subject to the stochastic home- and foreign-specific disaster intensities, hence the sizable expected return coupled with the significant volatility.

In calibrating the model, I follow the literature (e.g., Backus, Foresi, and Telmer, 2001) by imposing complete symmetry in that all model parameters are identical across any two countries. Within a given country, I calibrate the variable disaster process according to (i) the international evidence on its intensity and magnitude (e.g., Barro, 2006), (ii) the match of some key moments for the aggregate stock. Across countries, I calibrate consumption correlation during normal times according to Brandt, Cochrane, and Santa-Clara (2006), and I choose a predominant global disaster component to match the observed high degree of risk sharing. The preference parameters are at levels deemed reasonable in the literature (e.g., Mehra and Prescott, 1985; Bansal and Yaron, 2004, Bansal, Gallant, and Tauchen, 2007). Finally, I estimate an inflation process to convert real variables into nominal ones.

To link the model to the data, I collect from Bloomberg option quotes written on three currency pairs that form a triangular relation: JPYUSD, GBPUSD, and GBPJPY. The option quotes are expressed as Garman and Kohlhagen (1983) implied volatilities at fixed times to maturity and fixed moneyness in terms of the Garman-Kohlhagen delta. In addition, I collect from Datastream the spot and one-month forward exchange rates of five major currencies, AUD, CAD, CHF, GBP, and JPY, quoted against the USD, which are used to study implications on carry trade.

The calibrated model delivers reasonable matches of the regularities in currency and currency option markets. First, it generates an average 9% volatility implied from one-month ATM options, as compared to the 10–11% volatilities implied from option quotes written on JPYUSD and GBPUSD. This result is in contrast to the traditional consumption-based model in which the implied volatility is usually more than an order of magnitude higher than that in the data (e.g., Brandt, Cochrane, and Santa-Clara, 2006).

Second, the model generates substantial variations including frequent sign switches in the risk-neutral skewness of currency returns as measured by the slopes of the smile pattern for currency options. Quantitatively, the risk-neutral skewness is captured by risk reversal (RR)—the difference between the price of an out-of-the-money (OTM) call option and the price of an OTM put option with symmetric strikes. Taking the three-month ten-delta RR, for example, the model-implied RR standard deviation is 18.6%, as compared to its data counterparts of 19.0%, 13.4%, and 15.3% implied from JPYUSD, GBPUSD, and GBPJPY, respectively. Furthermore, I study the time variations of risk-neutral skewness based on (i) RR series where the model implications are computed from the home- and the foreign-specific disaster rates backed out from the panel data of currency option quotes; (ii) series of currency return skewness spanned from currency option prices in the spirit of Bakshi, Kapadia, and Madan (2003). The model again matches the data fairly well in both cases.

Third, the model replicates the UIP anomaly, i.e., high interest rate currencies tend to appreciate. The implied UIP slope coefficient is negative at -2 with a standard error of 1.2, which is consistent with their usually reported empirical values.

Fourth, the model matches the first two moments of carry trade returns. Under complete symmetry between the home and the foreign country, the expected carry trade returns are close to zero, and the implied volatility is 11.3%. By assuming a lower jump magnitude in the foreign country so that the foreign currency on average pays a higher interest than the home currency, the model is able to generate sizable expected returns of carry trade while keeping the implied volatility within 10.7–15.2%. Empirically, carry trades based on the fixed currency pairs yield low expected returns with volatilities ranging from 9% to 13%. I also consider dynamically rebalanced currency pairs based on their interest rate differentials, as embedded in the forward discount, whereby the lowest- (highest-) yielding currencies are selected to be sold (bought). This strategy is subject to around 11% volatility together with sizable expected returns that are replicated by the model as I vary the foreign disaster magnitudes from 20% to 15%.

In the model, the key to simultaneously matching the low level of ATM volatility and the substantial cross-sectional variations for currency options lies in the highly but imperfectly shared economic disasters. To understand the source of the unshared disaster component to which exchange rates are subject, it is helpful to interpret country-specific disaster as a broader concept than “a disaster that strikes one country but not the other”. For example, Table I in Barro (2006) reveals that the disaster associated with World War II struck major economies at different times. It is arguable, at least qualitatively,