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CARRY TRADES AND FINANCIAL CRISIS: AN ANALYTICAL PERSPECTIVE

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Carry Trades and Financial Crisis: An Analytical Perspective

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Abstract

This paper develops an analytical framework to explain how a liquidity shock or a shock to the aggregate haircut on collateralized assets amplifies financial crisis in a carry trade recipient country. The model allows roles for shocks to the size of a haircut, strategic behaviour across currency carry traders and the feed-back effect between asset prices and exchange rates. The paper finds that there is a threshold level of the aggregate haircut at the equilibrium. After introducing small exogenous noise, the model shows that a liquidity shock leads asset prices and the exchange rate to depart from the steady state level, triggering a financial crisis. Further, a negative shock to the interest rate differential also has the potential to trigger a liquidity crisis in the domestic market and amplify a financial crisis in the carry trade recipient country. A possible policy implication suggests that keeping policy rates low entails risks for financial systems. Therefore, instead of low interest rates and foreign exchange intervention policies, monetary authorities should focus on introducing macro-prudential regulations and establishing a sustainable and effective financial architecture to prevent future financial crisis.

Keywords: haircut, global games, unwinding carry trades, financial crisis

JEL Classification: F4, G12, F31, G01

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1 Introduction

Many countries have experienced inflows of foreign exchange driven by the carry trade during the last decade. Examples include Australia, Iceland, New Zealand and South Africa. The currency carry trade is a speculative financial operation that consists of an investment in a high interest rate currency such as the Australian dollar or the Icelandic króna (the 'investment' currency), financed by borrowing in a low interest rate currency such as the Japanese yen or the Swiss franc (the 'funding' currency). This strategy is based on the underlying motivation of exploiting profit opportunities presented by the persistently low cost of funds in one market segment combined with high returns in another, and possibly also by exchange rate variations.

Greater vulnerability to financial crises in the context of a sudden unwinding of carry positions is a vexing issue for the carry trade economies. Carry traders, such as banks or financial institutions, gain from both interest rate differentials and exchange rate movements. Traders require capital to structure a carry trade in another country, and usually borrow money from each other at the low interest rate, often using high yielding securities as collateral. The value of this collateral may exceed the amount of cash deposited in exchange for the collateralized asset. The difference between the market value of the security and the collateralized asset is called the 'haircut'. When there is a financial distortion, currency traders observe private signals about the impact of such a shock on funding constraints, this takes the form of an increase in the size of the haircut (Gorton and Metrick, 2009).

As currency traders are risk averse, they take 'precautionary hoarding' measures in distress situations such as financial market crises. During such times they expect an increase in the size of the potential haircut and a tightening in the funding constraint. If the size of the expected haircut increases, the liquidity of an individual carry trader decreases. Therefore, in order to maintain liquidity, currency traders either call back their loans made to other carry traders, or unwind their positions in the country in which the carry is invested. Withdrawal from a carry trade recipient country by one trader raises the cost for all carry traders. This may lead other carry traders to foreclose their investments in the carry trade recipient country. As a consequence, the banking system in the carry trade recipient country fails to finance itself and is forced to sell illiquid assets in their domestic market to meet funding requirements. This distress liquidation drives down the asset prices in the carry trade recipient country and leads the

exchange rate to depreciate sharply.

The goal of this paper is to provide a theoretical explanation for currency bubbles and crashes, which allows roles for strategic behaviour across currency carry traders, feed-back effects between asset prices and the exchange rate in the carry trade recipient country, and the amplification of the effects of shocks to the haircut on collateralized assets. At its core, the analytical framework presented in this paper attempts to capture how a shock such as the sub-prime shock affects carry traders through their funding constraints, forcing them to withdraw from carry trade recipient countries and leading to a sharp decline in that country's exchange rate and key asset prices such as housing.

This paper combines several strands of literature in finance and game theory. Particularly, the paper contributes to the existing literature by i) extending the theoretical framework of feed-back effects between asset prices and exchange rates as presented in Shin (2005); ii) integrating the concepts of the strategic behaviour across currency carry traders or the global game approach in Morris and Shin (1998) and Goldstein (2005); and iii) the haircut applied to collateral discussed by Gorton and Metrick (2009) and Gai et al. (2011). These three concepts have not been combined to analyse how a liquidity shock leads to an asset price bubble and ends with a severe currency crisis in the carry trade recipient countries.

This paper explores the view that positive externalities amongst traders generates a unique equilibrium path with endogenous triggers for currency bubbles and crashes. After introducing small exogenous noise to the model, this paper finds that liquidity shocks in the form of a shock to the size of the aggregate haircut, leads to a more than one-to-one decrease in both asset prices and the exchange rate in the carry trade economy. Liquidity shocks influence the behaviour of currency traders in two ways. First is the direct effect. A shock to the aggregate haircut increases premature liquidation by some carry trades, inducing a sale of assets and driving down of both asset prices and the exchange rate in the carry trade recipient country. Second is the strategic effect. As withdrawal of funds by one carry trader raises the cost for other carry traders in the market, an increase in the haircut leads them to foreclose their positions, following the *herd*[1]. This is the tendency for individual carry traders to mimic the actions of a larger group. This leads the investors in the carry trade recipient country to sell even more of their illiquid assets. As a consequence, asset prices and the exchange rate in the carry

[1]See Bikhchandani and Sharma (2000) for an overview of the recent theoretical and empirical research on herd behavior in financial markets.

trade recipient country decrease more than proportionately to the withdrawal of funds, triggering a financial crisis.

Comparative static analysis shows that a negative shock to the interest . rate differential also has the potential to trigger a liquidity crisis in the domestic market and amplify a financial crisis in the carry trade recipient country. The policy implications of this work suggests that the interaction between the size of the haircut and foreign exchange inflows has the potential to destabilize carry trades, creating a vicious cycle which drives down market prices sharply. Therefore, policy makers in the countries which are open to large inflows of foreign investments should focus on introducing macro-prudential regulations and establishing a sustainable and effective financial architecture to prevent currency crashes.

The rest of the paper is structured as follows. Section 2 motivates the concepts of the paper by drawing out the circumstances surrounding the recent carry trade collapse in Iceland. Section 3 relates this paper to the existing literature. Section 4 describes the model structure. Section 5 establishes the equilibrium asset price and the exchange rate in the carry trade country, using the equilibrium outcome of the global game among carry traders. Section 6 analyses how an exogenous liquidity shock and a shock to the interest rate differential affects the equilibrium in both the asset market and the foreign exchange market in the carry trade recipient country. This section also examines whether the behaviour of interest rates, currencies and asset prices in carry trade countries are consistent with the model. Finally, Section 7 concludes.

2 Motivation

The approach of this paper is motivated by the stylized evidence on the recent unwinding of the carry trade of the Icelandic króna. This event attracted much attention, given its alleged role in triggering the financial crisis in Iceland. Iceland has a history of high inflation and the Icelandic Central Bank, which adopted inflation targeting in 2001, kept official interest rates at high levels to curb an investment and consumption boom (Aksentic et al., 2008). The króna carried an interest rate higher than did the currencies of most developed countries as illustrated in Figure 1.

The high interest rate differentials that prevailed during the period 2006-2008 fuelled capital inflows via the banking sector and through the issuance of króna denominated Eurobonds-the so-called 'glacier bonds'. Glacier bonds became an

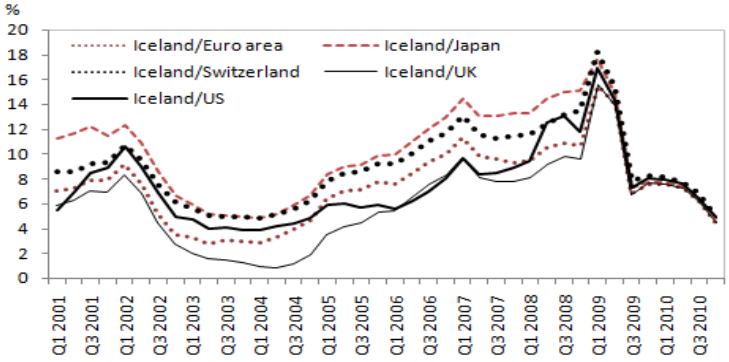


Figure 1: Selected quarterly interest rate differentials for Iceland: 2001-2010. Interest rate differentials are calculated based on the 3-months interbank LIBOR rates. (Source: Datastream)

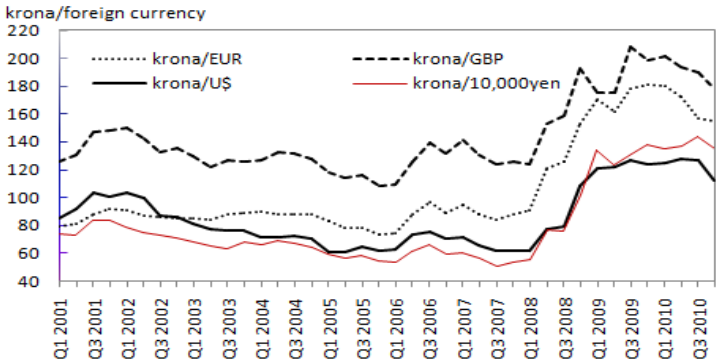


Figure 2: Selected quarterly exchange rates of the króna: 2001-2010. Exchange rates are depicted against euro, GBP, USD and yen. (Source: Datastream)

important source of funding for investment projects in Iceland (Jónsson, 2009). The main reason behind this large inflow of capital was the failure of the exchange rate channel in offsetting the effects of the weakening interest rate channel as predicted by textbook macroeconomics (Plantin and Shin, 2010). The effects of stet interest rates by the Central Bank of Iceland in response to high inflation led to a vicious circle of an appreciating exchange rate and further capital inflows (Plantin and Shin, 2010). The behaviour of the nominal exchange rate of the króna against a selection of major currencies is depicted in Figure 2.

