Behavioral Heterogeneity and Shift-Contagion:
Evidence from the Asian Crisis

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02 April 2008

Abstract
This paper develops and estimates a behavioural model spanning two equity markets, with boundedly rational representative agents. These fund managers use three different types of information and change the relative weights on the information sources. The model is estimated for Hong Kong and Thailand, in the period surrounding the Asian crisis. We find that fund managers are boundedly rational in their expectation formation strategy and that they switch between information sources conditional on the price impact of these information sources in previous periods. The model shows that the crisis is triggered in Thailand as a result of an increased focus on the fundamental price, and aggravated by a subsequent focus on technical analysis. Furthermore, it is shown that the crisis spills to the Hong Kong market as a result of increased attention for foreign markets; therefore, there is evidence of shift-contagion.

Keywords: heterogeneous expectations; contagion; Asian crisis; dynamic models

JEL-classification: G12, G15

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The authors would like to thank Carl Chiarella and Tony He for extensive discussions. Also, participants of the CeNDEF lunch seminar University of Amsterdam (June 2006), IEE Seminar University of Groningen (November 2006), Australasian Finance and Banking Conference (December 2006), Quantitative Methods in Finance (December 2006) and Conference on Heterogeneous Agents in Financial Markets, Nijmegen (January 2007) is acknowledged.
1. Introduction

The observation that an extreme financial event in a certain country can cause a chain of events in other, not only closely related, countries has triggered a vast line of research starting in the end of the 1990’s; see, for instance the literature review of Claessens and Forbes (2001) and Kaminsky et al. (2003). Although the literature is diverse concerning the exact definition, the term used to describe this observation, is contagion. The commonly used definitions for contagion can be split in two broad groups. The first group considers the spread of crises across countries a result of the linkages that exist between countries, such as trade linkages, financial linkages, and common shocks. Forbes and Rigobon (2002) label this interdependence; the underlying assumption is that there are no structural changes during extreme events. The second type of definition is narrower in the sense that it states that the spread of shocks is not only the result of the every day linkages, but that crisis-contingent mechanisms come into play. That is, linkages between assets change during crisis periods. Forbes and Rigobon (2002) refer to this type of contagion as shift-contagion. Crisis-contingent mechanisms can be based on multiple equilibria, endogenous liquidity shocks, and a political transmission mechanism. The underlying assumption is that the typical conduct of markets changes. The price of assets is, in the end, determined by agents trading in a financial market. The behaviour of agents forming the market thus changes during crises given that the degree of co-movement between assets changes during crisis periods.

A second strand of literature assuming that agents condition their behaviour on the state of the market, comparable to the crisis-contingent theories, is the heterogeneous expectations literature; see for instance Day and Huang (1990), Brock and Hommes (1998), Lux (1998), LeBaron (2006), and Hommes (2006) for an extensive overview. In this setting of bounded rationality, there are groups of agents who condition their expectations on different sources of information. The resulting market price is the weighted average of the expectations of the different groups. Usually there are two groups, fundamentalists and chartists, who base their expectations on economic fundamentals and technical analyses, respectively. Behaviour is state dependent as agents can change their strategy as how to form their expectations conditional on the past performance of that strategy. Consequently, the distribution of agents over the groups, thus the weights given to the various strategies in determining the market price, varies through time conditional on the goodness of fit of the different strategies.

The combination of shift-contagion and heterogeneous agents has, to our best knowledge, never been explored. Therefore, in this paper we develop a model inspired by the
heterogeneous agents literature in order to give an explanation for the notion of shift contagion. Instead of introducing heterogeneous agents, we propose a model with a boundedly rational representative agent who each period updates the weights she or he gives to different information sources. Also, instead of focusing on a single asset market, we introduce a system spanning multiple asset markets with explicit time varying linkages between the markets induced by investor behaviour.

Studies by Allen and Taylor (1990), Taylor and Allen (1992) and Jongen et al. (2008) indicate that fund managers at large financial institutions base their expectations and subsequent trading behaviour on both economic fundamental and technical analyses. Since capital markets are dominated by large, often institutional, investors, it is safe to assume that all have equal access to information. Also, from Beine et al. (2003) we know that market participants have a tendency to imitate each other. Based on these insights, we model the market as being dominated by a boundedly rational but representative fund manager. The expectation and behaviour of the fund manager is not only based on fundamental and technical analysis, as in the heterogeneous agents literature, but also on foreign developments. Based on the existence of real and financial linkages between different markets, the fund manager also incorporates information from foreign markets. The source of observed price changes is evaluated each period by the fund manager, and the relative weights on the three different information sources for forming next period’s expectation are adapted accordingly.

The relation between the different asset markets in the model is established by introducing a third source of information for the fund manager, next to fundamental and technical, which is conditional on past returns in the foreign markets. By doing so, we incorporate the existence of linkages between the markets, while staying in the line of reasoning of the model that the market price is determined by a boundedly rational fund manager. Like the other sources, the relative weight on the international information in determining the market price changes through time. As the fund manager focuses more on foreign markets in forming expectations, the co-movement between the markets increases. Our model therefore combines the two definitions of contagion; there is interdependence because of the ever existing fundamental relation between markets, and there is shift-contagion because this relation contains the flexibility to change over time.

By explicitly modelling the behaviour of market participants, we can determine whether the focus on the foreign market changes during crises, so whether shift-contagion is present or not. If it is observed that the behaviour of market participants changes significantly during crises, i.e. if the weight on the foreign market becomes larger, it can be interpreted as
evidence of shift-contagion. In doing so, we develop a model that gives a behavioural underpinning, on a micro-level, of the notion of contagion. Furthermore, the model is shown to be vector auto regressive (VAR), with time-varying coefficients. Contrary to what is the case with a regular VAR, an economic model is underlying the empirical one, thus providing an economic intuition. The time variation in the coefficients is induced by the changing weights.

We estimate the model for two countries during the Asian crisis. By doing so, we attempt to shed some light on the (changing) mutual dependence between asset markets during the crises. Within the literature of heterogeneous agents models, the added value lies in the fact that we have a model with multiple asset markets and a boundedly rational fund manager basing expectations on three sources of information. Literature on heterogeneous agents models usually apply simulation techniques; the scarce papers that do confront the models with actual data use a relatively low frequency (monthly or lower). In this paper, the model is empirically estimated using high frequency data (daily). The contagion literature is enriched by the fact that we offer a totally different viewpoint on the notion of changing mutual dependence between markets. Also, a (micro) behavioural underpinning is suggested.

In accordance with the results of Reitz and Westerhoff (2003, 2007), Boswijk et al. (2007), and De Jong et al. (2007), we find evidence of the use of different information sources and switching between them. All three sources are found to be used simultaneously, and the relative weights put on the information sources are found to be time-variant. Our results do not corroborate the most recent results concerning shift-contagion of e.g. Forbes and Rigobon (2002) and Candelon et al. (2005). As the weight on international information increases at the onset of the crisis, we find evidence of shift-contagion of the crisis in the Thai market to the Hong Kong market during the crisis period.

