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The Expectations of Hong Kong Dollar Devaluation and their Determinants

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SUMMARY

During the Asian financial turmoil over the 1997-1998 period, only the Hong Kong dollar peg escaped the wave of huge devaluations which hit Asian currencies. But speculative pressures did not spare the Hong Kong currency board. Indeed, several attacks were launched against the Hong Kong dollar and the expectations of devaluation fluctuated sharply over the period. The motivation of the paper is threefold.

First, it deals with the key determinants driving the expectations of a possible breakdown of the peg in a VAR framework. It uses currency options on the Hong Kong dollar to estimate the expected probability and intensity of devaluation over a one-month horizon, from February 1997 to the end of 1998. Because Hong Kong did not suffer from bad fundamentals at least in 1997, which could have justified the attacks against its currency, one explanation to the observed speculative pressures rests on possible contagion effects stemming from the Asian crisis. To account for the propagation of shocks, three possible channels can be emphasized: a common cause stemming for example from the industrial countries and affecting the emerging economies in the same way (monsoonal or external effects), a crisis in one country entailing a modification of macroeconomic fundamentals in another (spillover effect), and the shift in market sentiment about the fundamentals of a country triggered by a crisis elsewhere, which is a pure contagion effect. These three channels of propagation are tested, the variables aiming at capturing these effects being introduced with an exogenous status.

Second, the paper focuses on the cross-market speculation, which involved the stock exchange and the markets of Hang Seng Index (HSI) futures and options, in addition to the foreign exchange market. The way the speculation worked in Hong Kong during the 1997-1998 period is closely linked to the operation of the Hong Kong currency board, where an automatic adjustment mechanism links capital inflows and outflows to the overall level of liquidity in the banking system. The predictable sensitivity of interest rate to capital flows was exploited by some speculators who engaged into the so-called "double play": they entered the money market to borrow huge amounts of HK dollar, then short-sold stocks and HSI futures abruptly before shorting Hong Kong dollar. The HK dollar sell-off wave was aimed at provoking a spike in interest rates, then forcing the stock exchange to plunge. To measure the impact of such speculative dynamics on the expectations of a HK dollar devaluation and the extent to which the expectations of a peg breakdown fuelled the double play, three endogenous variables were introduced in the VAR: the intensity of devaluation, the HSI futures prices and the implied volatility of the stock index.

Third, the paper shows that the significant determinants originating the expectations of devaluation in Hong Kong as well as the pernicious speculative dynamics are important factors in order to understand both the interventions of the Hong Kong Monetary Authority (HKMA) and the reform of the currency board in September 1998. Over the period, the Monetary Authority changed its strategy to defend the peg. In a first place, the measures undertaken relied on discretion and were aimed at influencing different market

prices. The most controversial action was its interventions in the stock and HSI futures markets in August 1998. Then, a reform was undertaken to strengthen the currency board, which basically consisted in grounding the regime on a more rule-based system. The impact of the different measures on the expectations of a HK devaluation are assessed via dummies introduced in the VAR.

Three major conclusions can be drawn. First, only two channels of shock propagation are plainly robust and significant in explaining the formation of expectations on the HK dollar: the external effects of a world shock, observed and expected, captured by the value of the dollar/yen exchange rate and by its expectations, and the pure contagion effects relying on the reassessment of risk by international investors. Second, the presence of a double play is made clear. The impulse response functions underline the circularity of expectations: the expectations of a HK dollar devaluation fuelled speculation in the stock futures and options markets, which in turn was conducive to fears of an impending demise of the currency board. Third, the reflexivity in the formation of expectations led the HKMA to engage in unusual interventions, departing from its traditional free-market philosophy. All the discretionary measures adopted by the HKMA to break this self-fulfilling speculative scheme proved to be ineffective. In contrast, when the HKMA undertook reforms to introduce a more rule-based system in September 1998, it succeeded in dampening the pressures against the HK dollar.

Keywords: Currency Board, Hong Kong, speculative attack, probability density functions, contagion

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RÉSUMÉ

Lors de la tourmente financière de 1997-1998, le dollar de Hong Kong est la seule monnaie à avoir échappé à la vague de dévaluations qui a touché toutes les monnaies asiatiques. Cette monnaie présente la particularité d'être ancrée au dollar américain par un currency board, système dans lequel l'émission de monnaie nationale est strictement dépendante de l'afflux de réserves. Un tel système, plus contraignant que les régimes de taux de change fixe et donc plus crédible, assure en principe une protection importante contre les attaques spéculatives. Pourtant, plusieurs attaques ont été lancées contre le dollar de Hong Kong et les anticipations de dévaluation ont à de nombreuses reprises mis à mal la crédibilité du régime. Deux indicateurs reflétant les anticipations de décrochage du peg ont été construits. Il s'agit de la probabilité et de l'intensité d'une dévaluation du dollar de Hong Kong anticipée à l'horizon d'un mois. Ils ont été calculés à partir de la densité de probabilité du taux de change futur, inférée des prix d'options de change. L'objectif de ce papier est d'identifier l'origine des pressions spéculatives, d'analyser la forme particulière de la dynamique spéculative ainsi que les réponses des autorités monétaires.

En premier lieu, on identifie les déterminants des anticipations de dévaluation du dollar de Hong Kong dans le cadre d'une modélisation VAR. Hong Kong ne souffrait pas de déséquilibres macro-financiers de l'ampleur de ceux accumulés par ses voisins asiatiques, susceptibles de justifier les différentes attaques spéculatives à l'encontre de sa monnaie. Une explication possible à ces attaques a trait à des effets de contagion issus de la crise asiatique. Trois canaux de contagion sont mis en avant pour expliquer comment une crise peut se propager vers d'autres marchés et d'autres pays. Le premier est associé à un choc commun mondial provenant des pays développés et affectant les économies émergentes. Le second canal résulte de l'interdépendance des économies partageant des caractéristiques similaires, une crise dans un pays entraînant une modification des fondamentaux dans un autre (perte de compétitivité ou choc de liquidité sur les marchés d'actifs). Enfin, le troisième canal de propagation des crises est associé à une contagion psychologique. Il implique soit une réévaluation du risque sur des pays considérés comme semblables, soit une augmentation de l'aversion au risque des investisseurs internationaux qui, ayant subi des pertes importantes sur certains marchés émergents, deviennent plus frileux et investissent sur des marchés moins risqués (fuite vers la qualité). Ces trois canaux de transmission des chocs sont testés, les variables de contagion étant introduites avec un statut d'exogène dans le modèle VAR.

En second lieu, on montre que la coexistence d'un currency board et de marchés financiers développés, ouverts et libéralisés induit une vulnérabilité du régime. Dans un tel régime de change, les entrées et sortie de capitaux modifient mécaniquement le niveau de la liquidité interbancaire et donc le taux d'intérêt. Le caractère prévisible et prononcé de l'évolution des taux d'intérêt a été exploité par les spéculateurs à travers un double jeu : les spéculateurs ont emprunté des dollars de Hong Kong, puis ont vendu massivement des actions et des contrats à terme sur indice boursier, avant de déclencher l'attaque sur la monnaie hongkongaise. Ces ventes de dollars de Hong Kong ont immédiatement entraîné une augmentation des taux d'intérêt, qui a fait plonger la bourse. Les profits issus de la vente des contrats à terme sur indice, convertis en dollars américains, ont à leur tour alimenté les

pressions spéculatives contre la monnaie hongkongaise et contribué à la hausse des taux d'intérêt. Pour analyser l'interaction entre les anticipations de décrochage du dollar de Hong Kong et les anticipations qui ont été à l'origine des prises de positions sur les marchés boursiers, les trois variables endogènes suivantes ont été introduites dans le VAR : l'intensité d'une dévaluation anticipée, le prix des contrats à terme sur indice boursier et la volatilité implicite dans le prix des options sur ce même indice.

Enfin, le troisième objectif de cet article est d'étudier l'efficacité des mesures prises par les autorités monétaires pour juguler les pressions spéculatives. Dans un premier temps, les réponses ont reposé sur des interventions discrétionnaires visant à influencer certains prix de marché. L'action la plus controversée a sans aucun doute été l'intervention sur les marchés d'actions et de *futures* sur indice boursier en août 1998. Le but était alors d'enrayer la baisse brutale des prix de ces actifs. Par la suite, une réforme a été entreprise en septembre 1998 pour asseoir le régime sur un système davantage fondé sur des règles précises et transparentes.

Trois conclusions émergent de cette étude. Tout d'abord, seuls deux canaux de transmission des chocs apparaissent pertinents pour expliquer la formation des anticipations sur le dollar de Hong Kong. Le premier est lié à un effet de choc mondial, observé et anticipé, reflété par la valeur du dollar/yen et sa volatilité implicite. Le second a trait à un effet de contagion pure reposant sur la réévaluation du risque par les investisseurs internationaux. Quant au double jeu spéculatif sur les marchés de contrats à terme et d'options sur indice boursier, les fonctions de réponses mettent en évidence la circularité des anticipations : les anticipations de dévaluation du dollar de Hong Kong ont alimenté la spéculation sur les marchés de *futures* et d'options sur l'indice boursier, qui en retour a renforcé les craintes d'une dévaluation imminente. Enfin, la réflexivité dans la formation des anticipations spéculatives a conduit les autorités monétaires à s'engager dans des interventions inhabituelles, et à se départir de leur philosophie non interventionniste. Toutes les mesures discrétionnaires adoptées pour rompre ce schéma spéculatif auto-réalisateur se sont avérées inefficaces. Au contraire, les réformes entreprises en septembre 1998 visant à renforcer la robustesse du currency board ont permis de réduire les pressions à l'encontre du dollar de Hong Kong.

THE EXPECTATIONS OF A HONK KONG DOLLAR DEVALUATION AND THEIR DETERMINANTS DURING THE 1997-1998 CRISIS

Bronka Rzepkowski[1]

INTRODUCTION

The Asian financial crisis of 1997 and 1998 hit most market-traded currencies in the region, one after the other. The Hong Kong dollar's peg on the US dollar was one of the very few instances of tight foreign exchange anchors that escaped the wave of huge devaluations hitting the Asian currencies.[2] But the Hong Kong dollar was not spared by speculative pressures. Several attacks were launched against the linked exchange rate system. What were the driving factors beyond the expectations of a devaluation of the HK dollar? To what extent did the operation of its exchange rate system, a currency board, fuel some specific speculative dynamics, involving the stock, index futures and options markets? Were the successive, non-standard interventions of the Hong Kong Monetary Authority successful to counter the speculative pressures?

Because Hong Kong did not suffer from deteriorating fundamentals at least in 1997, which could have justified the attacks against its currency, one explanation to the observed speculative pressures rests on possible contagion effects stemming from the surrounding tense context. Several papers attempt to identify the channels by which a crisis in one country might propagate towards another (Gerlach and Smets, 1995; Sachs, Tornell and Velasco, 1996; Valdés, 1997; Eichengreen, Rose and Wyplosz, 1996). Albeit often loosely used, the reference to contagion has recently benefited from an analytical effort of definition (Masson, 1998).

Masson distinguishes three origins in the propagation of shocks: a common cause stemming for example from the industrial countries and affecting the emerging economies in the same way (monsoonal or external effects), a crisis in one country entailing a modification of macroeconomic fundamentals in another (spillover effect), and the shift in market sentiment about the fundamentals of a country triggered by a crisis elsewhere. According to Masson, only the third category is deemed to be a pure contagion, because it implies changes in expectations not driven by a change in fundamentals; it relies instead either on a reassessment of the risk, given unchanged fundamentals, or an increase in the risk aversion from international investors. It rests on self-fulfilling expectations like in Jeanne (1997), but the framework is extended so that a crisis in one country can polarise investors' expectations onto a bad equilibrium in another.

[1] Economist at CEPII. The author thanks Michel Aglietta and Agnès Bénassy for helpul comments and suggestions.

[2] The other exception is the renminbi (RMB) of Mainland China, but the latter currency is not freely convertible.

