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Exchange Rate Risk, Distribution Asymmetry and Deviations from Purchasing Power Parity

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Exchange Rate Risk, Distribution Asymmetry and Deviations from Purchasing Power Parity[♦]

Michael G. Arghyrou*, Wenna Lu**, Panayiotis M. Pourpourides***

28 April 2020

Abstract

Firstly, we show that domestic prices of net importer countries incorporate a risk premium, driven by higher moments of future nominal exchange rate returns and secondly, using US dollar exchange rates against three currencies of major net exporting countries to the US such as Canada, Japan and the European Union, we find that the skewness of the future nominal exchange rate is the major and statistically robust moment-based factor of the deviations from purchasing power parity (PPP). Our estimates further suggest that only low and moderate exchange rate risks induce risk premia that drive deviations from PPP.

Keywords: Purchasing Power Parity, risk-aversion, exchange rate, downside risk

JEL classification: G15, F31, F41

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1. Introduction

In this paper, we demonstrate the association of deviations from purchasing power parity (PPP) with the shape of the distribution of future nominal exchange rates in periods of floating exchange rates. In particular, we associate the agents' higher order risk attitude and deviations from normality of distributions of future nominal exchange rate returns with deviations from PPP. Firstly, we demonstrate theoretically, the link between higher moments of future nominal exchange rates and deviations from PPP and secondly, using US data, we show that among moments and moment-based measures of the future nominal exchange rate, skewness is the only statistically robust determinant of the real exchange rate. Our estimates further suggest that merely low and moderate exchange rate risks matter in driving deviations from PPP.

To show the relationship between higher moments of the future nominal exchange rate and deviations from PPP, we extend the framework developed by Arghyrou, Gregoriou and Pourpourides (2011) - hereafter AGP - who show that deviations from the law of one price depend on the interaction between consumer risk aversion and the variance of future nominal exchange rates. Using this framework, we demonstrate that deviations from normality of the distributions of future nominal exchange rates coupled with the agents' higher order risk attitudes, give rise to a risk premium paid by domestic agents to domestic importers of producers of a net importing country. The risk premium, generated by the interaction between the agents' higher order risk attitude and the corresponding exchange rate skewness and kurtosis, is the cause of the deviations from PPP. We evaluate this result using bilateral exchange rates between the US and three of its major trade partners for which the US is a net importer. Our findings suggest that the skewness of future nominal exchange rates is the dominant, and in almost all cases the sole, moment-based determinant of the deviations from PPP. Our findings further suggest that risk-averse agents, only price low and moderate

exchange rate risk which then drive the risk-premium incorporated in domestic prices, and as a consequence the deviations from PPP.

A long-established financial literature, dating back to Roy (1952) and Markowitz (1959), links investors' behaviour to downside market risk. The main assumption underpinning this literature is that risk averse investors place greater weights in their utility function on negative rather than positive market outcomes (Farago and Tédongap, 2018). As a result, they are willing to pay significant premia to insure against negative tail events, where their marginal utility is high (Karagiannis and Tolikas, 2019); and/or demand increased expected returns as compensation for holding assets involving downside risk (Ang et al, 2006). A large empirical literature has established the role of downside risk in determining portfolio choices and cross-sectional returns for a wide variety of financial assets, including stocks, options, hedge fund investments and others.¹

In the international finance literature the nexus between downside risk and market behaviour has been used to explain deviations from Uncovered Interest Parity, as reflected in the forward premium puzzle and positive carry-trade returns (see Brunnermeier et al (2008), Burnside et al (2011), Lettau et al (2014) and Dobrynskaya (2014)).² More recently, Farhi and Gabaix (2016) present a model involving a time-varying probability of rare but extreme global disasters and numerous asset markets, including national currencies presenting heterogeneous and time-varying exposures to global disasters. In addition to the forward premium puzzle and positive carry trade returns, their model also accounts for the exchange rate disconnect puzzle,

¹ Among others, see Ang et al, (2006), Barro (2006), Bali et al (2009), Bollerslev and Todorov (2011), Gabaix (2012), Chang et al (2013), Kelly and Chiang (2014), Schneider (2015), Agarwal et al (2017), Farago and Tédongap (2018) and Karagiannis and Tolikas (2019).

² There is a large pre-existing literature explaining deviations from Uncovered Interest Parity on the basis of time-varying risk premia (see, for example, Sarno et al (2012) and the references therein). That literature, however, does not focus on downside risk, as the studies quoted above.

that is the lack of a statistically significant relationship between nominal exchange rate and economic fundamentals, initially proposed by Meese and Rogoff (1983).³

To the best of our knowledge, however, no study has so far explored the role of downside risk in explaining probably the most researched puzzle in international finance, namely the failure of standard time-series techniques to validate Purchasing Power Parity (PPP) for the period of floating exchange rates. The main theoretical explanations offered for PPP's empirical failure, defined in the literature as the first PPP puzzle (Sarno 2005), include: shifts in the demand of domestic goods relative to foreign, e.g. changes in consumers' preferences or fiscal shocks (Alesina and Perotti, 1995); shifts in relative productivity, as originally suggested by Balassa (1964) and Samuelson (1964); and market imperfections (e.g. transaction costs and other barriers to trade) resulting into deviations from the cornerstone assumption of PPP, the law of one price (LOOP).⁴ Market imperfections are also the main explanation offered for the second PPP puzzle, that is the excessive persistence of deviations from PPP (Rogoff, 1996). Dumas (1992) and Sercu et al. (1995) show that deviations from the LOOP are non-mean reverting as long as transaction costs are small enough relative to arbitrage-trading costs but become quickly mean-reverting when arbitrage profits exceed the costs of arbitrage trading imposing the LOOP. Empirical studies, reviewed by Sarno (2005), provide substantial evidence for non-linear PPP adjustment, justifying the aforementioned failure of standard linear time-series techniques to validate long-run PPP.⁵

A common characteristic of the explanations for the two PPP puzzles discussed above is that they refer to movements of the first moment of nominal or real exchange rate. To the best

³ The study by Farhi and Gabaix (2016) also accounts for a number of other empirically established links between options, exchange rates, and stock market movements.

⁴ See, among others, Engel and Rogers (1996), Betts and Devereux (2000) and Parsley and Wei (2007).

⁵ A related, but different explanation for the two PPP puzzles has been offered by Imbs et al (2005). They show that heterogeneous adjustment dynamics to the LOOP across the individual components of a basket of goods, caused by varying impediments to arbitrage and nominal rigidities across different goods, result in a positive bias in standard panel and time-series estimates of persistence of shocks to the aggregate real exchange rate. They also show that persistent adjustment heterogeneity at the disaggregated level is fully compatible with the nonlinear dynamics observed in the movements of aggregate real exchange rates.

of our knowledge, except from AGP, no study has so-far explained deviations from PPP on the basis of higher moments of the exchange rate distribution.⁶ The intuition underlying the analysis of AGP is identical to the financial literature quoted above on the effect of downside risk in determining portfolio selection and asset returns. However, their measure of risk (variance of nominal exchange rate returns) does not differentiate between “good” and “bad” uncertainty. Nevertheless, downside risk refers specifically to negative market outcomes captured by higher moments of the distribution of assets returns, i.e. skewness and kurtosis (see e.g. Bali et al (2009), Chang et al (2013) and Kelly and Jiang (2014)). In this paper we present a theoretical framework explaining deviations from the LOOP, and by extension its generalisation, PPP, on downside risk captured by the skewness and kurtosis of the distribution of future nominal exchange rate returns, coupled with the agents’ higher-order risk attitude. Deviations from the PPP occur when risk-averse buyers (firms and consumers) purchase goods in foreign prices, while payments are either due in future periods or transactions clear in future periods at exchange rates, not known at the time transaction are initiated. Extending the AGP framework, we show that the uncertainty about future nominal exchange rates, induces buyers with higher-order risk attitudes to pay a risk premium to domestic importers and/or domestic producers of homogeneous goods. The premium is driven not only by the interaction between the agents’ second-order risk attitude and the variance of future nominal exchange rates, as AGP demonstrate, but also the interaction between the corresponding skewness and/or kurtosis and the agents’ third and/or fourth order risk attitudes, respectively. In theory, agents can fully insure against any exchange rate risk via foreign exchange derivatives such as options, forward and futures contracts. Since hedging against any risk is not feasible due to high insurance fees,

⁶ AGP present a theoretical framework where nominal exchange rate uncertainty, captured by the variance of future nominal exchange rate returns, leads risk-averse consumers without access to hedging instruments to pay domestic importers of a foreign good a positive premium over the price quoted by the foreign producer of the good, when both prices are expressed in domestic currency. AGP provide empirical evidence from a near-perfect market (on-line air tickets) supporting their theoretical model.

