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How raising interest rates can cause inflation and currency depreciation

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ABSTRACT

In this paper we derive a new model on exchange rate response to a lasting higher interest rate level. Contemporary models do not provide a convincing explanation for this relationship, but recent research suggests that models based on demand-pull effects to be somewhat confined to small funding cost increases. This would make cost-push effects more relevant when the interest rate differential (IRD) is larger and longer-lasting. The new model accounts for cost-push effects and suggests that a persistent higher IRD can evoke multiple responses, including currency depreciation, specialization, inflation, and wage drift. The model suggests that excessive long-lasting IRD can spark a chronic interaction between inflation and currency depreciation. Empirical data substantiate the prediction capability of the new model. We also demonstrate how the uncovered interest rate parity (UIP) principle is a special case, which can explain its empirical research anomalies, and when carry trade is a profitable investment strategy.

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Exchange rate: exchange rate modeling; interest rates; interest rate differential; IRD; monetary policy; control rates; cash-in-advance; central bank policy; uncovered interest rate parity; UIP; carry trade; factor price equalization

1. Introduction

The difficulty lies not so much in developing new ideas as in escaping from old ones.

John Maynard Keynes

The exchange rate response to an interest rate change is an important transmission channel for monetary policy, in addition to the fact that the exchange rate is probably the most important price in any economy, since it affects all other prices; see, e.g., Frieden (2016). The exchange rate is influenced by many factors, including short-term interest rates, which is the topic of this paper. Now, however, it is widely accepted that contemporary models do not provide a convincing explanation for this relationship; see, e.g., Priewe (2017).1

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This article has been corrected with minor changes. These changes do not impact the academic content of the article. ¹Textbook models of the long-term exchange rate response to an interest rate differential (IRD), such as the well-known Mundell-Fleming model and the Dornbusch (1976) overshooting model, assume that interest rate parity will hold. But interest rate parity principles like uncovered interest rate parity (UIP) have almost universally been empirically rejected. The first study to reject the UIP theory was conducted in 1980 by Bilson (1980), but many others have rejected it as well: Cumby and Obstfeld (1980), Meese and Rogoff (1981), Hansen and Hodrick (1980), Rogoff (1983), and most famously, Fama (1984).

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Contemporary economic theory assumes that raising interest rates reduces growth in aggregate demand in the economy, which leads to lower inflation. This assumption rests on demand-pull effects, which also suggest that raising interest rates reduces consumer spending and investment because the cost of borrowing increases and saving becomes a more attractive option. The increase in saving reduces the supply of money in circulation, curbs inflation, and increases the value of the currency. Appreciation of the currency hurts the export sector and eases potential wage pressures since labor demand declines as a result of reduced competitiveness for local tradable goods and services.

A different school of thought is based on the cost-push effects, which suggests that raising interest rates will be reflected in a higher price level. But despite higher funding costs associated with higher interest rates, a leading explanation in the economic literature is that monetary policy has real demand-pull effects because firms incur a cost when changing prices. In economics, a menu cost is the cost to a firm when it changes its prices. It is argued that if there are small changes in cost factors such as funding costs, a firm might prefer to exist in slight disequilibrium rather than incur the menu cost. With the aforesaid argument, the cost-push effects have been mostly brushed aside. However, Eric Anderson, Jaimovich, and Simester (2015) have provided evidence that the menu cost channel operates only when cost increases are small in magnitude. If so, what if the increased funding cost is not "small in magnitude"? Will a lasting interest rate differential (IRD) translate into funding cost-push effects, and if so, how?

The Gibson paradox, a concept dating back to 1923, refers to the observation that real interest rates and changes in the general price level are positively correlated at times. The term was first used by John Maynard Keynes. Shiller and Siegel (1977) confirmed such a positive correlation using British data covering 25 years. Friedman and Schwartz (1982) found long periods of such a positive correlation but offered a variety of possible explanations (p. 631). Barth and Ramey (2001) argued that the cost-push channel was the primary monetary policy transmission mechanism for some industries, but its potency was found to vary over time. Allen and Gale (2000, 2004) also concluded that the cost-push channel effect varied over time. Tillmann (2009a, 2009b) described how firms' reliance on borrowing working capital caused higher interest rates to translate into a higher cost of working capital and a rise in inflation. He also posited that even if no working capital was borrowed from banks, firms' opportunity cost of own funds would rise with market interest rates; therefore, in this way, higher interest rates would affect the price level. Tillmann (2008) argued further that cost-push effects could explain inflation dynamics in forward-looking price and wage stickiness models for the US, the UK, and the eurozone. Ravenna and Walsh (2006) showed that a cost-push shock arises endogenously when a cost-push channel for monetary policy is introduced into the new Keynesian model. Chowdhury, Hoffmann, and Schabert (2006) examined the cost-push channel for inflation dynamics for the G7 countries and demonstrated significant but varying effects for the majority of countries. With simulation, an inverse inflation response was demonstrated if the cost-push channel was sufficiently strong relative to the demand channel. In a study of five OECD countries and 21 manufacturing sectors, Dedola and Lippi (2005) demonstrated that monetary policy decisions affected both the cost-push channel and the demand channel. Adolfson, Laséen, Lindé, and Villani (2005) found the cost-push channel to be dominant in the eurozone, while Rabanal (2007) argued that the demand channel dominated the US economy.

Should exchange rate models consider the cost-push effects of higher funding costs? And, are the observed empirical anomalies, due to varying magnitudes of cost increases, and the real response oscillating between demand-pull and cost-push effects, or a combination of both? In 2018, emerging markets around the world, from South Africa to Indonesia, experienced plummeting currencies and an outflow of foreign investment. The triggers for the currency collapses in Argentina, Turkey, South Africa, and Indonesia have all been different but with the same outcome - loss of confidence, an outflow of funds, and a currency devaluation. Argentina, which had stabilized after a crisis earlier in the year, fell back into emergency mode in August, raising interest rates to 60%. Its currency, the peso, depreciated 50% in 2018 and further 37% in 2019 against the US dollar. Taking the above into consideration, a crucial question was asked in a recent WEF news story:² Why are all these different countries – on different continents, with different economic situations and leadership - suffering from the same symptoms?

