

Conventions in the Foreign Exchange Market: Can they really explain Exchange Rate Dynamics?

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Abstract

The present article provides an unorthodox model exchange rate dynamics based on conventions that prevail among market participants. We build a theoretical model that highlights the mechanisms underlying the formation of market conventions. We then test this model empirically on the euro/dollar exchange rate between January 1995 and December 2008. We rely on two alternative methods: a macroeconomic analysis and an econometric analysis based on the estimation of a time-varying parameter model. Both methods show that market switches between fundamentals considered in a bull convention and in a bear convention explain the euro/dollar dynamics between January 1995 and December 2008. Besides, at horizons longer than 1 month, the out-of-sample forecasting power of the convention model beats the traditional exchange rate models and the random walk.

Keywords: Exchange Rate Dynamics, Convention Theory, Imperfect Knowledge Economics, Kalman filter, Genetic Algorithm

JEL Codes: G10, G12, F31

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1. Introduction

The present paper provides an unorthodox way to model exchange rate dynamics based on conventions that prevail among market participants. The intuition behind the convention model is based on a stylised fact highlighted by De Grauwe (2000). De Grauwe argues that agents tend to look for fundamentals that confirm the observed movements in the exchange rate. For instance, economists attributed the large depreciation of the euro relative to the dollar between January 1999 and December 2002 to the strong growth performances in the United States relative to the euro zone. On the contrary, the appreciation of the euro relative to the dollar between December 2002 and December 2004 was justified by large current account deficits in the United States compared to the euro zone. Bachetta and Van Wincoop (2005) theorised this idea in the scapegoat model. A fundamental variable is taken as a scapegoat to explain the exchange rate dynamics in a given period of time. Our approach differs strongly from Bachetta and Van Wincoop (2005). Our convention model borrows more elements from the Imperfect Knowledge Economics (IKE) approach pioneered by Frydman and Goldberg (2007).

We first build a theoretical model to explain the mechanisms underlying the formation of market conventions. The simulated exchange rate from the theoretical convention model replicates several stylised facts highlighted empirically in the exchange rate dynamics. We then test this model empirically on the euro/dollar exchange rate. The period of analysis spans January 1995 to December 2008. We rely on two alternative methods. The first method is a macroeconomic analysis that aims at explaining the euro/dollar movements by relying on the consensus of economists. This method is based on the analysis of the fundamentals used by the economic and financial to justify the euro/dollar dynamics. The second method is based on an econometric approach. We estimate a time-varying parameter model to find the conventions that drive the euro/dollar dynamics.

Both methods show that market switches between fundamentals considered in a bull convention and in a bear convention explain the euro/dollar dynamics between January 1995 and December 2008. More precisely, the model shows that during the period of analysis, the market puts a large accent on the US and European productivity indices and dividend yields in times of optimism while a large weight is put on the US and European external debts, oil prices and US house prices in times of pessimism. The analysis underlines the existence of a non-linear relationship between fundamentals and the euro/dollar exchange rate. In other words, some fundamentals may be more important at some periods of time for the determination of exchange rate dynamics while other fundamentals are important at other periods of time.

Both methods identify three major conventions in the euro/dollar market. The first convention is the new economy convention that covered the period January 1995 - December 2000. Investors were relatively more optimistic in the growth perspectives of the US economy than in European economies. The dollar experiences a strong appreciating trend in this period. Between January 2001 and June 2003, the market relies on a bear convention based on the huge external debt of the US economy. The dollar starts a strong depreciating trend in this period. Then, between July 2003 and December 2005 two competing conventions prevailed in the market. A bear convention that focused mainly on the large US current account deficits; and a bull convention that pointed to the spectacular recovery of the US economy from the internet bubble burst. During this period the dollar alternates between short-lasting appreciating and depreciating trends according to whether the bull convention dominates the bear one. After January 2006, fundamentals worsened in the US economy. The bear convention started to dominate the bull one. The spark of the subprime crisis in June 2007 definitely led to the domination of the bear convention in the market.

The article compares the predictive performances of the convention model with regards to alternative models. Results show that at horizons longer than 1 month, the out-of-sample forecasting power of the convention model beats the ones of traditional models of exchange rate and of the random walk.

Section 2 presents the main pillars of convention theory and proposes a theoretical model that defines the mechanisms underlying the formation of market conventions. Sections 3 and 4 find the possible conventions that prevailed for the euro/dollar exchange rate among market agents between January 1995 and December 2008. Section 3 identifies the conventions by relying on a macroeconomic analysis while section 4 rests on an econometric approach based on the estimation of a time-varying parameter model. Section 4 tests the out-of-sample predictive power of the convention model relative to alternative models. Section 5 concludes.

2. Theoretical concepts

2.1 The main principles of convention theory

Convention theory has been developed by the pioneered work of Lewis (1969), Sugden (1989) and Peyton Young (1996). Convention theory comes as an alternative to the traditional theory of asset pricing. Traditional models of asset pricing are based on the efficient market hypothesis (EMH) and the rational expectation hypothesis (REH). Such models assume objectivity *ex ante* of the future and the existence of a unique intrinsic asset value (the fundamental value). In the tradition of the Arrow-Debreu model, the REH states that a representative agent can predict the future value of an asset by associating *ex ante* predetermined probabilities to exogenous future events. A rational agent can hence assess the fundamental value of an asset by computing the expected returns of the asset in each state of the Nature conditional on the disposable stock of information. According to the EMH, every asset price has a unique fundamental value that includes all the relevant information of the asset.

Models based on the EMH and the REH offer poor empirical performances concerning the explanation and prediction of asset price dynamics, especially exchange rates (Meese and Rogoff (1983), Cheung, Chinn and Garcia Pascual (2005)). Such models led to unresolved asset pricing puzzles. Besides, assuming the existence of a unique fundamental value for an asset appears rather unrealistic. In a previous work, Bouveret and Di Filippo (2009) show that for the euro/dollar exchange rate, the market does not rely on a unique definition of the fundamental exchange rate but rather on a large panel of fundamental values. Each fundamental value belongs to a specific model designed by a particular agent. These facts cast doubts on the relevance of models based on the traditional asset pricing theory.

Convention theory adopts a rather opposite view to the traditional theory. Following Knight (1921) and Keynes (1936), convention theorists claim that the future is totally uncertain. No agent has the ability to know the probability distribution of future outcomes. The future is here shaped by the heterogeneity of opinions that agents frame on the fundamental value of an asset. There are as many fundamentals as there are opinions about the fundamental value of an asset. The future becomes hence subjective: each agent has his/her own opinion about the future value of the asset. All these opinions - translated into models of exchange rate determination - lead to the existence of multiple asset price equilibria in the market. The key question is how do these opinions converge towards a particular equilibrium? Individual opinions converge towards a particular equilibrium through a mimetic mechanism. This mechanism was early illustrated by Keynes (1936) in his beauty contest. The primary objective for an agent in the market is to anticipate the reaction of the majority of

participants in the market. As a matter of fact, if a market is bull on a given asset, an agent will have to buy the asset even if fundamentals tell him/her to sell the asset. This self-referential behaviour is rational at an individual level although it can lead to irrational phenomena (such as price bubbles) at a collective level. The self-referential behaviour consists in detecting striking events that could catch the attention of the majority of agents in the market. The choice of striking fundamentals is based on a trial-and-error strategy. Agents bet on the possible striking fundamentals that could catch the attention of the majority of agents in the market. Agents then build a model based on the selected fundamentals. The revisions of mistaken bets (or of bad models) imply an increasing volatility in asset prices. The market will stabilise itself when all agents - through mimetism - will focus on a particular striking set of fundamentals. At this point, agents have found a particular model based on a specific set of fundamentals. All agents in the market legitimate this model. This model is called a convention. A convention is therefore a fundamental model legitimated by all agents in the market, in a given time period. A convention therefore creates a focal point that helps resolving the problem of multiple asset price equilibria in the market. Once a convention is determined in the market, asset price volatility decreases. A convention therefore acts as a guide through the uncertainty concerning the future dynamics of asset prices. Indeed agents can rely on the convention to form their expectations on the future value of the asset.

A convention can thus be defined as a particular fundamental model adopted by the majority of agents in a market concerning the future economic perspectives (Orléan (2006)). A convention often ignores other fundamentals that go against it. In order to live long enough, the asset price dynamics fitted by the convention has to match the actual dynamics of asset prices. However, market agents will not abandon a convention at the first anomalies *i.e.* when the empirical dynamics of asset prices go against the ones assumed by the convention. Agents will do so when there will be a series of events that are in opposition to the fitted exchange rate provided by the current convention. Agents' beliefs in the current convention vanish and the convention disappears from the market. The uncertainty on the future dynamics of asset prices increases and with it, exchange rate volatility. Market participants will then have to find a new convention.

2.2 A simple theoretical exchange rate model based on conventions

We set a simple theoretical model to explain the mechanisms underlying the formation of market conventions in the foreign exchange market. The model borrows elements from the Imperfect Knowledge Economics (IKE) approach by Frydman and Goldberg (2007).

We assume two countries (domestic and foreign) in an asymmetric world. The assumption of an asymmetric world implies that the influence of a given fundamental in the domestic and foreign countries does not have the same effect on exchange rate dynamics.

Following the IKE approach, the model considers two types of representative agents in the market: an optimistic (or bull) agent and a pessimistic (or bear) agent. The model is based on the following mechanism. When agents are relatively more optimistic in the domestic country than in the foreign country, they expect an appreciation of the domestic currency (and *vice versa*). Conversely, when agents are more pessimistic in the domestic country than in the foreign country, they anticipate a depreciation of the domestic currency (and *vice versa*).

Agents are characterised by bounded rationality. Following a trial-and-error strategy, agents choose a bunch of fundamentals among the available set of fundamentals that best explain past exchange rate dynamics. We model the choice of fundamentals through a genetic algorithm².

² This algorithm is indeed very close to the building logic of market conventions.

The first step of the genetic algorithm is the initialization of the variables. We assume a set of 8 pairs of fundamentals split into two subsets.

$$\begin{aligned}\Omega^{Bull} &= \{(f_1, f_2^*), (f_3, f_4^*), (f_5, f_6^*), (f_7, f_8^*)\} \\ \Omega^{Bear} &= \{(f_9, f_{10}^*), (f_{11}, f_{12}^*), (f_{13}, f_{14}^*), (f_{15}, f_{16}^*)\}\end{aligned}\quad (1)$$

The bull (bear) subset represents the stock of information used by optimistic (pessimistic) agents to forecast future exchange rate dynamics. As agents have bounded rationality, they rely on a particular stock of fundamentals to make their forecasts and ignore other fundamentals. In other words agents do not take account of the entire stock of information (Ω^{Bull} and Ω^{Bear}) but rely instead on a particular subset of information to make their forecasts (either Ω^{Bull} or Ω^{Bear}).