it is reasonable to expect hedging only against extreme risk. As the evidence suggests (e.g. Brown, 2001; Guay and Kothari, 2002), large corporations hold derivative portfolios which are managed by foreign exchange management committees. We argue that even if risk from extreme appreciations of the foreign currency is eliminated via forex derivatives, low and moderate risks, which is costly to insure against, still generate a risk premium. As the risk-premium is incorporated in domestic prices, it drives permanent deviations from the LOOP, thus explaining the first PPP puzzle. Persistent shocks to the higher moments of the future exchange rate distribution result into persistent deviations from the LOOP, explaining the second PPP puzzle. Finally, under a perfectly credible fixed exchange rate regime, the premium reduces to zero. This is consistent with the findings of previous studies supporting PPP under fixed exchange rate regimes.⁷

We test the empirical validity of our theory by estimating the derived model with time-varying coefficients. In particular, the theory is tested using US dollar real exchange rate rates, capturing deviations from PPP, against three major international currencies of countries that the US is a net importer, namely the Canadian dollar, the euro and the Japanese yen. We thus consider the US as the domestic market. Our analysis covers the period 1973-2016 using monthly data. Our benchmark series of real exchange rates use CPI series while PPI based real exchange rates are also utilized for robustness. Our benchmark estimates validate the fact that higher order risk constitutes a factor that drives deviations from PPP. Our empirical findings provide strong evidence that the variance of future nominal exchange rate returns is statistically insignificant in explaining deviations from PPP. The skewness of the distribution on the other hand, appears to be a statistically significant and robust factor of the deviations from the PPP. Our estimates indicate that an increase in skewness, which is equivalent to an increase of extreme exchange rate risk and a decrease in low and moderate risk, always increases the real

⁷ See, for example, Gaillot (1970) and Taylor and McMahon (1988).

exchange rate against all three currencies. We attribute this result to the fact that risk from expected extreme appreciations of the foreign currency is eliminated via derivatives of foreign exchange while expected low and moderate risks are not hedged due to deterrent insurance fees. Brown (2001) presents an extended case study which suggests that a large US corporation focuses mainly on downside exchange rate risk than on upside risk. The case study also suggests that the cost of hedging is non-trivial.⁸ Therefore, it is reasonable to expect that, at least, at the aggregate level hedging is limited only to extreme risk, as hedging against any risk would be very costly. The latter is also consistent with the finding of Guay and Kothari (2002) that the use of corporate derivatives is moderate, as it would be the case if firms hedge only against extreme events.

In the absence of extreme exchange rate risk (due to hedging), domestic agents only price low and moderate risks which decrease as skewness increases, inducing positive deviations from PPP as domestic agents tend to reduce the risk-premium incorporated in domestic prices over foreign ones.⁹ In particular, a unit increase in skewness leads to an average deviation from PPP, of about one percent, mainly for transaction clearing horizons of one or two months ahead. Such deviation is substantial given that the standard deviation of the measure of skewness in most cases is significantly higher than unity. Although most of the coefficients on kurtosis are statistically insignificant, in the limited cases where they are significant, they are positive, providing support to the underlying argument that only low and moderate risks are priced by domestic agents and thus contribute to deviations from PPP. In other words, as kurtosis increases, there is decrease in the risk-premium that domestic agents are willing to pay as the left tail of the exchange rate distribution becomes fatter and longer, while the right tale is

⁸ He also documents the positive relationship between hedging and exchange rate volatility as well as the increasing up-front cost of hedging via options as volatility increases, which then tempers the degree of hedging.

⁹ As noted by Brown (2001), it is difficult to overcome the joint hypothesis that financial risk is not priced and that a company eliminates financial risk by hedging. We adopt this assumption that implies that the risk from extreme appreciations of the foreign exchange is eliminated via hedging and so only low and moderate risk is priced.

irrelevant due to hedging of extreme risk. Our main results also hold when the real exchange rates are constructed using the producer price index (PPI). To address concerns of possible bias in the confidence intervals, we estimate rolling samples of fixed length which demonstrate the stability and robustness of the confidence intervals.

The remainder of this paper is structured as follows: Section 2 presents our theoretical model. Section 3 discusses our data and presents estimates of the higher moments of the distribution of future nominal exchange rate returns. Section 4 presents estimates of the time-varying effects of the higher moments on real exchange rates. Section 5 evaluates the robustness of the confidence intervals and discusses hedging of extreme exchange rate risk. Finally, section 6 offers concluding remarks.

2. Theoretical Background

AGP (2011) argue that nominal exchange rate uncertainty induces deviations from the law of one price (LOOP). Within an expected utility framework, domestic agents are willing to pay a premium to domestic importers and/or domestic producers of homogeneous goods over the prices of foreign produced goods, in order to insure against nominal exchange rate uncertainty, captured by the variance of future nominal exchange rate returns. This drives a wedge between the domestic and the foreign price of a homogeneous good, explaining deviations from the LOOP. Their model can be extended to capture the role of higher moments of the future nominal exchange rate distribution in explaining deviations from the LOOP. This introduces a novel financial approach explaining deviations from PPP at an aggregate level.

It is assumed that there are two countries, domestic and foreign and that agents in both countries consume a homogeneous good. It is further assumed that the market in the domestic country is perfectly competitive and that there is a representative risk-averse agent summarising the decisions of the average agent in the domestic market. The agent's utility

function, denoted by $u(w_t)$, is defined over her real wealth, w_t . The utility function is continuously differentiable, increasing in wealth and strictly concave (since the agent is risk-averse). For illustrative purposes, we consider the case where the home country is a net importer of the homogeneous good. Let x denote the per capita real net imports of the domestic country, and P_t and P_t^f denote the domestic price index and the foreign price index, respectively. Without loss of generality x is normalised to unity. The domestic agent has two options, either buy the good from the domestic market (i.e. from a domestic importer or a domestic producer) or buy it directly from the foreign producer. We follow AGP by assuming zero transportation and transaction costs since the idea is to demonstrate that there are deviations from PPP even in the absence of such costs.

There are two possible cases. In the first case, the agent purchases x from the domestic market, in which case, her ex-post net real wealth, per unit of the domestic currency is known with certainty. Specifically, it is equal to $w_t - 1$, where $w_t = W_t P_t^{-1}$. In the second case, the agent purchases x directly from foreign market and the transaction is cleared $d \geq 1$ periods from the date of the purchase. The agent may not necessarily be an individual consumer but a risk averse firm that agrees to pay in foreign currency for production equipment or other items, with payment due in d periods. Over the time interval $[0, d]$, w_t remains unchanged while the nominal exchange rate exhibits variation. If the exchange rate for the foreign currency weakens during the intervening d periods, the buyer will have to spend more domestic currency to buy the foreign currency it needs to pay the foreign producer. Therefore, the agent's ex-post net wealth is written as $w_t - S_{t+d} P_t^f P_t^{-1}$, where S_{t+d} denotes the nominal exchange rate at time $t+d$ when the transaction is cleared. As a consequence, the agent's ex-post net wealth is subject to some degree of uncertainty since S_{t+d} is not known with certainty at the time of the

purchase.¹⁰ The agents have expectations about S_{t+d} , given information up to period t , and they may also use hedging techniques to reduce or eliminate the transaction risk of expected future high appreciations of the foreign currency. In modern economies there are advanced and complex options markets of foreign exchange which enable agents to obtain insurance against high levels of exchange rate risk.¹¹ Abstracting from technical details, we incorporate hedging by allowing the representative agent to hold insurance worth h that ensures compensation if an extreme appreciation of the foreign currency occurs. The compensation has an impact on wealth in period $t + s$, with $s > d$. To simplify the notation, we assume that wealth, w , is net of the real insurance fee h/P . The growth rate of the nominal exchange rate evolves according to the following log-returns process:

$$\frac{S_{t+d}-S_t}{S_t} \approx \ln(S_{t+d}) - \ln(S_t) = \varepsilon_{t+d},$$

where $E_t \varepsilon_{t+d} = 0$ and $E_t \varepsilon_{t+d}^2 = \sigma_{t+d}^2$.¹² As shown by AGP, in equilibrium, prices must be such that the domestic agent is indifferent between buying x from the domestic market, via a domestic importer or the domestic producer, and buying it directly from a foreign supplier. In other words, in equilibrium, prices must be such that the utility of the consumer under the former scenario must be equal to the expected utility of the consumer under the latter scenario that is,

$$u(w_t - 1) = E_t u(w_t - S_{t+d} P_t^f P_t^{-1}). \quad (1)$$

As demonstrated by AGP, due to the uncertainty about the nominal exchange rate, if the risk-averse domestic agent purchases the good from the domestic importer or producer, she will pay

¹⁰ A few examples related to individual consumers would include online purchases where the price is expressed only in foreign currency and the transaction clears at a later stage and appears on bank statements several days after; Payments in foreign currency by travellers, using credit cards issued in the traveller's country of origin; Payments made by checks, payable at foreign banks. Such checks usually take several weeks to clear (6 weeks or more).

¹¹ We assume that domestic buyers (consumers or firms) focus only on hedging extreme exchange rate risk as low and moderate risk might be too costly to insure against.