We can extend this question and ask why this is nothing new, even when the hard-hit economies are following prudent monetary policy practices based on contemporary theory and economic models. Is it possible that theory and the derived monetary policy practices are somehow a part of the problem? Over the last half century, the world has witnessed 796 episodes where a national currency has depreciated more than 20% in a calendar year, and 235 episodes where the depreciation was more than 50%; see Figure 1. A currency crash tends to cause economic turmoil, disruptions that harm long-term economic growth, even political unrest, human suffering, and tragedy. In the past two decades, the so-called advanced economies had only six incidents where the shock exceeded 20%, and one incident where the shock exceeded 30% (49% in Iceland in 2008). Furthermore, we see that a large interest rate differential (IRD) is a common precursor to depreciation episodes. For example, over the last three decades, in the year leading up to a currency shock exceeding 20%, among the advanced economies, the average IRD³ was 11.5%, with a median of 6.6%.

In this paper, we model how the exchange rate might respond to a lasting IRD. We use a simple two-country model wherein each country has its own currency. The respective interest rates are governed by monetary authorities. The local country is a small open economy, small enough compared to a large foreign country that it does not affect the foreign country. The production function has a cash-in-advance (CIA) constraint, since we assume that production output must be funded before the product is sold. Firms are assumed to maximize profits. We assume labor markets to be interlinked long term, and we assume that prices and factors of production are constrained by international price gaps. Because the model assumes economic principles that are shown empirically to hold better long term than short term, the model should be considered an indication for longterm effects of a lasting wider IRD, but not for short-term predictions.

A persistently wider IRD will affect an economy's relative funding costs, a factor of production, and these higher costs will probably be passed into pricing unless cost increases are small enough that they can be absorbed. The longer a higher interest rate level lasts, the more it eats into firms bottom lines, eroding profit margins and increasing

²Published September 4th, 2018, and written by Michael Hanley, World Economic Forum.

³IRD calculated as the difference between the national money market (MM) interest rates and the US money market interest rate. Out of 15 currency shock episodes, we have MM information for 13 of them.

20%

Number of shocks per decade*	Advanced Economies	ı	Emerging and Developing Asia	Emerging and Developing Europe		Middle East, North Africa, Afghanistan, and Pakistan	;	Sub-Saharan Africa		Western Hemisphere	1	Other nternational Finance Statistics	Total
From 1970 untill 1980	10		17	5	r	3	r	10		34		2	81
From 1980 untill 1990	28		21	17		17		104		85		13	285
From 1990 untill 2000	8		26	74	r	19	r	100		51		2	280
From 2000 untill 2010	6		3	8		2		30		4		0	53
From 2010 untill 2020	0		3	14	•	10	•	19	•	11		0	57
Total	52		70	118		51		263		185		17	756

*) number of shocks when annual depreciation of a national currency against the US dollar exceeded:

Shocks to National Currencies

- between 1970 and 2020 -

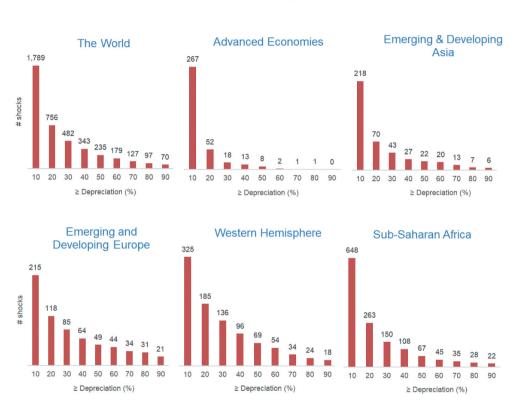


Figure 1. Currencies shocks. Note: The figures show the number of currency shocks per year, accumulated over the last 50 years (vertical axis), equal and above a certain % threshold shock value (horizontal axis). The shock is a measure of the depreciation of a national currency against the USD. The table and figures are derived from data retrieved from the IMF International Financial Statistics (IFS) database. The countries are grouped according to the IMF taxonomy, see Appendix B.

their funding needs. Such an increase in the volume of borrowing is a source of money creation through new bank lending.⁴ All else being equal, the increased money supply can induce inflation.

⁴As described in a recent bulletin from the Bank of England McLeay et al. (2014): " banks create money whenever they lend to someone in the economy."

Higher export prices resulting from higher funding costs make high-IRD economies less competitive. Impaired competitiveness can reduce exports, hurting the exchange rate and inducing a currency depreciation. A depreciation can gradually restore export price competitiveness, but if a relatively unfavorable funding cost structure remains, the depreciation is just a temporary fix. In such a case, currency depreciation and a higher price level reduce purchasing power and real wages, potentially inducing wage drift. The model suggests multi-channel responses to a persistently wider IRD, including currency depreciation, economic specialization, a rising price level, and wage level erosion.

We do not claim that the model is capable of perfectly explaining the complex response of an economy to the interest rate level; however, it does demonstrate how the response can be transmitted through various channels – not only the exchange rate. The new model shows how uncovered interest rate parity (UIP) can be viewed as a special case valid under particular circumstances. The model is substantiated by comparing it with empirical data for nine countries.

The remainder of this paper is organized into two main parts. In the first part, we lay out the argument for the new model, review the relevant literature, and derive the model. In the second part, we interpret the new model and compare model predictions with empirical data.