Generally, carry trades tend to unwind during conditions of financial market stress. The unwinding of carry trades commenced with intensity in Iceland, following the US sub-prime crisis. Currency carry traders were hit with margin calls as prices of all assets began sliding in the US. To meet these margin calls, assets had to be sold, putting even more downward pressure on their prices. As

credit conditions tightened dramatically, risk appetite fell and investors sought to reduce the size of their exposure to risky trades such as the carry trade. Therefore, Icelandic banks not only had to sell their assets at fire sale prices, but also had to repay their foreign loans even when the foreign currencies were surging in value. Repatriation of foreign currency made the króna weaker, and in addition, the interest rate differential between the króna and other currencies decreased as the Icelandic Central Bank cut its official interest rate in order to stimulate the economy. Finally, the currency bubble in Iceland burst resulting in a severe financial crisis when the Icelandic banking system collapsed and a large fraction of the business sector became insolvent.

The theoretical model of this paper is presented in terms of the pre-crisis carry trade scenario where the Icelandic króna is representative of the investment currency and the US dollar the funding currency. In this model, currency carry traders borrow in US dollars at a low interest rate and deposit in Iceland in order to exploit the interest rate differential. Within this set-up, the theoretical framework is built up in three steps. First, a basic global game framework is employed to identify the threshold level of the aggregate haircut size where the actions across carry traders are strategic complements. Then, the threshold level of the aggregate haircut at which the carry traders take their decision to roll over their investment is incorporated in the feed-back model of market prices to identify the equilibrium asset prices and the exchange rate in Iceland. Finally, a small exogenous liquidity shock is introduced into the model to analyse how asset prices and the exchange rate in the carry trade recipient country behave in the face of financial distress. Because of the strategic complementarity nature of carry traders' behaviour, a liquidity shock leads the asset prices and the exchange rate to depart from the steady state level, triggering a financial crisis, as in the vicious cycle described for Iceland.

3 Related Literature

This study is related to and incorporates together three stands of literature: i) liquidity and the dynamics of arbitrage by capital or margin-constrained speculators; ii) static coordination games with private information, that is 'global games' and iii) the balance sheet approach to financial crisis.

The literature focusing on liquidity and the dynamics of arbitrage by margin-constrained carry traders shows how shocks can be amplified and result in a fi-

nancial crisis when liquidity evaporates. Traders provide market liquidity, and their ability to do so depends on the margin constraint (or the haircut) applied to collateral. This concept is clearly documented in Gorton and Metrick (2009) and Gai et al. (2011). Increases in the size of the haircut is reflected in withdrawals from securitized banks. The haircut on the securities used as collateral reflects the market risk of the collateral.

Brunnermeier and Pedersen (2009) explore the extent to which the capital and margin requirements of carry trades depend on the liquidity of assets and the important role played by liquidity constraints in amplifying financial shocks. Similarly, Kiyotaki and Moore (1997) argue that small shocks can result in large effects because of the role of collateral. A shock that lowers asset prices lowers the value of collateral, leading to a decline in net worth and less ability to borrow. As a consequence, asset prices decline further, leading to further decline in the value of collateral in a downward spiral. Existing literature also finds episodes of fire sale pricing and even destabilizing price dynamics as a result of a negative shock that tightens speculators' margin constraints (Kyle and Xiong, 2001; Xiong, 2001). However, whether the amount an investor can borrow against securities can be treated as given is still a question in doubt. For example, Kiyotaki and Moore (1997) and Geanakoplos (2010) present two different views regarding this particular issue.

The theoretical literature on global games with incomplete information is drawn on the type space of a player is whole determined by their own actions, the actions of others and noisy signals of the underlying state. With strategic complementarities, global games often have a unique equilibrium, as small noise in the players' perception of the game's payoffs makes the game dominance solvable (Morris and Shin, 2001). Morris and Shin (1998) use the method of global games based on the theory developed by Carlsson and Van Damme (1993), to show that non-common knowledge holds a unique equilibrium, depending on the value of fundamentals. Applying the global game approach in the context of bank runs, Goldstein and Pauzner (2005) solve for threshold values of switching strategies for both bank depositors and for foreign creditors. Plantin and Shin (2008), recently explore a unique equilibrium that exhibits the classic pattern of the investment currency appreciating for extended periods, followed by sharp depreciations.

Angeletos and Werning (2006) and Hellwig et al. (2006) have argued that if private information is aggregated in a large market, the global game approach may fail and the model may be characterized by multiple equilibria. However, as explained

by Plantin and Shin (2010), the global game approach has two advantages given these limitations. First, the global games approach assumes sequential trades, which arguably best describes a decentralized over-the-counter market, such as the foreign exchange market compared to simultaneous submissions of market orders. Second, equilibrium uniqueness does not rely on the presence of insiders with very accurate private information since the distinction between private and public information is immaterial here, which again seems appropriate in the case of foreign exchange markets. Therefore, the approach developed by Burdzy et al. (2001) to obtain full selection for a model in which the players' actions have inertia and fundamentals follow a random walk seems to better suit the foreign exchange market.

The final strand of literature in which this paper draws focuses on how the balance sheet position of the investment country inducing carry traders to pull back their carry positions, leading to a financial crisis. According to this approach, currency carry traders observe performances of their investments. If there is uncertainty on the liability side of the balance sheet of the investment country, currency traders may decide to foreclose their investments. Investors in the recipient country then have to pay back their loans in foreign currency. This induces a fire sale of illiquid assets and and depreciates the exchange rate. Shin (2005) shows how this feedback effect of market prices-the so-called 'liquidity black holes'-leads to unwinding carry positions, creating twin crises, namely a currency crisis and a banking crisis. Morris and Shin (2004) have also developed a formal model to capture this phenomenon.

4 The Model

The economy consists of two types of key players. i) Currency carry traders investing in Iceland who usually take the form of financial intermediaries. There are multiple entities of this type in the economy. ii) A single Icelandic commercial bank. The carry traders are identified as a continuum of risk neutral investors with unit mass. Each carry trader holds some amount of money (an endowment) to transform or invest to produce a stream of returns (Gai and Trivedi, 2009). In this model, it is assumed that each carry trader borrows US dollars from one of the other carry traders at a zero interest rate ($r = 0$) and invests in Icelandic kròna assets at a rate of r^*, where $r^* > 0$.

The model is a two period model with $t = 0$, 1 and 2. The order of events in

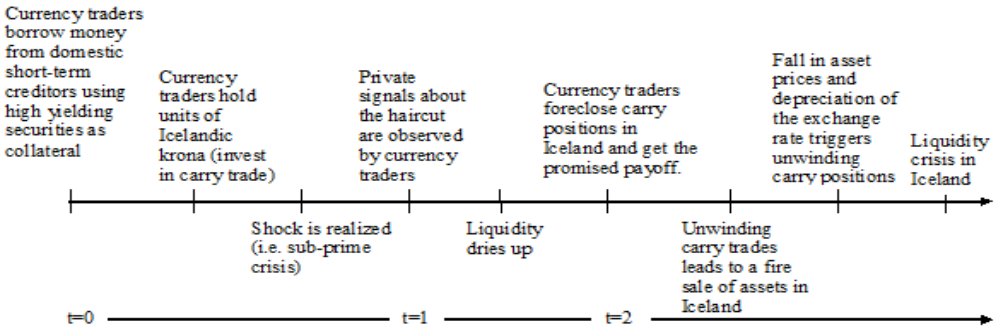


Figure 3: The order of events in the economy

the economy is depicted in Figure 3. Carry traders structure their carry trades in $t = 0$. At the end of period 1, each trader decides whether or not to roll over its funds in Icelandic kròna assets until the end of period 2, based on the liquidity condition of their respective balance sheets. If the carry traders decide to foreclose at the end of period 1, they receive the promised amount, which is less than the amount they would receive if they roll over when all other carry traders continue to do so. However, they receive nothing if they mistakenly decide to roll over when all others pull back their investment.

The return on an investment in Icelandic króna ($\pi(e)_1$) financed by borrowing in US dollars is denoted by:

$$\pi(e)_1 = \frac{R}{e_0} e_1 - \Delta e_1, \tag{1}$$

where, $R = (r^* - r)$ is the interest rate differential between Iceland and the US. The return on investment is adjusted by the exchange rate denoted by e, and is defined as units of króna per US dollar. Thus, a high value of e corresponds to a weak króna. The depreciation of the investment currency is $\Delta e_1 = \frac{e_1 - e_0}{e_0}$. The key assumption here is that the net return increases with the appreciation of the kròna/dollar exchange rate. Equation(1) is a measure of exchange rate returns in excess of the prediction under uncovered interest parity (UIP) since under UIP, $\pi(e)$ should not be forecastable:

$$E_0[\pi(e)_1] = 0.$$

One can think of $\pi(e)$ as the abnormal return to a carry trade strategy.