Agents are assumed to have knowledge of economic theory. In other words, they know the theoretical sign of the relationship between a given fundamental and the exchange rate. We assume that:

$$\frac{ds_t}{df_{1,t}} > 0 ; \frac{ds_t}{df_{2,t}^*} < 0 ; \frac{ds_t}{df_{3,t}} > 0 ; \frac{ds_t}{df_{4,t}^*} < 0 ; \frac{ds_t}{df_{5,t}} > 0 ; \frac{ds_t}{df_{6,t}^*} < 0 ; \frac{ds_t}{df_{7,t}} > 0 ; \frac{ds_t}{df_{8,t}^*} < 0 \quad (2a)$$

$$\frac{ds_t}{df_{9,t}} < 0 ; \frac{ds_t}{df_{10,t}^*} > 0 ; \frac{ds_t}{df_{11,t}} < 0 ; \frac{ds_t}{df_{12,t}^*} > 0 ; \frac{ds_t}{df_{13,t}} < 0 ; \frac{ds_t}{df_{14,t}^*} > 0 ; \frac{ds_t}{df_{15,t}} < 0 ; \frac{ds_t}{df_{16,t}^*} > 0 \quad (2b)$$

For example, if $f_{1,t}$ and $f_{2,t}$ are considered respectively as the domestic and foreign interest rates, then an increase in the interest rate differential in favour of the domestic economy ($d(f_{1,t} - f_{2,t}) > 0$) will induce an appreciation of the domestic currency ($ds_t > 0$). Also, if $f_{9,t}$ and $f_{10,t}$ are considered respectively as the domestic and foreign stocks of external debt, then an increase in the stock of domestic debt other things being equal ($d(f_{1,t} - f_{2,t}) > 0$) leads the domestic currency to depreciate ($ds_t < 0$).

Fundamentals are assumed to follow a random walk:

$$f_t^k = f_{t-1}^k + \varepsilon_t^k \quad (3)$$

Where ε_t^k mimics the impact of news on the fundamentals $\varepsilon_t^k \rightarrow iidN(0, \sigma_\varepsilon^k)$

The second step of the genetic algorithm is the selection of the variables. As agents cannot take account of all fundamentals due to bounded rationality, they select a limited bunch of fundamentals. We assume that in a given state, agents select two pairs of fundamentals among the four pairs available in a given state. Thus, agents include four fundamentals (either from Ω^{Bull} or from Ω^{Bear}) in their model.

The selection of fundamentals that in turn creates a model of exchange rate determination is based on a fitness process. Agents first test the in-sample historical explanatory power of each possible model based on the above pairs of fundamentals. They then select the model (or the fundamentals) that best explain past exchange rate dynamics.

Thus, each category of agents (optimistic or pessimistic) tests 6 possible models. We therefore end up with 12 models.

Bull agents test the following models (bull models are indexed from 1 to 6):

$$s_t^i = \beta_{0,t} + \beta_{k,t} f_{k,t} - \beta_{k,t} f_{k+1,t}^* + \beta_{l,t} f_{l,t} - \beta_{l+1,t} f_{l+1,t}^* \quad \text{With } k \neq l \quad (4a)$$

Where $k=2a+1$ and $l=2a$ ($a=0$ to 4); $i=1$ to 6 ; $\beta_{0,t}$ is a constant

Bear agents tests the following models (bear models are indexed from 7 to 12):

$$s_t^j = \beta_{0,t} + \beta_{m,t} f_{m,t} - \beta_{m+1,t} f_{m+1,t}^* + \beta_{n,t} f_{n,t} - \beta_{n+1,t} f_{n+1,t}^* \quad \text{With } m \neq n \quad (4b)$$

Where $m=2b+1$ and $n=2b$ ($b=5$ to 8); $j=7$ to 12 ; $\beta_{0,t}$ is a constant

In order to assess the fitness of the above models, each agent estimates the models by ordinary least squares (OLS). The aim is to find the coefficients β that minimize the sum of squared residuals of the model:

$$\hat{\beta}^h = \arg \min_{\beta} \sum_{t=1}^n (s_t - x_{h,t}^T \beta)^2 \quad \text{With } h = 1 \text{ to } 12 \quad (5)$$

The estimated coefficients are given by:

$$\hat{\beta}^h = \left(\frac{1}{n} \sum_{t=1}^n x_{h,t} x_{h,t}^T \right)^{-1} \frac{1}{n} \sum_{t=1}^n x_{h,t} s_t \quad \text{With } h = 1 \text{ to } 12 \quad (6)$$

The fitted exchange rate is defined by:

$$\hat{s}^h = \frac{1}{n} \sum_{t=1}^n x_{h,t} \left(\frac{1}{n} \sum_{t=1}^n x_{h,t} x_{h,t}^T \right)^{-1} \frac{1}{n} \sum_{t=1}^n x_{h,t} s_t \quad \text{With } h = 1 \text{ to } 12 \quad (7)$$

Each agent computes the in-sample mean squared error (MSE) based on the past exchange rate dynamics:

$$MSE_t^h = \frac{1}{n} \sum_{t=1}^n (s_{t-h}^h - \hat{s}_{t-h}^h)^2 \quad \text{With } h = 1 \text{ to } 12 \quad (8)$$

The selected models satisfy the following conditions:

$$s_t^{i*} = \text{Min} \left\{ MSE_t^i \right\}_{i=1 \text{ to } 6} \quad \text{With } i = 1 \text{ to } 6 \quad (9a)$$

$$s_t^{j*} = \text{Min}\{MSE_t^j\}_{j=7 \text{ to } 12} \quad \text{With } j = 7 \text{ to } 12 \quad (9b)$$

The expected exchange rate from the model used by each agent is defined as:

$$E_{o,t}(s_{t+1}^i) = \hat{\beta}_{0,t} + \hat{\beta}_{k,t}f_{k,t} - \hat{\beta}_{k+1,t}f_{k+1,t}^* + \hat{\beta}_{l,t}f_{l,t} - \hat{\beta}_{l+1,t}f_{l+1,t}^* \quad \text{With } i = 1 \text{ to } 6 \quad (10a)$$

$$E_{p,t}(s_{t+1}^j) = \hat{\beta}_{0,t} + \hat{\beta}_{m,t}f_{m,t} - \hat{\beta}_{m+1,t}f_{m+1,t}^* + \hat{\beta}_{n,t}f_{n,t} - \hat{\beta}_{n+1,t}f_{n+1,t}^* \quad \text{With } j = 7 \text{ to } 12 \quad (10b)$$

The third step of the genetic algorithm is the reproduction of the best model. Agents drop the fundamental variables that do not explain well the dynamics of exchange rate and look for the ones that provide a better fit of past exchange rate dynamics. In other words, agents re-iterate the procedure described above.

We assume that the proportion of optimistic and pessimistic agents in the market varies through time. We define the proportion of optimistic and pessimistic agents in the market as:

$$\omega_{o,t} = \frac{\exp(\gamma\pi'_{o,t})}{[\exp(\gamma\pi'_{o,t}) + \exp(\gamma\pi'_{p,t})]} \quad \text{and} \quad \omega_{p,t} = \frac{\exp(\gamma\pi'_{p,t})}{[\exp(\gamma\pi'_{o,t}) + \exp(\gamma\pi'_{p,t})]} \quad (11)$$

$$\text{Where } \omega_{o,t} + \omega_{p,t} = 1 \text{ and } 0 < \gamma < 1$$

The parameter γ represents the intensity at which agents revise their forecasting rules. Usually, we set γ close to zero and away from unity since as underlined in section 2.1, a convention does not disappear at the first anomalies between the fitted asset price dynamics by the convention and the actual asset price dynamics.

The profitability $\pi'_{i,t}$ of each rule is evaluated according to the profit $\pi_{i,t}$ and the risk $\sigma^2_{i,t}$ related to this rule:

$$\pi'_{i,t} = \pi_{i,t} - \mu\sigma^2_{i,t} \quad i = o, p \quad (12)$$

The parameter μ represents the coefficient of risk aversion. The risk associated to a forecasting rule is defined as the variance of the forecasting error:

$$\sigma^2_{i,t} = [E^i_{t-1}(s_t) - s_t]^2 \quad i = o, p \quad (13)$$

The profit $\pi_{i,t}$ related to a forecasting strategy is defined as the one-period earnings of investing one unit of domestic currency in the foreign asset:

$$\pi_{i,t} = [s_t(1 + r^*) - s_{t-1}(1 + r)] \text{sgn}[E^i_{t-1}(s_t)(1 + r^*) - s_{t-1}(1 + r)] \quad i = o, p \quad (14)$$

$$\text{Where } \begin{cases} \text{sgn}[x] = 1 \text{ if } x > 0 \\ \text{sgn}[x] = 0 \text{ if } x = 0 \\ \text{sgn}[x] = -1 \text{ if } x < 0 \end{cases}$$

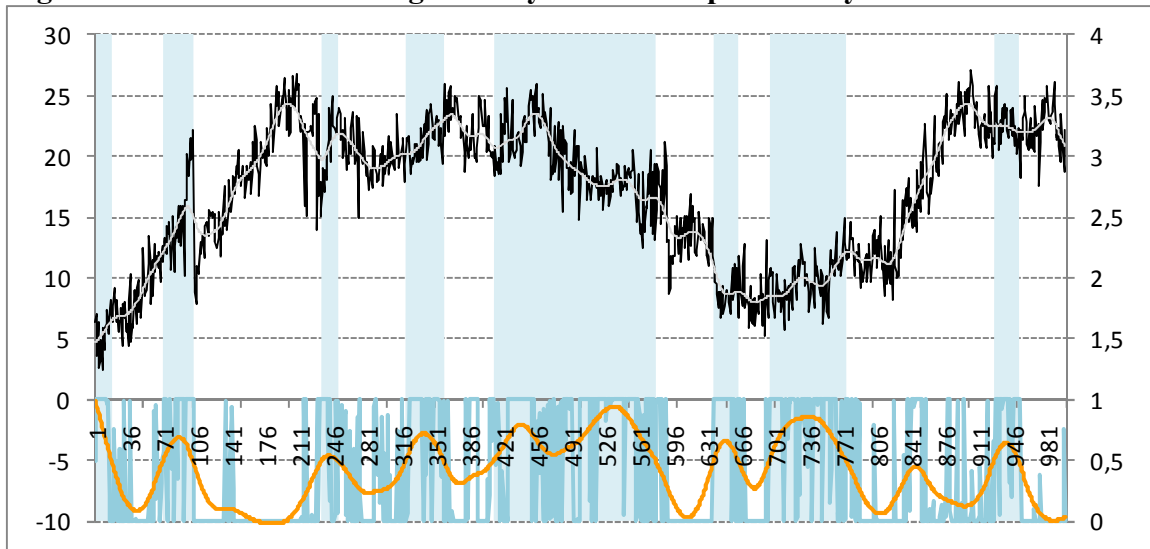
We obtain the expected exchange rate at time $t+1$ by aggregating agents' forecasts in the market:

$$E_t(\Delta s_{t+1}) = \omega_{o,t} E_{o,t}(\Delta s_{t+1}) + \omega_{p,t} E_{p,t}(\Delta s_{t+1}) \quad (15)$$

$$\text{Hence: } \Delta s_{t+1}^{\text{Market}} = -\omega_{o,t} \Delta s_{t+1}^{\text{Bull}} + \omega_{p,t} \Delta s_{t+1}^{\text{Bear}} + \varepsilon_{t+1} \quad (16)$$

Figure 1.1 shows the simulations results of the theoretical convention model for 1000 periods (we assume $\mu = 5$ and $\gamma = 0,2$). The blue margins mean that the market is in majority optimistic ($P(S_t = \text{Bull} | I_t) > 0,5$) while the white margins mean that the market is globally pessimistic ($P(S_t = \text{Bull} | I_t) < 0,5$).