Empirically, contagion is often measured by cross-country correlations among similar assets (Baig and Goldfajn, 1998; King and Wadhwani, 1990; Rigobon, 1999). The historical correlation between two stock indexes, interest rates or exchange rates observed in a quiet period should increase significantly during the crisis period to attest to contagion effect. The perspective adopted here is quite different because contagion effects are measured on the expectations of a HK dollar devaluation. These expectations are derived from Over The Counter (OTC) currency options, and not from the well-known drift adjustment method of the target zone literature (Bertola and Svensson, 1993). Unlike the forward exchange rate, which provides a point estimate of the future exchange rate value, options reveal a broader range of possible outcomes for the exchange rate, as well as their respective probability. A jump diffusion process is estimated from the 21st February 1997 to the 31st December 1998 to recover the implied probability density function (PDF thereafter) of the future exchange rate, in the same way as in Malz (1996). The probability and intensity of a HK dollar devaluation are then derived from the PDF over a one-month horizon. While Campa, Chang and Refalo (1999) attempt to explain the change in the credibility of the Brazilian peg, inferred from currency options on foreign exchange, by domestic fundamentals, the framework is extended here to allow for pure contagion effects affecting expectations on the HK dollar.

This paper addresses three issues in a VAR framework. First, the three channels of contagion from the Asian turmoil are tested with exogenous variables. Second, it focuses on the way the speculation worked in Hong Kong during 1997 and 1998, which is indeed closely linked to the operation of the currency board. Especially it questions the relevance of the so-called double play. To determine to what extent the expectations of devaluation in Hong Kong fuelled speculative positions in the index futures and options markets and to assess at the same time the impact of this latter speculation on the probability of abandoning the peg, a VAR methodology was implemented. Third, the paper measures the efficiency of the HKMA non-standard interventions aiming at reducing the intensity of a HK dollar devaluation via dummies.

The paper is organised as follows: the first section presents the operation of the Hong Kong currency board, the second one describes the method used to infer the probability and intensity of devaluation from the PDF of the future exchange rate. The third section comments the evolution of these two indicators with respect to the main episodes of tension prevailing in the Asian area. The fourth section presents both the variables likely to influence the expectations of HK dollar devaluation and the VAR methodology. In the fifth one, the results of the estimation are displayed. The last section concludes.

1. THE OPERATION OF THE HONG KONG CURRENCY BOARD

In its pure form, currency board is a rule-based system with two main characteristics. First, the board is subject to an explicit legislative commitment to exchange on demand the local currency for a specified foreign currency, the reserve currency, and vice versa at a fixed exchange rate. Second, the monetary rule stipulates that any change in the monetary base must be matched by a corresponding change in the foreign reserves at this fixed exchange rate. In practice, currency boards respect more or less this theoretical definition.

In comparison with the traditional fixed exchange rate regimes, a currency board is more rigid and hence theoretically more credible. The scope in undertaking discretionary credit policy is removed or at least severely limited. No independent monetary policy relative to the anchor country can be conducted. Furthermore, it is more difficult to alter the exchange rate parity or to abandon a currency board, because it would involve a change in the law. Another characteristic of currency boards relies also on the predictability of the interest rate to capital flows. The main device of a currency board to achieve exchange rate stability is the automatic adjustment mechanism, based upon interest rate arbitrage. This mechanism links capital inflows and outflows to the aggregate balance[3], i.e. the overall level of liquidity in the banking system. When there is a capital outflow, banks sell domestic currency for foreign currency to the Monetary Authority, which debits their clearing accounts, entailing a decrease in the aggregate balance and thus in the monetary base. This process is an automatic one, and does not require the exercise of discretion on the part of the Monetary Authority. It is a normal consequence of the operation of a currency board. Because the liquidity level in the banking system declines, the interest rate increases mechanically. The induced expansion or contraction of the monetary base therefore implies a change in the level of the domestic interest rates, which stabilises the foreign exchange market by releasing new capital inflows or outflows.

The first currency board in Hong Kong was introduced in 1935, after the silver standard had been forsaken.[4] From 1935 to November 1967, the HK dollar was pegged to the sterling pound at a rate of 1£=16HK$[5]. Because of the sterling devaluation in 1967, this rate moved to 14.55 until June 1972. Then for at least two years, the anchor was maintained with the US dollar. But the inflow of capital induced by the devaluation of the US dollar forced the HK dollar to float on November 1974. In October 1983 the linked exchange rate was adopted, which is basically a currency board. [6] The rate applicable to the issue and redemption of Certificates of Indebtedness backing the banknotes was set to HK$7.8 to US$1. This rate was guaranteed by the Convertibility Undertaking. Since 1983, the Hong Kong currency board experimented significant institutional changes. Reforms were undertaken, essentially after 1988, to give the Hong Kong Monetary Authority (HKMA)[7] the ability to influence the

[3] The Aggregate Balance refers precisely to the sum of the balances in the clearing accounts maintained by the banks with the Monetary Authority for settling inter-bank payments and payments between banks and the Monetary Authority.

[4] See Kwan and Lui (1996) for further details on the historical background of the Hong Kong's currency board.

[5] This peg ceased during the World War II.

[6] At that time, the interbank clearing system was not run by the currency board, but by a commercial bank, the Shanghai Banking Corporation (HSBC), which provided the liquidity in the banking system. In fact, all licensed banks in Hong Kong maintained a clearing account directly or indirectly with the HSBC. From October 1983 to July 1988, the aggregate balance was determined by the commercial activities of the HSBC, and although it is a crucial element of the monetary base, it was not subject to the monetary rule. Banknotes were backed by US dollars, but no requirement posited that the aggregate balance should also be backed. See Chan (1999) for further details.

[7] In fact, the HKMA was created only in April 1993 ; broadly speaking it replaced the Office of the Exchange Fund.

inter-bank liquidity and hence the interest rate. Since then, the Hong Kong currency board has not been operating as a pure currency board, because the HKMA has acquired new tools of intervention to regulate the inter-bank market. In July 1988, new Accounting Arrangements[8] made open market operations feasible. In March 1990, Exchange Fund Bills were introduced to promote the local debt market. Then a Liquidity Adjustment Facility (LAF) was opened to provide overnight funds to banks holding Exchange Fund papers. But this LAF was not intended to provide a regular source of liquidity. Actually, penal offer rates could be charged to banks using the LAF repeatedly. Finally, the Accounting Arrangements were replaced in December 1996 by a new very efficient inter-bank payment system (RTGS), which gave the HKMA a more direct and effective tool to manage money market operations.[9] Within this new system, the aggregate balance has remained at a very low level around HK$ 2 billion, because banks have been able to forecast their liquidity needs accurately so that the size of the clearing accounts of banks with the HKMA was reduced. The natural sensitivity of interest rate to capital flows has been exacerbated by the latter measure: due to the small size of the monetary base, a very small amount of capital outflows could then trigger a sharp increase of the interest rate. As shown below, the way the speculation worked in Hong Kong during the 1997-1998 period was closely linked to the great sensitivity and predictability of interest rates exploited by speculators who resorted to a cross-market speculation involving the stock markets and the foreign exchange market.

2. PROBABILITY AND INTENSITY OF A HK DOLLAR DEVALUATION

Several approaches based on the target zone literature have been used to infer the realignment probability of European exchange rates within the narrow Exchange Rate Mechanism. The most common is the drift adjustment method (Bertola and Svensson, 1993).[10] However, because its performance in predicting crises has been weak[11] compared to option-based indicators, this approach has been disregarded (Campa and Chang, 1996).

Options, whose payoff depends on a limited range of the expected exchange rate, offer broader information about market expectations than the forward exchange rate. Under the uncovered interest rate parity, the latter provides an indication about the mean of the distribution of the expected exchange rate, whereas the entire probability density function can be inferred from option prices. Indeed, a same forward value may correspond to either a distribution with a low probability of a large depreciation or a distribution with a large probability of a small depreciation. Because this difference matters in terms of policy

[8] With this measure, the HSBC was required to maintain an account with the currency board. For the first time, it was possible to define the aggregate balance (the HSBC 's clearing accounts), subject to the indirect control of the currency board.

[9] All banks have had to establish clearing accounts directly with the HKMA as opposed to the HSBC. Since then, the currency board arrangements has found a proper foundation, the aggregate balance being properly subject to the monetary rule.

[10] Cheng, Kwan and Lui (1999-a, 1999-b) apply this method to measure the *ex ante* probability of an HK dollar devaluation from 1997 to March 1999.

[11] See Rose and Svensson (1994, 1995).

responses, two indicators of devaluation risk are derived from the PDF: the probability and intensity of realignment.

2.1. Probability density function of the future exchange rate

A call (put) option gives the right but not the obligation to its holder to buy (to sell) a certain amount of foreign currency, at a given strike price and at a predetermined date. Unlike the American options, which can be exercised any time prior to their expiration date, the European ones, used here, can solely be exercised at the option maturity.

The approach aiming at recovering the probability density function from option prices consists in deriving a relationship between the option valuation formula and the underlying PDF. Breeden and Litzenberger (1978) show that the second derivative of a call valuation formula is directly proportional to the PDF; the formula must verify some monotony and convexity conditions and must be twice differentiable in strikes.

The payoff at maturity T of a European call with a strike price K is $\max(S_T - K, 0)$, where S_T is the exchange rate at time T. Let $C(S_t, t, K, T)$ be the value of a European call[12]:

$$\begin{aligned} C(S_t, t, K, T) &= e^{-r(T-t)} E^*[\max(S_T - K, 0)] \\ &= e^{-r(T-t)} \int_K^{\infty} (S_T - K) f(S_T, T, S_t, t) dS_T \end{aligned} \tag{1}$$

r is the risk free domestic interest rate, E* is the mathematical expectation under a risk neutral probability measure and $f(S_T, T, S_t, t)$ is the risk neutral density function of the future exchange rate S_T, conditional on the current exchange rate S_t. The first derivative of equation (1) is proportional to the cumulative distribution function:

$$\frac{\partial C(t, K, T)}{\partial K} = -e^{-r(T-t)} \int_K^{\infty} f(S_T) dS_T = -e^{-r(T-t)} (1 - F(K)) \tag{2}$$

$F(K)$ is the risk neutral cumulative distribution function. Finally, the PDF of the future exchange rate, evaluated at $K = S_T$, can be expressed as being proportional to the second derivative of the call valuation formula. The coefficient of proportionality is the present value of a zero coupon bond paying one domestic monetary unit at maturity, the discount rate being the risk free interest rate.

[12] Here, this equation is not used to discover the call price, but is used to infer the PDF from the option quotes.

$$f(S_T, T, S_t, t) = e^{r(T-t)} \frac{\partial^2 C(S_t, t, S_T, T)}{\partial K^2}\Big|_{K=S_T} \quad (3)$$

This risk neutral PDF differs from the true PDF the operators have in mind when they quote option prices, because it incorporates attitudes towards risk, in addition to beliefs about future outcomes. The PDF recovered from option prices is influenced by risk premia just as forward exchange rates are, so that the interpretation of the PDF's changes over time can be distorted by changes in risk premia.

Equation (3) shows that the PDF can be derived if a continuous, twice-differentiable valuation formula for the call exists or at least if a continuum of option prices with strike prices from zero to infinity is available.[13] Unfortunately, the range of observed option prices is limited and some procedures must be implemented to extrapolate beyond the highest available strike for calls, and below the lowest strike for put. Unlike the Black and Scholes (1973) model which postulates a lognormal distribution for the underlying asset, several approaches based on the Breeden and Litzenberger Theorem (1978) are able to take into account the skewness and kurtosis of the expected exchange rate implicit in the option prices. Following Malz (1996), the approach used in this paper to infer the PDF is based on the assumption that the exchange rate follows a jump diffusion process. This choice appears relevant to assess the credibility of pegged or fixed exchange rate regimes, because the expected jump of the underlying exchange rate as well as its probability can then be recovered from such a specification. The Bernouilli version of the jump diffusion are exposed in Annex I, as well as a brief presentation of other possible methods.

For fixed exchange rate regimes, the risk of devaluation can be identified by the area of the PDF beyond the official rate of the peg. The probability of devaluation is calculated from the risk neutral PDF as follows:

$$\text{prob}(S_T > \bar{S}) = \int_{\bar{S}}^{\infty} f(S_T) dS_T \quad (4)$$

where $\bar{S}$ is the official rate of the peg. It can also be the upper limit of a target zone regime. Implicitly, this measure is one-sided because it only considers the risk of devaluation of the domestic money. Once the probability density function is estimated, it is also possible to infer the intensity of realignment (Campa, Chang and Reider, 1997). By definition, the intensity of realignment sums all the possible values of the underlying exchange rate beyond a certain bound, weighted by their respective probabilities of occurrence.