¹² In most of the cases in our sample (discussed in the following section) the random walk hypothesis, for various d 's, cannot be rejected by the data. Even for the rest of the cases where the random walk is rejected, the processes are nearly random walks. Consequently, to simplify our analysis, we keep the assumption of random walk.

a strictly positive exchange rate induced risk-premium, per unit of the domestic price, denoted by π_t :

$$\pi_t = \frac{P_t - S_t P_t^f}{P_t} > 0.$$

Although we do not model the decision of domestic importers/producers, we implicitly assume that if they attempt to reduce the price in order to dominate the market, then the foreign producers will respond by decreasing the foreign price as well, and vice-versa. The latter assumption ensures that equation (1) always holds for a country which is a net importer. As noted earlier, agents may hedge future extreme appreciations of the foreign currency using forex derivatives.¹³ Even though, in principle, the agents can hedge low and moderate risk as well, the cost of complete hedging of exchange rate risk is deterrent for any agent, i.e. the level of x would be financially prohibited.¹⁴ Therefore, it is reasonable to assume that risk-averse domestic agents hedge only extreme exchange rate risk.

Approximating (1) around $\bar{w}_t = w_t - S_t P_t^f P_t^{-1}$ (the level of net real wealth if the agent purchases x directly from the foreign supplier at the current exchange rate) it reduces to

$$\begin{aligned} -u'(\bar{w}_t)\pi_t + \frac{u''(\bar{w}_t)}{2}\pi_t^2 - \frac{u'''(\bar{w}_t)}{3!}\pi_t^3 + \frac{u''''(\bar{w}_t)}{4!}\pi_t^4 + o(\pi_t) \approx \frac{u''(\bar{w}_t)}{2}\left(\frac{S_t P_t^f}{P_t}\right)^2 \sigma_{t+d}^2 - \\ \frac{u'''(\bar{w}_t)}{3!}\left(\frac{S_t P_t^f}{P_t}\right)^3 \frac{E_t \varepsilon_{t+d}^3}{\sigma_{t+d}^3} + \frac{u''''(\bar{w}_t)}{4!}\left(\frac{S_t P_t^f}{P_t}\right)^4 \frac{E_t \varepsilon_{t+d}^4}{\sigma_{t+d}^4} + o\left(\frac{E_t \varepsilon_{t+d}^n}{\sigma_{t+d}^n}\right), \end{aligned} \quad (2)$$

where the term $o(\cdot)$ incorporates all the rest of the higher order terms. Assuming that π_t is small (i.e. $\pi_t^2 \approx 0$) and that $o(\pi_t) \approx 0$ and $o(\frac{E_t \varepsilon_{t+d}^n}{\sigma_{t+d}^n}) \approx 0$, equation (2) reduces to

$$\pi_t \approx \alpha_{1t} \sigma_{t+d}^2 + \alpha_{2t} \text{Skewness}_{t+d} + \alpha_{3t} \text{Kurtosis}_{t+d}, \quad (3)$$

¹³For instance, consider an agent who owns a currency call option at price h that gives him the right to purchase the foreign currency on or before date $t + d$ at an exchange rate S^{fx} . When $S_{t+d} > S^{fx}$, then by exercising the option the agent can recoup the difference between S_{t+d} and S^{fx} . The agents can also use future and forward contracts if the exchange rate is expected to increase significantly.

¹⁴ For instance, consider a put option with an exercise price equal to S^{px} . Then, an agent can sell foreign currency at the exercise price when $S^{px} > S_{t+d}$ and purchase back foreign currency at the spot exchange rate, gaining from the price differential and recouping any loss from the appreciation of the foreign currency. However, insuring against any risk requires an unreasonably high insurance fee.

where $skewness_{t+d} = E_t \varepsilon_{t+d}^3 / \sigma_{t+d}^3$, $kurtosis_{t+d} = E_t \varepsilon_{t+d}^4 / \sigma_{t+d}^4$,

$$\alpha_{1t} = \frac{1}{2} \left(-\frac{u''(\bar{w}_t)}{u'(\bar{w}_t)} \right) \left(\frac{S_t P_t^f}{P_t} \right)^2, \alpha_{2t} = \frac{1}{3!} \left(\frac{u'''(\bar{w}_t)}{u'(\bar{w}_t)} \right) \left(\frac{S_t P_t^f}{P_t} \sigma_{t+d} \right)^3 \text{ and}$$

$$\alpha_{3t} = \frac{1}{4!} \left(-\frac{u''''(\bar{w}_t)}{u'(\bar{w}_t)} \right) \left(\frac{S_t P_t^f}{P_t} \sigma_{t+d} \right)^4.$$

Then, it follows that for a risk-averse agent, $\alpha_{1t} > 0$,

$$\alpha_{2t} \begin{cases} > 0 \text{ if } u'''(\bar{w}_t) > 0 \\ < 0 \text{ if } u'''(\bar{w}_t) < 0 \end{cases}$$

and

$$\alpha_{3t} \begin{cases} > 0 \text{ if } u''''(\bar{w}_t) < 0 \\ < 0 \text{ if } u''''(\bar{w}_t) > 0 \end{cases}$$

Approximation (3) suggests that the risk-premium is not only driven by the agent's second-order risk attitude (u'') but also by her higher-order risk attitude: $u''' > 0$ is labeled as prudence and $u''' < 0$ as imprudence, while $u'''' < 0$ is labelled as temperance and $u'''' > 0$ as intemperance.¹⁵ The approximation indicates that the sign of the impact of nominal exchange rate uncertainty on the risk-premium is strictly positive, while the signs of the impact of the corresponding skewness and kurtosis depend on the agent's higher order risk attitude. Prudence coupled with positive skewness and imprudence coupled with negative skewness contribute positively to the risk-premium, while any other combination of (im)prudence and skewness contributes negatively. Since kurtosis is always positive, whether it contributes positively or negatively to the risk-premium depends on whether the agent is temperate or intemperate. The agent's higher order risk attitude also determines the agent's behavior when exchange rate risk rise changes, i.e. when the variance of the future nominal exchange rate or the corresponding skewness and kurtosis change.

¹⁵ Arghyrou et al. (2011), did not consider terms of approximation (2) which involve third and fourth powers, and thus did not examine the role of skewness and kurtosis.

In the absence of hedging of extreme exchange rate risk ($h = 0$), if $u'''(\bar{w}_t) > 0$ then the agent exhibits downside risk-aversion (prudence) which means that the degree of ‘pain’ (utility loss) involved by adding risk increases as wealth w_t decreases (Eeckhoudt and Schlesinger, 2013). In this case, a risk-averse agent is willing to pay a risk-premium to domestic importers of foreign-produced goods or to domestic producers of similar goods that deliver her a certain level of net wealth at the end of a d -period horizon, because extreme appreciations of the foreign currency become more likely.¹⁶ In the presence of hedging however, extreme exchange rate risk is eliminated and so a prudent agent may exhibit an artificially imprudent behavior $u'''(\bar{w}_t) < 0$, which means that she would be willing to pay a lower risk premium as skewness increases. This would be a response to the fact that low and moderate risks are reduced.¹⁷ Likewise, in the absence of hedging, if $u''''(\bar{w}_t) < 0$ then as wealth decreases, the agent exhibits increasing downside risk aversion (temperance). This implies that as kurtosis increases, the agent is willing to pay a risk-premium because she dislikes excessively fat distribution tails.¹⁸ In the presence of hedging however, the extreme risk from excessively fat right tails (extreme appreciations of the foreign currency) is eliminated and so a temperate

¹⁶ As positive (negative) skewness increases, large positive surprises for the value of the future exchange rate, S_{t+d} , become more likely. In other words, it becomes more likely that agents will face a large negative shock on their remaining (post-purchase) wealth if they buy from the foreign supplier. When downside wealth risks become more likely, prudent agents ($\alpha_{2t} > 0$) price the more likely extreme appreciations of the foreign currency and thus, are willing to pay an insurance fee to avoid being exposed to this downside wealth risk. Note that in the absence of hedging instruments, agents may well be willing to pay a risk-premium to domestic importers or domestic producers, insuring themselves, not so much against overall risk (captured by the variance of nominal exchange rate returns) but mainly against the downside wealth risk.