2. The model

Higher interest rates can discourage new investment, encourage saving, and consequently dampen output and inflation. But higher interest rates also affect funding costs, a factor of production potentially reflected in the price level when the magnitude of the funding cost increase is sufficiently large.⁵ As the IRD is wider and longer lasting, the funding cost is likelier to be higher, and as a consequence, to be reflected in the price level through cost-push effects. Also, as both the magnitude and costs of funding increases, firms needing to fund their operation need to borrow more. All else equal, then increased bank lending is a source for money creation, which can induce inflation. So, even if a wider IRD can dampen inflation in the short run, it is likelier to induce inflation the longer it lasts. A relatively higher price level, as a result of a lasting wider IRD, is likelier to have a detrimental effect on the economy's exports and its competitiveness. Declining exports can induce currency depreciation, which can gradually restore export price competitiveness. But if the relatively unfavorable funding cost structure remains, the depreciation is only a temporary fix. Also, a depreciation and a higher price level erode local purchasing power and real wages, putting pressure on wages, a factor of production. A higher interest rate level will therefore affect the economy differently, depending on the duration of the condition, and the longer the IRD lasts, the likelier such cost-push effects are to materialize.

The model is a simple two-country model wherein both countries have their own respective currency, and the interest rate levels are governed by independent monetary authorities. The respective interest rate levels are assumed to be exogenous in the sense

⁵An argument for the absence of cost-push effects is when menu costs are higher than the increase in cost factors, such as funding costs. Also, Eric Anderson et al. (2015) have argued that the menu cost channel operates only when cost increases are small in magnitude.

that they are determined by monetary policy committees. The local country is assumed to be a small open economy, small enough compared to the foreign country that its policies do not alter world prices, interest rates, or incomes. Thus the local country is a price taker. There are two firms producing the same product: local and foreign. The local firm's funding costs are considered to be higher. The production function has a cash-inadvance (CIA) constraint; i.e., production must be funded before the product is sold. The firms are assumed to maximize profits, assuming perfect competition. Prices and factors of production are assumed to be constrained by international price gaps - we assume that labor markets and prices are interlinked long term. Because the model assumes economic principles that have been shown empirically to hold better long term than short term, the model should be considered an indication of the long-term effects of a lasting wider interest rate differential (IRD), not the short-term effects.

2.1. Firms

We assume two firms, one in each country, that produce the same product: local and foreign. We assume the Cobb-Douglas total production function⁶ with constant returns to scale (CRS) identical for both countries, and to satisfy the assumptions of concavity and differentiability:

$$Y = z \cdot F(N) = z \cdot K^{\alpha} \cdot N^{1-\alpha} \tag{1}$$

where *Y* is total production, *N* is the number of person-hours, *K* is the capital input, *z* is total factor productivity, and α is the output elasticities of capital (assumed to be a constant and determined by available technology).

We assume that production takes place one period before sales, which requires that firms borrow some proportion (y) of their variable production costs before they collect revenues from selling output. This is the model's cash-in-advance constraint. The cost function, C, is therefore defined as

$$C(N) = i \cdot K + (1 + \gamma \cdot i) \cdot N \cdot w \tag{2}$$

where i is the interest rate level, w is wage costs, and y is the funding need. K and N are the production function's capital and labor, respectively. The cost function is now affected by the interest rate level, since capital input and funding of variable costs are affected by it. The need to fund production (working capital and investments) may vary across sectors, economies, and between time periods. An important part of the economy's money creation is through banks or as is described in a recent bulletin from the Bank of England McLeay, Radia, and Thoms (2014): "banks create money whenever they lend to someone in the economy." A lasting higher interest rate level can eat into the bottom line, and increase funding needs for working capital and investments, and hence can be a source for money creation.

⁶A total production function is also referred to as a single-input production function.

2.2. The goods market

Empirical evidence supports the argument that the law of one price (LOOP) and purchasing power parity (PPP) hold better long term.⁷ The PPP principle states that, in the absence of transaction costs and official trade barriers, identical goods and services will have the same price in different markets when the prices are expressed in the same currency.

Market integration affects the validity of the law of one price (LOOP) and purchasing power parity (PPP). The study of international and regional markets, and of open- versus closed-economy models and policy, rests, for example, on the existence of one market or many. But economists disagree on the level of price convergence, which is the price gap between two markets measured in a common currency – i.e., if and then how prices will converge; see Taylor (2001).

For the long term, we assume that the goods markets' prices are constrained by international prices. There may exist international price differences for individual goods or baskets of goods. It is well known that fixed and variable trading costs, or risk aversion, can under certain scenarios lead to a "band of inaction" in which no arbitrage occurs despite a non-zero price gap. Only when prices move apart sufficiently will arbitrage occur and reversion begin; see, e.g., Taylor (2001).

We define the law of one price gap as⁸

$$\psi_p = \frac{P^*}{S \cdot P} \tag{3}$$

where S is the nominal exchange rate. P is the local price measured in the local currency, and P^* the price of the same good measured in the foreign currency. The LOOP gap, ψ_p is a wedge between the foreign price of goods and the domestic price of these imported foreign goods, an inverse mark-up between the global price of global goods and the domestic price of these imported global goods; see Liu (2006). We assume that the LOOP gap holds for all goods.

The law of one price (LOOP) therefore becomes a special case and is valid under the special conditions when $\psi_p = 1$; i.e.,

$$S \cdot P = P^* \tag{4}$$

2.3. The labor market

The second economic principle underpinning the model is the factor price equalization theory by Samuelson (1948), which assumes that cross-country production factor prices will converge over the long term. The theory states that prices for identical factors of

⁷See, e.g., Abuaf and Jorion (1990), who noted substantial short-term deviations but concluded that PPP holds long-term. Edison (1987) supported a qualified interpretation of PPP, stating that the proportionality between exchange rates and the relative price level emerged long-term, after taking into account the effects of changes in structural factors. Kim (1990) concluded that PPP holds in general. Lothian and Taylor (1996) and Lothian and Wu (2011) analyzed data spanning two centuries for dollar-sterling and franc-sterling real exchange rates and found strong evidence of mean-reverting real exchange rate behavior.