[13] Neuhaus (1995) constructs an implied risk neutral histogram from option prices with equidistant strikes from the cumulative distribution. But in the OTC markets, options are quoted in delta, so that the calculated strikes are not equidistant.

$$I_{\bar{S}} = \int_{\bar{S}}^{\infty} (S_T - \bar{S}) f(S_T) dS_T \quad (5)$$

Compared to the probability of devaluation, this latter indicator brings an added information to detect risks of speculative attacks. Because a small probability of realignment associated with a large jump can be at the heart of strong speculative pressures, it is also crucial to consider the size of expected fluctuations. *In fine*, if a realignment occurs, the profit of speculators is determined by the magnitude of the discrete jump of the exchange rate. For example, an expected devaluation intensity of 4.2% at a given maturity can be the result of a 6% jump size anticipated with a 70% probability, or a 7% size associated with a 60% probability of occurrence.

It must be kept in mind that this PDF is estimated under a risk neutral probability measure and is equivalent to the true one only when investors are risk neutral. Because the inferred PDF is influenced by risk premia, a careful day-to-day interpretation of the devaluation probability and intensity is required. However, under the hypothesis that the risk premium is relatively constant over time, the changes in these two indicators can reflect quite well the changes in market expectations.

Finally, choosing the relevant maturity to build an option-based indicator of devaluation risk is not trivial. Indeed, the PDF is all the flatter and expectations are all the more diffuse, the longer the time to expiration of the option. This result is linked to a market convention: OTC options are quoted according to constant deltas[14] instead of strike prices, so that when maturity grows, strikes corresponding to a given delta go further away from the forward exchange rate. The range of the future exchange rate widens mechanically with the maturity. Indeed, an out-of-the-money[15] option today is more likely to finish in the money if its time to expiration is remote. Therefore, the choice of a maturity conditions in part the result in terms of credibility of a target exchange rate: the further away the time horizon, the higher the probability that the target is overstepped at maturity. A one-month maturity is chosen because at this horizon the expectations react more to news and are likely to suffer less from hysteresis effects.

2.2. The data and estimation procedure

The data used to recover the probability density functions are European OTC call options drawn from the J.P. Morgan Internet site. This choice of OTC options stems from the superior liquidity of OTC currency trading over Exchange trading. Another advantage with OTC options stems from the fixed time to expiration, unlike Exchange options for which the

[14] The delta is a measure of the sensitivity of the option price with respect to a small variation of the underlying price. Mathematically, the delta of a foreign exchange option is the first derivative of the call formula with respect to the exchange rate.

[15] A call option is said to be out-of-the-money if the underlying price lies below the strike or if the delta is inferior to 0.5. It is in-the-money if the underlying price is beyond the strike or if the delta is superior to 0.5. For an at-the-money option, the strike is equal to the forward rate and the delta is roughly 0.5.

time to maturity progressively decreases with time. These OTC options are quoted in implied volatilities according to different deltas for several maturities. Five options quotes with delta values of 0.1 0.25 0.5 0.75 and 0.90 are available for a given maturity. Only the one-month maturity is considered here. These prices, available since the 21st February 1997, are averages of the bid and ask quotes.[16] The series of the Hong Kong dollar exchange rate and one-month interest rates for Hong Kong and the United States are those prevailing when the option prices were reported by J.P. Morgan. The non-linear least squares have been used to estimate the parameters of the jump diffusion. The procedure consists in minimising the distance between the observed option prices[17] and the theoretical prices stemming from the jump diffusion process. The estimation was implemented using the GAUSS software.

3. THE EXPECTATIONS OF A HK DOLLAR DEVALUATION AND THE HKMA RESPONSES TO SPECULATIVE ATTACKS

Over the period several assaults were launched against the Hong Kong currency board. Contagion effects from the surrounding Asian turmoil seem to have driven at least partly the expectations of a HK dollar devaluation. The contagion took a specific shape in Hong Kong, the speculative dynamics involving the Hong Kong stock index futures and option market and the foreign exchange market. To counter this double speculation, the HKMA engaged into unusual interventions and finally undertook a reform of the operation of the Hong Kong currency board.

3.1. The intensity of devaluation in Hong Kong and the speculative double play

Figure 1 exhibits the evolution of the probability and intensity of a HK dollar devaluation from February 1997 to December 1998. First, it can be noticed that the plunge of the Thai baht in July 1997 had no impact on Hong Kong, whereas the devaluation of the Indonesian roupiah the 15th August 1997 influenced slightly the intensity of an HK dollar devaluation. Although the average probability was quite high (22.3%) from the 15th August to the 3rd October 1997, the expected jump was only 3.8%. In contrast, the devaluation of the Taiwan dollar the 20th October 1997 was the catalyst of the speculative pressures against the HK dollar: from the 20th October to the 20th November, the average expected jump in case of a peg breakdown reached 17.7%, associated with a probability of 32%. The induced capital outflow entailed a huge spike in the short-term interest rates, triggered by the currency board mechanism, their magnitude being essentially due to the small size of the monetary base.

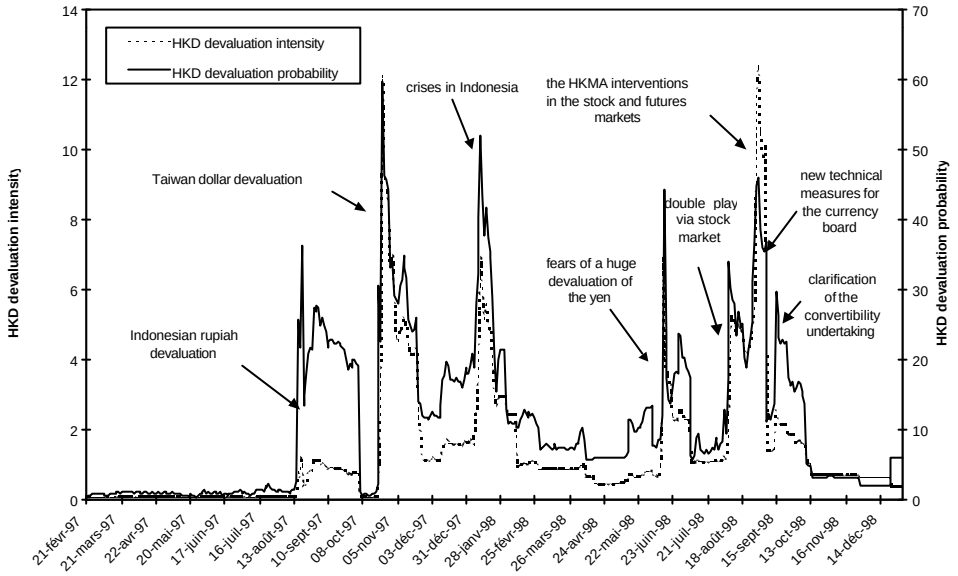
The HKMA's adherence to interest rate arbitrage (the auto-pilot of the currency board) to counter speculative pressures was posited as a key monetary rule: if the interest rates rise in

[16] Because the optimisation procedure uses these average implied volatilities, this could introduce some biases: specifically these data differ from the transaction prices.

[17] The Garman and Kohlhagen (1983) formula, a version of the Black and Scholes model for currency options, has been used to convert each implied volatility quote into option price. This model is not used here as a pricing model, but just serves as a conversion formula without relying on its assumptions.

reaction to capital outflows due to liquidity shrinkage, this should contribute to restore exchange rate stability by favouring renewed capital inflows. But, in an intent to magnify the interest rate response, the HKMA issued a circular the 23rd October 1997 to inform banks that penal LAF offer rates might be imposed on repeated borrowers for last resort liquidity support.[18] This discretionary decision entailed a panic within the banking system, pushing the overnight inter-bank interest rate to 280%.[19] Banks then discovered that the aggregate balance could become negative during speculative attacks and that the LAF was not reliable as a source of funding.

Figure 1:
Risk neutral probability and intensity of HK$ devaluationat a one month horizon



The sharp rise in interest rates hence triggered significant sales in the stock market as many foreign investors decided to switch out of the Hong Kong market, conducing to a sharp fall in the local stock market: the benchmark Hang Seng index (HSI) lost 10.4% of its value the 23rd October and more than 30% in the following week. The Hong Kong government 's *Report on the Financial Market Review* (1998) reported that there were no clear evidence of concerted speculative positions of speculators operating simultaneously in the foreign exchange market and the Hang Seng Index futures market. However, the press widely

[18] The precise statement was the following one : « In order to discourage licensed banks from repeated borrowings from LAF, penal LAF offer rates different from the advertised LAF offer rate will be determined on a case by case basis and at the absolute discretion of the HKMA for repeated borrowers. ».

[19] As Chen, Kwan and Lui (1999-a) argue, after buying HK dollar, the HKMA has the possibility to delay the liquidity injection (because the HK dollar will not be delivered before one or two days), so that the banks have to borrow HK dollar at an interest rate fixed by the HKMA for clearing purposes.

mentioned it at that time. Furthermore, a total of 816 615 HSI futures contracts were traded in October, representing an increase of 64% over the first nine months of 1997.

The second tense episode ran from the 7th to 21st January 1998 with a probability of a HK dollar devaluation rising above 50% in a context of intensified tensions in Indonesia, whose currency slumped dramatically as did the Taiwan dollar (Figure 4, Annex II). But the main factor driving the expectations on the HK dollar in January 1998 was fears of a renminbi devaluation. A short moment of stress can be observed around the middle of June 1998; at that time, the Asian stock markets were at record low levels and fears of a huge depreciation of the yen vis-à-vis the US dollar put pressures on the Asian currencies. The speculative pressures were then reinforced by a negative market sentiment about Mainland China's fundamentals.

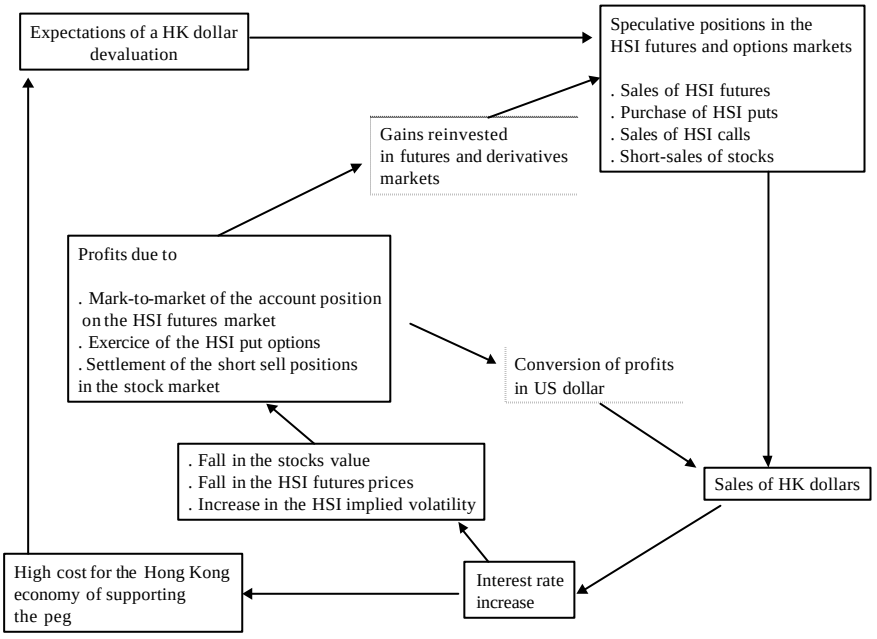
The last phase runs from the 5th August to the 4th September 1998 in a context characterised by a particularly low level of turnover in the stock market, contrasting with the sharply growing activity in the index futures market (Figure 1, Annex II) and by bad news about the Hong Kong GDP growth for the first quarter, revised down to –2.8%. The dynamics of this last attack rested on a cross-market speculation involving the foreign exchange and the stock index futures market. Building on the experience of the October crash, the speculators deliberately used the predictable high sensitivity of the domestic interest rate to capital flows in order to push down the stock index (Yam, 1998-b).

In essence this so-called "double play" rested on the following mechanism: starting at the beginning of 1998, speculators pre-funded themselves by swapping US dollars for HK dollar in the debt market with multilateral institutions that had raised HK dollars through the issue of debt. Unlike the October 1997 speculation, the August crisis thus reflected a largely planned attack, the positions taken by speculators providing them partly against a huge increase in the domestic interest rate. The HKMA estimates that the hedge funds borrowed about HK$30 billion from January to August 1998 (Yam, 1998-a). Then they borrowed shares at a relatively low cost[20] and engaged in short-selling the stock index and HSI futures abruptly before shorting the Hong Kong dollar. The HK dollar sell-off waves were aimed at provoking a sharp interest rate increase, then forcing the stock exchange to plunge. Figure 2 from Annex 2 shows the continuous decline of the HSI futures prices from April to August 1998, the latter movement being associated with a important growth of outstanding positions on HSI futures (Figure 1, Annex II). The implied volatility of HSI put options, which reveals the uncertainty on the future evolution of the stock index, mimics the futures market but in the opposite direction (Figure 3, Annex II).