¹⁷ Our argument differs from that of Eeckhoudt et al. (2005) who argue that it is possible that a risk-averse agent exhibits an imprudent behavior, by insuring risk at an unfair premium in the face of a non-insurable future risk, e.g. $u(w) = v_1 w - v_2 w^3$, with $v_1 > 0$ and $v_2 > 0$, implies that $u'' < 0$ and $u''' < 0$. We argue that in economies with highly developed options markets which allow agents to hedge extreme exchange rate risk, prudent agents may tend to pay lower risk premia in response to decreasing moderate and low risks that they are not insured against

¹⁸ The impact of kurtosis is distinctively different than that of skewness. If the distribution of S_{t+d} is symmetric with excess kurtosis, the probability of extreme outcomes is higher than under the normal distribution: All else equal, increasing kurtosis implies an increase in the probability both of an extreme positive and an extreme negative deviation of the future exchange rate from its expected value, respectively implying an increased probability both of a large negative and a large positive wealth shock for the agent. As indicated in approximation (3), since the representative (average) agent is risk-averse, in the absence of hedging instruments, she will price kurtosis, as long as she has temperate nature ($\alpha_{3t} > 0$). This is due to the fact that downside wealth risk carries higher weight in her decisions than upside wealth risk. An extended illustration and discussion on prudence and temperance can be found in Eeckhoudt and Schlesinger (2013).

agent may exhibit an artificially intemperate behavior, $u''''(\bar{w}_t) > 0$. In this case, as kurtosis increases, low and moderate risk is reduced while depreciations of the foreign currency become more likely. The latter implies that the agent would be willing to pay a lower premium. As noted by Courbage and Rey (2010), within an expected utility framework, a common assumption is “complete properness”, i.e. the feature where successive derivatives of the utility function alternate in signs.¹⁹

Since x refers to a basket of goods, (3) can be rewritten in terms of the logarithm of the real exchange rate, $Q_t = S_t P_t^f / P_t$, as follows:

$$q_t \equiv \ln Q_t \approx -\alpha_{1t} \sigma_{t+d}^2 - \alpha_{2t} \text{Skewness}_{t+d} - \alpha_{3t} \text{Kurtosis}. \quad (4)$$

Equation (4) implies that the price index of a net importer country, which is populated by risk-averse agents, incorporates a strictly positive risk-premium paid to domestic importers of foreign-produced goods or to domestic producers of similar goods, which is driven by higher moments of future nominal exchange rate returns.²⁰

3. Data and the distribution of future nominal exchange rate returns

3.1. Data

The empirical analysis that follows employs a dataset of nominal exchange rates which includes end of month closing bilateral nominal exchange rates for Canadian dollars, Euro and Japanese Yen per US dollars, from January 1973 to October 2016, except for the Euro which starts from January 1982.²¹ We define the net importer country as the country which has trade

¹⁹ The term “complete properness” is used by Pratt and Zeckhauser (1987), while Caballé and Pomansky (1996) refer to it as “mixed risk aversion”. This is the case with the commonly used constant relative risk aversion (CRRA) utility function, which implies that both α_{2t} and α_{3t} are strictly positive.

²⁰ Equation (4) extends the AGP (2011) results by showing that P_t (and by extension, the premium and the real exchange rate) is also a function of skewness and kurtosis of the future nominal exchange rate returns distribution.

²¹ Prior to January 1999, the Euro/USA exchange rate refers to a synthetic euro exchange rate which is calculated by weighting the bilateral exchange rates of the (then) eleven euro-area countries using weights based on country trade shares. When we run our main regression in the following section, we start the sample from January 1997.

deficits in goods. The data on trade balances are obtained from the United States Census Bureau. We do not consider trade in services as it includes an element of financial investment income. Since the US has trade deficit in goods against all three countries in most months of the sample, we consider the US as the home country and the net importer. The US has a bilateral trade surplus with Canada only in 5 months of our sample (May 2015 and March 2016 to June 2016) and with the EU only in 1 month of sample (February 1997) and none with Japan. Consumer price indexes for Canada, the Euro area, Japan and the US are included to calculate the CPI-based real exchange rate, Q_t and Producer price indexes are included to calculate the PPI-based exchange rate as a robustness test. Due to data availability, the CPI based real exchange rate for euro area starts from 1983M10 while PPI based real exchange rate for euro area starts from 1996M01. The data source is the IMF's International Financial Statistics databank.

3.2. Estimating higher moments of nominal exchange rate distributions

For notational convenience, let $\varepsilon_{t+d} = \ln(S_{t+d}) - \ln(S_t)$ and $\theta_t(d) \equiv E_t \varepsilon_{t+d}^2 = \sigma_{t+d}^2$, with the corresponding skewness and kurtosis, defined in section 2, as $Sk_t(d)$ and $Ku_t(d)$, respectively. We estimate $\theta_t(d)$, $Sk_t(d)$ and $Ku_t(d)$, following the methodology of León et al. (2005), by considering the following system of equations:²²

$$\theta_t(d) = \mu_{\theta 0} + \mu_{\theta 1} \varepsilon_{t+d}^2 + \mu_{\theta 2} \theta_{t-1}(d) \quad (5)$$

$$Sk_t(d) = \mu_{s0} + \mu_{s1} \eta_{t+d}^3 + \mu_{s2} Sk_{t-1}(d) \quad (6)$$

$$Ku_t(d) = \mu_{k0} + \mu_{k1} \eta_{t+d}^4 + \mu_{k2} Ku_{t-1}(d) \quad (7)$$

for $d \geq 1$, where

²² León et al. (2005), extends Harvey and Siddique (1999), by assuming time-varying kurtosis. León et al. (2005) also assumes that $d = 1$.

$$\varepsilon_{t+d}(d)|I_t \sim (0, \theta_t(d)), \eta_{t+d} = \varepsilon_{t+d}/\sqrt{E_t \varepsilon_{t+d}^2} \equiv \varepsilon_{t+d} \theta_t^{-\frac{1}{2}}(d),$$

with $\eta_{t+d} \sim (0,1)$ and I_t is a set that contains all information up to date t . Following León et al. (2005), we abstract from unnecessary constants so that the logarithm of the likelihood function

of the conditional distribution of $\varepsilon_{t+d} = \theta_t^{\frac{1}{2}}(d)\eta_{t+d}$ is given by

$$L_t = -\frac{1}{2} \ln \theta_t(d) - \frac{1}{2} \eta_{t+d}^2 + \ln \psi^2(\eta_{t+d}) - \ln \Gamma_t(d),$$

where,

$$\psi(\eta_{t+d}) = \left[1 + \frac{Sk_t(d)}{3!} (\eta_{t+d}^3 - 3\eta_{t+d}) + \frac{Ku_t(d)-3}{4!} (\eta_{t+d}^4 - 6\eta_{t+d}^2 + 3) \right],$$

and

$$\Gamma_t(d) = 1 + \frac{Sk_t^2(d)}{3!} + \frac{(Ku_t(d)-3)^2}{4!}.^{23}$$

The estimates of (5)-(7) are provided in the appendix.²⁴ Figures 1 to 3, display the estimated time series for the higher moments of the future exchange rate distribution for different transaction clearing periods, as defined by d . Our theory is expected to hold for relatively short transaction clearing periods as it is rather unlikely that sellers will agree to be paid several periods ahead with an unspecified exchange rate. Therefore, in the analysis that follows we limit the transaction clearing period to be rather short by choosing the maximum value of d to be 3 months, thereby we present estimates for $d = 1, 2$ and 3 .

The volatilities of the variance, skewness and kurtosis increase with d in most of the cases. That is, respectively, the uncertainty about the future nominal exchange rate increases, the distribution of the nominal exchange becomes more asymmetric and the tails of the distribution become heavier, as the transaction clearing period is lengthened. The only exceptions are the skewness and the kurtosis of the EU/USA bilateral exchange rate which are,

²³ Refer to León et al. (2005) for the details regarding the derivation of the p.d.f.

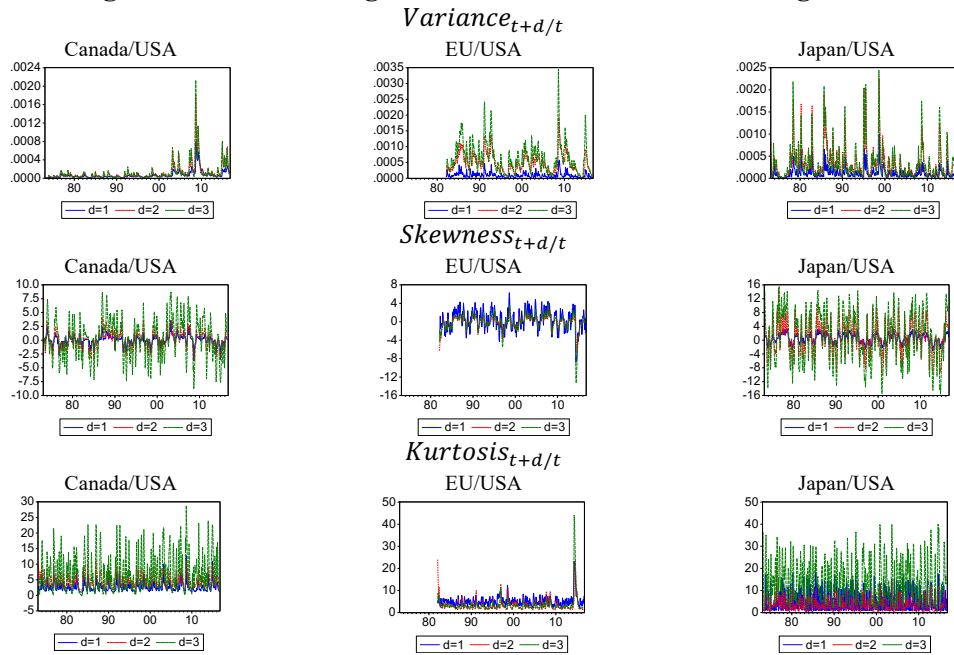
²⁴ The standard errors of the estimated coefficients correspond to the Bollerslev-Wooldridge robust standard errors and are calculated through $Var(\hat{\beta}) = J^{-1}(\beta_0)I(\beta_0)J^{-1}(\beta_0)$, where $J(\beta_0)$ is the negative of the expected Hessian matrix and $I(\beta_0)$ is the information matrix which can be calculated by the outer product of the score vector.