⁸This form of the law of one price (LOOP) gap is used, for example, in Liu (2006).

⁹The exchange rate is defined as the number of foreign currency units per one unit of local currency; i.e., an increase in *S* implies an appreciation of the local currency.

production, such as wages, will equalize across countries as a result of free and frictionless international trade. This assumption is supported, for instance, by Mundell (1957), who argued that trade in goods is, at least to some extent, a substitute for factor movements. Free trade implies commodity-price equalization: even when factors are immobile, there is a tendency towards factor price equalization. Stiglitz (1970) concluded further that free international trade completely equalized factor prices and that this proposition was proved under seemingly general conditions, albeit in the context of a static model. However, the world is not a single labor market, and despite free labor mobility across many markets, there exists inertia in wage convergence. With reference to the factor price equalization theory and the above-argued LOOP gap, we similarly assume a wage gap, ψ_{w} , defined as

$$\psi_w = \frac{w^*}{S \cdot w} \tag{5}$$

where w and w^* are local and foreign wages, respectively. The factor price equalization theory by Samuelson (1948), for wages, therefore becomes a special case when $\psi_w=1$, or

$$S \cdot w = w^* \tag{6}$$

In our model, we require neither ψ_w nor ψ_p to equal one. We define a country's capital– labor ratio as $k = \frac{K}{N}$ where K and N are the production function's capital and labor, respectively. The two countries have interlinked labor markets; therefore, the capitallabor ratio can change. Such a change would be induced if, for instance, one country has sufficiently lower wages. Employees can always emigrate to where wages are higher. Replacing experienced employees can be expensive, owing to the cost of finding and training new employees. It may therefore be economically rational to raise wages when there is a genuine threat of emigration. Comparing the two alternatives, raising wages or contending with emigration, should bring balance to labor flow between the two countries and make the capital–labor ratio, *k*, sticky.

2.4. The capital market

The two countries have their own respective currencies wherein the interest rate level is governed by an independent monetary authority. The respective interest rates levels are assumed to be exogenous in the sense that they are determined by the monetary policy committees. We assume a sustained higher local interest rate level. Higher interest rates could be a result of a risk premium inflicted upon the economy; e.g., by the central bank's interest rate policy. Therefore, we assume that the interest rate level is exogenous. The local interest rate level is set as θ percentage points above foreign interest rates. The local and foreign interest rate levels, respectively, are i and i^* , and their relationship is therefore as follows:

$$i = i^* + \theta \tag{7}$$

The local economy is a price taker and has no influence on the foreign economy, which is not affected by the local economy. What sets the economies apart is the constant and lasting IRD. Furthermore, it is assumed that the smaller currency area is considered riskier, but because of the higher interest rate level, cross-border capital flows are in equilibrium.

2.5. Profit maximization

Perfect competition in all sectors in both countries is assumed, where no firm can control prices. Prices are set one time period after production, and the profit function 10 is defined as

$$\pi(N) = P_{t+1} \cdot Y_t(N) - C_t(N) \tag{8}$$

or

$$\pi(N) = P_{t+1} \cdot z \cdot K^{\alpha} \cdot N^{1-\alpha} - i \cdot K - (1 + \gamma \cdot i) \cdot N \cdot w_t \tag{9}$$

Profit is at a maximum when $\frac{d\pi}{dN}=0$ and if $\frac{d^2\pi}{dN^2}<0$. We can assume $0<\alpha<1$ and $K,N,P_{t+1}>0$. Solving for $\frac{d\pi}{dN}=0$ yields

$$P_{t+1} \cdot z \cdot (1 - \alpha) \cdot k^{\alpha} = (1 + \gamma \cdot i) \cdot w_t \tag{10}$$

where $k=\frac{K}{N}$ is the capital–labor ratio. Solving for $\frac{d^2\pi}{dN^2}$ yields

$$\frac{d^2\pi}{dN^2} = -z \cdot P_{t+1} \cdot \alpha \cdot (1-\alpha) \cdot z \cdot K^{\alpha} \cdot N^{-\alpha-1}$$
(11)

This is a maximum since $\frac{d^2\pi}{dN^2} \le 0$ holds true when $0 \le \alpha \le 1$ and $K, N, z, P_{t+1} \ge 0$. Equation 10 can also be written as

$$P_{t+1} = (1 + \gamma \cdot i) \cdot w_t \cdot \frac{a}{k^{\alpha}}$$
 (12)

where a is set as

$$a = \frac{1}{z(1-\alpha)} \tag{13}$$

Similarly, we derive the relationship for the foreign country as

$$P_{t+1}^* = (1 + \gamma \cdot i^*) \cdot w_t^* \cdot \frac{a}{(k^*)^{\alpha}}$$
 (14)

Assuming interlinked labor markets and the law of one price gap, we use Equations (5) and (3) respectively, to rewrite Equation (12) as

$$\frac{P_{t+1}^*}{\psi_p \cdot S_{t+1}} = (1 + \gamma \cdot i) \cdot \frac{w_t^*}{\psi_w \cdot S_t} \cdot \frac{a}{k^\alpha}$$
 (15)

Inserting Equation (14) into Equation (15) gives the difference equation

$$\frac{(1+\gamma \cdot i^*) \cdot w_t^* \cdot \frac{a}{(k^*)^{\alpha}}}{\psi_p \cdot S_{t+1}} = (1+\gamma \cdot i) \cdot \frac{w_t^*}{\psi_w \cdot S_t} \cdot \frac{a}{k^{\alpha}}$$
(16)

By simplifying Equation (16), we have now derived our new exchange rate forecasting model:

¹⁰This is a one-variable profit function based in part on the production function. If we assume that production is a function of two variables, N and K, the profit function would be $\pi(N,K)$. Such profit maximization is put forward in Appendix A. As is demonstrated in the appendix, we show that the two-variable approach adds little to the story and comes at the expense of less clarity. We therefore prefer the simpler approach, since the main narrative is the same in both instances.



$$\frac{S_t}{S_{t+1}} \cdot \left[\frac{\psi_w}{\psi_p} \right] \cdot \left[\frac{k}{k^*} \right]^{\alpha} = \left[\frac{1 + \gamma \cdot i}{1 + \gamma \cdot i^*} \right]$$
(17)

3. Interpretation

The new model illustrates several things. First, the economy's various conditions determine the response to a lasting higher interest rate level. Specialization (k and α), the price gap (ψ_p), the wage gap (ψ_w), and the funding needs (γ) of the economy all affect the response. The response therefore depends both on the economy in question and on the time period under observation. Therefore, all currencies will not necessarily respond to higher interest rates in the same way. This is consistent with Stiglitz (1970), who investigated economic responses to a long-term interest rate differential using a two-country model. He argued that equal interest rate levels implied no specialization of either country, but that different interest rate levels would induce economic specialization; i.e., a change in the capital–labor ratio of the production function. Not only is our new model consistent with Stiglitz's findings, it is also more comprehensive and flexible. Contrary to the Stiglitz model, we allow for separate currencies and consider multi-channel responses to a lasting exogenous interest rate differential. The new model suggests that an economy can respond by specialization, as in the Stiglitz model, but also through other channels.

Second, if we assume a lasting higher interest rate level and some funding need (i.e., $i > i^*$ and $\gamma > 0$), the right-hand side of Equation (17) is > 1. In order for the model to be valid, the left-hand side must also be > 1. Therefore, the long-term response to lasting higher interest rates can be a currency depreciation (i.e., $S_{t+1} < S_t$), increased specialization (i.e., a higher k), lower local wages (i.e., higher ψ_w), a higher local price level (i.e., lower ψ_p), or a combination of some or all of the above. In other words, the new model shows that an economy can respond to an interest rate differential at many different levels and to varying degrees. For example, lower wages, instead of a currency depreciation, could compensate for a higher interest rate level or some combination of the two.

Third, based on the new model, we can claim that, under the condition of a zero interest rate differential (i.e., $i=i^*$), the model indicates no response by the exchange rate, capital-labor specialization, price level, or wages. A zero interest rate differential is therefore neutral for the economy. By the same token, we can state that an interest rate differential is not neutral for the economy.

Below, we consider two special cases of the new model; i.e., variations of Equation (17). The former special case is referred to as the "simple" case and the latter as the "limited" case.

3.1. The simple case

For the simple case, we assume a Leontief production function¹¹ with a constant capital-labor ratio, k, translating into no substitutability between factors and no possibility of specialization. Further, we assume that the law of one price (LOOP) and purchasing

¹¹Instead of the model's Cobb-Douglas production function.

power parity (PPP) are valid or the gaps to be equal; i.e., $\psi_p = 1 = \psi_w$ or $\psi_p = \psi_w$. The model's simple case is therefore reduced to the following equation:

$$\frac{S_t}{S_{t+1}} = \left[\frac{1 + \gamma \cdot i}{1 + \gamma \cdot i^*} \right] \tag{18}$$

For the simple case, the only option in response to lasting higher interest rates is a currency depreciation. However, the depreciation is not a one-to-one relationship between the IRD and the exchange rate change, unless the cash-in-advance funding need equals one time period; i.e., $\gamma = 1$. By inserting Equation (7) into Equation (18) and rearranging, we obtain

$$\frac{S_t}{S_{t+1}} = 1 + \frac{\gamma \cdot \theta}{1 + \gamma \cdot i^*} \tag{19}$$

Solving iteratively, we find that the exchange rate at time T is

$$\frac{S_T}{S_0} = \left[1 + \frac{\gamma \cdot \theta}{1 + \gamma \cdot i^*}\right]^{-T} \tag{20}$$

Equation (19) can be approximated as

$$\frac{S_t}{S_{t+1}} \approx 1 + \gamma \cdot \theta \tag{21}$$

Interestingly, the simple case is similar to the UIP relationship if $\gamma = 1$. The UIP relationship can be put forward as,

$$\frac{S_t}{E(S_{t+1})} = \frac{1+i_t}{1+i_t^*} \tag{22}$$

where i_t and i_t^* are the interest rate levels for the respective currency areas (local and foreign). We define S_t as the nominal exchange spot rate¹² at time t, and $E(S_{t+1})$ the expected spot exchange rate at time t+1.

The only difference between the two is that the simple case predicts the value for S_{t+1} , whereas UIP uses the expected value $E(S_{t+1})$. This similarity is particularly interesting because the uncovered interest rate parity (UIP) theory and the new model are derived independently and based on different assumptions. UIP assumes market efficiency and interest rate parity, whereas the new model is based on lasting higher funding costs and on optimizing the production function. The γ value reflects the economy's average funding time, see Equation (2). Different γ values therefore reflect varying funding dependency.

When $\gamma=1$ time period, the simple case mirrors UIP, i.e., becomes a special case of the new model. Empirical research testing the validity of UIP has indicated that the relationship between IRD and the exchange rate change is between 0 and 1.25; see, e.g., Lothian (2016). Through the lens of the simple case, this would suggest that average funding time varies from zero to 1.25 time periods (i.e., $0 \le \gamma \le 1.25$).