The remainder of the paper is organized as follows. In Section 2 we develop the model. Section 3 describes the empirical literature of both contagion and heterogeneous agents models, and estimation and data issues involved in estimating the model. In Section 4 we describe the estimation results and in Section 5 focuses on different issues of the Asian crisis. Section 6 concludes.
2. The Model

In this Section we describe the non-linear dynamic model with multiple asset markets, which we will estimate for two equity indices during the Asian crisis. Our model is a direct descendant of the celebrated model of Brock and Hommes (1997, 1998) for the stock market. In this type of model, the market price is formed by the weighted average expectations of a number of heterogeneous groups. The weights are determined by the past performance of the different groups, so agents can change their strategy of how to form price expectations. Our addition is twofold; first, we introduce a boundedly rational representative agent with different information sources and, second, we allow the model to span multiple asset markets.

The step from heterogeneous agents with a single source of information each to a representative agent with multiple sources of agents is motivated by the fact that capital markets are dominated by large, often institutional, investors. For example, the Bank of International Settlement in their 2006 report states that two thirds of the trade, and thus the price formation, in foreign exchange take place between large financial institutions. Because the institutions are large, we can assume that they have equal aces to information; information costs and the like do not play a significant role. Allen and Taylor (1990, 1992) and Jongen et al. (2008) indicate that these large institutions base behaviour on a combination of factors, namely fundamental and technical analysis. Beine et al. (2003) state that financial institutions imitate each other based on reputation effects and strategic considerations. Therefore, the market does not consist of heterogeneous individuals with a single source of information, but a boundedly rational, but representative agent with multiple sources of information.

The basic heterogeneous expectations model described in Brock and Hommes (1997, 1998) assumes that agents can invest in a risk-free asset and one risky asset. Westerhoff and Dieci (2006) and Chiarella et al. (2005) set up a model with interacting heterogeneous agents, who are able to invest in a risk-free asset and two risky assets. Westerhoff (2004) assumes that only chartists can switch between markets based on an information-cost argument. Westerhoff and Dieci (2006) show that the properties of two otherwise unrelated markets with common traders are related; Westerhoff (2004) and Chiarella et al. (2005) show that the existence of common investors can cause co-movement in markets.

Contrary to the models with multiple asset markets of Westerhoff and Dieci (2006), Chiarella et al. (2005) and Westerhoff (2004), we do not assume that individual agents can invest in multiple markets, but we introduce a third source of information for our representative fund manager in local markets, next to the technical and fundamental
information. The third source of information consists of (past) movements of foreign markets. In this way we incorporate the existence of real and/or financial linkages between asset markets, while remaining in the logic of the model. The fund managers, who dominate the market, take the existence of other traders into account in forming expectations. As such, we can model the total market by only incorporating the largest group. This setup embeds all different forms of potential linkages, while the aforementioned papers with multiple asset market solely rely on the existence of financial linkages due to internationally operating investors. The dynamics in the weights put on the foreign information are left to determine the actual co-movement between the asset markets.

The reason for investors to focus on foreign markets can be based on different motives. First of all, there can be real linkages (international trade, foreign direct investments) between the respective countries. In our case with two proximate countries, (Thailand and Hong Kong) this is clearly the case. Second, there can be financial linkages between countries causing the stock markets to be correlated. Westerhoff and Dieci (2006) show that internationally operating investors can cause correlations between markets based in liquidity needs. Furthermore, cross-listings introduce correlations. As Hong Kong, together with Singapore, is the financial centre of south-east Asia, there are numerous links to and fro the Hang Seng index. Finally, if both markets are hit by a common shock, markets will be correlated. This is not unlikely with countries with such geographical, cultural, and economic proximity as the ones in our sample. Given that fund managers know of these textbook linkages, it makes sense for this dominant market participant to take these into account when forming expectations.

As mentioned above, we assume that the fund manager’s expectation is formed by the weighted average expectation put forward by different information sources

$$E_r = \sum_{h=1}^{H} w_{h,t} E_{h,t}$$

in which $r_{t+1}$ is the return in period $t+1$ defined as $P_{t+1} + y_{t+1} - P_t$, with $P_{t+1}$ the log real price in period $t+1$ and $y_{t+1}$ log real dividends in period $t+1$; $w_{h,t}$ is the relative magnitude or weight of group $h$ with $\sum_{h=1}^{H} w_{h,t} = 1$ and $E$ is the expectation operator. Furthermore, as proposed in De Grauwe and Grimaldi (2005), because the representative fund manager$^1$ in makes up the

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$^1$ Which are the three heterogeneous groups in the case of De Grauwe and Grimaldi (2005).
representative majority of the market and acts directly in accordance with its expectations, the realised return in period \( t+1 \) equals the average or market expectation plus a random shock

\[
r_{t+1} = E_t r_{t+1} + \epsilon_t = \sum_{h=1}^{H} w_{h,t} E_{h,t} r_{t+1} + \epsilon_t. \tag{2}
\]

The fund manager expects dividends to follow a random walk with drift, i.e. \( E_t y_{t+1} = dy_t \), with \( d \) the drift equal to one plus the average growth rate of dividends. Equation (2) can then be rewritten as

\[
\Delta P_{t+1} = \sum_{h=1}^{H} w_{h,t} E_{h,t} \Delta P_{t+1} - (y_{t+1} - dy_{t}) + \epsilon_t, \tag{3}
\]

Given that \( d \) is the average growth rate of dividends, the \((y_{t+1} - dy_{t})\) term is i.i.d since dividends are assumed to follow a random walk. Assuming that innovations to the dividend process are independent from shocks to the price process as a whole, we end up with

\[
\Delta P_{t+1} = \sum_{h=1}^{H} w_{h,t} E_{h,t} \Delta P_{t+1} + \nu_t, \tag{4}
\]

with \( E\nu_t = 0 \) and i.i.d. As indicated before, the weights \( w_{h,t} \) are conditional on past performance of the different information sources. We use the procedure first proposed by Brock and Hommes (1997), which models the weights as a function of past fitness in a discrete choice model with multinomial logit probabilities

\[
w_{h,t} = \frac{\exp[y\pi_{h,t-1}]}{\sum_{i=1}^{H} \exp[y\pi_{i,t-1}]} \tag{5}
\]

in which \( \pi_{h,t} \) is the fitness of strategy \( h \) in period \( t \) and \( y \) is the intensity of choice. The latter is (one of the) features of the model that illustrates the boundedly rational behavioural setup. In a neo-classical setting, only the information source that most accurately predicts the actual price change would be used. This source would always have a weight \( w_h \) equal to one. In our
setup this can only occur as $\gamma \rightarrow \infty$, such that there is infinite sensitive to differences in forecasting accuracy. At the other extreme, so as $\gamma=0$, fund managers would not change information sources at all; the weights of all strategies would be uniformly distributed and equal to $1/H$, with $H$ the total number of strategies. The intensity of choice can therefore be interpreted as a measure of status-quo bias.