Figure 1.1: Simulated exchange rate dynamics and probability to be in the bull state



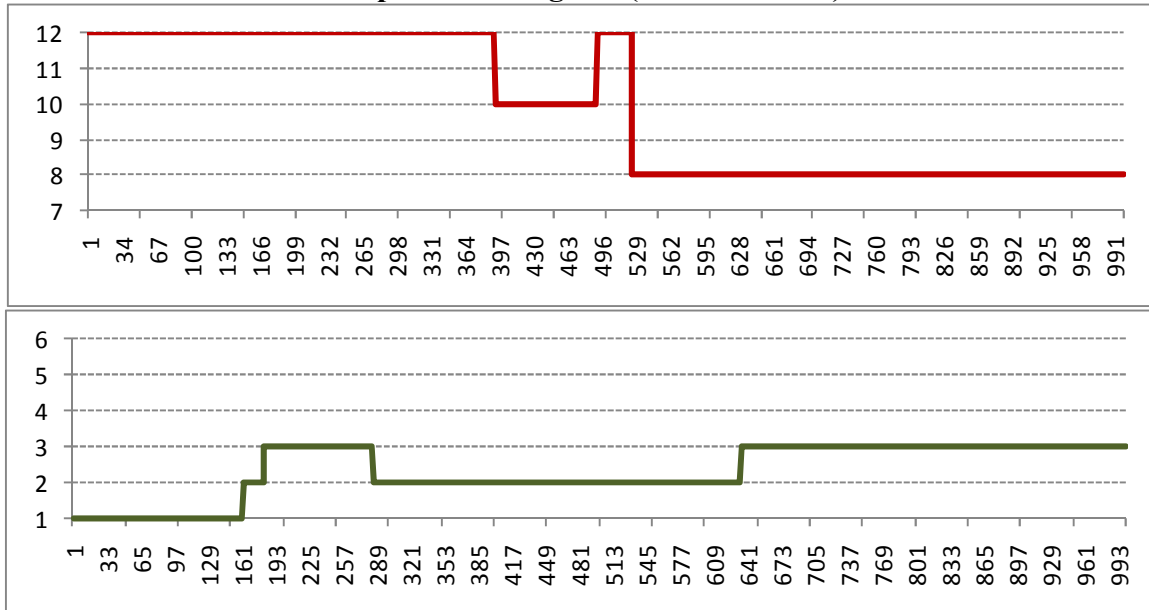
NB: The black lines represents the market exchange rate (left scale) ; the blue line represents the probability to be in the bull state (right scale); the orange line represents the Hodrick-Prescott filter ($\lambda = 14400$) of the probability to be in the bull state (right scale).

Figure 1.1 shows that the simulated exchange rate alternates between periods of appreciating and depreciating trends. Also, the proportion of bull and bear agents in the market varies through time.

In this model, agents go through two selection processes that define two switching mechanisms.

The first selection process (equations (1) to (10b)) is the selection of the best model by bull and bear agents. This choice is based on the relative performances of the past explanatory powers of exchange rate models based on fundamentals coming respectively from the bull and bear information stocks. Through time, bull and bear agents switch between their respective models and choose the model that provides the best explanatory power of past exchange rate dynamics. Figure 1.2 represents the models chosen by optimistic and pessimistic agents through time.

Figure 1.2: Model chosen by optimistic agents (models 1 to 6) and pessimistic agents (models 7 to 12)

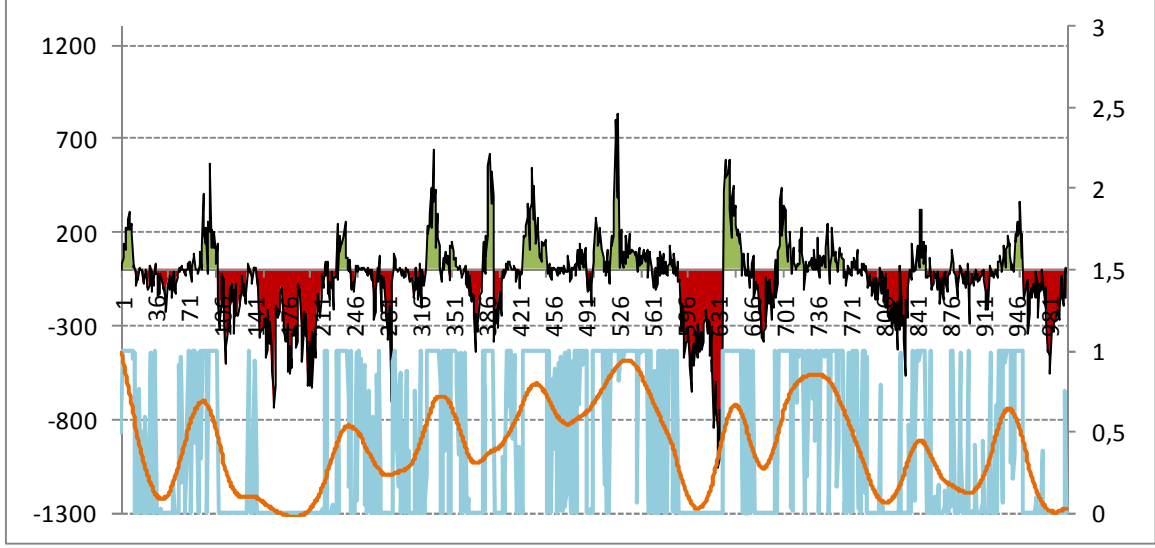


NB: The upper figure represents the model chosen by pessimistic agents (models 7 to 12); the lower figure represents the model chosen by optimistic agents (models 1 to 6). The left scale represents the models chosen; the horizontal scale represents the time period.

Figure 1.2 shows that between $t = 1$ and $t = 300$ optimistic agents alternate between model 1, 2 and 3. Over the same period, pessimistic agents rely on model 12. Thus in this period, model 12 provides the best explanatory power of past exchange rate dynamics given the stock of fundamentals used by bear agents.

The second selection process (equations (11) to (14)) is the choice of whether being bull or bear in the market. This choice depends on the relative profitability of the selected bull model relative to the selected bear model. Through time, agents can switch between being a bull or a bear agent given the profitability of the model selected by bull and bear agents. Figure 1.3 represents the relative profitability of being bull in the market ($\pi'_{o,t} - \pi'_{p,t}$). The green area means that the selected bull model generates a positive profitability relative to the selected bear model. Conversely, the red area means that being bull is less profitable than being bear.

Figure 1.3: Relative profitability of being bull in the market ($\pi'_{o,t} - \pi'_{p,t}$)



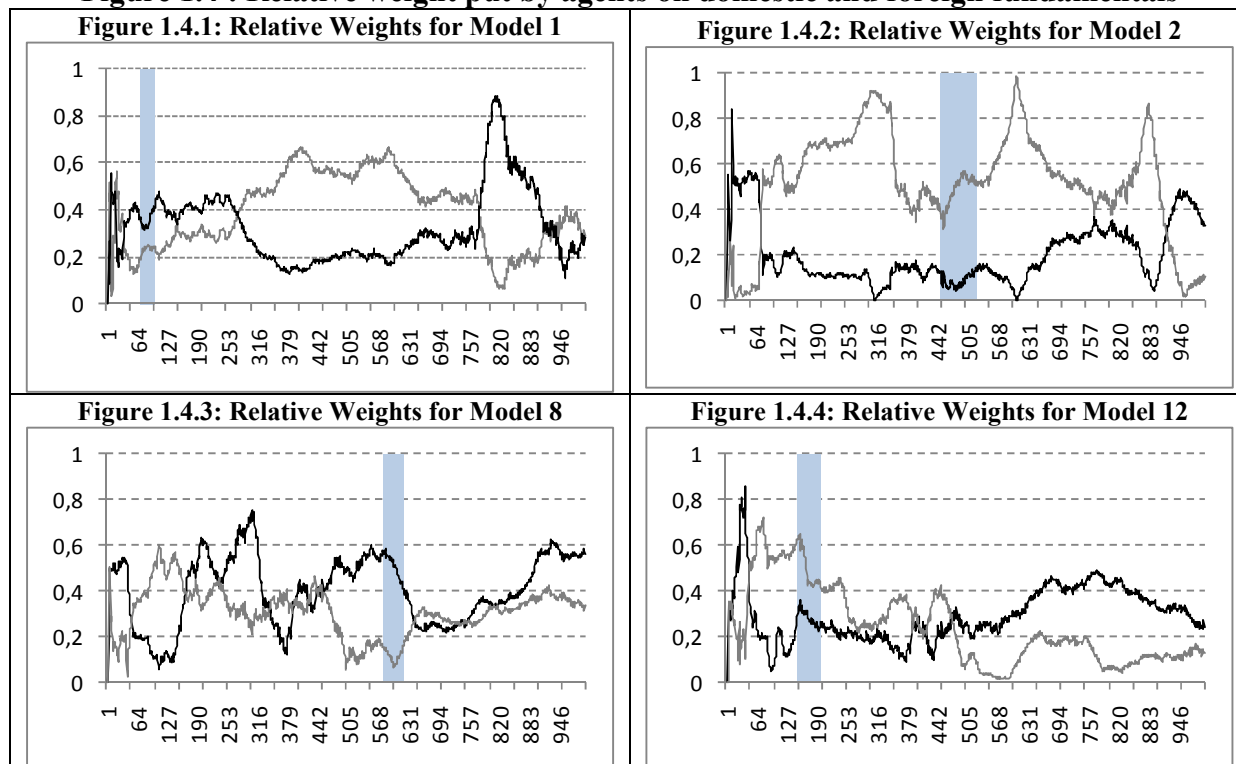
NB: The black lines represents the difference between the profitability of the selected bull model and the profitability of the selected bear model (left scale) ; the blue line represents the probability to be in the bull state (right scale) ; the orange line represents the Hodrick-Prescott filter ($\lambda = 14400$) of the probability to be in the bull state (right scale).

Figure 1.3 shows that when the selected model by bull agents generates a positive profitability relatively to the selected bear model, bull agents dominate the market. On the contrary, when the selected model by bull agents generates a negative profitability relatively to the selected bear model, bear agents become dominant in the market.

Figure 1.4 shows the relative weights put by agents on domestic and foreign fundamentals for model 1, model 2, model 8 and model 12. These relative weights put by agents on domestic and foreign fundamentals are computed as the contributions of the coefficients for the estimated models in the bull state (Ω_{Model1}^{Bull}) and in the bear state (Ω_{Model1}^{Bear}). For example, in the case of model 1, we have:

$$\Omega_{Model1}^{Bull} = \frac{|\hat{\beta}_1 f_1| + |\hat{\beta}_3 f_3|}{|\hat{\beta}_1 f_1| + |\hat{\beta}_2 f_2| + |\hat{\beta}_3 f_3| + |\hat{\beta}_4 f_4|} ; \Omega_{Model1}^{Bear} = \frac{|\hat{\beta}_1 f_2| + |\hat{\beta}_3 f_4|}{|\hat{\beta}_1 f_1| + |\hat{\beta}_2 f_2| + |\hat{\beta}_3 f_3| + |\hat{\beta}_4 f_4|} \quad (17)$$

Figure 1.4 : Relative weight put by agents on domestic and foreign fundamentals



NB: The black (grey) line represents the weight attributed to domestic (foreign) fundamentals.

The paragraph below provide a key understanding of the results from figures 1.1, 1.2, 1.3 and 1.4. We have here four cases in the market.

First, in figure 1.1, an appreciation (a depreciation) of the domestic (foreign) currency in the bull state means that agents are relatively more optimistic in the domestic economy than in the foreign economy. For example, in figure 1.1, from $t = 70$ to 100, the market is bull ($P(S_t=Bull/I_t) > 0,5$) and the domestic currency appreciates. Agents are in majority bull because being bull is more profitable than being bear (figure 1.3). Optimistic agents rely on model 1 in this period (figure 1.2) and put more weight on domestic fundamentals than on foreign fundamentals (figure 1.4.1).