Figures 4(a) and 4(b) present the compositions of the balance sheets of a representative carry trader and the Icelandic Commercial Bank, respectively. Total

Assets		Liabilities	
Mortgage backed securities	A_i^m	Retail deposits	L_i^d
Kròna assets	A_i^{kr}	Short-term borrowing	L_i^{sr}
Liquid assets	A_i^l	Capital	L_i^k

(a) A representative balance sheet of an individual carry trader i, denominated in US dollars.

Assets		Liabilities	
Domestic assets $(1 \times p)$	A_{ice}^p	Domestic liabilities	L_{ice}^d
		Foreign liabilities	L_{ice}^D

(b) A representative balance sheet of the Icelandic Commercial Bank, denominated in Icelandic kròna.

Figure 4: The simplified balance sheets of individual carry trader i and the Icelandic Commercial Bank.

liabilities of each carry trader (L_i^T) are comprised of short term borrowing secured with collateral (L_i^{sr}), retail deposits (L_i^d), and Capital (L_i^k). The total assets (A_i^T) of the individual carry trader i are comprised of mortgage backed assets (assets which can be used as collateral) (A_i^m), Icelandic króna assets (A_i^{kr}), and fully liquid assets such as cash and government bonds (A_i^l). These fully liquid assets can be used as collateral to obtain financing for investment, without the risk of a haircut.

The total liabilities of the Icelandic commercial bank (L_{ice}^T) are comprised of domestic liabilities (L_{ice}^d) and foreign currency liabilities (L_{ice}^D) which is equal to A_i^{kr}/e. The total assets (A_{ice}^T) of the Icelandic commercial bank is comprised of 1 unit of domestic assets, (A_{ice}^p), and 0 units of foreign assets, where p is the asset price.

Traders need capital to structure carry trades in Iceland. When carry traders buy securities, they can use these securities as collateral to borrow against. However, they cannot borrow the entire market value of the security. Thus, carry traders finance the difference between the market value of the security and the collateralized asset (the haircut) by other sources of funding. The model assumes that the amount invested by an individual carry trader in the Icelandic commercial bank by way of the carry trade is A_i^{kr}, and is financed by short term borrowing from other domestic carry traders using mortgage backed securities (A_i^m) as collateral, along with their own capital. It is assumed that the aggregate haircut associated with A_i^m to obtain financing for a carry investment is denoted by h. At

the same time, the model allows for the possibility of an individual lender-specific haircut, h_i. Therefore, the maximum amount of short term borrowing that can be obtained by an individual carry trader using A_i^m as the collateral asset is:

$$(1 - h - h_i)A_i^m, \tag{2}$$

in which $h_i, h\epsilon(0, 1)$. The remainder, $(h + h_i)A_i^m$, should be financed by carry trader i with their own capital. From the balance sheets of the two key players, it is clear that $A_i^{kr} = (L_{ice}^D)e$. The model assumes that an individual carry trader can use the Icelandic króna assets they hold as collateral to raise funds. These assets are also subject to the same aggregate and idiosyncratic haircuts. Therefore, the maximum amount of funding that an individual carry trader can obtain using kròna assets as collateral is $(1 - h - h_i)A_i^{kr}$.

Haircuts play an important role in financial markets. Haircuts are determined by participants in the market and are subject to change (Gorton and Metrick, 2009). The fluctuations in the value of the haircut determines the degree of funding available to a leveraged carry trader, since the haircut determines the maximum permissible leverage of the borrower. If the haircut is 2 per cent, the borrower can borrow 98 US dollars for 100 dollars worth of securities as collateral. Meaning that the borrower provides 2 dollars of equity. In this case, the maximum permissible leverage ratio, defined as the ratio of assets to equity, is 50. In the case of an adverse shock hitting the economy, the shock raises the haircut as asset values fall, and thus the borrower must either sell assets or raise more equity to find the gap. Assume that the haircut rises to 4 per cent, for example. Then, the permitted leverage ratio halves from 50 to 25. This implies that the borrower must either double the equity or sell half the assets or some combination of both (Gorton and Metrick, 2009).

Haircuts are associated with funding constraints. The more carry traders borrow in US dollars from the other carry traders in the market, the more relaxed the funding constraint, as the margin (or the haircut) drops. If a carry trader invests in Iceland, the cost of borrowing for other carry traders decreases. This encourages other carry traders to invest in Iceland, leading the price of assets to increase and the value of the kròna to appreciate. Therefore, the funding cost of maintaining the carry trade position depends on changes in the value of collateral in the funding currency (Gai and Trivedi, 2009). The sensitivity of the value of collateral to the flow of funds suggests that traders' decisions are strategically interrelated (Plantin and Shin, 2008). Therefore, the carry traders create positive

externalities for each other as they invest their endowment in high-yielding Icelandic assets. The greater the flow of funds into such assets, the greater the flow of profit that carry traders can earn.

Let the aggregate haircut, h, for the carry trader i be a function of the fraction of carry traders who foreclose their investment in Iceland, l, at the end of period 1. More precisely,

$$h = \bar{h} + \gamma l, \tag{3}$$

in which $\gamma \geq 0$ and $0 \leq l \leq 1$. The parameter γ measures the sensitivity of unwinding carry trades to the aggregate haircut and therefore the sensitivity to the funding constraint in the domestic market. If $\gamma = 0$, the fraction of carry traders who foreclose their investment in Iceland is insensitive to the funding constraint and $h = \overline{h}$, is the fundamental value. However, if $\gamma > 0$, there are negative network externalities, where an individual carry trader's decision to roll over its investment in Iceland is dependent on the actions of other carry traders, thereby decreasing the price of assets. If all the carry traders decide to roll over their funds in Iceland until the end of the period 2 ($l = 0$), the aggregate haircut is equal to its fundamental value. However, if γ is large enough, even a small fraction of carry traders fleeing from Iceland can have a significant impact on the haircut and thus the funding constraint.

An individual carry trader's decision on foreclosing carry trades in Iceland basically depends on the liquidity condition of the balance sheet. On the whole, a carry trader will remain liquid in each period provided that the amount of collateral available to raise funds is sufficient to cover the short term borrowing the carry trader has to repay. The carry trader has to finance the haircut from their own capital given any idiosyncratic liquidity shock, M_i. Given the balance sheet and the haircut assumptions above, and noting that $L_i^{sr} = (1-h-h_i)A_i^m+(h+h_i)A_i^m = A_i^m$, this implies that an individual carry trader is liquid if:

$$A_i^L + (1-h-h_i)A_i^m + (1-h-h_i)A_i^{kr} - A_i^m - M_i \geq 0. \tag{4}$$

Simplifying the above equation gives:

$$A_i^L - (h+h_i)A_i^m + (1-h-h_i)A_i^{kr} - M_i \geq 0. \tag{5}$$

Exogenous liquidity shocks, or shocks to aggregate or idiosyncratic haircuts, have the potential to trigger a liquidity crisis for carry trader i, if that carry trader is unable to raise enough funds to maintain the liquidity condition in Equation

(5). It is also clear that a sufficiently large shock to the aggregate haircut has the potential to trigger widespread liquidity stress, not only among other carry traders, but also in Iceland.

If a carry trader does not meet the liquidity condition stated in Equation (5), action needs to be taken to avoid defaulting on required payments. There are a few options. A carry trader can increase the interest rate on new liabilities in order to obtain sufficient new funding; liquidate fixed assets in a fire sale; hoard liquidity by withdrawing loans made to other carry traders; or hoard liquidity by unwinding carry trades in Iceland. The first two options are the least attractive as they may reduce a carry trader's future profitability and weaken the capital position. Thus a carry trader may prefer to withdraw loans made to other carry traders, or to unwind carry trades in Iceland.

To keep the model simple, it is assumed that carry trader i calls back the carry positions in Iceland. Because of this decision to unwind, a carry trader will lose a portion of the carry investment. In other words, the carry trader will only get the previously agreed amount, which is less than would be received at the end of period 2 if the project succeeded. The amount that the carry trader will receive because of the foreclosure decision can be stated as:

$$\theta[\frac{e_1 - e_0}{e_0} + r^* \frac{e_1}{e_0}]A_i^{kr} \tag{6}$$

in which $0 \leq \theta \leq 1$, e_0 is the exchange rate prevailing at the time carry trader i invested in the Icelandic commercial bank, and e_1 is the exchange rate at the time the individual carry trader receives the return on investment in Iceland. Here θ represents the proportionate amount that each carry trader gets from unwinding its position in Iceland. Carry trader i's liquidity condition now becomes:

$$A_i^L - (h + h_i)A_i^m + (1 - h - h_i)A_i^{kr} + \theta[\frac{e_1 - e_0}{e_0} + r^* \frac{e_1}{e_0}]A_i^{kr} - M_i \geq 0. \tag{7}$$

Simplifying Equation (7), and linking with the net worth of the Icelandic commercial bank using the fact that $(A_{ice}^p - L_{ice}^d)e_0 = A_i^{kr}$, the liquidity condition of an individual carry trader can be stated as follows:

$$A_i^L - (h + h_i)A_i^m + (1 - h - h_i + \theta[\frac{e_1 - e_0}{e_0} + r^* \frac{e_1}{e_0}])(A_{ice}^p - L_{ice}^d)e_0 - M_i \geq 0. \tag{8}$$

From Equation (8), it is clear that the value of θ is also a key determinant of the strength of the amplification of shocks in the model. The lower the value of

θ, the larger the shocks that can hit the liquidity condition of carry traders. In principle, the proportionate amount that each carry trader gets from unwinding their position in Iceland depends on the net worth of the Icelandic commercial bank and how much liquidity a carry trader needs to raise to meet the liquidity condition. If $\theta = 1$, the carry trader will receive the entire amount invested and the profit earned on that investment, without any loss. However, at the other extreme, $\theta = 0$ would correspond to an entire loss of the carry trade and the currency trader would receive nothing from investing in the Icelandic commercial bank. If one carry trader flees from Iceland, this raises the costs for all carry traders, and thus may lead the other carry traders to foreclose their investments in the carry trade country.