The performance of the information sources $\pi_{h,t+1}$ is modelled as $\left( E_{h,r_{t+1}} \right) r_{t+1}$, as in Westerhoff and Dieci (2006). If both terms, i.e. the expected and the realized returns, have the same sign, the fitness measure is positive; opposite signs result in a negative profit. Therefore, predicting the correct (wrong) direction of change of the price level results in a positive (negative) fitness value. Furthermore, the absolute magnitude of the expectation works multiplicative. In other words, taking risks by having a large expectation in absolute sense can return in a large profit if the realized return is of the proper sign, but also in a large loss if the realized return is of the opposite sign.

The final step is to define the expectation formation rules based on the different information sources. We assume that fund managers perceive that there are three different sources of information relevant for the market. The first source, fundamental information, conditions expectations on the level of the market price compared to what is perceive to be the level of the fundamental price (which is perfectly visible to, and the same for, all agents in the market)

$$E_{f,t-1} \Delta P_t = \theta_1 (P_{t-1} - P^*_{t-1})^+ + \theta_2 (P_{t-1} - P^*_{t-1})^-$$

in which $P^*_t$ is the fundamental price in period $t$. In order to introduce more flexibility, we allow the rule to respond differently to an overvaluation of the market vis-à-vis the fundamental $(P_{t-1} - P^*_{t-1})^+$, compared to an under-valuation $(P_{t-1} - P^*_{t-1})^-$. Based on prospect theory by Kahnemann and Tversky (1979), an undervaluation will be corrected quicker than an overvaluation.

The effect of the fundamental information depends on the sign and magnitude of $\theta_i$. If $-1 < \theta_i < 0$, expectations based on fundamental information are mean-reverting and thus stabilizing; however, as $\theta_i > 0$ they are destabilizing as the price is driven away from the

\footnote{In fact, Westerhoff and Dieci model the fitness as $D_{i,t}(\exp(P_t)\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\neg\ne
fundamental price. A value of $\theta_{i} < -1$, finally, represents overshooting. The market price will oscillate explosively around the fundamental price.

The second source, technical or chartist information, conditions expectations on past price movements

$$E_{c,t-1}\Delta P_{t} = \alpha_{1}(\Delta P_{t-1})^{+} + \alpha_{2}(\Delta P_{t-1})^{-}$$  \hspace{1cm} (7)

Depending on the sign and magnitude of $\alpha_{i}$ chartist expectations are either stabilizing or destabilizing. Values of $-1 < \alpha_{i} < 0$ imply stabilizing behaviour since previous periods’ price movements are (partly) reversed. If $\alpha_{i} > 0$, behaviour is destabilizing since past movements are (partly) extrapolated; $|\alpha_{i}| > 1$ always implies explosive expectations$^{3}$. Again, we introduce flexibility by introducing an asymmetry between positive $(\Delta P_{t-1})^{+}$ and negative $(\Delta P_{t-1})^{-}$ past returns.

The third and final source of information is international and conditions the expectation on past returns in the foreign market.

$$E_{i,t-1}\Delta P_{t} = \beta_{1}(\Delta P_{t-1})^{+} + \beta_{2}(\Delta P_{t-1})^{-}$$  \hspace{1cm} (8)

in which $\overline{P}_{t}$ is the price in the foreign market. In terms of real linkages, the correlation between the markets is positive if one country benefits from e.g. another countries’ growth by increased exports ($\beta_{i} > 0$). A negative correlation is also possible as two countries are e.g. competing on the world market ($\beta_{i} < 0$). Similar reasoning can be thought of concerning financial linkages. For example, an international investor might pull funds out of country A because of liquidity issues when stock prices in country B go down. This causes a positive correlation between country A and B. Because of the different possible linkages that exist between the markets, the reaction to positive and negative shocks is again asymmetric. The fund manager thus incorporates the existence of other market participants, such that it becomes a representative agent.

Equations (4) to (8) can be combined to form one equation representing the change in the asset price as a function of lagged price changes, both domestic and foreign, and

$^{3}$ Oscillative explosive for $<-1$ and explosive for $>1$
fundamental prices. This model can be applied to each stock market, such that it can be used to describe multiple markets simultaneously, next to each other, with explicit cross-linkages. As we focus on the interaction between two specific markets in this paper, we write the model as a system of two interacting equations, in which each equation represents a local version of the model. Rewritten in matrices, this results in

$$\begin{pmatrix} \Delta P_t \\ \Delta \bar{P}_t \end{pmatrix} = \begin{pmatrix} w_{f,t} & w_{c,t} \\ \bar{w}_{f,t} & \bar{w}_{c,t} \end{pmatrix} \begin{pmatrix} \alpha_1 & \alpha_2 \\ \beta_1 & \beta_2 \end{pmatrix} \begin{pmatrix} (P_{t-1} - P^*_{t-1})^+ + \theta_2 (P_{t-1} - P^*_{t-1})^- \\ \bar{P}_{t-1} - \bar{P}^*_{t-1} \end{pmatrix} + \begin{pmatrix} \Delta P_{t-1} \\ \Delta \bar{P}_{t-1} \end{pmatrix} $$

(9)

in which

$$w_{h,t} = \exp\left[\gamma(E_{h,t-2} \Delta P_{t-1}) \Delta P_{t-1}\right], \quad \bar{w}_{h,t} = \frac{\exp[\gamma(E_{h,t-2} \Delta \bar{P}_{t-1}) \Delta \bar{P}_{t-1}]}{\sum_{h=f,c,d} \exp[\gamma(E_{h,t-2} \Delta P_{t-1}) \Delta P_{t-1}]}$$

Variables and coefficients with an upper bar represent foreign equivalents of local variables and coefficients. Basically, the model formed by Equation (9) is vector auto regressive (VAR) with time-varying coefficients that are conditional on past price movements, with $\Delta P_t$ and $\Delta \bar{P}_t$ as endogenous and $(P_{t-1} - P^*_{t-1})$ and $(\bar{P}_{t-1} - \bar{P}^*_{t-1})$ as exogenous variables. The time variation in the coefficients is a function of the fit of the three different expectation formation rules. Contrary to a normal VAR, which is a method of determining the relation between variables without imposing an underlying (economic) model, the VAR proposed here is formed by modelling micro-behaviour of individual agents. Therefore, it provides an intuitive explanation for a normally (economic) theory-lacking VAR. Time-variation in the coefficients is often highly parameterized, by, for example, a Markov chain. In our case, the time variation is relatively parsimonious, and is based on an economic interpretation.