The more the Hang Seng Index fell, the higher the profits of speculators due to the marking-to-market of their margin accounts on the Futures Exchange. The marking to market implies that the future contract is settled daily rather than at the end of its life, so that the gains of a

[20] The Hong Kong government's *Report on the Financial Market Review* (1998) mentions « As there is a substantial pool of Hong Kong stocks held by international fund managers and custodians outside Hong Kong, and since the overseas stock borrowing and lending market runs a more efficient and less costly service, it is believed that stock borrowing and lending of Hong Kong stocks off-shore is more active than on-shore. ».

seller of HSI futures are added to its margin account at the end of each day when the future prices decline. The HKMA has estimated that 80,000 HSI futures contracts were sold by hedge funds,[21] which were conducive to a profit of HK$4 billion every thousand-point fall in the stock index. The gains have also stemmed from the continuous short sales of stocks, the speculators purchasing securities to meet their settlement obligations at a lower price they had short-sold them T+2 days before.[22] Finally, by exercising HSI put at maturity, as the HSI had fallen relative to the strike price of the options, their holders might have benefited from further gains. Buying HSI put options could be a pure speculative position, only motivated by the expectations of a decline in the stock index or could be taken to cover a long position in the stock index (the result is a synthetic HSI call). In this context, all the bearish strategies were successful, as long as, coupled with sales of HK dollar inducing an interest rate increase. These gains were then either converted into US dollars by foreign speculators, reinforcing the short HK dollar positions or reinvested in bearish speculative positions in the futures and options markets. The dynamics underlying the double play can be synthesized by the following scheme.



[21] The hedge funds involved in the speculation were identified as being the Quantum Fund of George Soros, the Tiger Fund, the Moore Global Investment and the Long Term Capital Management.

[22] As Yam (1998-a) argues, « The cost of borrowing was low and there were lax settlement requirements that specified T+2 but said at the same time that you could have a few days' grace if you did not have the stocks on settlement day, even though going naked short in stocks was against the law. ».

Such self-fulfilling speculative dynamics and the important sums it involved were considered by the HKMA as market manipulation conducted by some hedge funds and required an appropriate response: the Authority repeatedly argued that speculators did not contribute to the normal price adjustment process, but directly aimed at destabilising its monetary and foreign exchange policy framework.

3.2. The HKMA responses to the double play speculation

As a response to this double attack, between the 14th and 28th August 1998, the HKMA intervened via the Exchange Fund on the stock and futures markets.[23] It acquired a portfolio of equities and HSI futures for an amount of about US$15 billion, that is 7% of the capitalisation and around 30% of the current Hang Seng Index value (IMF's International Capital Markets Report, 1999). About 13% of its non monetary reserves, i.e. the reserves in excess that did not back the monetary base, were allocated to these interventions, inducing an important injection of liquidity into the money market. In attempting to increase the value of the HSI and HSI futures, the Monetary Authority sought to squeeze the speculators. They would have been constrained to close their short positions by purchasing stocks and futures contracts, before their expiration date at a higher price they had short sold them. But by acting so, the HKMA departed from free-market principles, and introduced some doubt about its future willingness to obey the automatic mechanism of the currency board.[24]

In a first stage, the HKMA considered high interest rates as a tool to defend the peg and to punish speculators. But, to work well, the automatic adjustment mechanism of the currency board should not suffer from a high risk premium, unless it becomes totally inefficient to induce new capital inflows. This premium is likely to be positive during speculative attacks, so that the normal operation of the interest rate arbitrage depends to a large extent on the confidence the markets place in the authorities' monetary commitment. Because high interest rates were not effective and because its discretionary responses to speculative attacks appeared unsuccessful, the HKMA adopted a new strategy the 5th September 1998 to reduce interest rate volatility. A set of technical measures was announced to strengthen the currency board, grounding it on a more rule-based system. They respected the fundamental precept of the currency board and were aimed at conveying the firm determination of the HKMA to its commitment to the linked exchange rate system.

First, the convertibility guarantee was extended from banknotes to include the aggregate balance. Before the reform, there was no clear convertibility undertaking to convert the aggregate balance or any definition of the domestic currency into foreign reserves at the fixed exchange rate of HK$7.8 to US$1. Indeed, the currency board had the discretion to trigger convertibility for domestic currency sold in the foreign market, with settlement

[23] Another action of the HKMA was blamed at this time. The HKMA has pled the need to fund the budget deficit to switch some of its accumulated fiscal reserves held in foreign currency to HK dollar. The immediate impact on this sale, of an amount exceeding the HK$30 billion accumulated by the hedge funds, was the non trigger of high interest rate.

[24] Voices were raised against such a non-standard measure to counter speculative pressures. The IMF's International Capital Markets Report (1999) mentions that these interventions could have created belief of an informal floor to the HSI, altering the perception of risk by international investors.

through the aggregate balance, at the exchange rate different from the official rate of HK$7.8. Actually, the HKMA had chosen a first "line of defence" at 7.75, its current intervention rate, and the current exchange rate fluctuated around this value since 1995. After the reform, all licensed banks in Hong Kong could convert the HK dollar against the US dollar, in their clearing accounts with the HKMA, at a fixed exchange rate of HK$ 7.75 to US$1. The circular also mentioned the intention of the HKMA to move the rate of the convertibility undertaking to HK$7.8, when the market conditions permit it.

Second, the LAF was supplanted by a discount window, where banks can use the Exchange Fund bills as collateral to obtain overnight liquidity henceforward, without restrictions and without penalties for repeated use. The base rate, the interest rate of the discount window, is set according to a formula taking into account both an average of the Hong Kong inter-bank interest rates and the Fed fund rate.

These measures have basically two main implications on the operation of the Hong Kong currency board. The banks can increase liquidity in their clearing accounts by rediscounting their holdings of Exchange Fund bills at the discount window. The HK dollars so obtained have the convertibility guarantee because they are part of the aggregate balance. But, implicitly, the convertibility guarantee is indirectly extended to the outstanding of Exchange Fund papers held by banks: the part of the Exchange Fund bills held in excess with respect to those needed to manage intra-day liquidity is also covered. Consequently, the monetary base has almost been doubled. It now includes in addition to the coins in circulation, the certificates of indebtedness (CI) backing the banknotes, and the aggregate balance, the outstanding of Exchange Fund bills and Notes.[25] Furthermore, to ensure that all new Exchange Fund papers are fully backed by foreign currency reserves, the measure stipulated that issue of new Exchange Fund papers is contingent to an inflow of US funds.

In case of a currency attack, banks can thereby use their holding of Exchange Fund Bills to inject liquidity into the aggregate balance to avoid capital outflows exceeding the interbank liquidity. Because the size of the aggregate balance can potentially be increased from HK$2.5 billion to 81 when needed, this limits seriously the scope for further double play speculation, based on the high sensitivity of interest rate. Due to a greater inter-bank market depth, the interest rate movement in response of capital flows was thereby dampened.

An interpretation of these Exchange Fund bills and notes is that they are equivalent to put options on the HK dollar. In fact, the first, legally binding measure guarantees that all the banks holding Exchange Funds Bills and Notes denominated in HK dollars would be covered in case of a HK dollar devaluation beyond 7.75.

But the measures announced the 5th September did not specify the period over which the convertibility undertaking should apply. As Chen, Kwan and Lui (1999) point out, if the

[25] At the end of 1998, the assets in US dollar backing the monetary base (in HK$ billion, coins: 5.8, CI: 86.5, aggregate balance: 2.5 and outstanding of Exchange Fund bills and notes: 98.3 of which held by licensed banks: 81) amounted to HK$ 209.7 billions, i.e. about 21% of the total foreign reserves held by the Exchange Fund.

HKMA decides to devalue, it can claim that the guarantee has already expired. This ambiguity entailed brief speculative pressures, so that the 14th September, the HKMA announced that the rate of 7.75 would be maintained for at least six months. But a second source of uncertainty then prevailed concerning the convertibility undertaking of HK$7.75 after the period of six months. This uncertainty was totally removed the 26th November, when the HKMA clarified the pattern to move the rate from HK$7.75 to HK$7.8: from the 1st April 1999, it would be gradually changed from 7.75 to 7.8HK$ by a pip (i.e. HK$0.0001) each calendar day over a 500 days period.

Furthermore, to avoid the renewal of future double game strategies, these measures were also accompanied by reforms of the operation of the securities and futures markets, aiming at increasing the cost of speculative activity and tightening the regulation.

4. THE DETERMINANTS OF THE INTENSITY OF A HK$ DEVALUATION

To analyse the interaction between the intensity of a HK dollar devaluation and the expectations underlying the cross-market speculation, a VAR methodology is implemented. More specifically, we want to assess whether expectations of devaluation have fuelled bearish speculation in the stock futures and options markets and vice-versa. The VAR framework appears the most appropriate to investigate these questions, because it allows different variables to be considered as endogenous in the system without constraining *a priori* the relations between them. Then, to examine some possible contagion effects arising from the Asian crisis, different variables are introduced with an exogenous status. Because the Hong Kong currency board did not fail, the speculative attacks against the HK dollar were unlikely to have triggered devaluation in the Asian markets. Finally, the efficacy of the HKMA interventions and reforms will be assessed via dummies.

4.1. Variables

Cross-market speculation

To address the question of the double play, the estimated VAR includes overlapping markets. Three endogenous variables are considered: the intensity of a HK dollar devaluation, the Hang Seng Index futures returns, and the volatility of the stock index implied in at-the-money put options (in first difference). The analysis is implemented with the intensity of devaluation rather than the probability, because it reveals an additional information about the magnitude of the expected jump of the exchange rate in case of devaluation. HSI futures, instead of HSI itself, have been retained because the futures market aggregates information quicker than the spot market, and indicates the current market expectations about the price of the index at a specific date in the future. Besides, the volatility implied in option prices, reflects the uncertainty over the future evolution of the stock index up to the maturity. The higher this volatility, the higher the probability that the HSI put options will be exercised at maturity. In fact, profitable speculative strategies could have involved this market due to the leverage effects of the derivatives instruments. The more the index shrinks at maturity, the higher the gains for speculators who have bought HSI puts. For less risk-adverse speculators, another strategy would have been to sell HSI calls to obtain the premium, this premium increasing with the implied volatility.

The contagion effects

The potential effect of a *common world shock* disturbing the Asian area is catched by two variables: the exchange rate of the dollar/yen and its one-month implied volatility. This volatility reflects the *ex ante* dispersion of the expectations on the dollar/yen value at maturity. It has been argued that the depreciation of the yen vis-à-vis the dollar from 1995 to 1998 has put some pressure on the Asian currencies that were linked to the dollar, via a potential loss of competitiveness for these countries. As the yen reached a low level especially in June 1998, the implied volatility spiked to levels rarely observed, revealing the uncertainty about the future evolution of the yen.[26]

The *spillover effect* results from the interdependence among emerging countries displaying some similarities in foreign trade or macroeconomic imbalances. A crisis in one country may alter the fundamentals of another (Glick and Rose, 1998; Eichengreen, Rose and Wyplosz, 1996). To deal with this effect, two different channels are considered. The first one rests on the loss of competitiveness if the surrounding countries devalue. The direct trade link between Hong Kong and the Asian countries, except Mainland China, is not very convincing. Indeed Taiwan, the first Asian partner, accounts for about 3% of the total exports in 1997 and 1998. However some indirect trade linkage due to third market competition could have played a role, because the Asian countries exported a large part to the US and Japan. The second channel refers to liquidity shocks stemming from the portfolio reallocation of international investors (Valdés, 1997). If a crisis hits a country, entailing a stock crash, margin calls, regulatory margins and credit rationing can induce selling waves in similar countries to meet speculators' obligations. Asian stock indexes and exchange rates are considered in the analysis to take into account these potential effects.

Finally, the *pure contagion effect* is not easy to capture by some data series. Indeed, it involves either a reassessment of perceived risk, given current information, or an increase in the risk aversion from international investors. However, we assume that if a higher risk is priced for the emerging markets as a whole, then the Brady bonds, which have become a speculative instrument for taking short positions offshore, are likely to reflect it. Indeed, the empirical evidence tends to show that speculators short sell these bonds, when they have a negative perception of the fundamentals of some countries, entailing a decrease of their prices and potentially fuelling a further speculation via onshore channels (IMF's International Capital Markets Report, 1999). Furthermore, the volatilities of Asian currencies implicit in option prices are supposed to reveal the shift in market expectations about the future evolution of Asian exchange rates, and more generally the overall uncertainty in the Asian area. Finally dummies reporting the dates of the devaluations of the Asian currencies also serve as a source of contagion[27].