Secondly, in figure 1.1, an appreciation (a depreciation) of the foreign (domestic) currency in the bull state means that agents are relatively more optimistic in the foreign economy than in the domestic economy. For instance, in figure 1.1, from $t = 450$ to 525, the market is bull and the domestic currency depreciates. Figure 1.3 shows that over the period the profitability of being bull is higher than the one of being bear. The best model selected by bull agents in this period is model 2 (figure 1.2). Based on model 2, bull agents put more weight on foreign fundamentals than on domestic fundamentals (figure 1.4.2).

Thirdly, in figure 1.1, a depreciation (an appreciation) of the domestic (foreign) currency in the bear state means that agents are relatively more pessimistic in the domestic economy than in the foreign economy. As a matter of facts, from $t = 580$ to 620 in figure 1.1, the market is bear ($P(S_t=Bull/I_t) < 0,5$) and the domestic currency depreciates over the period. The profitability of being bear is higher than the one of being bull (figure 1.3). The selected model by bear agents is model 8 (figure 1.2). Model 8 puts more weight on domestic fundamentals than on foreign fundamentals (figure 1.4.3).

Fourthly, in figure 1.1, a depreciation (an appreciation) of the foreign (domestic) currency in the bear state means that agents are relatively more pessimistic in the foreign economy than in the domestic economy. For instance, we observe in figure 1 from $t = 150$ to

200 that the market is bear and that the domestic currency appreciates. Being bear is indeed more profitable than being bull in this period (figure 1.3). The model chosen by bear agents is model 12 (figure 1.2). Model 12 puts a lower weight on domestic fundamentals than on foreign fundamentals (figure 1.4.4).

Finally, the theoretical convention model shows that exchange rate dynamics are driven by the time-varying fundamental models or equivalently by the convention models selected by market agents.

The convention model offers several advantages compared to recent models of exchange rate such as the heterogeneous agents models (De Grauwe and Grimaldi (2007)). Heterogeneous agents models explain exchange rates dynamics based on the behaviour of fundamentalist and chartist agents. Such models fully predetermine the behaviour of economic agents by associating an exogenous rule to each agent. Agents therefore act as robots in these models. On the contrary, the convention model follows the IKE approach by partially predetermining the behaviour of agents. Indeed, agents can use whatever rules or investment strategies. Such rules are allowed to evolve over time based on a trial-and-error strategy. Moreover, the convention model does not rely on the controversial definition of a fundamental exchange rate. On the contrary, heterogeneous agents models have to specify an arbitrary value for the fundamental exchange rate in the fundamentalist rule.

Having highlighted the mechanisms behind the formation of market conventions, we now test the theory of conventions in the foreign exchange market. The asset of interest is the euro/dollar exchange rate. The period of analysis runs from January 1995 to December 2008.

We rely on two methods to identify the fundamentals considered in conventions by market agents. The first method is a macroeconomic analysis. This method analyses the weight given to a particular fundamental by the economic and financial literature in a given period of time. The results are presented in section 3. The second method relies on the estimation of a time-varying parameter model. This method computes the time-varying dynamics of the coefficients value associated to a particular fundamental through time. The results are presented in section 4.

3. A macroeconomic analysis of market conventions

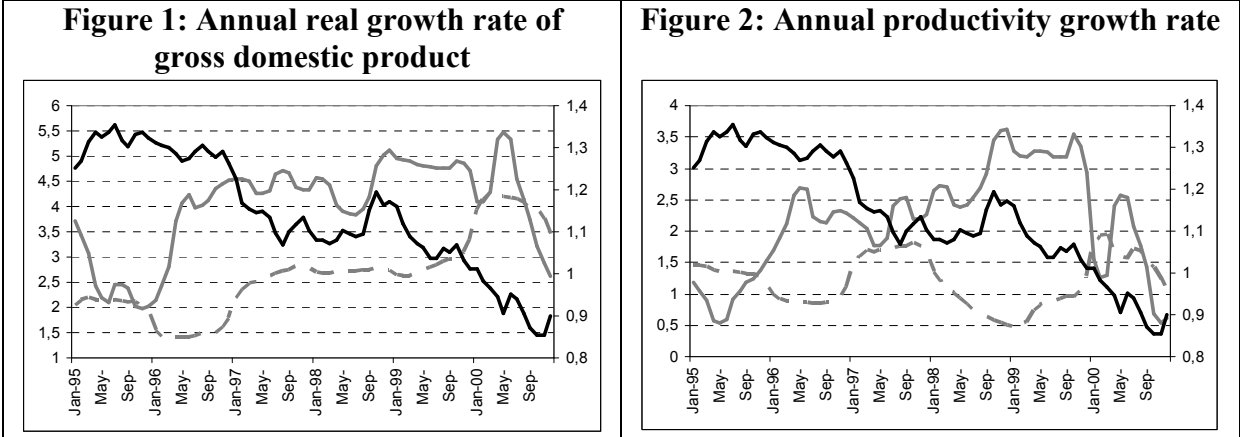
This section highlights the conventions that prevail in the euro/dollar market by relying on a macroeconomic analysis. The aim is to rely on the consensus of the market concerning the fundamentals that explains the euro/dollar movements. We rely on major articles from financial journals (*Wall Street Journal* and *The Economist*) as well as academic ones. We justify each argument by using figures from Thomson Datastream and from the Bureau of Economic Analysis³. The results of this analysis are organised in the following five sections.

3.1 January 1995 - December 2000: the internet convention or the superiority of the US economy compared to the euro zone

In the second half of the 1990s, the US economy experienced a stronger growth rate than Europe (an average of 8,3 % for the United States *versus* 5 % for Europe (figure 1)). Stronger growth in the United States was attributed to larger investments in new technologies compared to Europe. Such investments helped increase the productivity differential in favour

³ For figures 1 to 23, data comes from Thomson Datastream and the Bureau of Economic Analysis concerning capitals flows (figures 3, 7 and 21).

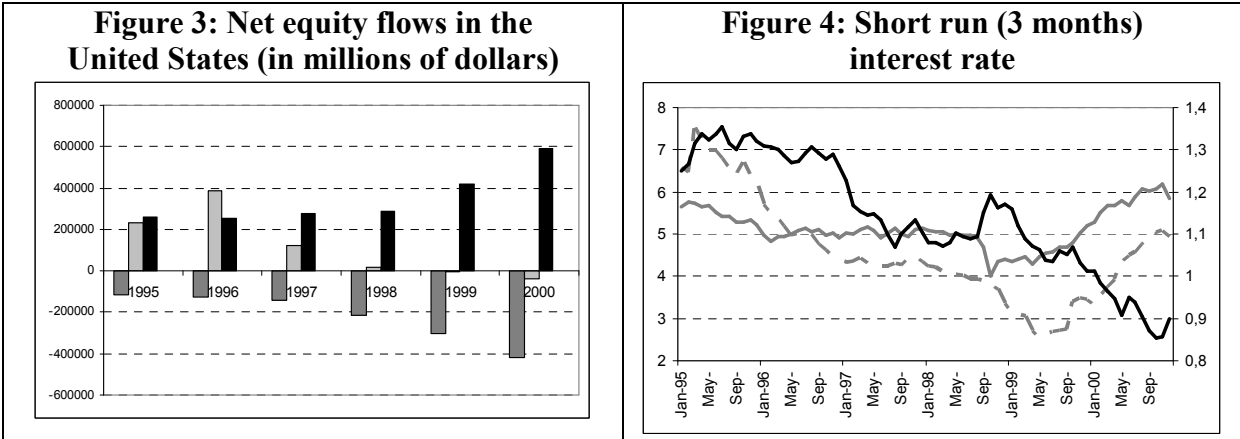
of the United States (figure 2). In December 2008, the differential in productivity growth rates amounted to 3 %. Numerous economists praised the glorious perspectives offered by the US economy. Some economists (of whom Jeremy Rifkin) even claimed that the US economy had reached a higher structural growth rate. The market was clearly in presence of a convention defining the US economy as more profitable than the European economy.



NB: The dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate.

Financial investors therefore expected higher returns in US stocks than in European stocks. They invested massively in US stocks, especially in companies belonging to the sector of the new economy (the ever-known start-ups). Net equity flows in the United States increased by an average of 24 % a year between 1998 and 2000 (figure 3). The annual average growth rate of the S&P500 between January 1995 and December 2000 amounted to 21 % a year (figure 23).

The birth of the euro zone in 1999 and the youth of the European Central Bank (ECB) - which had to set its credibility among market agents - led investors to be more timorous in the European economy than in the US economy.



NB: For Figure 3, the dark grey represents the US current balance; the light grey represents net flows of investment in Treasury bills and government bonds; the black represents net flows of investment in equity and foreign direct investment. For Figure 4, the dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate.

The net inflow of capitals in the United States led to an appreciation of the dollar against the euro between January 2001 and December 2000. This appreciation was also induced by an interest rate differential in favour of the United States.

Therefore, between January 1995 and December 2000, markets were relatively more optimistic on the perspectives of the US economy relative to the ones of the European economy. The bull sentiment that prevailed in the market was referred to as the new economy convention or the internet convention.

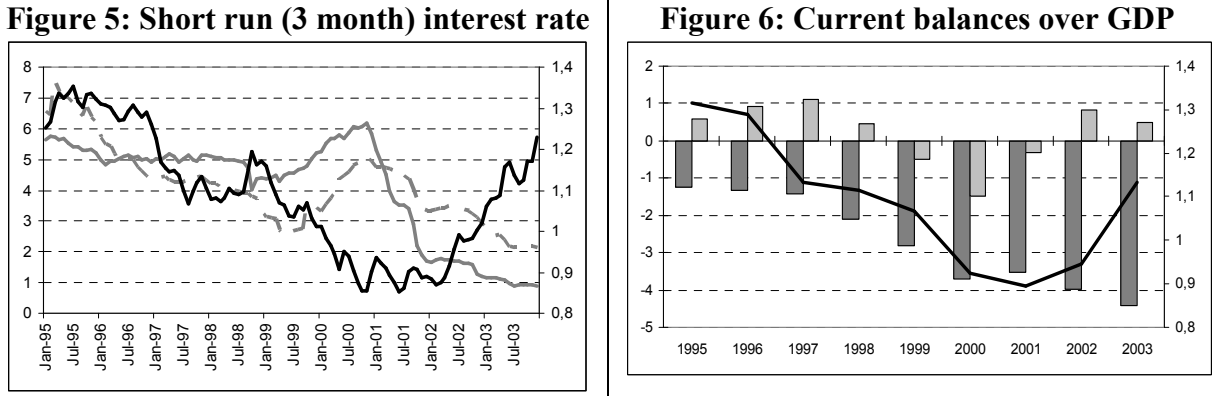
3.2 January 2001-June 2003: the burst of the internet bubble and the end of the new economy convention

The over-optimistic sentiment in the US economy led to a bubble in stock prices: the internet bubble. This bubble burst in January 2001. This exogenous shock put an end to the new economy convention. Investors realised that their expectations on the perspectives of the US economy were too optimistic.

Financial papers began to put the accent on variables hidden during the internet convention. Stronger US growth rate was gauged on a growing debt of the public and the private sectors. US companies over-estimated the future demand and faced higher debt and excess capacities. The high level of US consumption rested on an increasing debt allowed by the positive wealth effect induced by the rise in stock prices.

The increase in public and private debt induced mechanically an increase in the deficit of the current account balance (figure 6) and induced the return of the twin deficits. A lot of economists began to ask about the sustainability of US deficits (Mann (2002)) and a possible fall in the dollar.