The time variation in the coefficients is also the mechanism driving contagion in our setup. The correlation between the markets is given by coefficient $\beta_i$ in the international information times the weight $w_{i,t}$ put on this source (in both markets). Without switching between information sources, the correlation would be constant. However, after introducing

4 To be more precise, the misalignment is not truly exogenous; the fundamental price is strictly exogenous, but the lagged price is predetermined.
switching, the correlation between markets also becomes time varying. With increasing variability in market A, the accuracy of forecasting based on international information in market B will go up because the returns of the two markets will be more similar. This is still interdependence, because weights do not change; the correlation does not change, but returns are more similar as a result of the increase in variance (see Forbes and Rigobon, 2002). As profits resulting from the international information increase, more weight will be put on the international information. Increasing weight (with constant coefficients) implies a higher correlation between the markets; the product $w_i \beta_i$ increases. Therefore, an increase in volatility in one market (for example caused by a crisis) in our boundedly rational setup causes contagion.

3. Empirical Considerations

3.1 Empirical Literature Review

The early empirical papers on contagion are unanimous in their conclusions concerning the existence of contagion. Irrespective of the method and definition they employ, contagion is found to be significant. For instance, King and Wadhwani (1990) find increased cross-market correlations between the U.S., U.K., and Japan after the U.S. stock market crash. Lee and Kim (1993) extend this analysis and find similar results. Increased co-movement is also found after the 1994 Tequila crisis and 1997 Asian crisis by Calvo and Reinhart (1995) and Baig and Goldfajn (1998). Using a limited dependent variable setup, Eichengreen et al. (1996) and Kaminsky and Reinhart (2000) find increased probability of a crisis after another country has been hit by a crisis.


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5 This is exactly why Forbes and Rigobon (2002) argue that one should take the increase in volatility into account when examining changing correlation between markets during crises.

The heterogeneous expectations literature is focused on three issues. The first topic is the dynamic properties of the nonlinear models. Given the nonlinear setup, the behaviour of the model depends heavily on the magnitude of coefficients and the starting values in a simulation setup. Chiarella et al. (2002) and Chiarella and He (2002) characterize the parameter space of the models according to the local stability or instability of the equilibrium. The second topic is the replication of stylized facts known from financial markets. By using simulations combined with time-series techniques, Lux (1996), LeBaron et al. (1999) and De Grauwe and Grimaldi (2005, 2006) show that models with heterogeneous interacting agents are capable of replicating the stylized facts of financial markets (i.e., extreme values, volatility clustering, disconnection from the fundamental, excess volatility). The third topic comprehends the estimation of models with heterogeneous interacting agents. This is a relatively new and unexplored topic since the estimation of the non-linear switching mechanism proofed to be difficult. Vigfusson (1997) and Ahrens and Reitz (2005) have circumvented the problem of estimating the non-linear switching mechanism by replacing it by a Markov regime-switching approach. Baak (1999) and Chavas (2000) find significant evidence of agent heterogeneity in the beef market. Winker and Gilli (2001) estimate a heterogeneous agents model by minimizing a loss function consisting of the kurtosis and ARCH-estimates of the simulated data by adjusting the coefficients of the model. Reitz and Westerhoff (2003, 2007) directly estimate a model of chartists and fundamentalists with switching mechanism for daily exchange rates from 1980 to 1996. Boswijk et al. (2007) rewrite the model of Brock and Hommes (1997) and estimate it directly for the S&P500 using a non-linear least squares technique. De Jong et al. (2007) estimate a heterogeneous agents model for the EMS exchange rates. All papers find evidence in favor of the heterogeneous agents models; both trader heterogeneity and, to a lesser extend, switching believes, are found.

3.2 Data and Sample

We have chosen to focus on the Asian crisis for a number of reasons. First of all, especially during crises, we expect the heterogeneous agents model to perform well, as there is clearly a shift in sentiment during extreme events. Therefore, introducing different types of investor behaviour and flexibility to switch between types should be beneficial in explaining the evolution and spread of crises. The Asian crisis is chosen as it is more widespread than
previous crises in terms of both the geographical scope and the impact on the real side of the economies involved. Given the central role of the fundamental price in our model, the Asian crisis provides an appropriate case study. The Thai stock exchange, Bangkok S.E.T., and the Hong Kong stock exchange, the Hang Seng, have been chosen because the first is the country in which Asian crisis “officially” started with the attack on the Thai Baht in July 1997. The latter is chosen as Hong Kong, together with Singapore, is the financial centre of the south-east Asian region, a leading stock exchange. Furthermore, Forbes and Rigobon (2002) note that it was not until the crash of the Hong Kong market in October 1997 that the press started to focus on Asia and that the words “crisis” and “contagion” appeared. Corsetti et al. (2005) follow Forbes and Rigobon (2002) in this respect.

All raw data used in this paper are taken from Datastream. We use daily data from February 1981 to December 2006, which are 6760 observations. This sample is chosen because we want to focus on the potentially changing behaviour of agents during the build-up of the crisis, the crisis, and its aftermath.

3.3 Fundamental Price

In order to construct a fundamental price, which is used in determining the expectation of fundamentalists, we consider a dynamic version of the classical Gordon growth model for equity valuation. Gordon (1962) states that the price of equity $P_t$ is equal to

$$P_t = \frac{1 + g}{r - g} Y_t$$

(10)

in which $g$ is the growth rate of dividend, $r$ the discount rate and $Y_t$ dividends. One of the issues concerning this model is the period over which to consider the growth and discount rates. In our boundedly rational setup, agents cannot use future information in order to determine the current fundamental value; that is, $g$ and $r$ in period $t$ can only contain information up to period $t$. Therefore, we make the model dynamic by assuming that $g$ and $r$ are time-varying. To be more specific, the growth rate $g$ in period $t$ is the average over all available past values until period $t$ and the discount rate $r$ is the expected (i.e. average) return in period $t$, determined from past values until period $t$. Thus, $g_t$ and $r_t$ are rolling averages of the growth rates of dividend and returns, respectively.
Fama and French (2002) state that the average stock return $r$ is the sum of the average dividend yield, $E(Y_t / P_{t-1})$, plus the average rate of capital gain, $E((P_t - P_{t-1}) / P_{t-1})$. The Gordon model implies that the average rate of capital gain is equal to the average growth rate of dividends, $g$. Therefore, Equation (10) simplifies to

$$P_t = \frac{1 + g_t}{E(Y_t / P_{t-1})} Y_t$$

(11)

in which $g_t$ is the average growth rate of dividend and $E(Y_t / P_{t-1})$ is the average dividend yield (both averages up to period $t$).

In order to create a fundamental price for our two markets, we applied Equation (11) to the stock price indices of Thailand, the Bangkok S.E.T. and Hong Kong, the Hang Seng. For $Y_t$ we use earnings instead of dividends since we believe that earnings are less affected by management choices compared to dividends. This is especially the case in recent years with respect to the increasing importance of firms who enter the stock market on the basis of expected future dividends (i.e. IT-firms). Nominal data is discounted using CPI. To create the rolling averages of the growth rate $g_t$ and earnings yield $E(Y_t / P_{t-1})$, we used as much data as was available to us, so assuming that agents have equal access to information. For Thailand the starting point is 1975; for Hong Kong 1973. The sample we concentrate on when estimating is 1981 - 2006, so the rolling averages used in our sample are based on a relatively large number of observations, also at the start of the sample. Earnings data are updated weekly, such that our fundamental stock price is also updated weekly.