Carry traders move into the carry trade if and only if they believe $l_{t+1} < l_t$. According to Equation (1), carry traders move into carry trade whenever the expected profit is positive. Carry traders invest in Iceland when the interest rate differential is greater than zero ($r^* - r > 0$). Therefore, net profit is positive when $e_1 - e_0 < 0$. In other words, the net flow of the carry trade increases if the króna appreciates. A strong exchange rate implies a higher dollar value of collateral and a lower cost of borrowing. This happens when $l_{t+1} < l_t$. This means that carry traders move into the carry trade market in Iceland if they believe that the fraction of carry traders who flee in the next period will be smaller than in the current period, or that the fraction of carry traders who hold króna in the next period will be greater than in the current period.

5 Equilibrium

5.1 Equilibrium aggregate haircut

Noisy signal

Suppose that each carry trader receives a noisy signal (x_i) about liquidity, or the aggregate or idiosyncratic haircut, in the face of tightening credit supply in a period of financial market distress. Then,

$$x_i = h + h_i, \tag{9}$$

in which the noise terms or the idiosyncratic component of the carry trader i's signal, h_i, are independent and identically distributed (i.i.d.) and have uniform density over the interval $[-\varepsilon, \varepsilon]$. Note that h_i and h_j are independent when $i \neq j$,

and h_i is independent of h. As the common element of the signal, h, itself has a uniform *ex ante* distribution, signals $\{x_i\}$ are also uniformly distributed over the interval $x_i \sim u[h-\varepsilon, h+\varepsilon]$.

A strategy for carry trader i is a decision rule that maps each realization of x_i to an action, i.e. to roll over the loan, or not. The equilibrium of this sub game is a profile of strategies, so that a carry trader's strategy maximizes the expected payoff, conditional on the information available, when all other carry traders follow the strategies in their own profile. Following Morris and Shin (1998) the model solves for an equilibrium in terms of 'threshold strategies', which are strategies where a carry trader has a critical realization of x^*. If the realization of x_i is above x^*, then carry trader i will foreclose their investment and if x_i is below x^*, then carry trader i will roll over. This implies that there is a threshold level h^*, below which carry traders will continue to invest in Iceland.

Critical level of the signal (x^*) and the threshold level of the size of the haircut (h^*)

The next step is solving for the critical signal x^* and the threshold level h^* simultaneously. The mass of carry traders who flee are those with signals to the right of x^*:

$$l = \frac{h+\varepsilon-x^*}{2\varepsilon}. \tag{10}$$

Therefore, at the critical state h^*,

$$h^* = \bar{h} + \gamma[\frac{h+\varepsilon-x^*}{2\varepsilon}]. \tag{11}$$

Now there is one equation with two unknowns, h^* and x^*. If the carry trader rolls over the funds in Iceland, the net gain is $\pi(e)_1 = [(1+r^*)e_1/e_0] - e_0$ and if the carry trader forecloses, the net gain is only a fraction, denoted by $\theta\pi(e)_1$. If the carry trader rolls over when others flee, the carry trader loses everything. Conditional on x, the state h is distributed uniformly over the interval $[x-\varepsilon, x+\varepsilon]$. Therefore, the expected payoff from rolling over, conditional on getting a signal x is:

$$\pi(e)_1 \cdot \frac{h^*-(x-\varepsilon)}{2\varepsilon} + 0 \cdot \frac{x+\varepsilon-h^*}{2\varepsilon}, \tag{12}$$

and the payoff from foreclosing is non-random and given by:

$$\theta\pi(e)_1. \tag{13}$$

At the switching point, x^*, the domestic creditor bank is indifferent to rolling over and foreclosing. Therefore, at x^*,

$$\pi(e)_1 \cdot \frac{h^* - (x - \varepsilon)}{2\varepsilon} = \theta\pi(e)_1 \tag{14}$$

or

$$h^* - x^* = \varepsilon(2\theta - 1). \tag{15}$$

Solving equations (11) and (15) together,

$$h^* = \bar{h} + \gamma\theta. \tag{16}$$

There is a threshold level of the aggregate haircut. Above the threshold carry traders do not meet the liquidity condition stated in Equation (8) and thus they unwind carry trades in Iceland, and below the threshold the opposite holds. Equation (16) says that the threshold level of the aggregate haircut linearly depends on the amount that the carry trader receives at foreclosure at the end of the period 1. In other words, the threshold level of the aggregate haircut is an increasing function of the marginal cost of premature liquidation. An important feature of the solution is that h^* does not depend on the size of the noise term, ε. The switching point x^* in terms of margin requirement, or the aggregate haircut is:

$$x^* = h^* - \varepsilon(2\theta - 1). \tag{17}$$

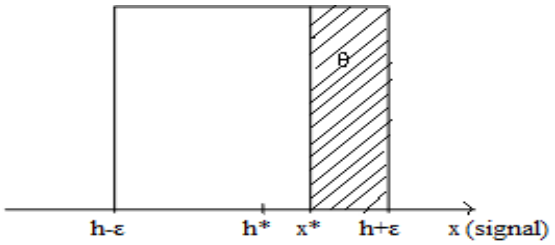
This implies that:

$$h^* = x^* + \varepsilon(2\theta - 1). \tag{18}$$

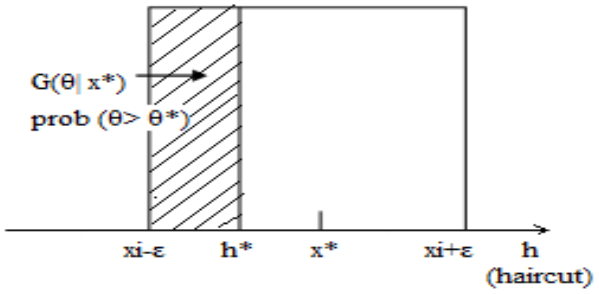
The net effect of the equilibrium of the global game depends on the interplay between fundamental uncertainty, which is uncertainty concerning the state of nature (h), and strategic uncertainty, which is uncertainty concerning the actions of other investors. In the limiting case, where the carry traders are perfectly informed about the collateral constraint which they face ($\varepsilon \to 0$), the switching point x^* is exactly equal to the critical level, h^*. Thus, there is no fundamental uncertainty. However, the strategic uncertainty is unchanged even when the private signals become common knowledge.

Deriving cumulative distribution function $G(. \mid x^*)$

Then, it is interesting to know the probability that l is greater than θ if carry traders receive the signal x^*. The answer to this question yields the value of the cumulative distribution function $G(. \mid x^*)$. The steps to deriving the cumulative



(a) Uniform distribution of the signal x_i over the interval $(\theta - \varepsilon, \theta + \varepsilon)$ when the common element of the signal is h.



(b) The posterior density over h, given $x_i(= x^*)$.

Figure 5: Derivation of the cumulative distribution function $G(\theta|x)$:(a) Uniform distribution of the signal x_i over the interval $(\theta - \varepsilon, \theta + \varepsilon)$ when the common element of the signal is h (b) The posterior density over h, given $x_i(= x^*)$.

distribution function are illustrated in Figure 5 and the density over l is then derived by differentiating this function. It is clear that $l > \theta$ when h is sufficiently high, so that the area under the density to the right of x^* is squeezed out. There is a value of h at which l is precisely equal to θ and this occurs is when $h = h^*$. Panel (a) of Figure 5 shows the uniform distribution of the signal x_i over the interval $[\theta - \varepsilon, \theta + \varepsilon]$ when the common element of the signal is h. Carry traders who foreclose their positions in Iceland are those who face haircut above x^*. This mass is given by the shaded area.

The individual carry trader's posterior density over h conditional on x^* is used to determine the probability of $l > \theta$. As the *ex ante* distribution over h is uniform, this posterior density is uniform over the interval $[x_i - \varepsilon, x_i + \varepsilon]$. Panel (b) of Figure 5 depicts this posterior density over h. The probability that $h > h^*$ is the area under the density to the left of h^*. This is:

$$\frac{(x^* + \varepsilon) - h^*}{2\varepsilon} = \frac{(x^* + \varepsilon) - (x^* + \varepsilon - 2\varepsilon\theta)}{2\varepsilon} = \theta. \tag{19}$$

This means that the probability of $l < \theta$ conditional on x^* is exactly θ. The cumulative distribution function is:

$$G(\theta \mid x^*) = \theta. \tag{20}$$

The density over l is obtained by differentiation of the above equation:

$$g(l \mid x^*) = 1 \quad \text{for all } l. \tag{21}$$

That is, the density over l is uniform. This result also shows that the constant ε does not enter into the expression for the density over l. Thus, the changing ε squeezes or stretches the respective regions, but does not alter the fact that the two regions are equal in size.