[26] This market configuration may have been at the origin of the concerted intervention of the Fed and the Bank of Japan, the 19th June 1998.

[27] The 2nd July for Thailand, the 14th July for Malaysia, 17th July for Singapore, the 15th August for Indonesia, the 20th October 1997 for Taiwan and the 17th November for Korea. We retain this last date instead of the official devaluation time, which occurred the 16th December, because it corresponds to the beginning of the won depreciation.

The HKMA interventions

The efficiency of the interventions and reforms decided by the HKMA are gauged relative to their aim of reducing speculative pressures in order to preserve the Hong Kong currency board. Dummies are introduced in the regressions to evaluate the impact of these interventions. The first dummy picks up the impact of the HKMA memorandum sent to all licensed banks the 23rd October 1997. It equals 1 this day and 0 otherwise. The second captures the influence of the HKMA interventions on the stock market and index futures markets from the 14th to 28th August 1998. It takes the value of 1 during the days of intervention and 0 elsewhere. The third dummy, devoted to measure the impact of the institutional changes decided by the HKMA the 5th September 1998 takes the value of 0 before and 1 after.

4.2. The data

The data are in daily frequency. The period under consideration extends from the 15th August to December 1998, after the Indonesian roupiah devaluation. The one-month currency implied volatility for Thailand, Malaysia, Singapore, Indonesia and the United States are drawn from the J.P. Morgan web site. These volatilities come from at-the-money options, i.e. their delta equals 0.5. They are more liquid than quotes corresponding to other deltas. The exchange rates also stem from this site. Asian Stock Indexes come from the WEFA database. They include stock indexes of Malaysia, Korea, Thailand, the Philippines, Indonesia, Taiwan, Singapore and China. The volatility of the stock index implied in at-the-money put options and the Brady bonds index are both drawn from Bloomberg and are closing quotes. HSI futures prices come from Hong Kong Futures Exchange[28]. HSI futures prices are open prices corresponding of the nearby delivery month.

4.3. VAR methodology

Stationarity Tests

Because the specification of the VAR depends on the stationarity of the series, stationarity tests were run (Annex III). They first consist in "Augmented" Dickey Fuller tests (ADF). Because these tests conclude too frequently that the series are non-stationary, Kwiatkowski, Phillips, Schmidt and Shin tests (1992) (KPSS) were also performed. These last tests are more appropriate in cases of overlapping data, where actually the daily frequency is higher than the maturity of some data. ADF test uses non-stationarity as null hypothesis, whereas the KPSS test considers stationarity as null hypothesis. When the non-stationarity of the different variables in level is not rejected by ADF and accepted by KPSS, regressions are run with the variables in first difference. These tests reveal that the intensity of a HK dollar devaluation is I(0), whereas the implied volatility of the HSI and the HSI futures are I(1). Given the presence of unit roots in the last two series, a Johansen test of cointegration was performed. It concludes that no cointegrating vectors can be found between the implied volatility of the HSI and the price of HSI futures.[29]

[28] More information about details and specifications about futures contracts and options is available from the site http://www.hkfe.com/products.

[29] The results are not reported here for reasons of space, but can be obtained on request from the author.

The Asian implied volatilities, stock indexes, exchange rates and the Brady bonds index are all I(1).[30] The dollar/yen exchange rate is I(1), while its implied volatility is I(1) for both tests when only a constant is introduced, whereas it is I(0) when a trend is added in the regression.[31] This volatility is introduced in level in the VAR regressions.

The VAR specification

We specify the VAR with exogenous variables in the following form:

$$Y_t = A_0 + \sum_{i=1}^{n} A_1 Y_{t-i} + A_2 \sum_{i=0}^{n} X_{t-i} + \varepsilon_t \qquad (6)$$

The vector of endogenous variables Y_t depends on a constant term A_0, on its *n* own, lagged values, and on a lagged polynomial of the vectors of exogenous variables X_t, where A_1 is a squared matrix and A_2 is a matrix of significant coefficients.

Three variables make up the endogenous vector: the intensity of a HK dollar devaluation, the Hang Seng Index futures returns and the volatility of the stock index implied in the at-the-money put options (in first difference). The exogenous variables, denoted as X_t are the Asian stock indexes, exchange rates and currency implied volatilities[32], in addition to the dollar/yen returns, its implied volatility and the Brady bonds index returns. It also includes two kinds of dummies: dummies of Asian devaluation dates and dummies corresponding to the HKMA interventions.

The Choleski method, which implies a recursive structure between the shocks, is used to calculate the impulse response functions, so that the order chosen for the endogenous variables influences the shape of the response functions. The following order was kept so as to measure the impact of HK dollar devaluation expectations on the evolution of stock markets, and to assess the relevance of the double play.

$$Y_t = (INT_t, dFUT_t, dVOL_t) \qquad (7)$$

[30] The Johansen cointegration test indicates the absence of cointegrating vectors between the different Asian stock markets, between the implied volatilities and between the different exchange rates. They are introduced in log first difference in the VAR.

[31] KPSS test does not reject the stationarity for the implied volatility of the dollar/yen at a 1% significant level.

[32] More precisely, the currency implied volatility is available for Thailand, Singapore, Malaysia and Indonesia. The stock indexes are those of the Malaysia, Indonesia, Philippines, Thailand, Singapore, Korea, Taiwan and China. Finally, the exchange rates returns are those of the Philippines, Korea, Indonesia, Taiwan, Thailand, Malaysia and Singapore.

An important econometric problem is raised by the overlapping data, which introduce serially correlated errors in the regression: the daily frequency of the endogenous variables is higher than their maturity. To circumvent this difficulty, the White procedure and the Newey West (1987) estimator were used. The optimal lag proved to be 3, with regard to the Schwarz Bayesian Information Criterion and to remove the autocorrelation of the estimations.

5. THE RESULTS OF THE ESTIMATIONS

This section underlines the forces driving the expectations of a HK dollar devaluation and the way the speculation worked in Hong Kong from the 15th August 1997 to the end of December 1998. A better understanding of the specific speculative dynamics linking several markets is necessary to assess the relevance and the efficiency of non-standard HKMA interventions.

5.1. Contagion effects

One measure of contagion rests on a significant increase in the correlation between similar assets during the crisis period, relative to tranquil market conditions. In calm periods, the intensity of devaluation does not differ from zero. In contrast, during a speculative attack, it becomes positive and all its exogenous determinants entering with a significant coefficient can be considered as revealing one of the three channels of transmission of shocks.[33]

One interesting result of the estimations highlights a significant and robust external effect, an actual one and an expected one: the value of the dollar/yen and its one-month implied volatility appear to be important factors in explaining the evolution of the intensity of a HK dollar devaluation (see Annex IV). On the one hand, the argument of a continued loss of competitiveness of the HK dollar with respect to the whole Asian area and more prominently Japan can be put forward (Figure 4, Annex II). On the other hand, the significance of the implied volatility of the dollar/yen reveals a risk of a new wave of competitive devaluations in the Asian area, likely to shift the HK dollar expectations toward a bad equilibrium (Figure 5, Annex II). In the prevailing context, the higher the volatility, the greater the expected magnitude of the yen depreciation at maturity. The fears of foreign investors in January 1998, but especially in June 1998 were linked to the size of the yen depreciation, which could have been possibly large enough to question the benefits of the former Asian devaluations.

[33] But, the interpretation is different for the exogenous variables explaining the HSI futures returns, and the implied volatility of the stock index. This cannot be termed neither monsoonal or spillover effects nor pure contagion. The significant link between the Taiwan stock index and the HSI futures can stem from standard relationships. Indeed, it is not possible here to discriminate between a historical interdependence and an increase in the coefficient of correlation stemming from the crisis. However, these latter significant exogenous variables have been kept to achieve a better specification of the VAR and to measure the additional influence of the other endogenous variables. The exogenous variables that had no explanatory power on any endogenous variables were dropped from the regressions.

Indeed, the Asian exchange rate returns have no explanatory power, except for the Taiwan dollar and to a very less extent for the Singaporian currency. However, the Taiwan variable seems to have impacted Hong Kong, not through a trade-linked effect, because this country accounts for only a very small part of the Hong Kong trade balance, but through a pure contagion effect. As Figure 6 (Annex II) shows, the devaluation of the Taiwan dollar in October 1997 triggered an immediate speculation against the HK dollar. This explanation is confirmed by the significance of the dummies reflecting the psychological shocks of each Asian devaluation. Except the cases of Thailand and Singapore, the announcements of devaluation of the Indonesian roupiah, the Taiwan dollar and the Korean won have all increased the intensity of a HK dollar devaluation. Besides, the Malaysian implied volatility (in first difference) appears also significant. Its impact on the expectations on the HK dollar can also be described as a psychological one, because it only moves in response to specific events, due to the thin depth of the ringgit option market (Figure 7, Annex II). Pure contagion effects are furthermore revealed by the significance of the Brady bonds. The more the index shrinks, revealing sell-off waves from speculators and more broadly a suspicion hitting the emerging markets, the higher the intensity of a devaluation in Hong Kong (Figure 8 Annex II). Although most of the Asian countries did not issue Brady bonds, the Brady bonds fall over the period, made all the emerging markets more vulnerable.

The purely Asian spillover effects stemming either from a loss of competitiveness via the devaluations of the Asian currencies or from liquidity shrinkage reflected by the different stock index falls, did not impact the expectations of a devaluation in Hong Kong. The only exceptions are the Malaysian stock index, which decreased continuously over the period (Figure 9, Annex II).

Finally only two channels of contagion appear to be actually significant to explain the formation of expectation on the HK dollar: the common external effect and especially the pure contagion.[34]

5.2. Cross-market speculation and the Impulse response Functions

To ascertain the relevance of the double play, orthogonalised impulse response functions were calculated (Annex V). First, the responses of the three endogenous variables to a shock on the devaluation intensity are displayed. The response of the expectations of a HK dollar devaluation to such a shock tends to confirm the stationarity of the devaluation intensity: the persistence of the shock is limited to two days. More interesting are the responses of the HSI futures returns and the implied volatility of the HSI: the stronger the

[34] Another important factor driving the expectations of a HK dollar devaluation over the period was the fear of a Renminbi devaluation. An indicator of this risk perceived by international investors can be inferred from the offshore nondeliverable forward market. Forward Renminbi data are avaible for several maturities from Bloomberg. From July 1997 to December 1998, they were quoted at a weekly frequency. To deal with the mismatch frequency, the weekly available data have been assumed to be constant from one observation to the other to obtain a daily series**.**The one-month Renminbi forward, introduced in the VAR as exogenous, appears to be highly significant. However, the change from weekly to daily frequency can be venturesome, so that the estimation has disregarded this variable in the text. The results are available on request from the author.

expectations of an impending HK dollar devaluation, the greater the fall of the futures and the higher the uncertainty about the future evolution of the index. These significant, temporary effects -being corrected from the influence of other exogenous variables introduced in the VAR- tend to demonstrate the presence of a double speculative play involving the derivatives stock markets, prompted by an expected devaluation of the HK dollar.

The analysis of shocks in the stock markets shows that a negative shock on HSI futures returns tends to raise the implied volatility of the stock index, but that the reverse is not significant. The more the futures prices slump, the higher the uncertainty perceived in the market. Furthermore, when a shock of the HSI volatility is considered, the growing uncertainty about the future value of the index proved to have increased the probability of a collapse of the Hong Kong peg: the higher the volatility, the higher the intensity of a HK dollar devaluation. However, a shock of the HSI futures to the intensity gives a quite counter-intuitive result: the higher the futures returns, the higher the intensity of a devaluation.

A circular scheme characterised the formation of self-fulfilling expectations. The intensity of a HK dollar devaluation induced a sharp decrease in the index futures prices, which contributed to make the volatility of the HSI soar, in turn exacerbating the speculative pressures against the HK dollar. Such vicious circle led the HKMA to depart from the free-market philosophy of the currency board and to venture into non-standard discretionary actions.

5.3. Efficiency of the HKMA interventions

Over the period, the HKMA responses were non-standard, first in the light of the market discipline in a currency board, and second with respect to the instruments used and the markets involved.