Figure 1 displays the log real market price and fundamental price determined using the dynamic Gordon model as described above for 1981 - 2006. The Hang Seng market price oscillates relatively close around the fundamental price during the entire sample. Clearly recognizable is the Asian crisis in 1997 and 1998, when the index loses 58% of its value, starting in October 1997 with the attack on the Hong Kong Dollar and the accompanying interest rate hikes in Hong Kong to defend the currency board. Remarkable is that only 28%...
of the drop is a correction to the fundamental price. As a result of the sharp drop, the fundamental price itself also decreases in 1998, while the market price is rising again.

The picture for Thailand differs considerably. Striking is the bubble period from 1987 until 1996, reflecting the immense foreign capital inflows into the country at that time in reaction to the liberalization of the capital account. Just before the decline in May 1996, the market is 85% overvalued relative to the Gordon-based fundamental. During the decline, from May 1996 until August 1998, the market loses 85% of its value. The immense drop in stock value causes the fundamental value to drop as well. After the correction, the market value remains close to the fundamental, and is actually considerably undervalued for a number of years. Both the Thai and Hong Kong market start climbing again halfway 1998. Note that the decline in the stock market in Thailand (May 1996) commences well before the attack on the pegged exchange rate (July 1997).

Table 1 presents the summery statistics of the realized (log real) market prices and their first differences (so the return in the model), the constructed fundamental price, and the misalignment (i.e. the difference between market and fundamental price). The descriptive statistics confirm the image from the graphs. For Hong Kong we find that the mean, median, and standard deviation of the market price are significantly higher than the fundamental price. Both series are integrated of order one, and cointegrated\(^7\). The fact that the Thai market is overvalued during a large part of our sample period causes the mean and median of the market price to be significantly larger compared to the fundamental price. Range and standard deviation are also significantly higher for the market price. The market and fundamental prices for Thailand are both integrated of order one and cointegrated\(^6\).

Despite the crash in the Hong Kong market, the average return is 0.02% positive over the total sample; for Thailand this is 0.007%. The variability of the Bangkok S.E.T. return is significantly smaller than of the Hang Seng return given the range and standard deviation. The positive trends for Hong Kong and Thailand are reflected in the signs of the

\(^{6}\) Johanssen cointegration test indicates one cointegrating vector.
skewness. Black Monday in October 1987 causes the Hang Seng index to decrease by 40%\(^8\); this single observation affects the abovementioned results somewhat.

The mean misalignment is significantly different from zero for Hong Kong, implying that the market is, on average, overpriced. The Bangkok market is significantly overpriced as well; the maximum overvaluation and variability in the misalignment is also larger compared to Hong Kong.

3.4 Estimation Issues

As indicated in Section 2, our model is basically a VAR with time varying coefficients. Standard VAR’s can be consistently estimated by using equation-by-equation OLS. However, because of the non-linearities induced by the switching mechanism, we chose to estimate the model using equation-by-equation maximum likelihood. Also because of the non-linear structure of the model, the estimation results appeared highly sensitive to the starting values of the estimation procedure; especially the intensity of choice parameter appeared to be the source of this sensitivity. To resolve this issue, we performed a grid-search over all dimensions using the log-likelihood as selection criterion, such that we were ascertained that the results represented a global maximum.

The estimation process consists of a number of sub-analyses. First of all we estimate the model without switching mechanism in order to test whether the three information sources are used at all. Second, we add the switching mechanism to see whether there is also switching between the sources. A comparison between these static and dynamic cases can show us whether the switching mechanism is able to add significantly to the fit of the model. As a second differentiation we estimate the model for three different sub-periods, pre-crisis, crisis, and post-crisis, next to the total sample. This gives an impression of the robustness of the estimation results. Furthermore, given the fairly long sample, market behaviour might have changed altogether. The results to these tests are presented in the next Section.

4. Empirical Results

The results of estimating the model described in Section 2 using the fundamental price and estimation procedure developed in Section 3 are presented in this Section. We first focus

\(^8\) A dummy was added to the analyses for this date, as the model did not converge.
on the estimated coefficients in two cases: with and without switching mechanism. By doing so, we attempt to stress the importance of the non-linear structure of the model, i.e. the possibility of the fund manager to adapt its forecasting strategy. Second the estimation results of the sub samples are presented and finally we examine the development and characteristics of the weights $w_{i,t}$ attached to the different sources of information in expectation formation.

4.1 Estimation Results

Table 2 presents the estimation results of the model described by Equation (9) with and without switching mechanism. In terms of the model, without switching implies that $\gamma=0$; the distribution of weights over the different sources is uniform and constant through time, i.e. $w_{h,t}=1/3 \; \forall h,t$. With switching implies that the switching parameter $\gamma$ is estimated simultaneously with the expectation formation function.

Concentrating on the linear case first (left two columns), we observe in general that all three sources are significantly used in both the Thai and Hong Kong stock exchanges.

Fundamental information is only stabilizing in case of an overvaluation for Hong Kong (negative $\theta_1$) and in case of an undervaluation for Thailand (negative $\theta_2$). In case of an overvaluation in Thailand or an undervaluation in Hong Kong, the fundamentals are destabilizing given the positive $\theta_1$ for Thailand and positive $\theta_2$ for Hong Kong. The magnitudes of the coefficients are relatively small, and indicate that around 0.4% of the misalignment is translated to tomorrow’s price change. This modest magnitude is the result of the daily frequency; it is known that mean-reversion to the fundamental occurs only in the long run, and will therefore not be particularly strong at the daily frequency. The coefficients for under-valuation are significant for both countries.

All but one technical analysis coefficients are positive, indicating that this source extrapolates recent price changes (i.e. $\alpha_i > 0$). Only negative price changes in Hong Kong are (partly) reversed, leading to stabilizing dynamics in that case. The magnitude of the coefficients indicates that on average one third of the price shock of today is transferred to tomorrow. Coefficients for Thailand appear to be somewhat larger in absolute value. In
addition, positive shocks are extrapolated stronger than negative shocks; this difference is significant for both indices. All of the coefficients of the chartist information are significant, indicating that (this form of) technical analysis is indeed broadly applied in these markets. This is in a way surprising because returns in financial markets are known not to contain any autocorrelation.