Equation (19) demonstrates that, over the long term, the exchange rate will fall as long as there is any interest rate differential and funding need. Because the simple case assumes the law of one price, $SP = P^*$, any change in S will be offset by an equal but inverse change in S; i.e.,

¹²The exchange spot rate is defined as the foreign currency price of one unit of local currency. Therefore, the local currency appreciates when S increases.

$$\frac{S_t}{S_{t+1}} = \frac{P_{t+1}}{P_t} \tag{23}$$

By combining Equations (23) and (19), we obtain

$$\frac{P_{t+1}}{P_t} = 1 + \frac{\gamma \cdot \theta}{1 + \gamma \cdot i^*} \tag{24}$$

or inflation (π)

$$\pi = \frac{\Delta P}{P} = \frac{\gamma \cdot \theta}{1 + \gamma \cdot i^*} \tag{25}$$

Equation (25) implies that the interest rate differential and inflation are positively correlated over the long term for the simple case.

The simple case also provides insight into carry trade as an investment strategy. If the UIP relationship always held true, carry trade would not be profitable. But carry trade can be profitable and as an investment strategy is both common and popular, as is demonstrated by Doskov and Swinkels (2015). Carry trade profit (CTP) is a function of the interest rate differential (IRD) and exchange rate developments over the same period. Carry trade profit over one time period can be calculated as

$$CTP = (1+\theta) \cdot \frac{S_{t+1}}{S_t} - 1 \tag{26}$$

where θ is the interest rate differential and S is the exchange rate.

If we use the simple case to predict exchange rate developments – i.e., Equation (21) – and insert it into Equation (26), we can calculate the carry trade profit as

$$CTP \approx \frac{1+\theta}{1+\gamma \cdot \theta} - 1 \tag{27}$$

The simple case therefore suggests that carry trade is a profitable investment strategy as long as $\theta > 0$ and $\gamma < 1$.

3.2. The limited case

We now derive the second special case – the limited case – by assuming the initial Cobb– Douglas production function, and by assuming that either, LOOP and PPP to be valid, or the gaps to be equal.¹³

The limited case is then equal to,

$$\frac{P_{t+1}}{P_t} \cdot \left[\frac{k}{k^*} \right]^{\alpha} - 1 = \frac{\gamma \cdot \theta}{1 + \gamma \cdot i^*}$$
 (28)

Equation (28) suggests that a small open economy will respond to a lasting IRD (θ) with chronic inflation, or economic specialization, or a combination of the two. The limited case further suggests that long-term inflation and specialization can be hindered by a zero interest rate differential; i.e., $\theta = 0$ when $\gamma \neq 0$. Samuelson (1965) argued that if there is no

¹³That is, either $\psi_p = 1 = \psi_w$ or $\psi_p = \psi_w$.

specialization between two countries, then interest rates should equalize. In a similar vein, Stiglitz (1970) demonstrated that unless two identical countries have identical long-run interest rates ($\theta = 0$), at least one of the two countries must specialize. But neither Samuelson nor Stiglitz assumed different currencies for the two countries, but a single currency for both of the countries.

Assuming a single currency for both countries translates into assuming one price $(P = P^*)$. The new model does not assume one price; it assumes the law of one price gap. This difference allows the currency to respond to lasting higher funding costs by depreciating, in addition to specialization. But a depreciation affects the price level, causing lower real wages, and unless the wage gap changes, it will be corrected by higher nominal wages. Therefore, a cycle of depreciation, inflation, and wage drift can be initiated. The new model adds to the work done by Stiglitz and Samuelson and demonstrates how an exchange rate adjustment, is as likely as a specialization, as a response to a lasting interest rate differential.

Lastly, we compare the model's predictions with empirical data. The model's forecasts are based on the interest rate differential time series inputs, see Figure 2. All of the cases studied substantiate the model's long-term prediction capability. Based on the model, the current and past currency depreciations (Argentina, South Africa, Indonesia, Chile, India, Turkey, and Iceland), were predictable, just as the stable and appreciating currencies of Korea and Switzerland, respectively. The model is focused on long-term currency development and omits how an interest rate raise can potentially boost the currency temporally. A forecasting model that combines both short- and this model's long-term effects was developed by Egilsson (2019).

4. Conclusion

The intuition behind the new model is that higher funding costs affect the relative competitiveness of production. In the long run, a less favorable funding environment is reflected in the price level and affects exports if exporters can only offset higher funding costs by raising export prices. But higher export prices cut into demand, which adversely affects the current account and causes the exchange rate to fall. Currency depreciation and a higher price level then affect purchasing power and real wages. Unless nominal wages are raised to compensate, workers have the option of emigrating, therefore putting pressure on wages and production costs. Therefore, wages and other factors of production linked to the law of one price gap cause the producer to set even higher prices in the following period. A chronic spiral of wage drift and falling exchange rate is created.

If higher funding costs are not to be reflected in the price level, they must be offset by other production cost factors, such as wages. But because labor markets are interlinked, lower real wages are sticky. If labor emigrates in response to a lower wage level, the labor supply will shrink, exacerbating upward wage pressures. But instead of lowering wages, firms could theoretically reduce overall payroll costs by increasing capital input at the expense of labor; that is, by increasing specialization. Therefore, the capital-labor ratio k will have to increase. Such a change translates into increased investment in capital goods by the IRD country, which is profitable as long as the derived labor cost savings exceed the investment cost, and more so as the IRD widens. A likelier general response might be an adjustment through the exchange rate.