on average, more volatile when the transaction clearing period is short, i.e. $d = 1$. This implies that extreme values of the EU/USA exchange rate are, on average, less likely if the transaction clearing period is long, i.e. $d = 3$, apart from the momentous event of the oil price collapse which occurred in the mid 2014.²⁵ All moments capture the event while $d = 3$ exhibits a much larger swing than $d = 2$ and $d = 1$, not only for the variance but also for skewness and kurtosis, with skewness being negative in almost all periods from mid 2014 until the end of 2015. Negative skewness suggests that the markets expect that appreciations of the Euro, the Canadian dollar and the Yen against US dollar are more likely, while the probability of extreme appreciations of the US dollar are non-zero. The fact that $d = 3$ exhibits larger swings than $d = 1$ and $d = 2$ for all moments, suggests that in the event of a significant oil price decline, not only exchange rate uncertainty increases as the transaction clearing horizon extends but also markets expect that most of the probability mass will be even more concentrated to the right tail of the exchange rate distribution while extreme depreciations and appreciations of the foreign currencies (Euro, Canadian dollar and Yen) are even more likely, especially extreme depreciations. The large negative skewness and the fatter tails of the distribution as a consequence of the oil price collapse are due to the fact that the US is relatively more exposed to oil price fluctuations than the EU. The variances of all exchange rates exhibit a sharp upswing in September of 2008, and in the case of EU/USA $d = 3$ a month before, following the Lehman Brothers episode. The skewness reaches very negative values in September 2008 for CA/USA and EU/USA and significantly positive values for JP/USA. This implies that following the episode, markets expected a high probability of US dollar depreciations relative to both the Canadian dollar and the Euro without ruling out the possibility of extreme depreciations of both the Euro and Canadian dollar. On the contrary, following the Lehman episode, the markets expected a high probability of US dollar appreciations relative to the Yen,

²⁵ The oil price collapse of mid 2014 was one of the three biggest declines in oil prices since World War II.

without ruling out the possibility extreme appreciations of the latter. As in the cases of the other two moments, kurtosis for all exchange rates and transaction clearing horizons, exhibit increases in September, following the Lehman episode, with more evident the increases in the exchange rates of CA/USA and JP/USA. The EU/USA exchange rate increased in September, but the increase was not as sharp as the upswings of the other two exchange rates because the former began increasing from July.

Figure 1: Estimated Higher Moments of Bilateral Exchange Rate



Across the sample, exchange rates exhibit positive skewness about 59% of the time and excess kurtosis about 58% of the time.²⁶

²⁶ In particular, the skewness of the CA/USA exchange rate is positive 57%, 55% and 57% of the time at $d = 1$, $d = 2$ and $d = 3$, respectively. The skewness of the EU/USA exchange rate is positive 59%, 52% and 56% of the time at $d = 1$, $d = 2$ and $d = 3$, respectively, while the skewness of the JP/USA exchange rate is positive 62%, 61% and 54% of the time at $d = 1$, $d = 2$ and $d = 3$, respectively. Our estimates also indicate that the exchange rate series exhibit excess kurtosis 0.27%, 0.69% and 0.73% of the time for CA/USA, 0.91%, 0.37% and 0.39% of the time for EU/USA, and 0.45%, 0.46% and 0.92% for JP/USA, respectively at $d = 1$, $d = 2$ and $d = 3$.

4. Time-varying effects of higher moments

Equation 4 (equation 3) suggests that if a net importer country is populated by risk averse agents, there is a negative (positive) relationship between the real exchange rate (risk-premium) and the variance of the logarithm of the future nominal exchange rate, while the signs of the impact of the corresponding skewness and kurtosis depend, as shown in section 2, on the representative (average) agent's higher order attitudes toward risk. Stationarity tests suggest that the bilateral real exchange rates for all three countries are unit root processes. Therefore, we a priori impose the unit root on the real exchange rates, using the first difference of the real exchange rate as our dependent variable. The latter allows us to have a regression which consists of four stationary variables as follows:²⁷

$$\Delta \ln Q_t = \alpha_{0t} + \alpha_{1t} \sigma_{t+d}^2 + \alpha_{2t} \text{Skewness}_{t+d} + \alpha_{3t} \text{Kurtosis}_{t+d} + u_t, \quad (8)$$

where $\Delta \ln Q_t$ is the first difference of the logarithm of the real exchange rate and u_t is a random error term.²⁸ Since all variables in (8) are stationary, the time-varying coefficients are estimated using the semi-parametric approach of Robinson (1989). Parameter α_{it} is defined as $\alpha_{it} = \alpha_i(z_t)$ for $i = 0, 1, 2, 3$, where z_t is a smoothing variable such that $z_t = \tau = t/T$ and $\alpha_i(z_t) = f(\tau)$ for $t = 1, 2, \dots, T$. The time-varying coefficients are obtained by combining ordinary least squares and a local polynomial kernel estimator, known as the Nadaraya-Watson approach, as described in Casas and Fernandez-Casal (2019).²⁹ Following Cifarelli and Paladino (2015), we

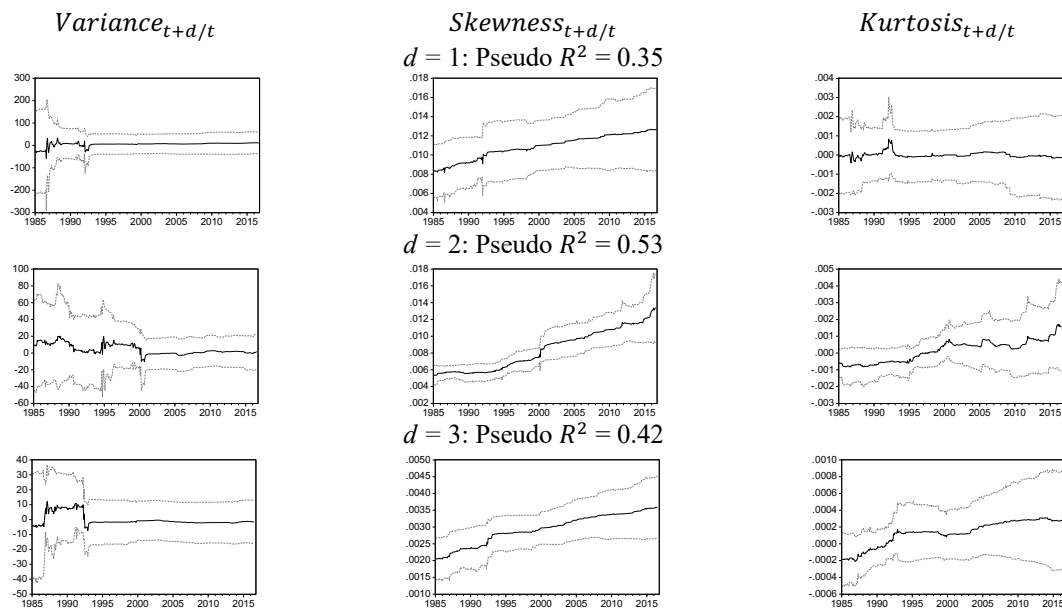
²⁷ Unit roots cannot be rejected for either country at the 5% significance level. The unit root results are available upon request.

²⁸ The percentage of months where the US deficit becomes surplus is tiny. Even if intercept dummies are included, effectively taking those observations off the sample, the results remain the same.