One striking result about the efficiency of these interventions is linked to the sharp contrast between its discretionary actions relative to those aimed at introducing a more rule-based system (Annex IV). The first attempt to penalise speculators through a sharp interest rate increase in October 1997 proved to be counter productive. It provoked a pronounced spike of the intensity of a HK dollar devaluation, and resulted in an abrupt drop in futures prices and a huge increase in volatility of the stock market. The second measure taken in order to deter the Hong Kong stock market "manipulation" in August 1998 took the market by surprise and fuelled further expectations of a HK dollar devaluation. However, the interventions achieved to push up temporarily the index futures price, but induced a significant rise in the market volatility. Finally, the new technical measures to strengthen the currency board introduced in September 1998 were conducive to a greater credibility of the Hong Kong dollar's peg: the intensity of a HK dollar devaluation has decreased significantly since then. The superiority of the rule versus discretion has once more been established from these results, as far as defending a fixed peg is concerned.

6. CONCLUSION

This paper proposes an indicator of the expectations of devaluation in Hong Kong based on information delivered by currency option prices. Although the linked exchange rate system did survive the various attacks over the 1997-1998 period, it is crucial for the future to identify the key determinants which have driven the expectations of a peg breakdown. Indeed, the nature of these variables, their potential disturbing role and the way the speculation operated involve different responses in terms of policy-oriented measures, and may deliver lessons for the HKMA towards a better defence of the Hong Kong currency board.

Three major conclusions are drawn. First, only two channels of shock propagation are plainly robust and significant in explaining the formation of expectations on the HK dollar: the external effect, captured by the value of the dollar/yen exchange rate and its implied volatility and the pure contagion relying on the reassessment of risk by international investors. Unlike the point of view sustained by Davies and Vines (1995), who argue that currency board may deter self-fulfilling runs and multiple equilibria, it is shown that the logic underlying the several attacks against the HK dollar rests essentially on self-fulfilling expectations and on a pure contagion.

Second, the presence of a double play was made clear. The impulse response functions show the circularity of expectations: the expectations of a HK dollar devaluation fuelled speculation in the stock futures and options markets, which in turn was conducive to fears of an impending demise of the currency board.

Finally, the reflexivity in the formation of expectations led the HKMA to engage in unusual interventions, departing from its traditional free-market philosophy. All the discretionary measures adopted by the HKMA to break this self-fulfilling speculative scheme proved to be at best ineffective and at worst counter productive, since they led to greater speculative pressures on the foreign exchange market. In contrast, when the HKMA undertook reforms to introduce a more rule-based system in September 1998, it succeeded in dampening the pressures against the HK dollar.

ANNEX I

The implied probability density function

Different approaches are commonly used to infer the PDF from options prices. The first approach is totally non-parametric, but requires a considerable amount of observations, which obviously prevent its use (Aït Sahalia and Lo, 1995; Hutchinson, Lo and Poggio, 1994). The second one postulates a particular, functional specification on the volatility smile[35] or on the quoted option prices. It consists in interpolating a function minimising the distance between the observed volatilities (or option prices) and the theoretical volatilities generated by the function, then extrapolates beyond the available strike prices (Bates, 1991; Shimko, 1993; Malz, 1997; Campa, Chang and Reider, 1997). The third approach proposes some possible *a priori* "candidates" for the PDF and consists in minimising the distance between the postulated density and the one implied in option prices. For example, the implicit density can be issued from a lognormal mixture (Melick and Thomas, 1997; Bahra, 1996, 1997; Söderlind and Svensson, 1997) or from a Burr distribution (Sherrick, Garcia and Tirrapur, 1996). Finally, the fourth method is strongly parametric; it postulates strong assumptions on the underlying dynamics to obtain a closed form solution for the valuation formula. The assumed process can, for example, be a Brownian Motion correlated with a stochastic volatility (Hull and White, 1987; Wiggins, 1987; Chesnay and Scott, 1989; Melino and Turnbull, 1990 and Heston, 1993) or a mixed jump diffusion process (Merton, 1976; Jorion, 1988; Malz, 1996; Bates 1991, 1996-a and 1996-b). The latter approach is used here.

Keeping the Malz notations, such dynamics can be modelled by the following equation:

$$S_T = S_0 + \int_0^T (r - r^* - \ddot{e}E[k])S_t dt + \int_0^T \acute{o}_w S_t dW^*_t + \int_0^T S_t k dq_{t,T} \qquad (1)$$

where $\acute{o}_w$ is the volatility of the exchange rate, $q_{t,T}$ is a Poisson counter on the time interval (t,T) with a jump probability $\lambda(T-t)$, k is the magnitude of the possible jump and W_t^* is a Wiener process. To simplify the formula, k is postulated non-stochastic: there is either one jump until the maturity or none. In fact, under these assumptions, this formula turns out to be a mixture of two lognormal distributions. The evaluation formula under a Bernoulli distribution (Ball and Torous, 1983,1985) is the following one:

[35] Implied volatility plotted as a function of the strike prices (delta) look like a smile, because volatility quotes tend to be higher when the strikes are far away from the forward exchange rate (the delta are far away from 0.5).

$$C(S_t, t, T; K, \sigma_w, r, r^*, \lambda, k) = \tag{2}$$

$$[1-\lambda(T-t)]\left[\frac{S_t e^{-r^*(T-t)}}{1+\lambda k(T-t)}\Phi\left(d_0+\sigma_w\sqrt{(T-t)}\right)-Ke^{-r(T-t)}\Phi(d_0)\right]$$
$$+\lambda(T-t)\left[\frac{S_t e^{-r^*(T-t)}}{1+\lambda k(T-t)}(1+k)\Phi\left(d_1+\sigma_w\sqrt{(T-t)}\right)-Ke^{-r(T-t)}\Phi(d_1)\right]$$

with

$$d_0=\frac{\ln(S_t/K)-\ln[1+\lambda k(T-t)]+(r-r^*-\sigma_w{}^2/2)(T-t)}{\sigma_w\sqrt{(T-t)}}$$

$$d_1=\frac{\ln(S_t/K)-\ln(1+\lambda k(T-t)+\ln(1+k)+(r-r^*-\sigma_w{}^2/2)(T-t)}{\sigma_w\sqrt{(T-t)}}$$

This formula is an average of the Black and Scholes option value conditional to a jump, multiplied by the probability of a jump, and the value of the option conditional of the absence of jump multiplied by the probability of no jump. Under the Bernoulli distribution, the Poisson counter equals zero with probability (1-λ (T-t)) and 1 with probability λ(T-t). This formula postulates that the risk neutral parameters (k, λ and σ_w)[36] are constant until the time to expiration of the options.

Finally, the second derivative of this function numerically calculated and multiplied by $e^{r(T-t)}$ gives the risk neutral PDF of the future exchange rate.

[36] The risk neutral parameter λ can be greater than the subjective probability anticipated by the market, if agents are risk adverse.

ANNEX II

Figure 1: HK$ devaluation intensity and the open interest on HSI futures

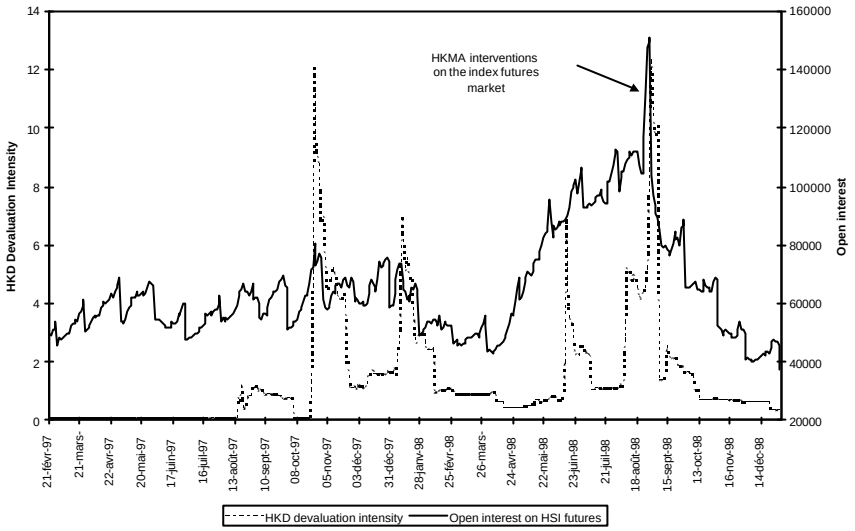


Figure 2: HK$ devaluation Intensity and the HSI futures prices

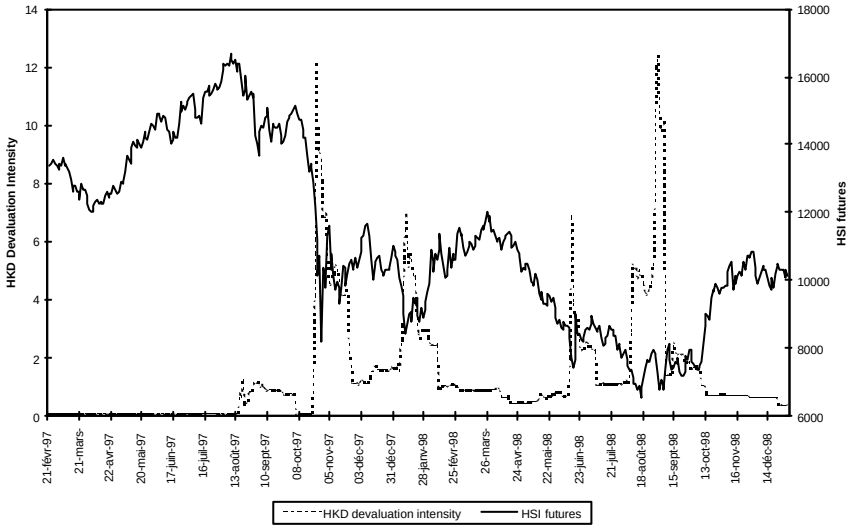


Figure 3: HK$ devaluation intensity and the HSI put implied volatility

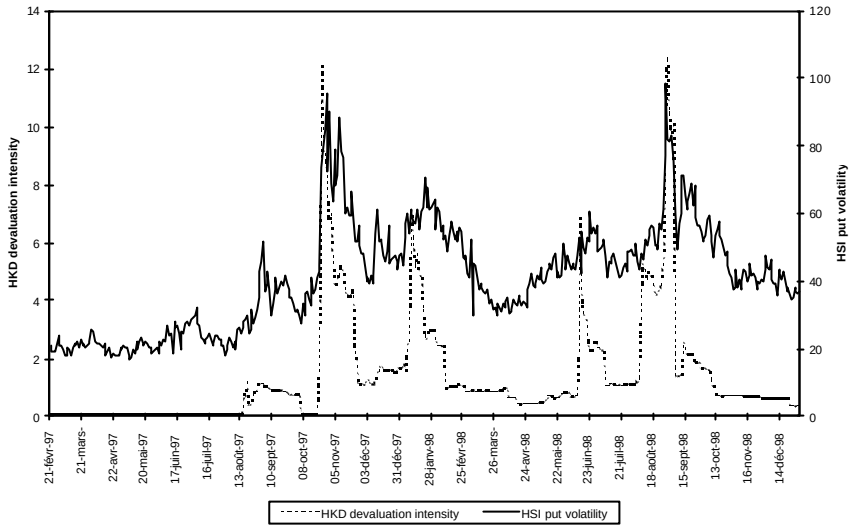


Figure 4: HK$ devaluation intensity and the Dollar/yen exchange rate

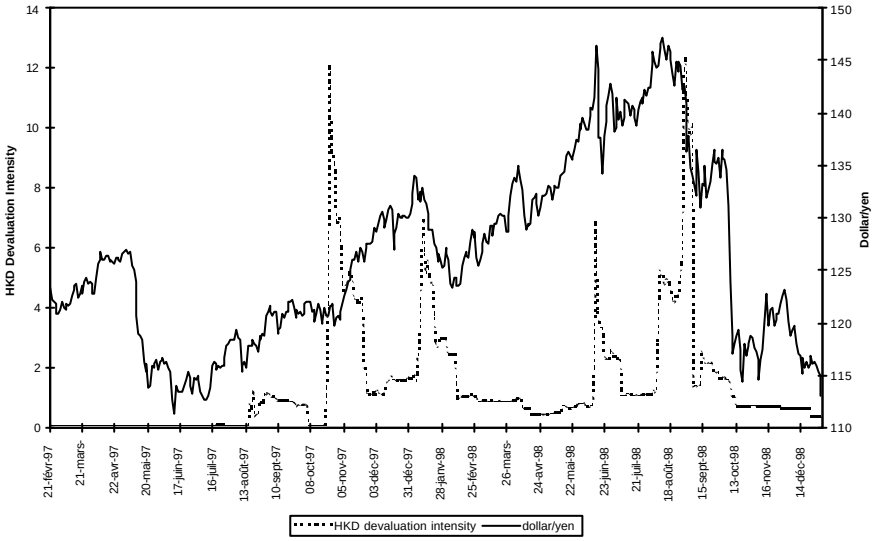


Figure 5: HK$ devaluation intensity and the one-month implied volatility on the Dollar/yen