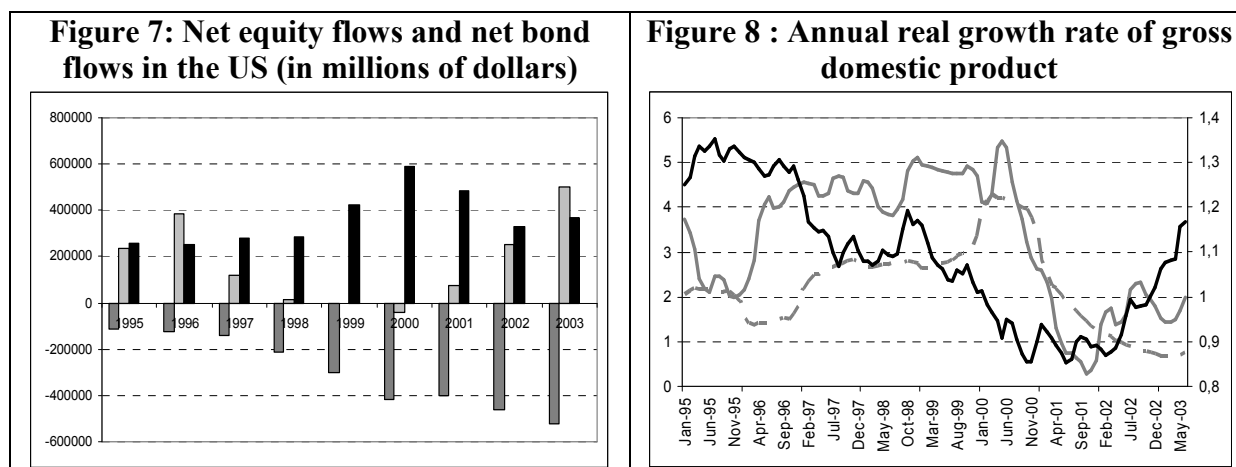
To counter the economic slowdown induced by the internet bubble burst, the Federal Reserve decreased dramatically its rates of interest. The interest rate differential became now in favour of the European economy (figure 5).



NB: For Figure 5, the dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate. For Figure 6, the dark grey represents the US current balance and the light grey represents the European current balance.

Investors became thus relatively less confident in the US economy than in the European economy. They reduced investments in stocks and foreign direct investment (FDI) in the United States. Between January 2001 and June 2003, the S&P500 lost 44 % and the Eurostoxx 60 %. The financial scandals of Enron and Worldcom and then the attacks of the 11th September 2001 kept increasing the bear sentiment on the US economy. Equity flows in the United States decreased (figure 7) and the dollar stopped its appreciating trend begun earlier in January 1995 (figure 8). The dollar started to depreciate in June 2002. This depreciation was however contained by interventions of East-Asian central banks. Such agents bought US bonds to prevent a severe appreciation of their currency against the dollar.

The bear sentiment of investors on the US economy does not mean that investors became bull in the European economy. Indeed, the excess in the current balance experienced by the euro zone at that period (figure 6) suggests that the growth rate has been very low and is still very low in the euro zone during this period.



NB: For Figure 7, the dark grey represents the US current balance; the clear grey represents net flows of investment in Treasury bills and government bonds; the black represents net flows of investment in equity and foreign direct investment. For Figure 8, the dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate.

As a result, between January 2001 and June 2003, financial markets faced an increase in uncertainty concerning economic recovery either in the Euro zone or in the United States. Deflation fears induced by lower growth rates prevailed among economists and central bankers. The market definitely abandoned the internet convention. Agents became bear either in the United States and or in the euro zone. The bear sentiment was however relatively stronger in the United States than in the euro zone.

3.3 July 2003-December 2005: The birth of two competing conventions: the US consumption as the engine of the world economy *versus* the US as a net debtor

From July 2003, fears of deflation induced by the bubble burst vanished. The US economy was recovering surprisingly fast from the burst of the internet bubble (figure 9). Factors behind the US recovery were the large decrease of interest rates by the Federal Reserve (figure 10) coupled with an increase in public spending (through the decrease in taxes under the Bush government and the increase in military spending (related to wars in Iraq and in Afghanistan)).

Conversely, the Euro area was dealing with a weaker growth rate. Economists started to ask about the relevance of the institutional structure of the euro zone. They began to blame the Growth and Stability Pact because it could prevent the euro area from higher growth rates. Members of the euro zone seemed unable to lead a relevant fiscal policy to counter the economic slowdown. Between July 2003 and December 2005 the annual growth rate reached 1,7 % in the euro zone compared to 4,8 % in the United States (figure 9). Lower interest rates associated to surging house prices (figure 13) allowed US households to ease their access on credit and to increase their consumption. At that time, financial papers argued that the US consumption was the engine of the world economy.

Figure 9: Annual real growth rate of gross domestic product

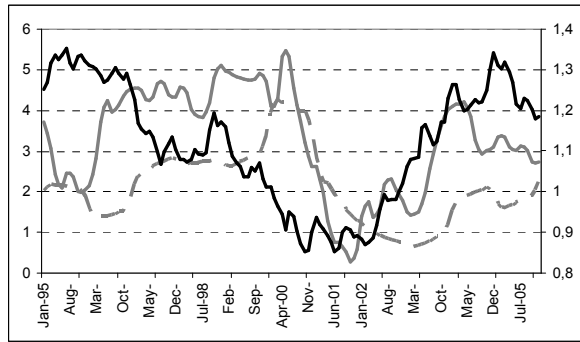
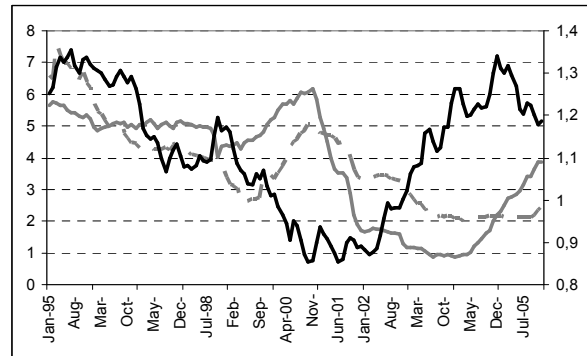


Figure 10: Short run (3 months) interest rate



NB: The dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate.

However, several factors seemed to limit investors' confidence in the US economy. Indeed, the US consumption was gauged on a higher level of debt for US households. Besides, the return of growth in the United States generated no increase in employment. As shown in figure 11, the growth rate of employment was close to the one in the Euro zone although the growth differential was strongly in favour of the United States (figure 9). This fact was partly explained by relocations of US firms to China. Such relocations led the US economy to increase imports of Chinese goods which contributed to increase the US deficit (figure 12). In 2005, the US current deficit reached 6 % of GDP.

All these factors can explain why the dollar still depreciates even after the recovery of the US economy between July 2003 and December 2004.

Figure 11: Employment growth rate

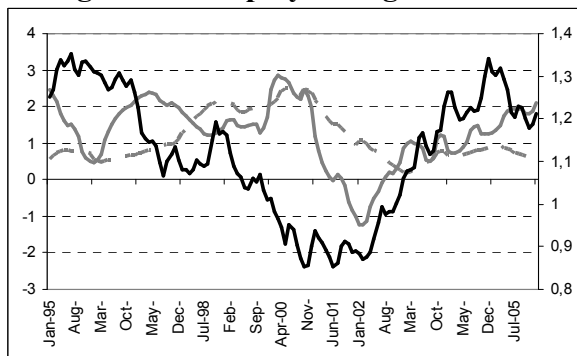
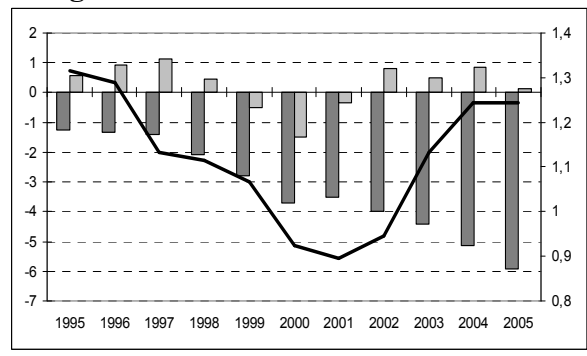


Figure 12: Current balance over GDP



NB: For Figure 11, the dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate. For Figure 12, the dark grey represents the US current balance and the light grey represents the European current balance.

At the beginning of 2004, higher growth in the US and increasing oil prices led the Federal Reserve to increase its rates of interest (figure 10). The interest rate differential became in favour of the US economy in December 2004.

Finally, between July 2003 and December 2005, two competing conventions appeared in the market. A first convention (bear convention) focused mainly on large US current deficits and expected a fall in the dollar. A second convention (bull convention) pointed to the fast recovery of the US economy after the bubble burst and its good resistance relative to the increase in oil prices (figure 14). The bull sentiment was also attributed to the success of the fine monetary policy by Alan Greenspan, chairman of the Federal Reserve at that time. The

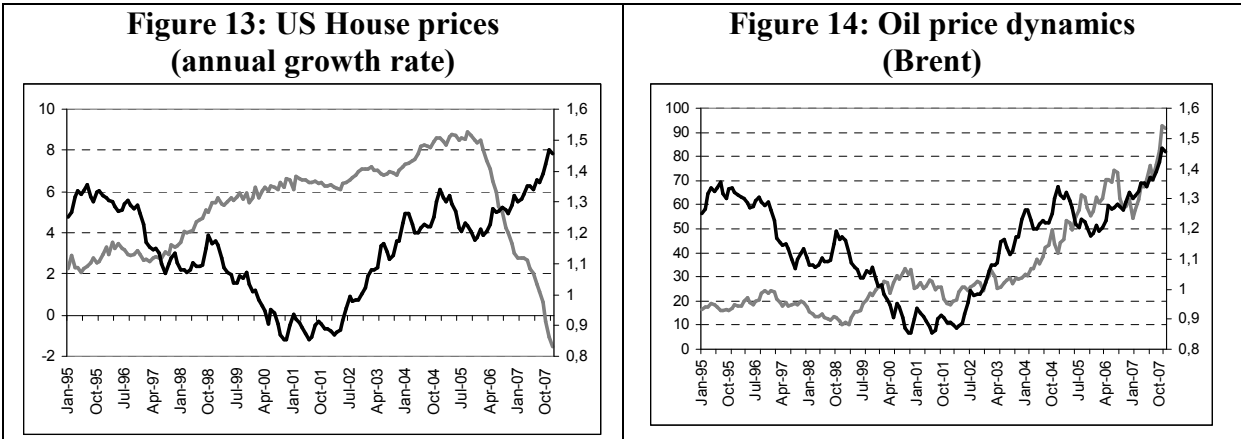
domination of the bear convention may explain the depreciation of the dollar between July 2003 and December 2004. Conversely, the domination of the bull convention may explain the appreciation of the dollar between January 2005 and December 2005.

3.4 January 2006 - June 2007: the weakening of the bull convention

Between January 2006 and June 2007, the bull sentiment associated to the resistance and the high potential of the US economy became more and more threatened by several negative news about the US economy.

Indeed, the sustained growth in the United States between July 2003 and December 2005 was gauged on a positive growth rate of house prices. Between January 2006 and September 2007, the growth rate of US house prices decreased (figure 13). Economists began to warn about a possible burst of a bubble in US house prices.

On the other hand, oil prices were surging and acted as a burden on the budget of US households. The barrel of Brent reached 96,05 \$ in November 2007 (figure 14). Investors feared a decrease in US households’ consumption either by the decrease in house prices that could close access to credit for US households or by the increase in oil prices that would reduce the disposable income of US households. Fears were also accentuated by the increase in interest rates by the Federal Reserve (figure 18) which raised the burden of debt for US households.



NB: For Figure 13 and 14, the solid black line represents the euro/dollar nominal exchange rate.