The results for the third and final source, international information, indicate that the fund managers are indeed looking at other markets; there is significantly positive correlation between the stock exchanges of Thailand and Hong Kong, $\beta_i > 0$ and significant for all but one case. A positive return in the foreign market in period $t-1$ results in a positive return in the home market in period $t$. Managers in Hong Kong incorporate positive shocks from Thailand more than negative shocks; in Thailand this is reversed, positive shocks from Hong Kong are less strong incorporated than negative shocks. Both these differences are significant. Finally, it appears that the focus on Hong Kong by Thai investors is somewhat stronger than vice versa, on average.

The fact that there is positive correlation between the two stock markets is an indication that there is interdependence between the two markets on average over the total sample period. Given that the international information is significantly applied implies that past returns from the foreign market contain information on returns of the home market. We cannot conclude anything about shift-contagion from these results, because the coefficients are estimated over the total sample period, and therefore represent an average effect.

Concerning the non-linear case, so estimating the system with switching mechanism, we observe in the two columns on the right hand side of Table 2 that the coefficients for the three sources remain highly comparable. This is especially the case for the significant coefficients (i.e., chartists and international). Results for fundamental info change, but remain relatively weak. Introducing the possibility for fund managers to switch between information sources thus does not seem to have an impact on the weight they give to certain pieces of information when forming expectations.

The intensity of choice parameter $\gamma$ is negative and significant for both Hong Kong and Thailand. The negative signs imply that the weight attached to information with a relatively good forecasting ability in period $t$ is decreased in period $t+1$. In other words, sources that yield better forecasts than competing sources in a given period perform worse than the other sources in the next period, such that the fund manager moves uses less of the well performing information as they know it will not perform well the next period. The higher
absolute magnitude of $\gamma$ in Hong Kong compared to Thailand implies that traders are more sensitive to differences in performance between sources; they are more inclined to change strategy in response to a difference in forecasting performance. Finally, we observe that the log-likelihood for Hong Kong increases significantly after introducing the switching mechanism; flexibility therefore adds to the power of the model. For Thailand there is no significant difference in the likelihood; however, as the intensity of choice parameter is significant, switching does appear to be relevant.

The fact that we find significant coefficients for all three sources of information simultaneously makes us conclude that the agents active on the Thai and Hong Kong stock exchanges indeed use a combination of the proposed strategies. If the representative agent would use only one source, we would not have found significant coefficients for more than one at the same moment. Furthermore, the fact that the switching parameters are both significant and that the model fit is significantly higher in the switching case implies that there are not only heterogeneous information sources used on the market, but that the relative weight put on the different types of information also changes through time. Agents thus switch between strategies.

These results are consistent with the results of Boswijk et al. (2005), Reitz and Westerhoff (2003), and De Jong et al. (2007). All three papers find evidence of heterogeneous behaviour in the S&P500 and the major foreign exchange markets. Boswijk et al. (2005) find two groups of fundamentalists who differ in their mean-reversion coefficients; significant switching, however, is not found. Reitz and Westerhoff (2003) find a group of chartists and a group of fundamentalists, including significant and rapid switching between the groups. De Jong et al. (2007) show the existence of different groups and the importance of switching during crisis periods.

Our results are not yet directly comparable to the contagion literature, because the use of the international information in both countries does not provide a firm conclusion concerning shift-contagion; it only indicates significant interdependence on average during the total sample period. The significant switching is a first indication that the importance of the international source possibly changes over time, though. This would imply that the correlation between the markets is also time-varying, thus pointing towards shift-contagion. However, it could also be the case that managers only switch between chartist and fundamental information, leaving the correlation between the two stock markets constant. Also, contagion refers to the change in correlation during extreme periods, or crises. The
sheer observation of time-variation does not say anything about the timing of these changes. We will look further into these matters surrounding the Asian crisis in Section 5.

4.2 Estimation Results Sub-Samples

Table 3 presents the estimation results of our model for three sub-samples, the pre-crisis period (1981 – 1990), which includes the massive inflow of foreign capital, the crisis period (1991 – 1999), and the post-crisis period (2000 – 2006). Estimations represent the model with switching mechanism.

The pre-crisis period shows strong use of technical analyses, given the high and highly significant $\alpha$-coefficients. The extrapolation is stronger in this early period compared to the total period. International information is only significantly used in the Thai market; shocks from Bangkok are not transmitted to Hong Kong, which is opposite to the total sample. The switching parameter finally again turns up negative and significant. The magnitude of this intensity of choice is, especially for Thailand, lower in absolute sense compared to the total sample. During the crisis-period, behaviour changes somewhat. Technical analysis remains strong, albeit somewhat less so than in the pre-crisis period. Most striking difference is the fact that the Hong Kong market starts incorporating information from the Thai market; it remains equally important in the Thai market. The intensity of choice in Thailand rises considerably. The post-crisis period, finally, shows a different image altogether. Chartist information only remains significant for Thailand, while it is only marginally present for Hong Kong. International information only turns up significantly for negative shocks in both markets; it also turns negative for Hong Kong. The intensity of choice parameters both become very large in absolute sense, but lose their significance.

The fact that the parameters of the expectation formation rules change considerably through time, is another indication that there is indeed time variation in the way market participants form their expectations. So, next to the switching induced by the model, we observe time variation in a broader perspective. Given that also the coefficients for the international information change over the three sub-samples, the correlation between the markets is different in the three periods. In other words, while the correlation between
markets in our model changes due to changing weights, the correlation changes in this case due to changes in the expectation formation rule itself, i.e. the $\beta$-coefficients. Also, the behaviour of agents concerning switching changes through time, given the changing intensity of choice parameter.

The use of fundamental information remains relatively modest through time, as a result of our high frequency data. The importance of technical analyses, on the other hand, appears to decrease over the three sub-periods considered. This can be explained by the fact that the liquidity of these markets increases through time; developed financial markets are characterized by the absence of auto-correlation. We recognize this particularly in our results for the Hong Kong market, which is obviously by far the larger and more developed market. The relatively strong autocorrelation during the middle period can be explained by the crisis. This causes prices to move in a similar direction (down, in this case) for longer periods on end. Striking is also the change in coefficients for international information. The first period only shows transmission of shocks from Hong Kong to Thailand. This can be explained by the fact that the Thai market was still very small in that period and therefore unimportant for Hong Kong, while the Hong Kong market developed itself into a financial hub. The crisis period shows strong transmission in both directions; in other words, there is evidence of contagion, the correlation between the markets increases during the crisis by the increase in internationalist coefficients. This does not yet take into account the change in weights on the internationalist rule. The international focus disappears again for a large part in the post-crisis period.

4.3 Weights

The estimation results indicate that the representative agent in the market that has a time-varying forecasting strategy. In this subsection we will analyze the development and distribution of the weights through time, in order to determine the effect of the crisis. Furthermore, it allows us to draw inferences concerning the potential shift-contagion.