²⁹ Assuming that $\alpha_i(z_t)$ is twice differentiable, it can be linearly approximated around z , using the Taylor Rule as $\alpha_i(z_t) \approx \alpha_i(z) + \alpha'_i(z)[z_t - z]$, where $\alpha'_i(z)$ is the first derivative with respect to z . Then, estimates for $\alpha_i(z)$ and $\alpha'_i(z)$ are obtained by solving the minimization problem $\arg \min \sum_{t=1}^T [\Delta \ln Q_t - x_t^\top \theta_0 - (z_t - z)x_t^\top \theta_1]^2 K_b(z_t - z)$, where $x_t^\top = [1, \sigma_{t+d}^2, \text{Skewness}_{t+d}, \text{Kurtosis}_{t+d}]$ and $K_b(z_t - z)$ is the Epanechnikov kernel with bandwidth b . The latter is selected by leave-one-out cross-validation apart from a few cases where such procedure implies relatively large bandwidths, inconsistent with most of the other cases and oversmoothed

argue that any potential measurement errors in our regressors are more than compensated by the greater accuracy of the estimates of the conditional higher moments provided by the GARCH-type model.³⁰

Figure 2: Estimated time-varying coefficients: Canada – CPI



Figures 2 to 4 display the estimated time-varying coefficients for different transaction clearing horizons, along with 95% confidence intervals. The intercept coefficient is estimated to be about zero, thereby it is not reported to save on space. The time-varying confidence intervals for the variance cover zero in all exchange rates and transaction clearing horizons. The only case where the confidence interval is marginally statistically insignificant is the case of the JP/USA where the lower limit is close to zero and the positive region where the upper limit lies. The estimates on the variance effect essentially suggest that first-order

(constant) estimates. These are the cases of CPI-based EU/US $d = 3$, the three PPI-based EU/US cases and the two PPI-based cases of JP/US $d = 1$ and $d = 2$. For the first case, we choose the bandwidth to be equal to unity so that it is roughly equal to the other two CPI-based $d = 3$ cases and the other two CPI-based EU/US cases. For the PPI-based cases, we choose bandwidths which are equal to the corresponding values of the CPI-based cases. In this way, we avoid oversmoothed estimates. Further details on the estimation procedure can be found in Casas and Fernandez-Casal (2019).

³⁰ The use of GARCH measures of variance, derived from preliminary estimates, as regressors is not uncommon in the literature, e.g. French et al. (1987), Ramachandran (2004) and Ramachandran and Srinivasan (2007).

uncertainty is not statistically significant in driving the real exchange rate and deviations from PPP.

Figure 3: Estimated time-varying coefficients: EU – CPI

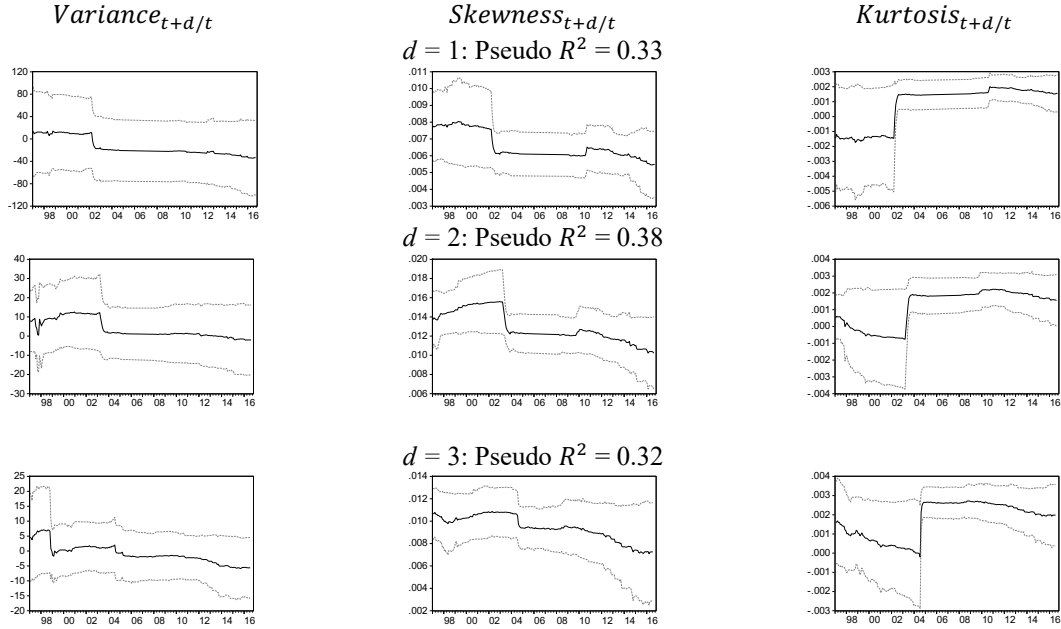
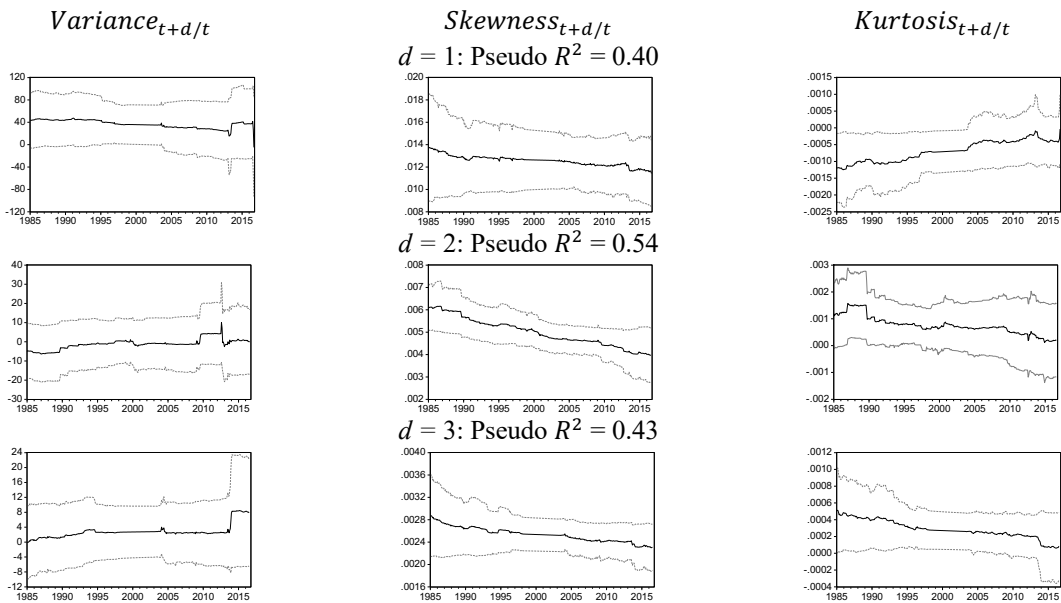


Figure 4: Estimated time-varying coefficients: Japan – CPI



The coefficients on skewness on the other hand, are positive and statistically significant, as they never cover zero, for all three exchange rates and transaction clearing horizons. This

result indicates that increases in skewness tend to increase the gap between the foreign price measured in US dollars and the domestic price. It provides support to the theoretical argument that US agents tend to pay a lower risk premium to domestic importers/producers in response to reduced low or moderate risk, exhibiting an artificially imprudent behavior towards rising extreme exchange rate risk, as the latter is already hedged via the options market. The estimates suggest that the positive effect of skewness on the real exchange rate is rising over time in the case of CA/USA and decreasing over time in the cases of EU/USA and JP/USA. The coefficient on skewness in the case of EU/USA exhibits a sharp decrease in the early 2002, in response to the sharp decrease in inflation in the EU area which began in April, relative to the April increase in US inflation. The fact that EU products became relatively cheaper decreased the impact of moderate exchange rate risk reduction. As table 1 suggests, a unit increase in skewness implies an average increase of the logarithm of the real exchange rate, or deviation from PPP, of about one percent, mainly for transaction clearing horizons of one or two months ahead. This is a non-negligible increase as the standard deviation of the measure of skewness in most cases is higher than unity.

Table 1: Means of coefficients on skewness and standard deviations of skewness - CPI*

	$d = 1$	$d = 2$	$d = 3$
	Canada/USA		
coef. on skewness %	1.1	0.8	0.3
conf. interval %	(0.8, 1.4)	(0.68, 1)	(0.2, 0.4)
s.d. of skewness	0.83	1.34	3.35
	European Union/USA		
coef. on skewness %	0.65	1.3	0.9
conf. interval %	(0.5, 0.8)	(1.04, 1.54)	(0.68, 1.2)
s.d. of skewness	2.16	1.28	1.84
	Japan/USA		
coef. on skewness %	1.3	0.5	0.3
conf. interval %	(1, 1.5)	(0.4, 0.6)	(0.21, 0.29)
s.d. of skewness	1.28	4.16	7.08

*The table reports the mean of the time-varying coefficients (α_{2t}) in percentages and standard deviations of estimated skewness across the sample using CPI based real exchange rates. In parenthesis, are the means of the upper and the lower bounds of the 95% confidence intervals, displayed in figures 2-4.

When the mean coefficient is significantly lower than unity, the standard deviation of skewness is significantly higher than unity (e.g. CA/USA and JP/USA for $d = 3$ and JP/USA for $d = 2$). The means of the 95% confidence intervals demonstrate that the coefficients are precisely estimated.