The new model demonstrates how an economy can respond in the long run to a lasting IRD through multiple channels, including increased specialization, currency depreciation, price level increase, wage level erosion, wage drift, inflation, or some

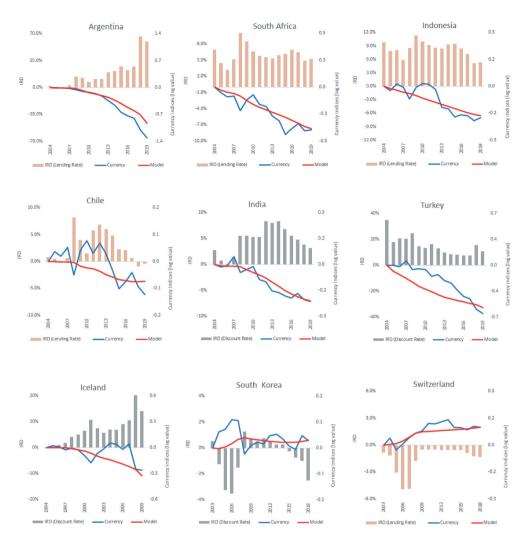


Figure 2. Currency development versus the model's long-term predictions. Note: The figures show how IRD (the difference between the local interest rates and comparable rates in the USA) and real currency development (blue) versus the model's prediction (red) based solely on IRD time series input. The IRD is either based on discount- or lending rates depending on IMF International Financial Statistics (IFS) database availability. The IRD values are on the left axis. Logarithmic values of a normalized indexes are calculated for both the real and predicted currency development. The gamma values used by the model are: Argentina (1.0), South Africa (1.0), Indonesia (0.3), Chile (0.4), India (0.7), Turkey (0.6), Iceland (0.8), Korea (1.0), Switzerland (1.0).

combination of these. Instead of a currency depreciation, lower wages or increased specialization could compensate for higher funding costs. It is not a given that all economies will respond to a higher interest rate level in the same way; instead, the response depends on various factors, i.e., the conditions of the economy in question. The model is consistent with the Stiglitz (1970) model, but we extend it on several fronts; e.g., by accounting for different currencies, which enables us to predict exchange rate responses in addition to a host of other response channels, such as specialization.

Uncovered interest rate parity (UIP) is shown to be a special simple case when y = 1, see Equation (18). The well-documented phenomena referred to hitherto as the UIP "puzzle" is analogue to γ deviating from one in the simple case. Empirical research testing the validity of UIP has indicated that the relationship between IRD and the exchange rate change is between 0 and 1.25; see, e.g., Lothian (2016). Through the lens of the simple case, this would suggest that average funding need varies from zero to 1.25 (i.e., $0 \le \gamma \le 1.25$). Might it be possible that the UIP "puzzle" reflects varying funding dependency? Why and how γ differs between economies, and potentially changes over time, is of interest and should be researched further, in addition to appropriate criteria for reference periods for y calibration.

The simple case can further explain when carry trade is a profitable investment strategy, i.e., as long as $\theta > 0$ and $\gamma < 1$, see Equation (27). The model demonstrates that a lasting IRD is not neutral for the economy but can cause multiple economic responses. Therefore, the overall response is likely to be economy-specific.

Finally, the model was tested against empirical data for nine currency areas that substantiate the model's long-term prediction capability. According to the model, the current and past currency depreciations (Argentina, South Africa, Indonesia, Chile, India, Turkey, and Iceland) were largely predictable, as were the stable and appreciating currencies of Korea and Switzerland, respectively.

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No potential conflict of interest was reported by the author.

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Appendix A Production function of two variables

If we assume that the production function to have two variables N and K, so does the profit function, $\pi(N,K)$

$$\pi(N,K) = z \cdot K^{\alpha} \cdot N^{1-\alpha} \cdot P_{t+1} - i \cdot K - w_t (1+\gamma \cdot i) \cdot N \tag{A.1}$$

We find the point of maximum profit by solving the partial derivatives for the two-variable profit function and perform a second derivative test. We start by solving the partial derivatives for the two variables

$$\frac{\partial \pi}{\partial N} = z \cdot (1 - \alpha) \cdot K^{\alpha} \cdot N^{-\alpha} \cdot P_{t+1} - w_t (1 + \gamma \cdot i) = 0 \tag{A.2}$$

$$\frac{\partial \pi}{\partial K} = z \cdot \alpha \cdot K^{\alpha - 1} \cdot N^{1 - \alpha} \cdot P_{t + 1} - i = 0 \tag{A.3}$$

By taking the sum of Equations (A.2) and (A.3) and simplifying, we obtain

$$P_{t+1} = \frac{w_t(1+\gamma \cdot i) + i}{z \cdot k(1-\alpha + \frac{\alpha}{k})}$$
(A.4)

where $k = \frac{K}{N}$.

Now we perform the second derivative test and make use of the Hessian matrix

$$H(N,K) = \begin{bmatrix} \frac{\partial^2 \pi}{\partial N^2} & \frac{\partial^2 \pi}{\partial N \partial K} \\ \frac{\partial^2 \pi}{\partial K \partial N} & \frac{\partial^2 \pi}{\partial K^2} \end{bmatrix}$$
(A.5)

We define the determinant to be

$$D(N,K) = det(H(N,K)) = \frac{\partial^2 \pi}{\partial N^2} \cdot \frac{\partial^2 \pi}{\partial K^2} - \left(\frac{\partial^2 \pi}{\partial N \partial K}\right)^2 \tag{A.6}$$

where

$$\frac{\partial^2 \pi}{\partial N^2} = -z \cdot \alpha \cdot (1 - \alpha) \cdot K^{\alpha} \cdot N^{-\alpha - 1} \cdot P_{t+1}$$
(A.7)

$$\frac{\partial^2 \pi}{\partial K^2} = -z \cdot \alpha \cdot (1 - \alpha) \cdot K^{\alpha - 2} \cdot N^{1 - \alpha} \cdot P_{t+1} \tag{A.8}$$

$$\frac{\partial^2 \pi}{\partial N \partial K} = \frac{\partial^2 \pi}{\partial K \partial N} = z \cdot \alpha \cdot (1 - \alpha) \cdot K^{\alpha - 1} \cdot N^{-\alpha} \cdot P_{t+1} \tag{A.9}$$

Solving Equation (A.6) by using Equations (A.7), (A.8), and (A.9) yields zero, which makes the critical point inconclusive. But because D(N,K)=0 and both $\frac{\partial^2 \pi}{\partial N^2}$ and $\frac{\partial^2 \pi}{\partial K^2}$ are negative (if $0 < \alpha < 1$ and $K,N,z,P_{t+1} > 0$), we can rule out the possibility that it is a local minimum.