From Equations (16) and (17) we can see that:

$$x^* = \bar{h} + \theta(\gamma - 2\varepsilon) + \varepsilon. \tag{22}$$

Therefore, with sufficiently small ε, the switching point x^* is an increasing function of the cost of premature liquidation. It is also necessary to verify that the switching strategy around x^* is the optimal strategy for an individual carry trader when used by all other carry traders. If $x_i > x^*$, fewer carry traders will hold Icelandic kròna assets, indicating an increase in l. Thus the optimal strategy is to opt out. Conversely, if $x_i < x^*$ the optimal strategy is to move into the carry trade. Morris and Shin (2002) have clearly verified this proposition.

5.2 Equilibrium asset prices and the exchange rate

The solution for the threshold level of h at which the carry traders take their decision to roll over or unwind their carry trade positions in Iceland can now be used in analysing how asset prices and the exchange rate in Iceland respond to the liquidity shock in the US. As carry traders' decisions exhibit strategic complementarity, or as the reaction among carry traders is reinforced, they begin to follow the herd. This study attempts to show that due to the strategically complementary nature of this behaviour, carry traders' attempts to take the most safe action in the period of financial stress causes the exchange rate of the kròna to depreciate against the dollar and the price of illiquid assets in Iceland to fall, leading to a currency crisis.

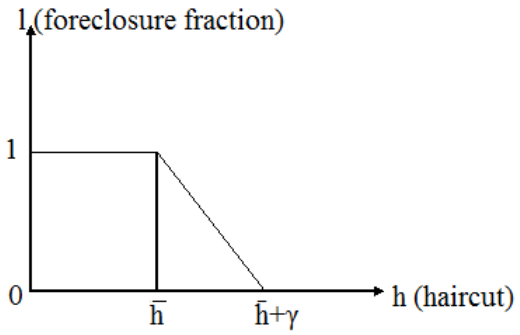


Figure 6: The proportion of carry traders who foreclose their positions.

Decision on foreclosing carry investment

Consider the carry trader's decision. A carry trader now knows the fundamental value of the haircut, $\bar{h}$ and the idiosyncratic component of the haircut, h_i. Also consider the threshold level of the aggregate haircut in Equation (16) obtained by solving the global game. This implies that there is a threshold level of the aggregate haircut above which an individual carry trader forecloses investment in Iceland. In other words, if $\bar{h} + \gamma l > h^*$, the carry trader's liquidity constraint tightens, and thus pulls back the carry positions in Iceland. If all the carry traders flee from Iceland, the aggregate haircut is $\bar{h} + \gamma$, the upper level. At the other extreme, if no one flees, the aggregate haircut is $\bar{h}$, the lower limit. Therefore, if $h^* > \bar{h} + \gamma$, the carry trader will certainly roll over funds in Iceland. However, the carry trader flees from Iceland if $h^* < \bar{h}$. Therefore, an individual carry trader remains liquid if $\bar{h} + \gamma < h^*$. These facts indicate that:

$$\bar{h} + \gamma < h^* < \bar{h}. \tag{23}$$

Given the decision rule (23), carry traders' behaviour can be depicted as in Figure 6 below.

Following Shin (2005), assume that the downward sloping portion of the foreclosure curve, l, is linear and given by:

$$l = f - c[(A_i^L - (h + h_i)A_i^m + (1 - h - h_i + \theta(\frac{e_1 - e_0}{e_0} + r^* \frac{e_1}{e_0}))(A_{ice}^p - L_{ice}^d)e_0] \tag{24}$$

in which f and c are positive constants. Terms in the square brackets are the net worth of an individual carry trader and this is denoted q for simplicity. Thus $l = f - cq$.

Total sale of illiquid assets

If all carry traders continue to invest in Iceland, the total sales, s, of the illiquid assets by the Icelandic commercial bank are 0. However, the Icelandic commercial bank has limited discretion when carry traders refuse to roll over their dollar investment. The Icelandic commercial bank then has to sell the illiquid assets to meet the funding need. Given the foreclosure decision of the carry traders, total sales of the Icelandic commercial bank must be such that this raises enough dollar revenue to repay the carry traders. Let $\bar{x}$ be the total holding of illiquid assets by the Icelandic commercial bank. The kròna value of sales is ps and the total dollar value of the sales is $ps.e$. Then from Equation (8), total sales s satisfies:

$$s = \begin{cases} 0 & \text{if } h^* > \bar{h} + \gamma \\ l/q & \text{if } l/q < \bar{x} \text{ and } h^* < \bar{h} + \gamma \\ \bar{x} & \text{otherwise.} \end{cases} \tag{25}$$

Equilibrium asset price

The total sale of domestic assets is decided by the dollar value of the illiquid assets holding over the dollar liabilities to the carry traders. Illiquid assets are sold in the domestic market in Iceland. The equilibrium price of the asset is determined within this market. Assume that the demand curve for the Icelandic kròna asset is downward sloping and linear, given by:

$$p = \bar{p} - bs. \tag{26}$$

If there is no foreclosure by the carry traders, the equilibrium price of the asset is $\bar{p}$ (in kròna). However, if carry traders foreclose their positions, the equilibrium price will be lower than $\bar{p}$. Substituting the sales equation into the demand equation, we can derive a relationship between the exchange rate (e) and the asset price (p).

$$p = \begin{cases} \bar{p} & \text{if } h^* > \bar{h} + \gamma \\ \bar{p} - b((f/q) - c) & \text{if } l/q < \bar{x} \text{ and } h^* < \bar{h} + \gamma \\ \bar{p} - b\bar{x} & \text{otherwise .} \end{cases} \tag{27}$$

This equation links the exchange rate with the asset price and the relationship is depicted in Figure 7.

According to the above relationship, the price, p, of the illiquid asset is a function of the exchange rate, e, and the haircut, h. In the region where $h^* \geq \bar{h}+\gamma$,

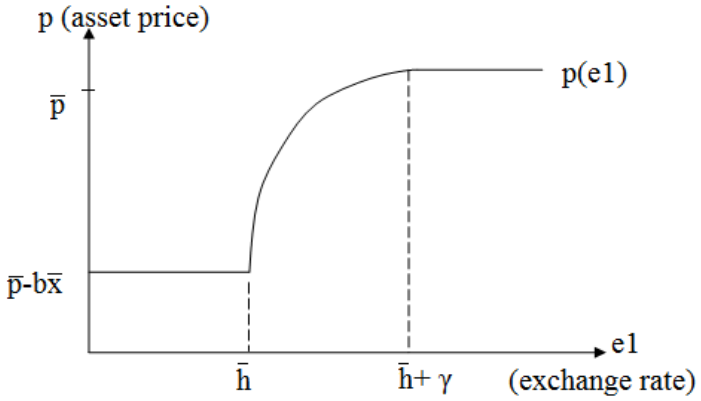


Figure 7: Asset price.

there is no foreclosure by carry traders, and $s = 0$. Therefore, the price of the illiquid assets is equal to $\bar{p}$. However, with $s > 0$, the price of the illiquid assets in Iceland decreases. This, in turn, affects the liquidity level of the carry trader. Putting it another way, a decline in the price of the illiquid assets in Iceland would makes it difficult for a carry trader to maintain the liquidity requirements given in Equation (8), or to tighten the liquidity constraints or increase the haircut. If it is difficult for a carry trader to meet the liquidity requirements, the carry trader will foreclose additional investments, forcing the Icelandic commercial bank to sell increasingly more of its illiquid assets.

Shin (2005) clearly explains that the increased sale of illiquid assets under such a situation is more than proportionate to the foreclosure by the creditor banks, as the domestic bank has to sell a greater amount of domestic assets to raise the same amount of dollars when the exchange rate depreciates. Increasing the haircut in the US triggers premature liquidation by carry traders, thereby inducing a fire sale and reducing the price of assets in Iceland. Thus, the price of illiquid assets declines faster as the exchange rate depreciates and as the aggregate haircut increases. The locally concave shape of the $p(e)$ curve depicted in the Figure 7 illustrates this claim. This decline in price continues until the entire illiquid asset has been sold on the market. At this point, $s = \bar{x}$ and from this point onward, $p = \bar{p} - b\bar{x}$.

Equilibrium exchange rate

Another equation that links the exchange rate and asset price can be obtained from the equilibrium condition in the foreign exchange market. The exchange rate, e, is

a decreasing function of short term sales of kròna and purchase of dollars, which arises from the foreclosure decision of the carry traders. Again, following Shin (2005), denote the linear short run demand curve as:

$$e_1 = \bar{e} - \tau l, \tag{28}$$

in which $\tau > 0$. In the absence of the sale of assets, the exchange rate is equal to $\bar{e}$, a constant. In other words, if none of the carry traders foreclose their investments in Iceland, $e = \bar{e}$. The degree of the short run illiquidity in the foreign exchange market is measured by the parameter τ. Therefore, a larger τ indicates that even a small amount of sale of illiquid assets leads the exchange rate to depreciate. A consequence of the depreciation of the exchange rate for the carry trader is a decline in the pay-off from premature liquidation.