Negative news about the US economy were also illustrated by the worrying concerns about the sustainability of the US debt. US current deficits were evaluated at more than 6 % of US GDP in 2006 and about 5,5 % of US GDP in 2007 (figure 15). Fears increased among investors about a possible fall in the dollar and hence in the value of assets denominated in dollars. Threats by Chinese authorities to convert part of their huge stock of accumulated dollars (figure 16) in another currency accentuated fears by investors about a possible dollar fall.

Figure 15: Current balance over GDP

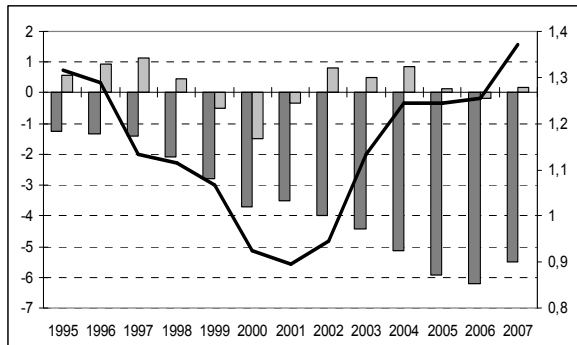
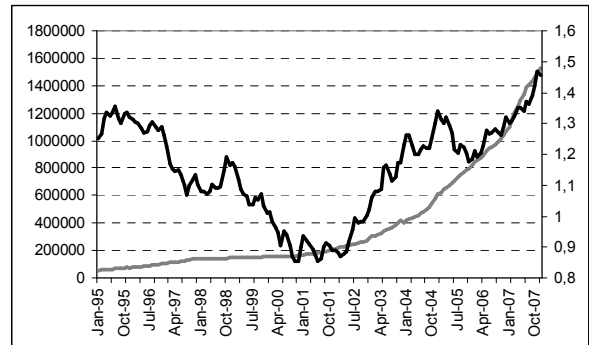


Figure 16: Chinese dollar reserves (in millions of dollars)



NB: For Figure 15, the dark grey represents the US current balance and the light grey represents the European current balance. For Figure 16, the solid grey line refers to Chinese reserves and the solid black line represents the euro/dollar nominal exchange rate.

The rising bear sentiment in the US economy led investors to be relatively more optimistic on the perspectives of the euro zone. Investors became aware that the US economy had not significantly outperformed the European economy in the recent years. Growth in the Euro area was at its fastest pace since January 2002 and the growth differential between the United States and the euro zone became very thin from January 2007 to December 2007 (figure 17). In 2007, inflation fears related to the increase in oil prices led the ECB to increase its interest rates. At the end of 2007 the interest rate differential became in favour of the euro zone (figure 18).

Figure 17: Annual real growth rate of gross domestic product

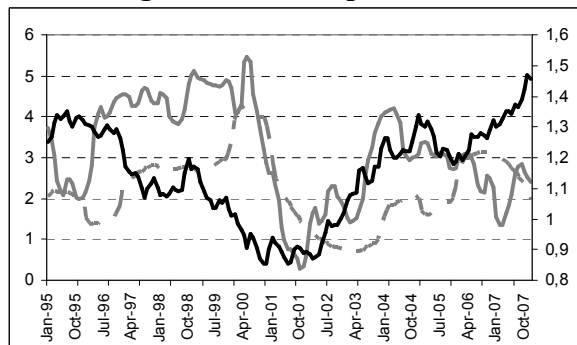
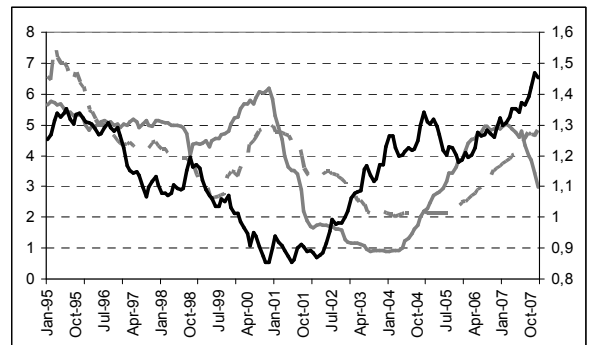


Figure 18: Short run (3 month) interest rates



NB: The dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate.

In December 2007, investors became uncertain about the perspectives offered by the US economy. Economists and central bankers began questioning whether the US economy would experience a soft-landing or a hard-landing. The bull convention that appeared between July 2003 and December 2005 in the United States was fading out at an increasing pace. The increasing domination of the bear convention may explain why the dollar depreciates between January 2006 and December 2007.

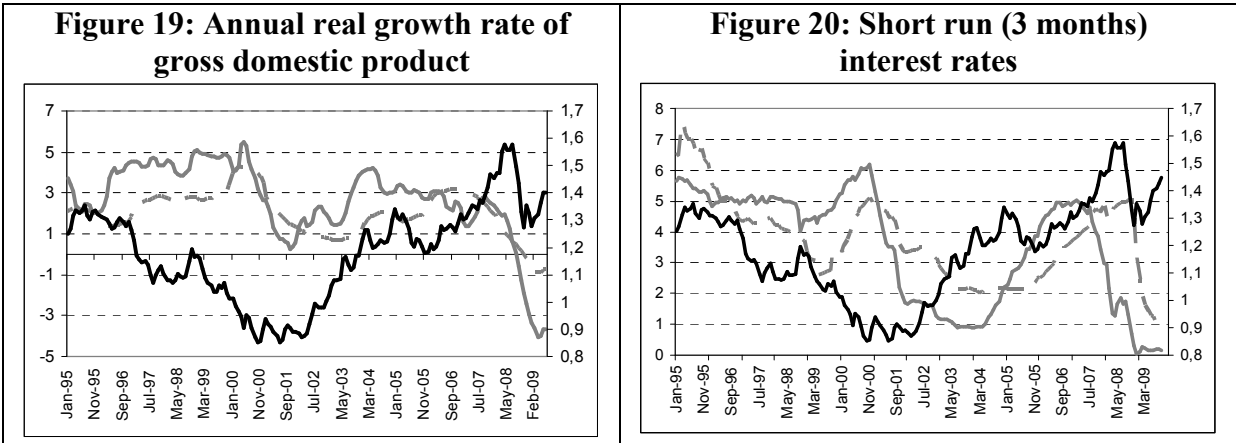
3.5 June 2007 - December 2008: The subprime crisis and the end of the bull convention in the US economy

The bankruptcy of two investment funds of Bear Stearns in June 2007 sparked a major financial crisis in the United States. In spring 2007, the Federal Reserve along with the ECB intervened massively in the interbank market to prevent a liquidity crisis.

The Federal Reserve began to decrease its interest rates in June 2007 (figure 20) while the ECB kept its rates unchanged because of inflation fears caused by increasing oil prices and also because growth forecasts were still more optimistic in the euro zone than in the United States (figure 19).

In October 2007, the bubble on US house prices burst (figure 13). Investors faced a great uncertainty about the future perspectives of the US economy. Nobody really knew how bad the subprime crisis would have hurt the US economy. Support brought by the Federal Reserve and the ECB to bad banks in the second half of 2007 prevented both economies from a large financial crisis. However, concerns were now surging about a possible contagion of the financial turmoil to the real economy. Economists feared especially a credit crunch triggered by unhealthy banks that invested in subprime assets. A credit crunch would indeed end access of US households to credit, hence stopping US consumption; one of the main components that sustained US growth until then.

In April 2008 growing evidence raised that the US economy was in recession. Conversely, the European economy seemed on a first time less affected by the financial crisis. Figure 22 shows that European employment still raised when unemployment in the US increased. Newspapers pointed to the relative resistance of European economies although the growth rate in the euro zone lowered. With oil prices still surging and preventing the ECB to decrease its interest rates, economists feared the return of stagflation in the Euro area as well as in the United States.



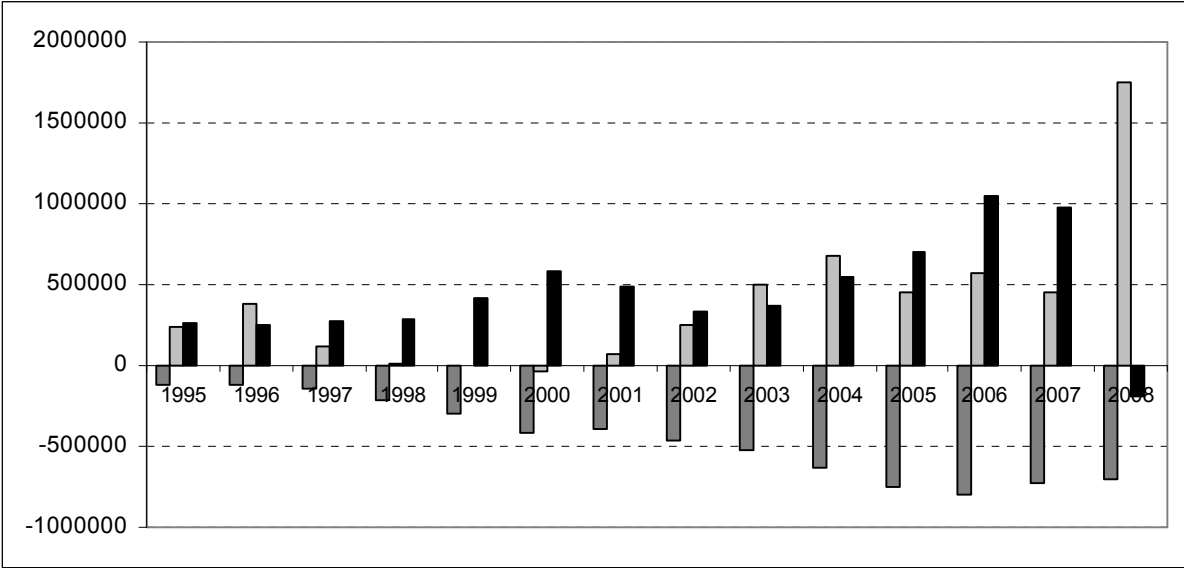
NB: The dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate.

The growth rate in the United States became negative and US unemployment surged in August 2008 (figures 19 and 22). Later, in November 2008, the Euro zone experienced a negative growth rate (figure 19). The ECB started to decrease its interest rates in December 2008 (figure 20).

A bear sentiment prevailed among financial markets concerning the economic perspectives either in the euro zone or in the United States. Stock indices started to fall in October 2008. Investors became more averse to risky assets. Net flows of equities in the United States became negative in 2008 (figure 21) and US investors retrieved their liquidities from the euro area. This outflow of capitals from the euro zone partly explains the

depreciation of the euro *vis-à-vis* the dollar between July 2008 and November 2008 (figure 19).

Figure 21: Net capitals flows in the United States (in millions of dollars)



NB: the dark grey represents the US current balance; the light grey represents net flows of investment in Treasury bills and government bonds; the black represents net flows of investment in equity and foreign direct investment.

From September 2008 until June 2009 the US and European governments were beginning to set plans to put an end to the financial crisis and to counter the economic recession. However, market agents cast doubts on the relevance of the successive plans proposed by both governments (especially the US government). In May 2009, some economists feared a W shaped recession such as in the 1939 financial crisis. From the peak of June 2007 to the trough of March 2009, the S&P500 fell by 50 % (figure 23). Over the same period, the Eurostoxx fell by 57 %.