Most of the confidence intervals of the coefficients on kurtosis cover zero, apart from a few cases where the coefficients are positive and marginally statistically significant in the sense that the lower limits are positive but very close to zero. These cases include EU/USA after May 2002 for all transaction clearing horizons and the case of JP/USA for $d = 2$, 80% of the months the period between 1/7/1986 and 1/5/1997, and for $d = 3$ in almost all the months of the period between 1/1/1985 and 1/3/2007.³¹ These results are consistent with the hedging argument of extreme exchange rate risk and the negative impact of reduced low exchange rate risk on the risk-premium that US agents are willing to pay to domestic importers and producers. Specifically, as kurtosis increases, since the risk from extreme appreciations of the foreign exchange rate is hedged, only the left tale of the exchange rate distribution matters. It follows that the left tail of the distribution becomes longer and fatter, a decrease in low or moderate exchange rate risk for US agents implies a lower risk premium and, as a consequence, lower domestic prices relative to foreign ones and positive deviations from PPP. Our theory suggests that this result can be interpreted by the artificially intemperate behaviour of US agents as the risk arising from extreme appreciations of the foreign currency is eliminated via hedging. Finally, the measure of the goodness of fit of the regressions, suggests that in all cases the transaction clearing horizon of two months fits the data the best. The main results from CPI-based real exchange rates are also confirmed when the real exchange rate is computed using

³¹ In the case of EU/USA after May 2002, the mean coefficients on skewness (%) and corresponding mean of 95% confidence intervals (%) are 0.16 (0.06, 0.26) for $d = 1$, 0.17 (0.05, 0.3) for $d = 2$ and 0.17 (0.08, 0.33) for $d = 3$. The standard deviations of kurtosis are 2.37, 2.85 and 3.79 for the cases of $d = 1$, $d = 2$ and $d = 3$, respectively. While the estimated coefficients do not cover zero and are positive, the confidence intervals are wider than those of skewness coefficients.

the Producer Price Index (PPI). Although there are a few cases where the estimated coefficients on the variance become positive without covering zero, the confidence intervals are extremely wide. There are also a few cases where the coefficients on kurtosis become negative for certain periods without covering zeros. However, these results provide very weak and limited evidence that kurtosis contributes positively to the risk-premium as the coefficients are not only very small but also do not cover zero for a very limited period. Table 2 displays the means of the coefficients on skewness, along with means of the 95% confidence intervals using PPI based real exchange rates, and the standard deviation of skewness.

Table 2: Means of coefficients on skewness and standard deviations of skewness - PPI*

	$d = 1$	$d = 2$	$d = 3$
	Canada/USA		
coef. on skewness %	0.8	0.6	0.2
conf. interval %	(0.62, 0.93)	(0.5, 0.8)	(0.15, 0.3)
s.d. of skewness	0.83	1.34	3.35
	European Union/USA		
coef. on skewness %	0.6	1.06	0.8
conf. interval %	(0.45, 0.71)	(0.8, 1.32)	(0.6, 1)
s.d. of skewness	2.16	1.28	1.84
	Japan/USA		
coef. on skewness %	1.2	0.5	0.24
conf. interval %	(0.94, 1.45)	(0.4, 0.6)	(0.19, 0.31)
s.d. of skewness	1.28	4.16	7.08

*The table reports the mean of the time-varying coefficients (α_{2t}) in percentages and standard deviations of estimated skewness across the sample using PPI based real exchange rates. In parenthesis, are the means of the upper and the lower bounds of the 95% confidence intervals, displayed in figures 2-4.

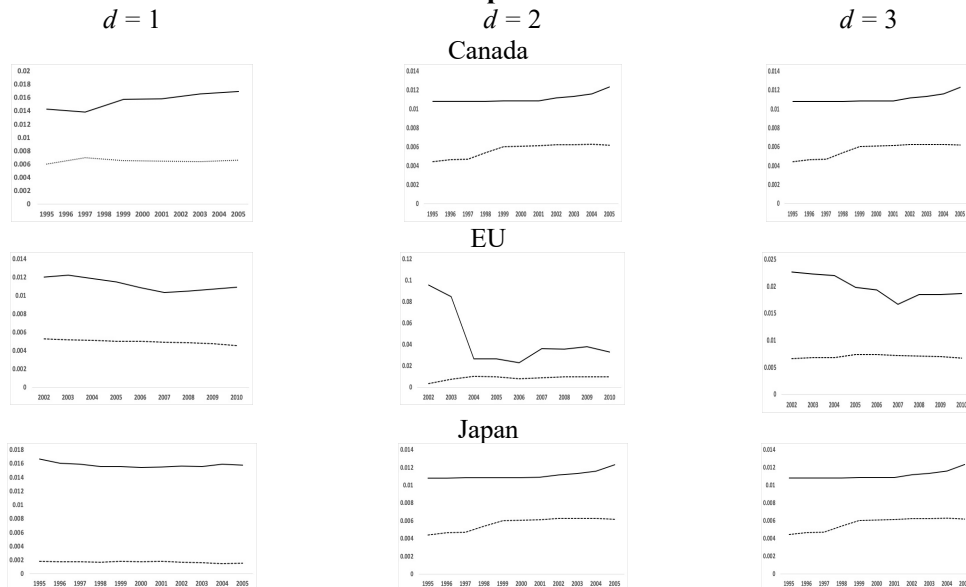
Figures displaying estimated coefficients from PPI based real exchange rates are reported in the appendix.

5. Robustness of confidence intervals and hedging hypothesis

As noted by Cifarelli and Paladino (2015), any potential errors-in-variables distortion is more than compensated by the greater accuracy of estimates provided by GARCH-type procedures, while the use of such estimates as regressors is not uncommon in the literature. Our main results implied by the time-varying estimates are reinforced by the fact that they hold

for both CPI based and PPI based real exchange rates. Evaluating potential generated regressor bias in models with time-varying coefficients is currently an unknown territory. Such bias may affect the confidence intervals of the estimated coefficients of equation (8), as the argument is that the uncertainty of estimating the regressors of (8) is not taken into account when estimating the coefficients in (8). To address this issue, we assess the stability of the confidence intervals of the estimated coefficients by estimating a rolling sample of fixed length and reporting the 97.5th percentile of the upper bound and the 2.5th percentile of the lower bound of a set period. By utilizing those percentiles, we get rid of the combined 5% of potential upper and lower extreme values. We focus in particular on the confidence intervals of CPI based skewness coefficients of which are the highlight of our main results.

Figure 5: Percentiles of Confidence Intervals of Skewness Coefficients from Rolling Samples*



*The focus period is set to 1995:1-2005:12 for CA/USA and JP/USA and to 2002:1-2010:12 for EU/USA. The rolling samples for CA/USA and JP/USA is fixed to 252 observations that start from 1/1/1985, rolling over for one year until and including 1/1/1994. The rolling samples for EU/USA is fixed to 168 observations that start from 1/1/1997, rolling over for one year until and including 1/1/2002. The percentiles reported on the figures are the 97.5th for the upper bound of the confidence interval and the 2.5th for the lower bound of the confidence interval. The real exchange rates are computed using CPI.

To save on space, we do not report results from other coefficients which are available upon request. Since CPI based results are indicative, we do not report results from PPI based

exchange rates which are also available upon request. Figure 5 demonstrates that the confidence intervals for all bilateral real exchange rates at all transaction clearing horizons do not cover zero and always lie within the positive region. This result provides strong support regarding the stability of the confidence intervals and the validity of the result that US agents respond to moderate and low exchange rate risks by increasing (decreasing) the risk-premium incorporated in domestic prices when such risks increase (decrease).

Hedging in Forex trading is deemed to be illegal in the US in the sense of buying and selling the same currency pair at the same or different strike prices. However, holding options of foreign exchange which enable recouping the difference between the market price and the strike price when extreme appreciations of the foreign exchange occur or using other derivatives when extreme appreciations of foreign currencies are expected is a perfectly legitimate strategy.³² We argue that US agents, especially large corporations that purchase foreign goods and services denominated in foreign currencies, hold derivative portfolios to hedge the exchange rate risk but only on a limited basis, focusing on extreme appreciations of foreign exchange. Operational hedging is also another option that agents can adopt when extreme appreciations of foreign exchange are expected.³³ Even though, direct testing of this hypothesis is challenging, existing empirical evidence from corporate derivatives is supportive to the hypothesis. Guay and Kothari (2002) find that the use of corporate derivatives, not inclusive to exchange rate risk, appears to be moderate by taking into account firm size,

³² The evidence suggests that option derivatives is a significant component of derivatives portfolios. For instance, when the foreign currency significantly appreciates, foreign call options enable domestic (US) agents to recoup the price difference and thus fully hedge extreme exchange rate risk, while moderate and low risks remain unhedged. Specifically, domestic agents can purchase foreign exchange at the exercise price which is lower than the market price and then sell it at the market price. Futures and forward contracts also enable domestic agents to eliminate extreme appreciations of the foreign exchange when the latter are expected. In principle, low and moderate exchange rate risks can also be hedged, however this would imply higher overall insurance fees than any premium paid to domestic importers or producers. For instance, domestic agents can use put options and sell foreign exchange at the exercise price which is higher than the market price and then purchase at the market price.