As the carry trader's foreclosure decision is based on the rollover rule given by Equation (8), a relationship between the exchange rate and asset price can be derived as follows:

$$e_1 = \begin{cases} \bar{e} & \text{if } h^* > \bar{h} + \gamma \\ \bar{e} - \tau[f - cq] & \text{if } l/q < \bar{x} \text{ and } h^* < \bar{h} + \gamma \\ \bar{e} - \tau & \text{otherwise.} \end{cases} \tag{29}$$

Equations (27) and (29) link the exchange rate e_1 with the asset price p. Equation (27) is the equilibrium condition in the illiquid asset market and Equation (29) is the equilibrium in the foreign exchange market. Following Shin (2005), these two equations can be plotted simultaneously in (p, e_1) space by defining the curve $g(p)$ as the inverse of the $p(e_1)$ curve. More specifically:

$$g(p) \equiv p^{-1}(e_1).$$

This relationship is depicted in Figure 8. The intersection of the $g(p)$ and $e_1(p)$ curves at E determines the equilibrium e_1 and p.

As discussed earlier, the margin requirement or the haircut plays an important role in triggering financial shocks. When there is a shock to the haircut, the margin requirement increases, making it difficult for a carry trader to maintain a healthy level of liquidity. Thus, the carry trader pulls back its investment in Iceland. This raises the cost for other carry traders and triggers the withdrawal of carry investments. As the sale of illiquid assets is more than proportionate to the foreclosure, the decline in the price of illiquid assets and the depreciation of the exchange rate is sharper than in the model developed by Shin (2005).

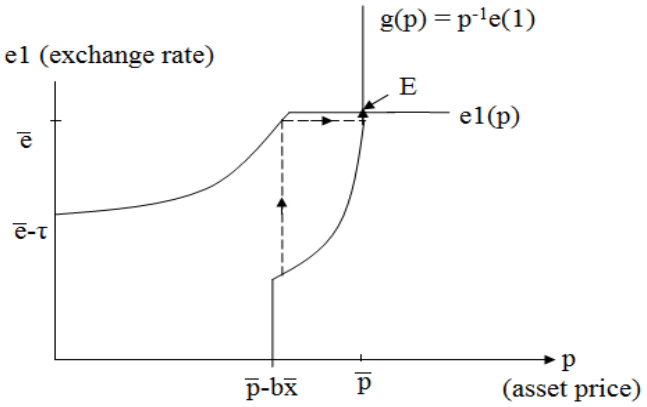


Figure 8: Determination of the equilibrium asset price and exchange rate.

Equilibrium during a period of financial market stress

According to Figure 8, it is clear that if prices drop by a small amount due to an exogenous shock, the system returns to the initial equilibrium, E. However, when the liquidity shock or the shock to the aggregate haircut is large enough, the carry trader cannot meet the liquidity requirements. Thus, premature liquidation after the liquidity shock pushes the economy to a situation of distress. If a large fraction of carry traders pulls back their investment due to the increase in the haircut ($s > 0$), the asset price decreases. A low asset price induces further selling of illiquid assets putting pressure on the exchange rate and tightening the liquidity constraint. This further depresses the asset price. The equilibrium in the periods of financial market stress implies low values for both the exchange rate and the asset price. This situation is depicted in Figure 9 and it is clear that the high asset price $\bar{p}$ is not sustainable in this case.

6 Comparative Statics and Discussion

A set of comparative static results can be now used to analyse how a shock affects the equilibrium in the asset and the foreign exchange markets. More specifically, this section examines the comparative statics effects of i) a liquidity shock or a shock to the aggregate haircut and ii) a shock to the interest rate differential.

6.1 Liquidity shock or shock to the aggregate haircut

This section examines how the foreclosure curve behaves in response to a sudden change in the level of the aggregate haircut. Consider the foreclosure equation

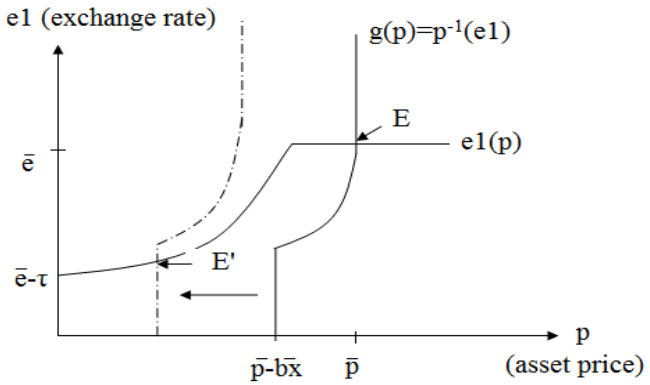


Figure 9: Equilibrium asset price and exchange rate during a period of financial market stress.

given in Equation (24). The fraction of carry traders who foreclose at the end of period 1 is a function of the aggregate haircut. Differentiating Equation (24) with respect to h gives

$$\frac{\partial l}{\partial h} = c[A_i^m + (A_{ice}^p - L_{ice}^d)e_0]. \tag{30}$$

If the Icelandic commercial bank has enough assets to cover its liabilities, there is a positive relationship between the aggregate haircut and the fraction of carry traders who flee from Iceland in the face of tightened liquidity constraints.

The total sale equation in Equation (25) clearly shows that an exogenous liquidity shock, or a shock to the aggregate haircut induces the sale of illiquid assets in Iceland.

$$\frac{\partial s}{\partial h} = \frac{f[A_i^m + (A_{ice}^p - L_{ice}^d)e_0]}{[q]^2}. \tag{31}$$

More interesting is the comparative statics of asset price p and the exchange rate e with respect to the size of the haircut h. In other words, this section analyses how the equilibria in the asset market and the foreign exchange market in Iceland change in response to an exogenous increase in the aggregate haircut applied to collateral. As can be clearly seen from Equation (27), $p = \bar{p}$ if $h^* > \bar{h} + \gamma$ and $p = \bar{p} - b\bar{x}$ if $h^* < \bar{h}$. Therefore, our interest lies in the downward sloping part of the demand function. Comparative statics shows that:

$$\frac{\partial p}{\partial h} = -\frac{bf(A_i^m + (A_{ice}^p - L_{ice}^d)e_0)}{[q]^2}. \tag{32}$$

Similarly, differentiate Equation (29) with respect to h to obtain

$$\frac{\partial e_1}{\partial h} = -\frac{\tau c(A_i^m + (A_{ice}^p - L_{ice}^d)e_0)}{\gamma\theta c[(A_{ice}^p - L_{ice}^d)(2 - r^*)]}. \tag{33}$$

Given that the Icelandic commercial bank remains liquid, that is $A_{ice}^p > L_{ice}^d$,

$$\frac{\partial p}{\partial h} < 0 \text{ and } \frac{\partial e_1}{\partial h} < 0.$$

Accordingly, an exogenous shock to the aggregate haircut applied to collateral has the potential to decrease asset prices and to depreciate the exchange rate between the króna and the US dollar. As the aggregate haircut increases, the fraction of carry traders who foreclose their carry position increases. This induces the sale of illiquid assets in Iceland, pushing down the asset price and the exchange rate. As a consequence of this exchange rate depreciation, the profit that a carry trader can earn declines. Thus, some carry traders may not meet their liquidity requirements. So, they call back their carry trade positions, inducing the sale of assets and driving down the asset price and the exchange rate.

As can be seen from Equations (32) and (33), the marginal increase in the aggregate haircut leads to a more than one-to-one decrease in asset price and the exchange rate. This reflects two separate factors. First is the direct effect. An increase in the aggregate haircut makes it difficult for an individual carry trader to maintain its liquidity requirement. So, the carry trader calls back the investment in Iceland. This premature liquidation, in turn, leads the Icelandic commercial bank to sell its illiquid assets and pay back the required amount in dollars. As a consequence, the equilibrium asset price and the exchange rate decrease.

The second effect is the strategic effect. This arises from the herd behaviour of carry traders. The increase in the haircut applied to collateral leads the carry trader to foreclose the carry positions in Iceland. Withdrawal by one carry trader raises the cost for other carry traders in the market. So, the number of carry traders who flee from Iceland starts to increase. Because of the strategic complementary nature of carry traders' behaviour, they tend to follow the herd. As the other carry traders flee from Iceland, the Icelandic commercial bank has to increasingly sell its illiquid assets. That is there is an asset fire sale. As h and s increase, the asset price in Iceland decreases more than proportionately. At the same time, the exchange rate depreciates as the Icelandic commercial bank converts króna into dollars. To the extent that the strategic effect increases the tendency of carry traders to unwind their carry positions, it triggers the fall in asset price and the depreciation of the exchange rate. Therefore, an exogenous liquidity shock, or a

shock to the aggregate haircut, amplifies the widespread liquidity constraints not only among carry traders, but also in the carry trade country.