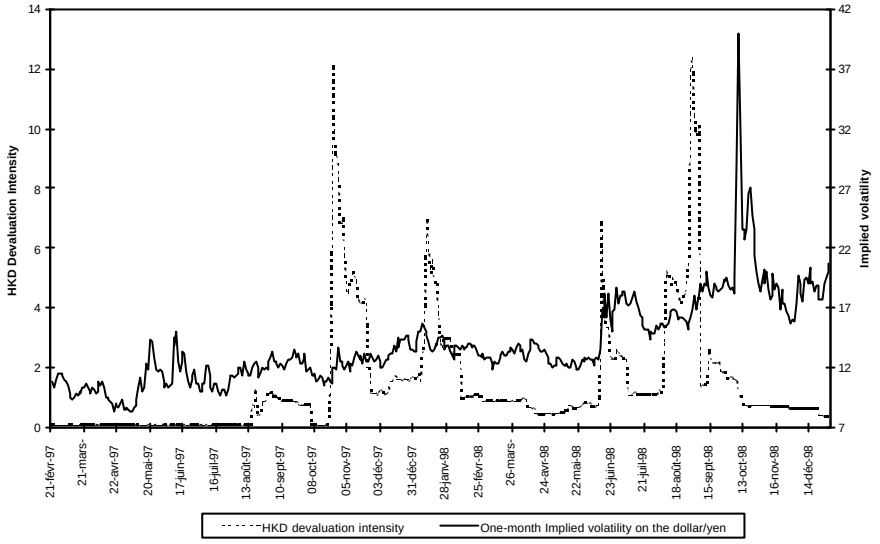


Figure 6: HK$ devaluation intensity and the Taiwan dollar value

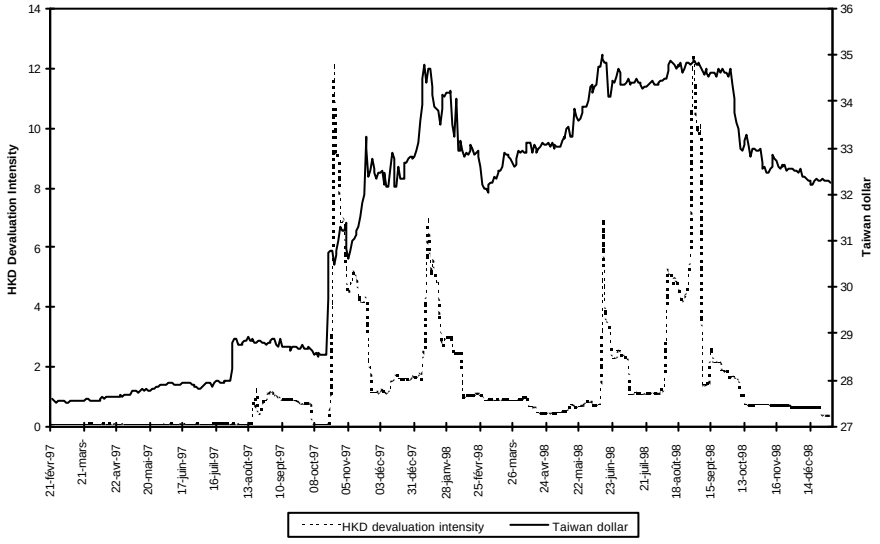


Figure 7: HK$ devaluation intensity and the Malaysian Implied volatility (in first difference)

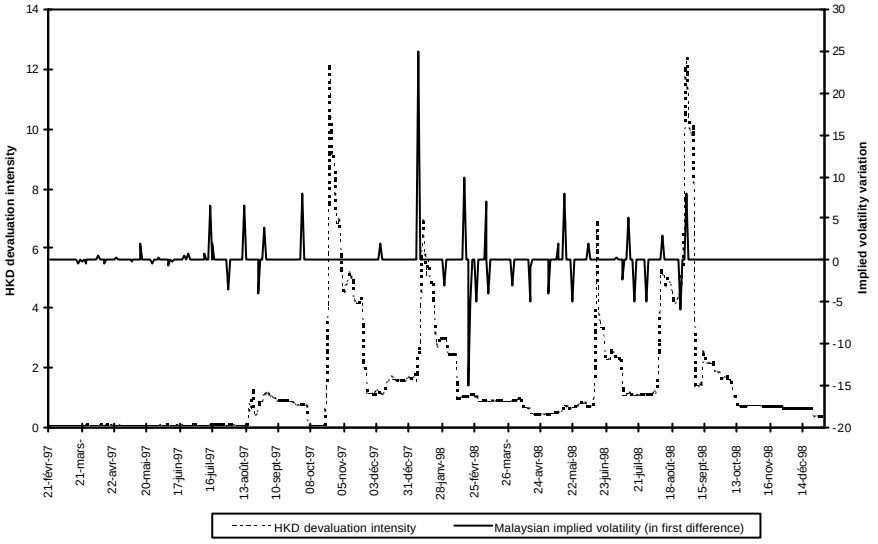


Figure 8: HK$ devaluation intensity and the Brady Bonds index

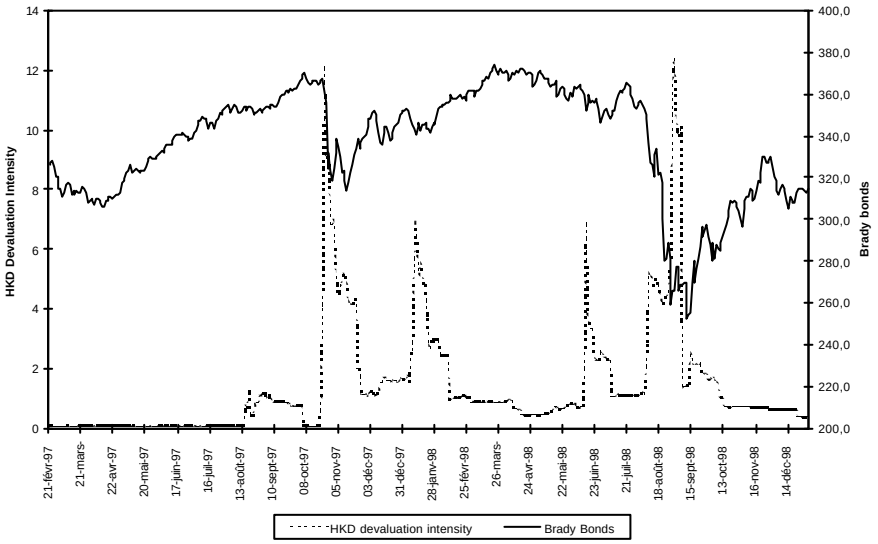
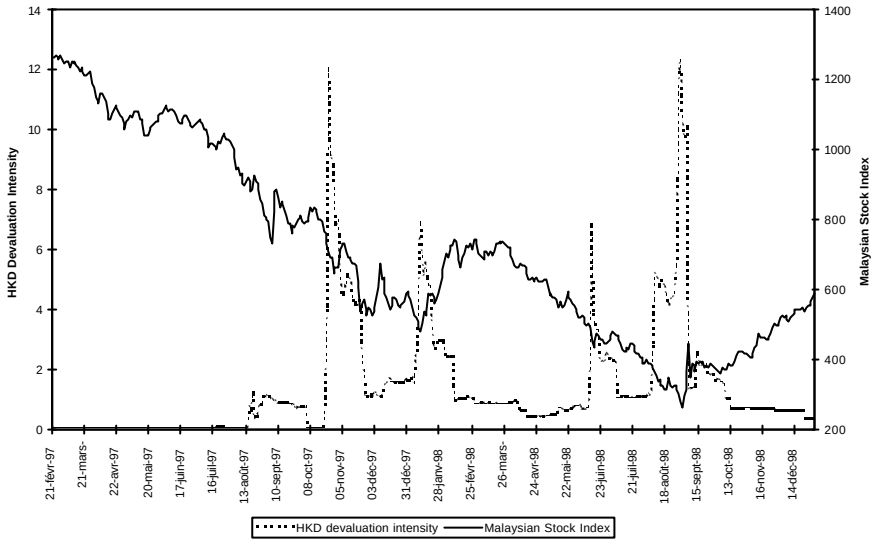


Figure 9: HK$ devaluation intensity and the Malaysian Stock Index



ANNEX III

Stationarity Tests

Variables	TESTS									
	Augmented Dickey Fuller						KPSS (21 lags)			
	C			C+T			C		C+T	
	Statistic	Lags	Results	Statistic	Lags	Results	Statistic	Results	Statistic	Results
Inte	-3.441**	8	I(0)	-3.509*	8	I(0)	0.3888	I(0)	0.1265	I(0)
HSI Fut	-1.308	9	I(1)	-1.770	9	I(1)	1.587**	I(1)	0.1577*	I(1)
HSI Vol	-2.652	13	I(1)	-2.845	16	I(1)	1.060**	I(1)	0.2386*	I(1)
USDY	-1.378	13	I(1)	-0.985	13	I(1)	0.8031**	I(1)	0.238**	I(1)
VIUS	-1.717	7	I(1)	-3.888*	7	I(0)	1.726**	I(1)	0.1793*	I(1)
VITH	-1.679	3	I(1)	-1.569	2	I(1)	0.4662*	I(1)	0.4411**	I(1)
VIIDR	-1.761	14	I(1)	-1.739	14	I(1)	1.399**	I(1)	0.3705**	I(1)
VISGD	-1.724	2	I(1)	-1.596	2	I(1)	1.272**	I(1)	0.4162**	I(1)
VIMY	-1.941	3	I(1)	-1.873	3	I(1)	1.009**	I(1)	0.4161**	I(1)
BMYR	-2.097	3	I(1)	-1.136	3	I(1)	1.956**	I(1)	0.2879**	I(1)
BIDR	-1.671	3	I(1)	-2.117	3	I(1)	1.791**	I(1)	0.1486*	I(1)
BKRW	-1.210	3	I(1)	-0.360	3	I(1)	1.682**	I(1)	0.2115*	I(1)
BOSB	-0.433	3	I(1)	-3.395	3	I(1)	2.599**	I(1)	0.1482*	I(1)
BTHB	-1.691	10	I(1)	-2.104	10	I(1)	2.651**	I(1)	0.1521*	I(1)
BPHI	-2.373	3	I(1)	-1.620	3	I(1)	1.598**	I(1)	0.2096*	I(1)
BTWN	-1.139	3	I(1)	-2.432	2	I(1)	1.11**	I(1)	0.205*	I(1)
BSGD	-1.541	9	I(1)	-0.521	9	I(1)	1.936**	I(1)	0.1793*	I(1)
TWN	-1.482	5	I(1)	-0.785	5	I(1)	1.85**	I(1)	0.3559**	I(1)
KRW	-1.948	16	I(1)	-2.069	16	I(1)	1.232**	I(1)	0.326**	I(1)
IDR	-1.399	3	I(1)	-1.499	3	I(1)	1.673**	I(1)	0.2405**	I(1)
MYR	-1.341	10	I(1)	-1.187	10	I(1)	1.89**	I(1)	0.3557**	I(1)
THB	-1.646	6	I(1)	-1.088	6	I(1)	1.14**	I(1)	0.4395**	I(1)
SGD	-0.791	14	I(1)	-2.023	14	I(1)	1.714**	I(1)	0.4311**	I(1)
PHI	-1.487	9	I(1)	-0.509	9	I(1)	1.916**	I(1)	0.3445**	I(1)
BRAD	-2.317	12	I(1)	-2.472	12	I(1)	0.3988	I(0)	0.339**	I(1)

* *denotes the rejection of H(0) at a 5% significant level.*

** *denotes the rejection of H(0) at a 1% significant level.*

Inte and Prob are respectively the intensity and the probability of a HK dollar devaluation at a one month horizon ; Fut is the Hang Seng Index future returns, vol is the HSI implied volatility (in first difference). USDY is the dollar/yen exchange rate returns, VIUS is the one-month implied volatility on the dollar/yen. VITH, VIIDR,VISGD and VIMY are respectively the one-month implied volatility on the dollar/bath, dollar/IDR, dollar/SGD and dollar/MYR (all in first difference). BMYR, BIDR, BKRW, BOSB, BTHB, BPHI, BTWN and BSGD are

respectively the returns of the stock indexes for Malaysia, Indonesia, Korea, Shangai (the B-Shares held by foreign investors), Thailand, Philippines, Taiwan and Singapore. TWN,KRW, IDR, MYR, THB, SGD and PHI are the exchange rates returns vis-à-vis the US dollar for Taiwan, Korea, Indonesia, Malaysia, Thailand, Singapore and Philippines. Finally, BRAD is the return of the Brady bonds index returns.