³³ For instance, an agent may postpone or cancel a purchase when an extreme appreciation of foreign exchange is expected to occur (e.g. see Boyabath and Toktay, 2004).

operating and investing cash flows.³⁴ Although increased use of derivatives among more geographically diverse firms is observed, the magnitudes of the derivatives positions are found to be quite small. Furthermore, Brown (2001), provides evidence that a large US based corporation would be more concerned with downside exchange rate risk than upside risk. As Brown's case study suggests, the cost of initiating and maintaining a derivatives program is not trivial. Therefore, the assumption of hedging extreme downside risk only, is justified by the fact that large-scale hedging would be too expensive and detrimental for either businesses and/or consumers.

6. Concluding Remarks

We extend the theoretical framework of Arghyrou et al. (2011), where transactions clear in future dates and induce deviations from the law of one price due to uncertainty about future nominal exchange rates. We show that the latter induces deviations from PPP, not only because of first-order uncertainty, as in Arghyrou et al., but also because of higher order uncertainty. We further argue that due to high insurance fees only extreme exchange rate risks realistically can be fully hedged via options markets. If extreme risk is hedged, then our framework suggests that only low and moderate risks induce risk premia incorporated in domestic prices which then drive deviations from PPP. To test our theory, we estimate the model derived from the theoretical framework with time-varying coefficients using data for bilateral exchange rates between the US, and three of its main net exporting partners, Canada, EU and Japan. Our estimates suggest that (i) higher-order uncertainty measured by skewness is a major factor driving deviations from PPP and (ii) US agents respond only to low and moderate risk and are willing to pay exchange rate risk premia incorporated in domestic prices which drive deviations

³⁴ Specifically, Guay and Kothari (2002), present detailed evidence on the cash flow and market value sensitivities of financial derivatives portfolios to extreme simultaneous changes in interest rates, currency exchange rates, and commodity prices using an extended random sample of large non-financial corporations.

from PPP. These findings confirm our argument that US agents insure against extreme exchange rate risk via options markets of foreign exchange and thus changes in such risk have no impact on domestic prices and thus on real exchange rates. The latter is supported by empirical evidence on the volumes of call and put options of foreign exchange.

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Appendix

Table A1: GARCHSK Estimation Parameters for Bilateral Exchange Rates: 1973:1-2016:10*

	Canada/USA			European Union/USA			Japan/USA		
	d=1	d=2	d=3	d=1	d=2	d=3	d=1	d=2	d=3
$\sigma_{t+d/t}^2 * 100$									
$\mu_{\theta 0}$	0.000 (0.000)	0.001 (0.000)	0.008 (0.003)	0.017 (0.001)	0.009 (0.002)	0.209 (0.007)	0.009 (0.000)	0.057 (0.003)	0.051 (0.001)
$\mu_{\theta 1}$	10.306 (0.100)	7.652 (0.100)	18.629 (3.272)	39.083 (0.327)	4.845 (0.522)	70.928 (1.507)	0.859 (0.023)	20.587 (1.736)	17.086 (1.686)
$\mu_{\theta 2}$	60.737 (32.985)	64.704 (32.985)	30.073 (20.287)	21.657 (18.374)	48.313 (77.284)	- (0.337)	69.145 (0.467)	53.103 (1.165)	47.038 (9.005)
<i>Skew</i> $_{t+1/t}$									
μ_{s0}	0.0763 (0.026)	-0.401 (0.026)	-0.714 (1.469)	0.001 (0.002)	0.829 (0.986)	0.033 (0.013)	0.026 (0.010)	0.093 (0.145)	-0.140 (0.133)
μ_{s1}	0.137 (0.002)	0.182 (0.002)	0.065 (0.021)	-0.002 (0.001)	0.203 (0.05)	-0.468 (0.371)	0.018 (0.007)	-0.175 (0.345)	0.005 (0.002)
μ_{s2}	-0.065 (0.001)	-0.029 (0.001)	-0.191 (0.251)	0.016 (0.014)	-0.053 (0.036)	0.476 (0.036)	0.831 (0.532)	0.330 (0.085)	-0.978 (0.006)
<i>Kurt</i> $_{t+1/t}$									
μ_{k0}	1.287 (0.488)	1.014 (0.488)	1.346 (4.875)	1.381 (11.142)	1.874 (0.885)	3.950 (1.193)	1.307 (0.346)	2.332 (2.709)	3.140 (0.314)
μ_{k1}	0.075 (0.000)	0.122 (0.000)	0.003 (0.000)	0.029 (0.005)	0.094 (0.007)	-2.770 (2.132)	0.027 (0.001)	-0.730 (0.851)	-0.526 (0.411)
μ_{k2}	0.057 (0.001)	-0.003 (0.001)	0.498 (1.879)	0.485 (4.192)	-0.024 (0.027)	0.023 (0.024)	0.478 (0.267)	0.262 (0.207)	0.186 (0.154)

*For the European Union, the sample begins from 1983M10 for the CPI, while for the PPI it begins from 1996M01.

Figure A1: Estimated time-varying coefficients: Canada – PPI

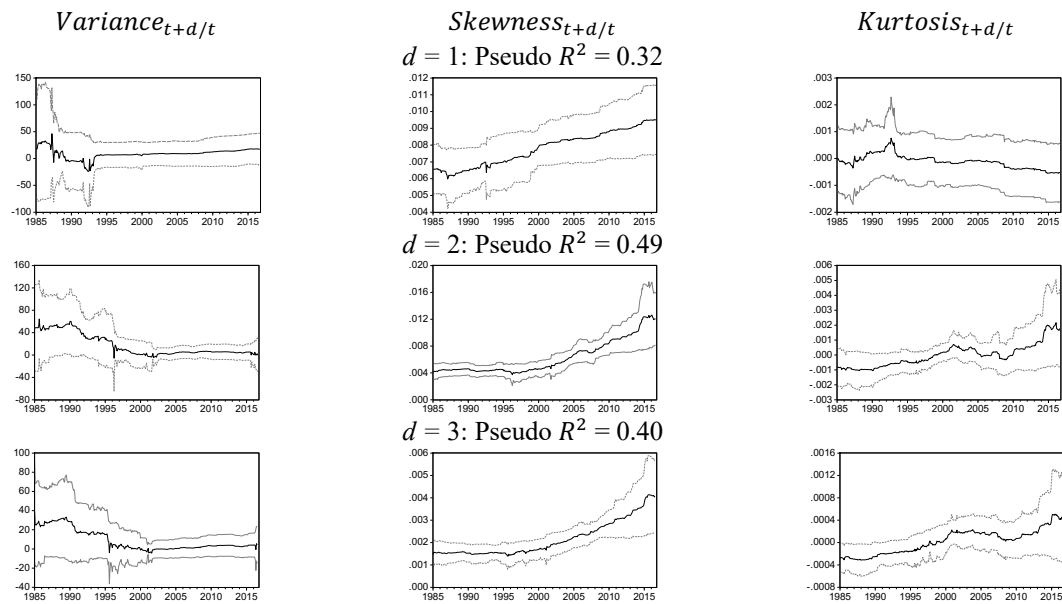


Figure A2: Estimated time-varying coefficients: EU – PPI

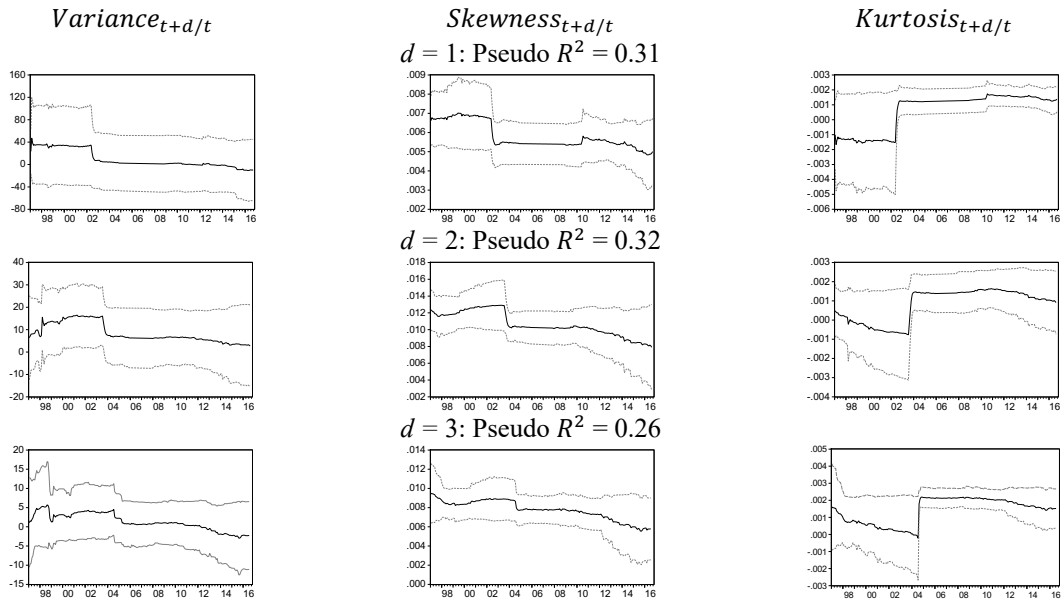


Figure A3: Estimated time-varying coefficients: Japan – PPI