6.2 Shock to the interest rate differential

By definition, the carry trade is a popular trading technique in the foreign exchange market that seeks to capitalize on the interest rate differential between currencies. However, if the interest rates of the currencies involved in carry trades are variable, it creates a risk for the currency carry trader as any increase in the interest rate of the funding currency, or a decrease in the target currency, reduces the expected return on holding carry positions. Therefore, how the change in interest rate differential, R, affects the equilibrium asset price and the exchange rate in Iceland is an interesting question to analyse.

Consider the carry trader's return on investment given in Equation (1), where $r > 0$. The carry trader's return increases as the interest rate differential increases, as long as the exchange rate between the funding and the target currencies appreciates, or as long as the exchange rate does not move in the opposite direction. With the increase in the interest rate differential, the carry trader's balance sheet strengthens and thus it is easy to meet the liquidity condition. Therefore, the carry trader will roll over the investment in Iceland. This reduces the cost for other carry traders of holding the carry positions. As a consequence, a lesser number of carry traders will flee from Iceland. Differentiating the foreclosure equation with respect to R gives

$$\frac{\partial l}{\partial R} = -c[\theta(A^p_{ice} - L^d_{ice})e_1]. \tag{34}$$

With the assumptions of $A^p_{ice} > L^d_{ice}$ and the exchange rate not depreciating at the end of period 1, the increase in the interest rate differential reduces the fraction of carry traders who unwind carry trades.

If the premature liquidation is reduced, the sale of illiquid assets by the Icelandic commercial bank decreases. The increase in the interest rate differential accounts for a decrease in sale of illiquid assets in Iceland. This can be clearly seen when differentiating the total sale equation with respect to R to get

$$\frac{\partial s}{\partial R} = -\frac{f[\theta(A^p_{ice} - L^d_{ice})e_1]}{[q]^2}. \tag{35}$$

Consider the Icelandic domestic asset and the foreign exchange markets. Differentiating the demand for illiquid asset equation with respect to R:

$$\frac{\partial p}{\partial R} = \frac{bf[\theta(A^p_{ice} - L^d_{ice})e_1]}{[q]^2}. \tag{36}$$

Differentiating the demand for foreign exchange equation with respect to R:

$$\frac{\partial e_1}{\partial R} = \frac{\gamma\theta c(A^p_{ice} - L^d_{ice})[\bar{e} - \tau f + \tau c(A^l_i - (h + h_i)A^m_i + (1 - h - h_i)(A^p_{ice} - L^d_{ice})e_0)]}{[\gamma\theta c(A^p_{ice} - L^d_{ice})(2 - R)]^2}. \tag{37}$$

Recall that $0 < \tau, f, c < 1$. As can be seen, both $\frac{\partial p}{\partial R} > 0$ and $\frac{\partial e_1}{\partial R} > 0$, under the same assumptions as explained above. An increase in the interest rate differential between the two currencies leads the asset price to increase and the exchange rate to appreciate, thus encouraging more carry trades. In contrast, a decrease in the interest rate differential leads asset prices in Iceland to decline and the exchange rate to depreciate, thus putting pressure on carry traders to unwind their position before the maturity date.

If the interest rate differential between the two currencies decreases for some reason, the profit that can be earned by a carry trader decreases, making it more difficult to maintain the required level of liquidity. In this case, the carry trader may unwind their carry positions. The increasing cost of maintaining carry positions leads other carry traders to withdraw, following the herd. As a result, the sale of assets increases. This leads the equilibrium asset price to decrease and the exchange rate to depreciate. Depreciation of the exchange rate reduces the profit of the carry trade, and tightens funding constraints. The more credit constraint tightens, the greater the foreclosing fraction and the higher the fire sale in Iceland. A decrease in the interest rate differential causes sudden unwinds of carry trades, creating a financial crisis in the carry trade country.

6.3 Consistency of the model with the real world

The model developed in this paper clearly demonstrates that any exogenous liquidity shock or a negative shock to the interest rate differential causes the equilibrium asset price and the exchange rate to deviate from steady state levels, amplifying the effects of a financial crisis in the carry trade recipient country. This section examines whether this hypothesis is consistent with recent events by analysing whether asset prices and exchange rates exhibit sudden reversals during the period of financial market stress. This study shows that the behaviour of economic fundamentals in carry trade recipient countries during the recent financial crisis is well explained by the model.

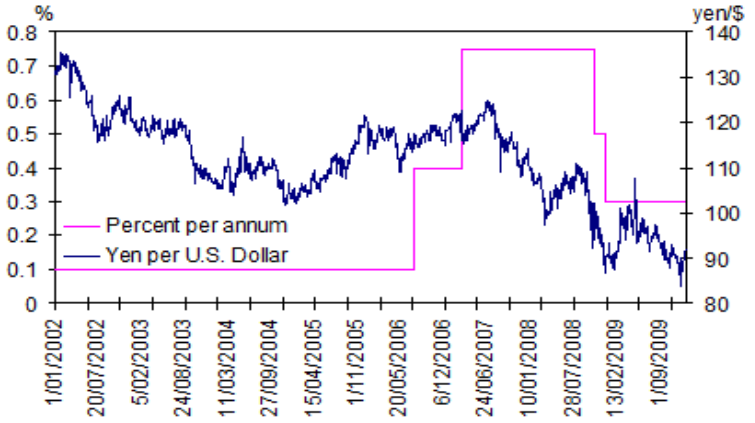


Figure 10: Daily nominal yen/US dollar exchange rate (right axis) and the cash rate of Japan (left axis) from 2002-2009. (Source: Datastream)

Yen/US dollar exchange rate and Japanese cash rate

The yen carry trade had been very popular over the last decade or more, given the extended period of low interest rates in Japan (Hattori and Shin, 2009). Figure 10 shows the yen/US dollar exchange rate and the interest rate of Japan over the period from 2002-2009. As can be seen, there was a crash in the yen/US dollar exchange rate in the period from mid 2007-2009. Brunnermeier and Pedersen (2009) suggest that this dramatic depreciation could be due to the unwinding of the carry trade. At the same time, there is a sharp increase in Japanese interest rates after 2006. This reflects the increased margin requirement in Japan. Increased interest rates in Japan led to a decline in the profits earned by currency traders, thus encouraging them to foreclose their yen positions.

Interest rates of selected carry trade currencies

Figure 11 depicts the behaviour of interest rates of selected target and funding currencies during the crisis. According to Figure 11(a), the interest rate of target currencies decreased remarkably after the sub-prime shock. The low interest rates of the target currencies reduced the return on carry trades. Figure 11(b) presents the interest rates of some funding currencies. Accordingly, the interest rates of the two most popular funding currencies namely Japanese yen and the Swiss franc increased during the period of financial market stress. These increased interest rates reflect the tightened funding constraints. The behaviour of interest rate differential between the currencies involve in carry trades therefore can be considered as a negative shock to the interest rate differential. Thus the model expects the

exchange rate and the asset price in the carry trade recipient countries to decline, encouraging unwinding carry trade positions.

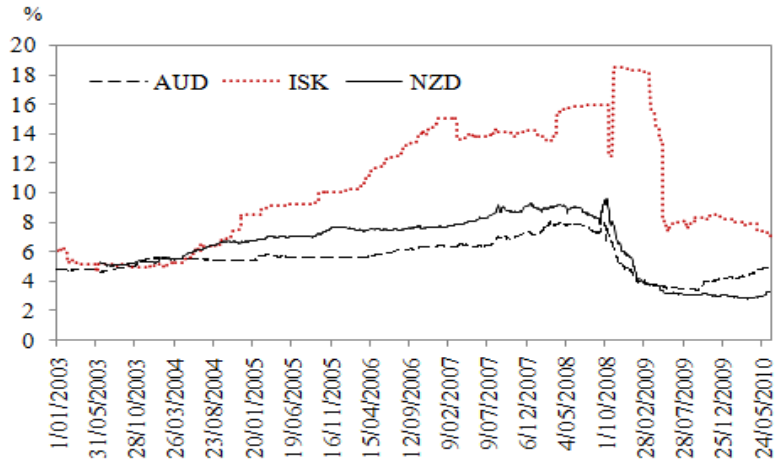
Exchange rates of selected carry trade currencies

An interesting feature of the carry trade is that it does not involve major currencies as target currencies. Instead, it involves currencies with high returns. Australian dollar, Brazilian real, Icelandic kròna, New Zealand dollar, the South African rand and Turkish lira are amongst the most important target currencies. Basically, euro, Japanese yen, Swiss franc and US dollar are mostly involve as funding currencies. Figures 12(a) and 12(b) show the behaviour of exchange rates of some selected target currencies and funding currencies, respectively. Figure 12(a) shows that the exchange rates of target currencies have depreciated from the 2nd quarter of 2007. As the profitability of the carry trade depends on the interest rate differential between the two currencies involve in the carry trade and the return on exchange rates, the depreciation of exchange rates of target currencies, together with the declined interest rate differential reduced the net profit on holding carry positions sharply. When considering the behaviour of exchange rates of funding currencies as per 12(b) it is clear that the Japanese yen has appreciated from the 2nd quarter of 2007, while the Swiss franc and the Icelandic króna from the 2nd quarter of 2008. This also contributed to the decline in profits earn by carry traders triggered the unwinding of the carry trade during 2008 because the carry trade recipient country had to sell more assets to repay its foreign loans. A real world example is the collapse of the Icelandic financial sector in October 2008.