Figure 2a displays the evolution of weights $w_{h,t}$ estimated by the model over the total sample period. The daily weights shift between zero and one, and oscillate around the uniform
distribution of one-third. There appear to be clusters of high volatility in the weights surrounding the periods in which volatility in the returns themselves is high. For example, there is an increase in volatility in 1993/1994, and very clearly a volatile period around the crisis in 1997/1998. For Hong Kong, the volatility appears to be highest for the technical information, followed by the fundamental information, and is clearly lower for the international information. As a result of the smaller intensity of choice (in absolute terms), the volatility in the weights is smaller for Thailand compared to Hong Kong. There does seem to be much difference between the three sources.

The plots of the smoothed weights\(^9\) in Figure 2b show a clearer image of the market dynamics. Because of the smoothing we observe a small band, with weights again moving around one-third, but during different periods we do observe very pronounced shifts. For example, during the Asian crisis we observe a strong rise in the use of technical analyses in Hong Kong, and a strong rise in fundamental analyses in Thailand. We will look further into this mechanism in Section 5. Table 4 presents descriptive statistics of the daily strategy weights. The numbers illustrate the findings from Figure 2 somewhat more.

\[
\text{Insert Table 4 Here}
\]

Mean values of the weights for both Hong Kong and Thailand are close to one-third for all periods, i.e. none of the sources is dominant or is put aside for long periods on end. The lowest mean value we observe is for the post-crisis period chartist information in Thailand (0.318). This illustrates the increasing quality of the market, as we have seen in Table 3. The range and standard deviations move in accordance with the magnitude of the intensity of choice; higher intensity of choice results in a higher variability and range of the weights. Generally weights range between zero and one; exceptions are the pre-crisis periods for both markets.

By interpreting the correlations between the weights, we get a general picture concerning the switching tendencies of the fund manager. The correlation coefficients are generally negative, reflecting the fact that the weights sum up to one. Also because of the fact that the three weights sum up to one, there exists something like “triangular-arbitrage”. This

\(^9\) Smoothed weights are 3-months moving averages of the daily weights.
can be most clearly illustrated by the pre-crisis sample for Hong Kong. There we observe that correlations between the importance of fundamental and technical information, and technical and international information, are close to minus one. As a result, the correlation between international and fundamental information is close to positive one.

In the Hong Kong market, switching is heaviest between fundamental and technical analysis, followed by switching between technical and international information. The resulting correlation between international and fundamental is generally low, meaning that the fund manager does not often change between these sources. This pattern can also be roughly observed in the Thai market.

5. The Asian Crisis

In order to examine the ability of the model to give an explanation of the notion of contagion, we are focusing on the period directly surrounding the Asian crisis in 1997 and 1998. By examining the evolution of the weights directly prior to the crisis, especially the weight on international influences, we will be able to judge the event that triggered the crisis. Furthermore, given that the weights on international information are an indication of the correlation between the markets, it will allow us to conclude about the existence of interdependence or contagion.

5.1 Evolution of Weights

Figure 3 shows a close-up of the evolution of the three time-series of (smoothed) weights for Hong Kong and Thailand around the time the markets started crashing. This is 1997 for Hong Kong, and 1996 for Thailand. For both markets, there is a clear turning point on which relative tranquility changes into high volatility. Weights are distributed around one third until August 1997 in the Hong Kong market, after which we see a surge in technical analysis, bringing the index down. In the months prior to this, it can be observed that fundamental and international effects gain influence at the expense of chartist influence. As the market was overvalued at that time (see Figure 2) and the Thai market was already falling, the increase in fundamental and international weights increases the downward pressure on
prices. As the market was in an upswing, technical analysis provided upward pressure to price. When the difference between the chartist weight versus the fundamental plus international weight became too large, prices started falling. This negative trend was picked up by the technical analysis, which extrapolated this, causing the large increase in weight on chartism.

The story for the Thai market is somewhat more straightforward. Until July 1996, weights are distributed around one third. Because of a sharp increase in the use of the fundamentalist rule, the price starts dropping. This drop is picked up by technical analysts, as can be seen by the increase in weight on technical analyses in August 1996. The increase in chartism is only temporary; fundamentalism continues to rise until the market price reaches the fundamental price, so the over-pricing has vanished.

In terms of contagion, we observe that the Hong Kong market indeed falls as a result of the crisis in Thailand; the focus on international information increases prior to the start of the crisis in Hong Kong. However, the fall of the market is not only triggered by this contagion effect, but also by the mean-reverting dynamics induced by fundamental analyses.

6. Conclusions

In this paper we combine insights from the contagion literature and the heterogeneous expectations literature in order to get a better understanding on market-dynamics during financial market crises. For this end, we developed and estimated a dynamic model with a boundedly rational representative agent for the asset market. The representative agent, a fund manager, forms expectations based on three sources of information: economic fundamental, technical, and international. The relative importance of each source is time varying conditional on its impact on price in the previous period. The notion of contagion is incorporated by modelling two such models next to each other; the fact that the representative fund manager in both markets conditions its expectations on information from the other market introduces conditional interaction between the two risky assets.

The model reduces to a VAR with time-varying coefficients and an economic underpinning. This time variation is induced by the fact that the fund manager adapts the weight it puts on the different sources of information. The model is estimated for the Hang Seng and Bangkok S.E.T. indices for a period surrounding the Asian crisis, 1981-2006. The paper therefore adds to the contagion literature by proposing a completely novel view on the notion of contagion. Furthermore, the heterogeneous agents literature is enriched by applying
a representative agent with multiple information sources in a model with multiple asset markets. Furthermore, the daily frequency is used, which is higher than has been done before when estimating heterogeneous agents models to our best knowledge.

Estimation results indicate that the fund manager indeed uses the different information sources in forming expectations on the Thai and Hong Kong stock markets; all three sources are found to be present. Second, we also find that there is switching between the sources; that is, agents change their strategy conditional on past performance of the rules. Over time, large shifts in behaviour are observed, caused by crises, but also by market development.

Concerning the behaviour of the fund manager at the onset of the crises, we observe that the crisis in Thailand is triggered by a shift of focus towards the fundamental price. The crisis in Hong Kong is triggered in first instance as a result of increased focus on information from the Thai market, but also from an increased weight put on the fundamental price. We therefore find evidence of the existence of shift-contagion.