Figure 22: Employment growth rate

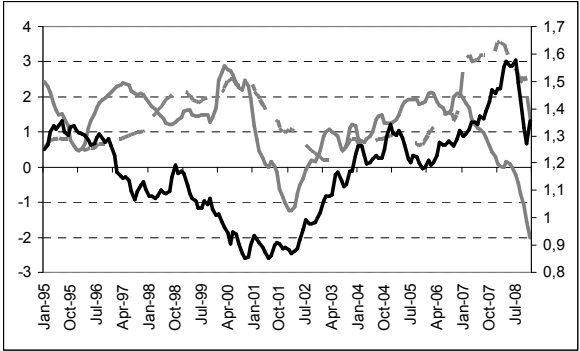
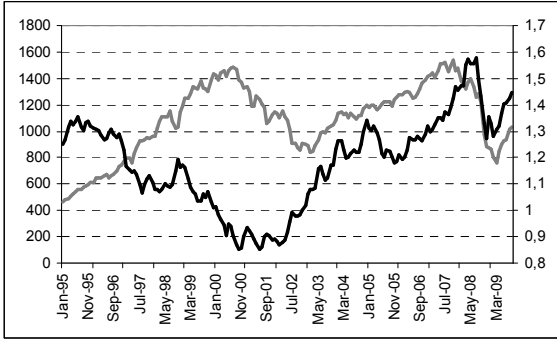


Figure 23: S&P500 dynamics



NB: The dashed grey line refers to the euro zone; the solid grey line refers to the United States and the solid black line represents the euro/dollar nominal exchange rate.

3.6 Conventions highlighted by the macroeconomic analysis

The above analysis allows distinguishing 5 phases and three main conventions for the euro/dollar exchange rate between January 1995 and December 2008.

The new economy convention prevailed from January 1995 to December 2000. Investors were relatively more optimistic on the perspectives of the US economy than on the ones of the European economy. Investors were fascinated by stronger US growth rates and higher expected profits offered by the US economy. The dollar experiences a strong appreciating trend in this period. The burst of the internet bubble put an end to the new economy convention.

Between January 2001 and June 2003, investors were bear either in the United States or in the euro zone. The market was looking for a new convention. The market started to build a bear convention based on the high external deficits of the US economy. The dollar starts a strong depreciating trend in this period.

From July 2003 to December 2005 two competing conventions prevailed among market participants. A bear convention focused mainly on large US current deficits and a bull convention focused notably on the spectacular recovery of the US economy from the internet bubble burst. During this period the dollar stops its strong depreciating trend and alternates between short-lasting appreciating and depreciating trends according to whether the bull convention dominates the bear one.

Between January 2006 and June 2007, the bear convention started to dominate the bull one. Indeed, several factors came against the bull convention notably the possible burst of the US house price bubble that could trigger an economic downturn in the United States and the surge in oil prices that acted as a burden on US households' disposable income.

In June 2007, the subprime crisis put an end to the bull convention. Investors became bear in the United States as well as in the Euro zone. The bear convention definitely dominates the market.

The next step of the analysis aims at testing the degree of relevance of the conventions highlighted by the macroeconomic analysis. We rely on an econometric approach based on time-varying parameter models.

4. An econometric analysis of market conventions

To test the significancy of the results highlighted in the macroeconomic analysis we define an alternative and more objective approach. We use econometric tools and estimate a time-varying parameter model. The aim is to identify the most important fundamentals among all the fundamentals considered in the macroeconomic analysis. We thus compute the time-varying dynamics of the coefficients value associated to fundamentals through time. To give credit to the econometric approach, we build a research procedure close to the theoretical convention model presented in section 2. The research procedure follows three steps. The first step identifies the most important fundamentals in the determination of the euro/dollar exchange rate. The second step builds all the models that can be built with the selected fundamentals. The third step analyses the predictive power of these models and selects the models that offer the best predictions of the euro/dollar exchange rate dynamics.

4.1 Analysis of the time-varying weight of fundamentals

The quest for the most important fundamentals in the determination of the euro/dollar exchange rate is based on the estimation of a time-varying parameter model. We use a state-

space model estimated with a Kalman filter. The state-space model allows us to find the variables that have the highest weight (*i.e.* the highest coefficient) in the determination of the euro/dollar exchange rate through the period of analysis.

The measurement equation includes all the fundamentals considered in the macroeconomic analysis (section 3). We consider the following fundamentals: the industrial production (*indprod*); the productivity (*pdy*); the net investment position over GDP (*niipgdp*); the number of employed people (*employ*); the price of oil (*op*); the house price index (*hpi*); the stock price index (*sp*); the expected profits on the related stock indices (*expprofit*); the dividend yield on the related stock indices (*divyield*); the short run (3-months) interest rate (*stinrate*); the long run (10-years) interest rate (*lginrate*). These fundamentals are also the ones considered by the literature concerning the determination of the euro/dollar exchange rate at a monthly frequency (Camarero *et al.* (2005), Bouveret and Di Filippo (2009)).

State-space models are composed by two equations: a measurement equation that describes the relation between the observed variables (exogenous fundamentals) and the unobserved state variables; and a state equation (or transition equation) that defines the dynamics of the state variables.

The measurement equation takes the following form:

$$\begin{aligned}
s_t = & \alpha_{0,t} + \alpha_{1,t} indprod_t^{EU} + \alpha_{2,t} indprod_t^{US} + \alpha_{3,t} pdty_t^{EU} + \alpha_{4,t} pdty_t^{US} \\
& + \alpha_{5,t} niipgdp_t^{EU} + \alpha_{6,t} niipgdp_t^{US} + \alpha_{7,t} employ_t^{EU} + \alpha_{8,t} employ_t^{US} \\
& + \alpha_{9,t} op_t + \alpha_{10,t} hpi_t^{US} + \alpha_{11,t} sp_t^{EU} + \alpha_{12,t} sp_t^{US} \\
& + \alpha_{13,t} exp\ profit_t^{EU} + \alpha_{14,t} exp\ profit_t^{US} \\
& + \alpha_{15,t} divyield_t^{EU} + \alpha_{16,t} divyield_t^{US} \\
& + \alpha_{17,t} st\ int\ rate_t^{EU} + \alpha_{18,t} st\ int\ rate_t^{US} \\
& + \alpha_{19,t} lg\ int\ rate_t^{EU} + \alpha_{20,t} lg\ int\ rate_t^{US} + \varepsilon_t
\end{aligned} \tag{18}$$

We assume that the coefficients in the state equations follow a random walk:

$$\alpha_{i,t} = \alpha_{i,t-1} + \varepsilon_{i,t} \quad \text{with } i = 0 \text{ to } 21 \tag{19}$$

Table 1 shows the estimation output for the coefficients over the period January 1995-December 2008. The fundamental variables are classified by the importance of their coefficient value⁴.

⁴ Other results relative to the state-space model such as the classification of the fundamentals through time are also available upon author request.

Table 1: Estimation output of the time-varying parameter model

Variables	<i>niipgdpeu</i>	<i>divyieldus</i>	<i>expprofiteu</i>	<i>pdtyus</i>	<i>diyyieldeu</i>	<i>pdtyeu</i>	<i>stintrateus</i>
Coefficients	1,0006 [4,57]	1,003 [2,68]	1,0002 [4,96]	1,0000 [1,99]	0,9998 [3,74]	0,9995 [1,88]	0,9994 [3,67]
Variables	<i>indprodus</i>	<i>niipgdpus</i>	<i>hpius</i>	<i>lgintrateeu</i>	<i>stintrateeu</i>	<i>lgintrateus</i>	<i>indprodeu</i>
Coefficients	0,9993 [1,29]	0,9992 [1,19]	0,9991 [4,01]	0,9989 [6,43]	0,9986 [0,59]	0,9985 [3,12]	0,9973 [3,15]
Variables	<i>op</i>	<i>expprofitus</i>	<i>spus</i>	<i>speu</i>	<i>employus</i>	<i>employeu</i>	<i>chineseres</i>
Coefficients	0,9972 [6,80]	0,9945 [4,70]	0,8899 [2,33]	0,8360 [2,64]	0,4687 [0,08]	0,4457 [0,25]	0,0963 [0,14]

NB: Student statistics are mentioned in bracket; critical values for the test of Student amounts to 1,96 at a 5 % confidence level and at 1,64 at a 10 % confidence level; the estimations are implemented and run in MATLAB.

Table 1 shows that in majority, US fundamentals have larger coefficients than European fundamentals. Thus, news coming from the United States have a larger impact on the euro/dollar exchange rate than news coming from the euro zone. This result has been found in earlier studies that analyse the effect of news on the euro/dollar exchange rate (Prast and De Vor (2000), Galati and Ho (2001) and Andersen *et al.* (2003)). The fact that investors react asymmetrically to news on a given fundamental between two countries justifies the assumption of an asymmetric world in the convention model.

The selection of the fundamentals to be included in the convention model obeys to the following procedure. We consider only the dominant fundamentals *i.e.* the fundamentals that have the largest coefficients. Fundamentals characterised by the lowest coefficients *i.e.* dominated fundamentals are rejected. Also, for sake of parcimony, we drop the dominated fundamentals that are correlated to dominant variables or that cover the same information set as dominant variables. For example, in table 1 the dividend yields *divyield* have larger coefficients relative to expected profits *expprofit* and to stock indices *sp*. As these variables cover the same information set *i.e.* information relative to the stock market, we consider only the dividend yield in the convention model. Also, the productivity *pdty* (defined as the gross domestic product over the number of employed people) has a higher coefficient than the industrial production *indprod* and the number of employed people *employ*. As these variables are highly correlated among each other we only select the variable *pdty*.

Besides, we do not select either the short run or the long run interest rates. Indeed the short and long run interest rate differentials between the United States and the euro zone are too low over the estimation period to explain the dynamics of the euro/dollar exchange rate.

Following this selection procedure, we end up with the following main fundamentals for the determination of the euro/dollar dynamics in the sample period: the net external position over GDP (*netiipgdp*), the productivity (*pdty*), the dividend yield (*divyield*), the US house price (*hpi*) and the price of oil (*op*).

The next step is to build all the possible fundamental models that can be built based on the selected fundamental variables. We will then keep the models that offer the best predictive power of the euro/dollar exchange rate dynamics.

4.2 Analysis of the predictive performances of the fundamental models

We test the predictive power of all the possible models that can be built with the fundamentals selected with the time-varying parameter model. In line with the theoretical convention model exposed in section 2, we include the respective couples of domestic and foreign fundamentals in the models. We thus end up with 6 possible convention models (table

2, column 2). We analyse the performance of the one month out-of-sample recursive forecasts⁵. For example, for model 1, the one-month out-of-sample exchange rate forecast is given by:

$$\hat{s}_{t+1}^{Model1} = \hat{\alpha}_0 + \hat{\alpha}_1 p d t y_t^{EU} + \hat{\alpha}_2 p d t y_t^{US} + \hat{\alpha}_3 d i v y i e l d_t^{EU} + \hat{\alpha}_4 d i v y i e l d_t^{US} + \varepsilon_{t+1}$$

The predictive performance is assessed based on three statistics: the root mean squared error (*RMSE*), the mean average error (*MAE*) and the prediction of the direction of change (*DoC*). Models are estimated in-sample from January 1995 to December 1995 based on monthly data. The out-of-sample period runs from January 1996 to December 2008. Forecast statistics of the different models are shown in table 2.

Table 2: Predictive power of the fundamental models

No	Models	<i>RMSE</i>	<i>MAE</i>	<i>DoC</i>
1	$s = f(p d t y e u, p d t y u s, d i v y i e l d e u, d i v y i e l d u s)$	0,0883	0,0666	0,5714
2	$s = f(p d t y e u, p d t y u s, n i i p g d p e u, n i i p g d p u s)$	0,0641	0,0514	0,4870
3	$s = f(p d t y e u, p d t y u s, o p, h p i u s)$	0,0785	0,0600	0,5195
4	$s = f(d i v y i e l d e u, d i v y i e l d u s, n i i p g d p e u, n i i p g d p u s)$	0,0826	0,0572	0,5714
5	$s = f(d i v y i e l d e u, d i v y i e l d u s, o p, h p i u s)$	0,0916	0,0675	0,5844
6	$s = f(n i i p g d p e u, n i i p g d p u s, o p, h p i u s)$	0,0720	0,0578	0,6039

NB: *RMSE* stands for the root mean squared error; *MAE* stands for the mean average error; *DoC* stands for the direction of change.