Finding the critical point of profit function for the foreign country firm, we obtain a result similar to the one we obtained in (A.4)

$$P_{t+1}^* = \frac{w_t^* (1 + \gamma \cdot i^*) + i^*}{z \cdot (k^*)^{\alpha} (1 - \alpha + \frac{\alpha}{k^*})}$$
(A.10)

Assuming interlinked labor markets and the law of one price gap, we can use Equations (5) and (3) respectively, to rewrite Equation (A.4) as

$$\frac{P_{t+1}^*}{\psi_p \cdot S_{t+1}} = \frac{\frac{w_t^*}{\psi_w \cdot S_t} (1 + \gamma \cdot i) + i}{z \cdot k^{\alpha} (1 - \alpha + \frac{\alpha}{k})}$$
(A.11)

Inserting Equation (A.10) into Equation (A.11) gives the difference equation

$$\frac{w_t^*(1+\gamma \cdot i^*) + i^*}{z \cdot (k^*)^{\alpha} (1-\alpha + \frac{\alpha}{k^*}) \psi_p \cdot S_{t+1}} = \frac{\frac{w_t^*}{\psi_w \cdot S_t} (1+\gamma \cdot i) + i}{z \cdot k^{\alpha} (1-\alpha + \frac{\alpha}{k})}$$
(A.12)

If we assume that $w \gg i$ and $w^* \gg i^*$, then

$$w_t^*(1 + \gamma \cdot i^*) + i^* \approx w_t^*(1 + \gamma \cdot i^*)$$
 (A.13)

and

$$\frac{w_t^*}{\psi_w \cdot S_t} (1 + \gamma \cdot i) + i \approx \frac{w_t^*}{\psi_w \cdot S_t} (1 + \gamma \cdot i)$$
(A.14)

Based on this approximation, we can solve Equation (A.12)

$$\frac{S_t}{S_{t+1}} \cdot \left[\frac{\psi_w}{\psi_p} \right] \cdot \left[\frac{k}{k^*} \right]^{\alpha} \approx \left[\frac{1 + \gamma \cdot i}{1 + \gamma \cdot i^*} \right] \cdot \left[\frac{1 + \alpha + \frac{\alpha}{k^*}}{1 + \alpha + \frac{\alpha}{k}} \right]$$
(A.15)

What the two-parameter solution demonstrates, in addition to the single-parameter solution, is that capital (K) and return on capital are also factors negatively affected by a lasting wider (IRD). However, comparing the two solutions, the one- and two-variable profit functions show that the latter solution does not add much more insight than the former in terms of understanding the long-term effects of a lasting wider IRD. The benefit of the single-parameter solution is therefore that it has the potential of enhancing understanding of the potential effects of a lasting wider IRD in a simpler way than the two-parameter solution does.

Appendix B Country classification

Advanced Economies

Euro Area Δuetria Relaium Cyprus Estonia Finland France Germany Greece Ireland Italy Latvia Luxembourg Malta Netherlands Portugal Slovak Republic Slovenia Spain Australia Canada China, P.R.: Hong Kong China, P.R.: Macao Czech Republic Denmark Iceland Israel Japan Korea, Republic of New Zealand Norway San Marino Singapore Switzerland Taiwan Province of China

Emerging and Developing Asia

United Kingdom

United States

Vietnam

Bangladesh Bhutan Brunei Darussalam Cambodia China, P.R.: Mainland French Polynesia India Indonesia Kiribati Lao People's Democratic Republic Malaysia Maldives Micronesia, Federated States of Mongolia Myanmar Nauru Nepal New Caledonia Palau Papua New Guinea Philippines Samoa Solomon Islands Sri Lanka Timor-Leste Tonga Vanuatu

Emerging and Developing Europe

Albania Bosnia and Herzegovina Bulgaria Croatia Farne lelande Hungary Kosovo Macedonia, FYR Montenegro Poland Romania Serbia, Republic of Turkey CIS Armenia Azerbaijan Belarus Georgia Kazakhetan Kyrayz Republic Moldova Russia Tajikistan Turkmenistan Ukraine Uzbekistar

Western Hemisphere

Eastern Caribbean Currency Union

Anguilla Antigua and Barbuda Dominica Montserrat St. Kitts and Nevis St. Lucia St. Vincent and the Grenadines Argentina Bahamas, The Barbados Relize Rermuda Bolivia Brazil Colombia Costa Rica Curação Dominican Republic Ecuador El Salvador Guyana Haiti Honduras Jamaica Mexico Netherlands Antilles Nicaragua Panama Paraguay Sint Maarten Suriname Trinidad and Tobago Uruguay Venezuela, Republica Bolivariana de

Sub-Saharan Africa

CEMAC Cameroor Central African Republic Chad Congo, Republic of Equatorial Guinea West African Economic and Monetary Union (WAEMU) Burkina Faso Cote d'Ivoire Guinea-Bissau Niger Senegal Togo Angola Rotswana Rurundi Cape Verde Comoros Congo, Democratic Republic of Eritrea Ethiopia Gambia. The Ghana Guinea Kenya Liberia Madagascar Malawi Mauritius Mozambique Namibia Nigeria Reunion Rwanda Sao Tome and Principe Sevchelles Sierra Leone Somalia South Africa South Sudar Swaziland Tanzania Uganda Zambia

Middle East, North Africa, Afghanistan, and Pakistan

Afghanistan, Islamic Republic of Algeria Bahrain, Kingdom of Diibouti Egypt Iran, Islamic Republic of Iraq Jordan Kuwait Lebanon Libva Mauritania Morocco Oman Pakistan Qatar Saudi Arabia Sudan Syrian Arab Republic United Arab Emirates Yemen, Republic of

Figure B1. IMF country classification. Note: The countries are grouped according to the IMF International Financial Statistics (IFS) database.