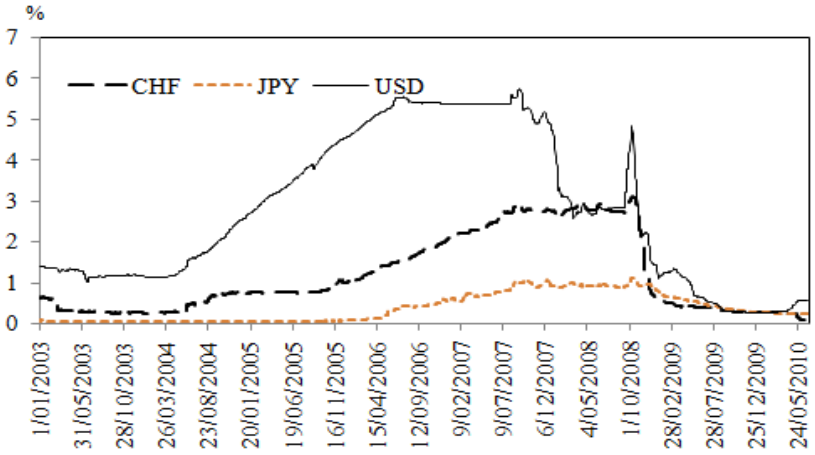
House prices

House price is a key indicator for asset prices. House prices in many carry trade recipient countries such as Iceland, New Zealand, South Africa, the UK and many western European countries have fallen significantly during the global financial crisis. However, it is interesting to notice that Australian house prices have held up relatively well. Historically low borrowing rates through cheaper mortgage rates have helped maintain a floor on Australian property prices. There had also been some switching of investments by some Australians following the start of the Global Financial Crisis, from equity markets into real estate, which is often perceived as being less risky.

Figure 13 depicts the quarterly change in house prices in some carry trade recipient countries: Australia, Iceland, New Zealand and South Africa. The figure

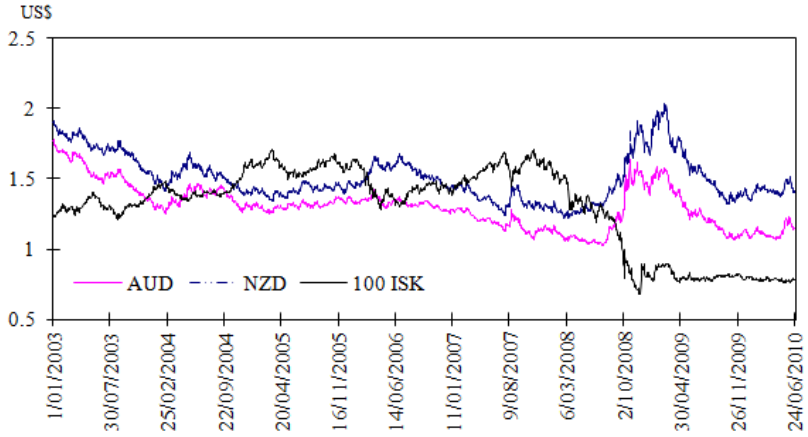


(a) 3-months interbank LIBOR of selected target currencies: Australian dollar(AUD), New Zealand dollar (NZD) and Icelandic króna (ISK).

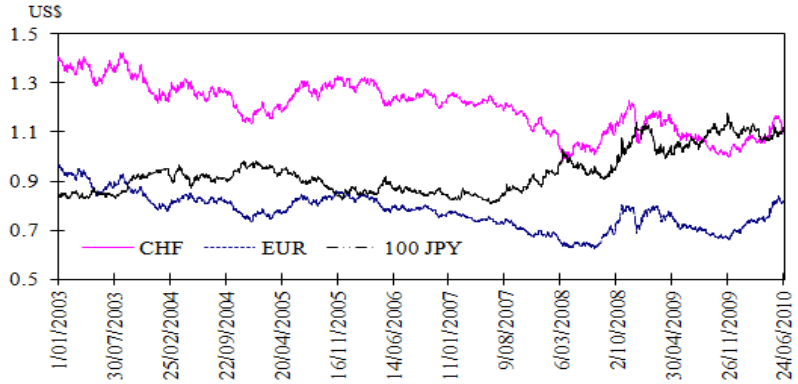


(b) 3-months interbank LIBOR of selected funding currencies: Japanese yen (JPY), Swiss franc (CHF) and US dollar (USD).

Figure 11: Behavior of interest rates of selected target and funding currencies during the crisis: (a) interest rates of selected target currencies (b) interest rates of selected funding currencies. (Source:Datastream)



(a) Daily nominal exchange rates of selected target currencies: units of USD per 1 unit of Australian dollar (USD/AUD), 1 unit of New Zealand dollar (USD/NZD) and 100 units of Icelandic króna (USD/100 ISK).



(b) Daily nominal exchange rates of selected funding currencies: units of USD per 1 unit of as euro (USD/euro), 1 unit of Swiss franc (USD/CHF) and 100 units of Japanese yen (USD/100 JPY).

Figure 12: Behaviour of daily nominal exchange rates of selected target and funding currencies during during the crisis: (a) exchange rates of selected target currencies (b) exchange rates of selected funding currencies. (Source:Datastream)

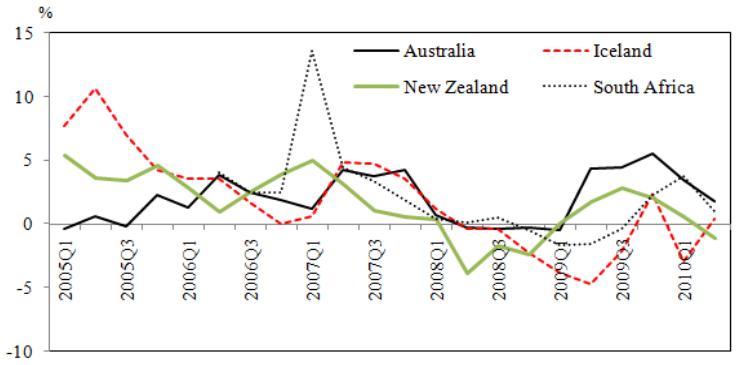


Figure 13: Quarterly change in house prices in carry trade countries: 2005-2010. (Sources: Quotable Value Limited, RBNZ, Statistics Iceland, Australian Bureau of Statistics, Amalgamated Banks of South Africa (ABSA))

clearly shows that the house prices in all countries except Australia have declined during the period from the 1st quarter of 2007-09. This reflects the decrease in asset prices during the crisis.

Interestingly, this evidence is consistent with the model developed in this paper, in which liquidity shocks tighten the funding constraints faced by currency carry traders, thus triggering the unwinding of carry trades, the depreciation of exchange rates and the decline in asset prices. Further, the impact of the behaviour of interest rates differential during the crisis is also consistent with the comparative static analysis described in the previous section.

7 Conclusion

This paper provided a theoretical explanation for the recent financial crisis using the role of carry traders as a conduit. The paper developed a model in which positive externalities among carry traders generated a unique equilibrium with endogenous triggers of currency bubbles and crashes. The analytical framework explained how a shock to the aggregate haircut on collateralized assets caused liquidity in countries with low interest rates to dry up suddenly and carrying the potential for a severe financial crisis in countries with high interest rates.

The paper extended the feed-back effects between asset prices and exchange rates in the carry trade recipient country developed by Shin (2005) in two ways. First, it introduced the haircut on collateralized assets, as described by Gorton and Metrick (2009), into the model to explain how funding constraints played a major role in unwinding carry trade positions. Second, the model employed the global

game method, or herding behaviour, of carry traders as in Morris and Shin (1998) and Goldstein (2005) firstly to describe the rationale behind the carry trader's behaviour, and secondly to propose a causal mechanism for the sudden unwinding of carry trades that marked the recent crisis. Based on these extensions, the model was solved in order to obtain equilibrium in both the asset market and the foreign exchange market in the carry trade recipient country.

Particularly, the model showed that there is a threshold level of the aggregate haircut, above which carry traders never roll over their investment in carry trade countries. Further, it explored how liquidity shocks or shocks to the size of the aggregate haircut on collateralized assets dried up liquidity among carry traders, thus forcing them to unwind carry investments and amplifying financial crisis in carry trade recipient countries by driving down asset prices and exchange rates. The model also showed that a negative shock to the interest rate differential between two currencies had the potential to trigger financial crises in countries with high interest rates. Interestingly, the behaviour of asset prices and the exchange rates of carry trade recipient countries following the sub-prime shock was consistent with this model.

Finally, a possible policy implication highlights the need for financial sector reforms based on the global nature of the crisis. The interaction between the size of the haircut and foreign exchange inflows has the potential to destabilize carry trades, thus creating a vicious cycle which drives market prices down sharply. Generally, keeping policy interest rates low even as inflation pressures pick up, or intervening in foreign exchange markets combined with a rise in the policy rate to address the implications for inflation, have all been used as important tools in handling macroeconomic imbalances related to a large inflow of foreign currency, especially in emerging market economies. However, these policy options entail risks for the financial system. Therefore, policy makers must look for other policy options, such as macro-prudential regulations with the role of self-governing markets and establishing a sustainable and effective financial architecture in order to prevent financial crises.

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