Future research in this field can spread into different directions. First of all, theoretical knowledge of the behaviour of heterogeneous interacting agents models with multiple asset markets is relatively limited. The focus thus far has been primarily on single asset markets, while global financial markets are becoming more and more interrelated. In the application of heterogeneous expectations models to the contagion issue, one can think of enhancing the two-market model to a multi-market model. In this way, it might be possible to distinguish the exact spread of a crisis across different countries. Finally it will be interesting to determine the exact triggers of changing behaviour. In this paper we have mainly focused on the behaviour of market participants, and matched turning points in an ad-hoc fashion with economic events. Knowing that behaviour of agents changes resulting from certain shocks is one, the next step is to determine why it changes.
References


Tables and Figures

Figure 1: Market and Fundamental Prices

Notes: Figure 1 presents the (log real) market and fundamental prices of the Hang Seng and Bangkok S.E.T. The fundamental prices are determined by the dynamic Gordon model, Equation (11).
Figure 2a: Weights

![Plot of weights for different groups](image1)

Figure 2b: Smoothed Weights

![Plot of smoothed weights for different groups](image2)

Notes: Figure 2 represents the weights of the three groups $w_{ht}$ as estimated by the model. Upper plot for daily weights, and lower for smoothed (3-months moving average) weights. FUN represents fundamentalists; CH chartists; INT internationalists. TH is Thailand and HK Hong Kong. W is weight and WS smoothed weight.
Figure 3: Weights during the Crisis

Notes: Figure 3 depicts the evolution of the weights $w_{h,t}$ for both Hong Kong (left) and Thailand (right) during the Asian crisis.
Table 1: Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>$P_{HK}$</th>
<th>$P'_{HK}$</th>
<th>$\Delta P_{HK}$</th>
<th>$P_{TH}$</th>
<th>$P'_{TH}$</th>
<th>$\Delta P_{TH}$</th>
<th>$P_{TH}$ - $P'_{TH}$</th>
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<td>6.495</td>
<td>6.422</td>
<td>.0000</td>
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<td>6.513</td>
<td>6.517</td>
<td>.0000</td>
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<tr>
<td>Maximum</td>
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<td>9.763</td>
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<td>7.932</td>
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<td>Minimum</td>
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<td>7.700</td>
<td>-0.405</td>
<td>5.497</td>
<td>5.241</td>
<td>-0.161</td>
<td>-1.459</td>
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<tr>
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<td>-0.017</td>
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<td>0.513</td>
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<td>-0.167</td>
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<tr>
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<td>2.500</td>
<td>63.106</td>
<td>1.774</td>
<td>2.303</td>
<td>11.921</td>
<td>3.049</td>
</tr>
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</table>

Notes: Table 1 presents the descriptive statistics of the (log real) prices $P_t$, fundamental prices $P'_t$, price changes $\Delta P_t$ and misalignments $P_t - P'_t$ of the Hang Seng and Bangkok S.E.T. stock markets.
Table 2: Estimation Results

<table>
<thead>
<tr>
<th></th>
<th>Without Switching</th>
<th></th>
<th>With Switching</th>
<th></th>
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</thead>
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<td>Fundamental</td>
<td>Hong Kong</td>
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<td>(.033186)</td>
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<td>(.069016)</td>
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<td>0.121852***</td>
<td>0.242656***</td>
<td>0.231034***</td>
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<td>International</td>
<td></td>
</tr>
<tr>
<td>γ</td>
<td></td>
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<td>-20.71975***</td>
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</table>

Log Likelihood

|         | 18341.41         | 18797.55   | 18373.04     | 18795.85   |

Notes: Table 2 presents the estimated coefficients and standard errors (in parenthesis) of the system in Equation (9), without (left two columns) and with (right two columns) switching mechanism, for Hong Kong and Thailand. *, **, *** represents significance at the 10, 5 and 1% level, respectively.
Table 3: Estimation Results Sub-Samples

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<td>-0.002</td>
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<td>(.003)</td>
<td>(.004)</td>
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<td>(.019)</td>
<td>(.029)</td>
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<td>(.003)</td>
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<tr>
<td>$\alpha_1$</td>
<td>0.962***</td>
<td>0.579***</td>
<td>0.682***</td>
<td>0.719***</td>
<td>0.091</td>
<td>0.429**</td>
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<td></td>
<td>(.151)</td>
<td>(.049)</td>
<td>(.117)</td>
<td>(.103)</td>
<td>(.073)</td>
<td>(.188)</td>
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<tr>
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<td>0.717***</td>
<td>-0.231***</td>
<td>-0.056</td>
<td>0.310*</td>
<td>-0.218***</td>
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<td>(.030)</td>
<td>(.053)</td>
<td>(.014)</td>
<td>(.046)</td>
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<td>(.023)</td>
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<tr>
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<td>0.418***</td>
<td>0.119**</td>
<td>0.038</td>
<td>0.042</td>
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<td></td>
<td>(.073)</td>
<td>(.078)</td>
<td>(.059)</td>
<td>(.055)</td>
<td>(.055)</td>
<td>(.082)</td>
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<tr>
<td>$\beta_2$</td>
<td>0.067</td>
<td>0.273***</td>
<td>0.143*</td>
<td>0.599***</td>
<td>0.161**</td>
<td>0.276***</td>
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<tr>
<td></td>
<td>(.121)</td>
<td>(.025)</td>
<td>(.077)</td>
<td>(.096)</td>
<td>(.074)</td>
<td>(.084)</td>
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<td><strong>Switching</strong></td>
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<td>$\gamma$</td>
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<td>-196.143</td>
<td>-162.545**</td>
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<td>(.418)</td>
<td>(6.529)</td>
<td>(5.096)</td>
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<td>(88.755)</td>
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<td>7868.775</td>
<td>6139.289</td>
<td>6018.055</td>
<td>5345.539</td>
<td>5121.220</td>
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</tbody>
</table>

Notes: Table 3 presents the estimation results of Equation (9) for the three sub samples 1981 – 1990 (pre-crisis), 1991 – 1999 (crisis), and 2000 – 2006 (post-crisis). *, **, *** represents significance at the 10, 5 and 1% level, respectively.
Table 4: Weights Characteristics

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<th>Thailand</th>
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<td>'81-'06</td>
<td>'81-'90</td>
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<tr>
<td>Mean</td>
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<tr>
<td>$w_f$</td>
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<td>0.333</td>
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<tr>
<td>$w_c$</td>
<td>0.334</td>
<td>0.334</td>
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<tr>
<td>$w_i$</td>
<td>0.331</td>
<td>0.332</td>
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<tr>
<td>Max</td>
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<td></td>
</tr>
<tr>
<td>$w_f$</td>
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<td>0.598</td>
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<tr>
<td>$w_c$</td>
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<td>0.999</td>
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<tr>
<td>$w_i$</td>
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<td>0.748</td>
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<tr>
<td>Min</td>
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<td></td>
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<tr>
<td>$w_f$</td>
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<td>3.11E-04</td>
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<tr>
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<tr>
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<td>3.08E-04</td>
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<tr>
<td>St.Dev</td>
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<tr>
<td>$w_f$</td>
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<td>0.056</td>
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<tr>
<td>$w_c$</td>
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<td>$w_i$</td>
<td>0.044</td>
<td>0.056</td>
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<td>$w_c - w_i$</td>
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<td>$w_f - w_i$</td>
<td>0.278</td>
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</tbody>
</table>

Notes: Table 4 presents the characteristics of the estimated weights for the pre-crisis period (1981-1990), the crisis period (1991-1999), the post-crisis period (2000 – 2006) and the total sample. $w_f$, $w_c$, $w_i$ represents weight on fundamental, technical, and international information, respectively.