ANNEX IV
VAR Estimations

	INTE	RFUT	DVOL
INTE(-1)	0.7894**	-0.8173**	0.7805**
INTE(-2)	0.0250	0.8380*	-0.4245
INTE(-3)	0.0501	-0.060	-0.5658
RFUT(-1)	0.0252**	-0.3771**	0.1504
RFUT(-2)	0.0092	-0.1109**	-0.1572*
RFUT(-3)	-0.0074	0.0066	0.1574**
DVOL(-1)	0.0282*	-0.2156**	-0.3302**
DVOL(-2)	0.0318*	-0.1028**	-0.1308**
DVOL(-3)	0.0056	-0.0739**	0.0680
BOMY	-0.0305**	0.1157**	-0.0049
BOPH	-0.0203	0.4107**	-0.2622**
BOTW	-0.0173	0.2798**	-0.0868
BOJP	-0.0577	0.5231**	-0.8119**
C	-0.5073	-1.3157	2.1827**
D23OC	7.5594**	-4.4473**	25.8166**
D5SEP	-0.3992*	-0.1455	0.5543
DUHKM	0.6660**	4.4070**	3.6488**
DUIDR	0.5043**	1.1358**	1.4134**
DUTWN	0.8816**	-1.3065*	3.1283**
DUWON	1.1755**	1.1292	4.1777*
DVMY(-2)	0.0538*	-0.0849**	0.0464
RBRA(-1)	-0.0522**	0.3365	-0.6278**
RSGD	-0.1957*	0.2693	0.2517
RTWN(-3)	0.2268**	0.0580	-0.7047
RUSD	0.0907**	0.296*	0.0493
VIUS	0.0519**	0.0828	-0.1466**
Serial correl $c^2(3)$	7.141	5.089	3.708
R^2	90.22%	53.66%	39.70%

* *denotes the rejection of H(0) at a 10% significant level.*

** *denotes the rejection of H(0) at a 5% significant level*

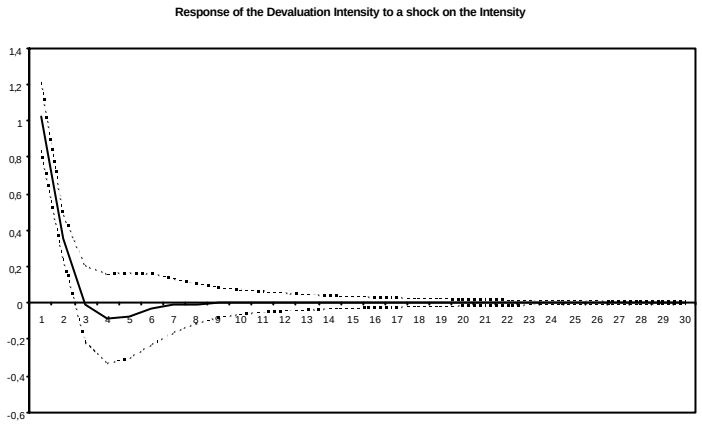
.

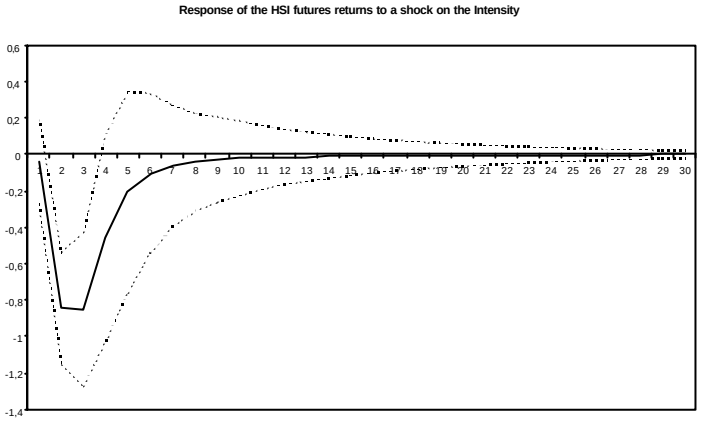
INTE is the intensity of a HK dollar devaluation at a one month horizon ; RFUT is the Hang Seng Index future returns, DVOL is the implied volatility of HSI at-the money put options (in first difference). USDY is the dollar/yen exchange rate returns, VIUS is the implied volatility on the dollar/yen, dVMY is the variation of the implied volatility on dollar/MYR. BOMY, BOPH, BOTW and BOJP are respectively the returns of the stock indexes for Malaysia, the Philippines, Taiwan and Japan. TWN and RSGD are respectively the exchange rate returns of the Taiwan and Singapore dollar vis-à-vis the US dollar. RBRA is the returns of the Brady

bonds index. D23OC, DUHKM and D5SEP are dummies reflecting the HKMA interventions and the impact of the currency board reform.

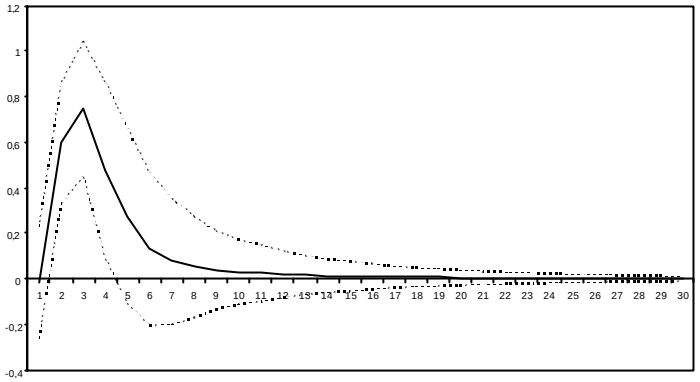
ANNEX V

Impulse response functions
Shock of a standard deviation on the Devaluation Intensity



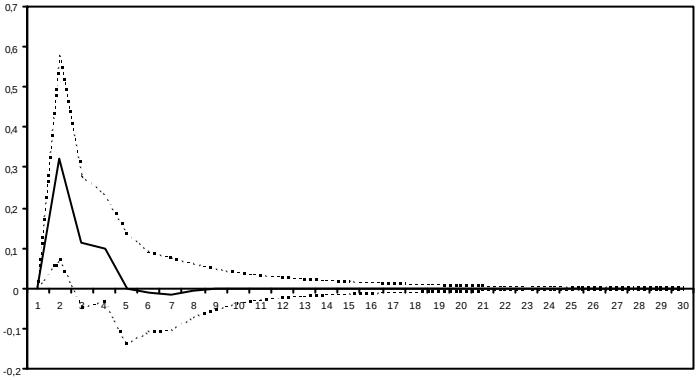


Response of the HSI implied volatility to a shock on the Intensity

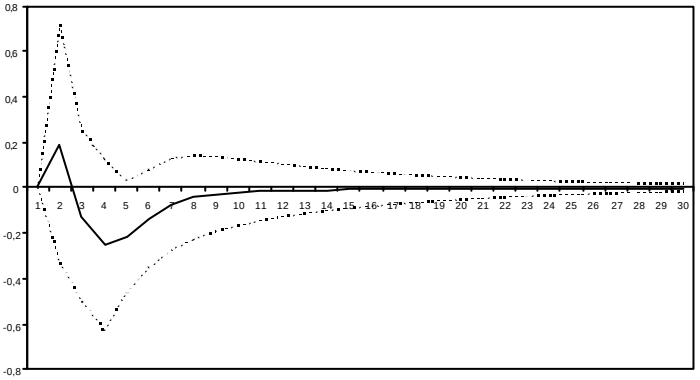


Shock of a standard deviation on the HSI put implied volatility

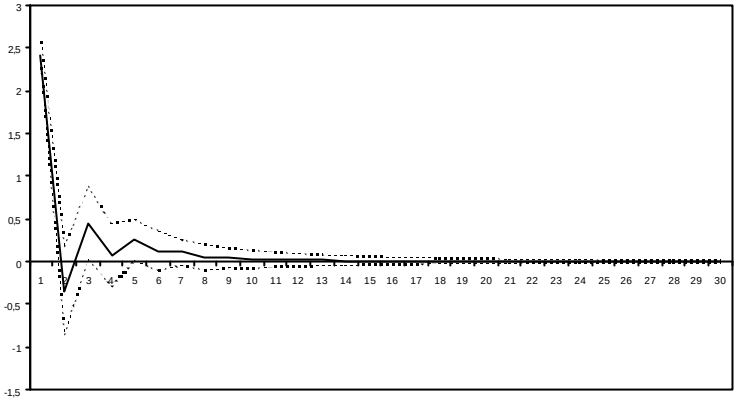
Response of the Devaluation Intensity to a shock on the HSI volatility



Response of HSI futures returns to a shock on the HSI volatility

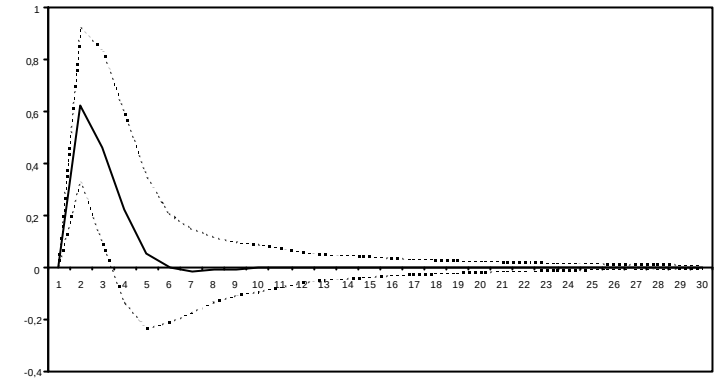


Response of the HSI implied volatility to a shock on the HSI volatility

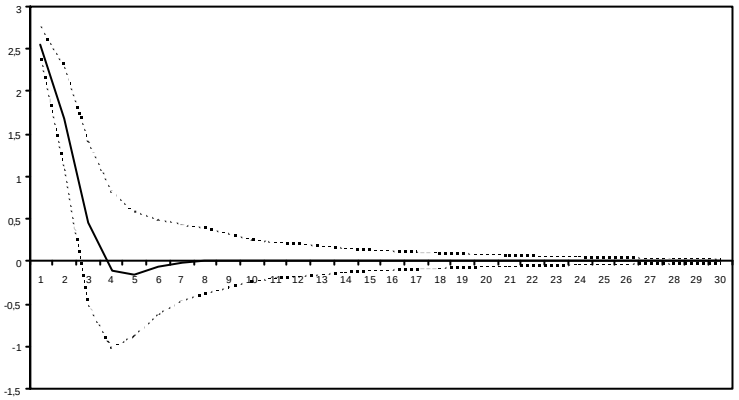


Shock of a standard deviation on the HSI futures returns

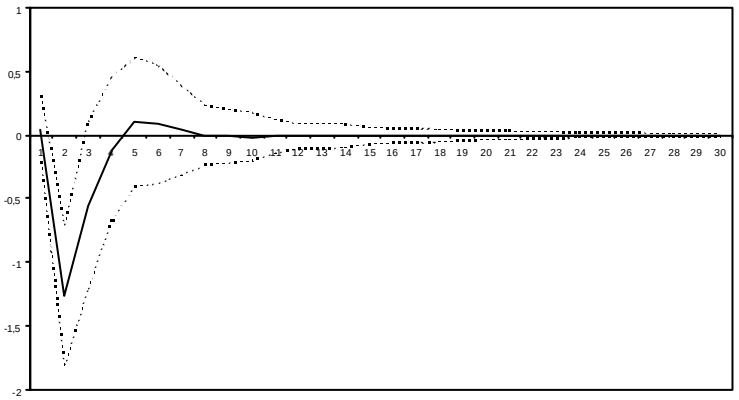
Response of the Devaluation Intensity to a shock on the HSI Futures returns



Response of the HSI futures returns to a shock on the HSI futures returns



Response of the HSI implied volatility to a shock on the HSI futures returns



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