Table 2 shows a lot of heterogeneity in the predictive performances of the models. For instance, model 2 has the lowest mean average error but only predicts the right direction of change of the euro/dollar exchange rate in 48,70 % of cases. Also, model 6 provides the highest performance in terms of the prediction of the direction of change. However model 6 has a lower performance relative to other models when predicting the value of the exchange rate (*RMSE* and *MAE*). Table 3 classifies the models according to their respective statistics.

Table 3: Classification of the fundamental models

Statistics	<i>RMSE</i>	<i>MAE</i>	<i>DoC</i>
Model Classification	Model 2	Model 2	Model 6
	Model 3	Model 4	Model 5
	Model 6	Model 6	Model 1 and Model 4

NB: *RMSE* stands for the root mean squared error; *MAE* stands for the mean average error; *DoC* stands for the direction of change.

Table 3 indicates that model 2 offers the best prediction of the future value of the exchange rate (*RMSE* and *MAE*) but performs poorly in the prediction of the direction of change of the euro/dollar exchange rate (*DoC*). Considering all statistics, model 6 appears as the best classified model relative to the other models.

⁵ Recursive forecasts aim at estimating the model in-sample for a given period of time and forecasting the endogenous variable out-of-sample. We then estimate the model by adding one observation to the previous in-sample period (the initial date of the in-sample period remains the same). We iterate this procedure until the end of the sample period.

As our theoretical model assumes that convention models do not share the same fundamentals, the other selected model has to be model 1. Indeed, model 1 shares a different set of fundamentals compared to model 6.

Therefore, we end up with two fundamental models or two convention models:

$$s_t^{Model1} = \alpha_0 + \alpha_1 pdy_t^{EU} + \alpha_2 pdy_t^{US} + \alpha_3 divyield_t^{EU} + \alpha_4 divyield_t^{US} + \varepsilon_t \quad (20)$$

$$s_t^{Model6} = \beta_0 + \beta_1 niipgdp_t^{EU} + \beta_2 niipgdp_t^{US} + \beta_3 op_t + \beta_4 HPI_t^{US} + \eta_t \quad (21)$$

Because market conventions are models used by agents in a given period of time, they can be interpreted as long term relationships between the exchange rate and the fundamentals considered in the conventions. We therefore test whether the selected convention models (equations (20) and (21)) have a significant long run relationship with the euro/dollar exchange rate. We follow the method of Engle and Granger (1987). We estimate both models based on an error correction mechanism (ECM):

$$\Delta s_t^{Model1} = \beta_1 \Delta pdy_t^{EU} + \beta_2 \Delta pdy_t^{US} + \beta_3 \Delta divyield_t^{EU} + \beta_4 \Delta divyield_t^{US} + \lambda [s_{t-1} - \alpha_0 - \alpha_1 pdy_{t-1}^{EU} - \alpha_2 pdy_{t-1}^{US} - \alpha_3 divyield_{t-1}^{EU} - \alpha_4 divyield_{t-1}^{US}] + \varepsilon_t \quad (22)$$

$$\Delta s_t^{Model6} = \beta_1 \Delta niipgdp_t^{EU} + \beta_2 \Delta niipgdp_t^{US} + \beta_3 \Delta op_t + \Delta HPI_t^{US} + \lambda [s_{t-1} - \alpha_0 + \alpha_1 niipgdp_{t-1}^{EU} - \alpha_2 niipgdp_{t-1}^{US} - \alpha_3 op_{t-1} - \alpha_4 HPI_{t-1}^{US}] + \varepsilon_t \quad (23)$$

The estimation period runs from January 1995 to December 2008. As all variables are stationary in the ECM (see appendices B and C), the estimation method is based on ordinary least squares (OLS). We take account of the eventual presence of heteroskedasticity and autocorrelation in the residuals by applying the HAC correction of Newey-West (1987). Table 4 shows the estimation output.

Table 4: Estimation output of the error correction models

Models	λ	α_0	α_1	α_2	α_3	α_4	R2adj	R2adj LT	ARCH	LM	J&B	RESET Test
Model 1	-0,07 [-3,13]	3,19	-1,33	0,53	-0,18	0,49	0,13	0,78	3,73 (0,02)	14,84 (0,00)	4,28 (0,11)	0,48 (0,48)
Model 6	-0,041 [-2,74]	1,80	-0,15	0,05	0,02	-0,06	0,08	0,87	3,41 (0,03)	12,29 (0,00)	1,11 (0,57)	1,50 (0,22)

NB: Student statistics are mentioned in squared brackets; *p-values* are mentioned in brackets; critical values for the test of Student amounts to 1,96 at a 5 % confidence level and at 1,64 at a 10 % confidence level; 5 lags are considered for ARCH and LM tests.

Diagnostic tests show that although there is heteroskedasticity and autocorrelation in the residuals for models 1 and 6 (in spite of the HAC correction), RESET tests do not reject the specification of the selected models.

Adjusted *R2* associated to the error correction models are rather weak (lower than 15 %). This result, often found in the literature (Camarero *et al.* (2005), Bouveret and Di Filippo (2009)), is related to the difficulty of explaining exchange rate returns based on macroeconomic fundamentals. Conversely, adjusted *R2* associated to the long run

relationships are more satisfying since both models explain at least 78 % of the variance of the euro/dollar exchange rate.

For both models, the coefficients λ are significant and negative. This result validates the existence of a significant long run relationship between the exchange rate and fundamentals considered in model 1 and in model 6. This fact justifies the persistence of the selected convention models through time.

However, the coefficients in the long run relationship are not correctly signed. Subperiods tests for both models indicate large changes in the coefficients' value⁶. This instability in the coefficients' value - often found in the literature - is justified by the high instability in the empirical link between a given fundamental and the exchange rate. Also, the asymmetric structure considered in models 1 and 6 fosters the presence of multicollinearity between the exogenous variables *i.e.* the fundamental variables. Multicollinearity is another factor that explains the instability in the coefficients' value of macroeconomic fundamentals.

4.3 Lessons from the convention model: can conventions explain the euro/dollar dynamics?

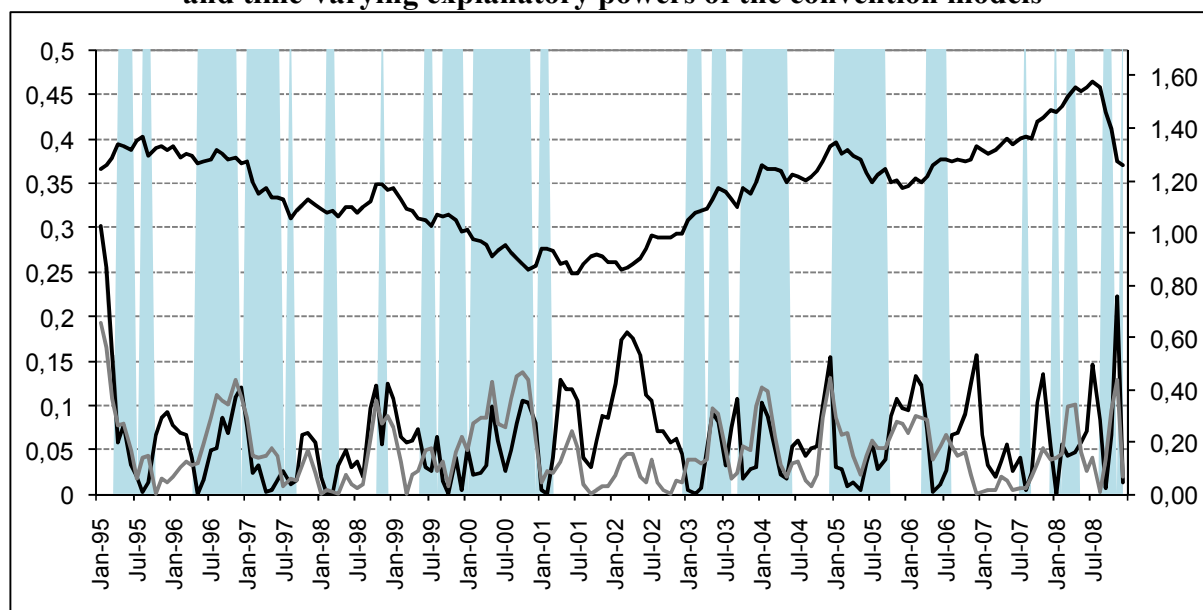
We present in figure 24 the dynamics of the euro/dollar exchange rate as well as the respective errors of the long term relationships of the selected convention models (model 1 (equation (20)) and model 6 (equation (21)); with:

$$\varepsilon_t = s_t - \hat{s}_t^{Model1} \quad (24)$$

$$\eta_t = s_t - \hat{s}_t^{Model6} \quad (25)$$

The blue margins indicate the periods where errors from models 1 are lower than errors from model 6. Thus in the blue margins model 1 provides a better explanatory power of the euro/dollar dynamics than model 6 (and *vice versa* for the white margins).

Figure 24: Euro/dollar dynamics and time-varying explanatory powers of the convention models



⁶ Results are available upon author request.

NB: the bold black line represents the dynamics of the euro/dollar exchange rate (right scale); the grey line represents the errors relative to model 6 (left scale); the black line represents the errors relative to model 1 (left scale); the blue margins represent the periods in which errors from model 1 are lower than errors from model 6.

Figure 24 shows that the relative explanatory power of model 1 and model 6 varies through time. More precisely, one can observe that model 1 dominates in the explanation of the euro/dollar exchange rate in periods of optimism (*i.e.* in bull market periods; blue margins in figure 24) while model 6 dominates in the explanation of the euro/dollar exchange rate in periods of pessimism (*i.e.* in bear market periods; white margins in figure 24).

Indeed, from January 1995 to December 2000, model 1 provides on majority the best explanatory power relative to model 6. During this period, investors were globally optimistic. The internet convention prevailed at that time. Investors were optimistic about the growth perspectives and the returns (or dividend yields) offered by the US and the European stock markets. The dollar has a strong appreciating trend in this period.

We note however that the explanatory power of model 6 is higher between September 1997 and March 1999. This observation is related to the Asian crisis of 1997 and then the Russian crisis of 1998 that causes financial turmoil in the US financial markets through the quasi-bankruptcy of the Long Term Capital Management fund (LTCM).

The burst of the internet bubble in January 2001 led to the collapse of the new economy convention. This convention suddenly disappeared from the market. The market became more pessimistic about the perspectives of both the US economy and the European economy. Between January 2001 and January 2003, the fundamentals considered in model 6 offer the best explanatory power. As mentioned in the macroeconomic analysis, the market was at that time concerned by the large external debt of the US economy - a fundamental variable found in model 6. The dollar starts a strong depreciating trend in this period.

From February 2003 to December 2005, the US economy recovers from the internet bubble burst. However, investors are still concerned about the increasing external debt of the US economy. During this period, the best explanatory power of the euro/dollar exchange rate dynamics is offered alternatively by model 1 and model 6. As a result, the market alternates between two convention models. On the one hand, there are agents who believe in a bull convention (model 1) based on the resistance of the US economy, its fast recovery from the internet bubble burst and the induced returns (dividend yields) offered by the US economy. On the other hand, there are agents who believe in a bear convention (model 6) related to concerns about the sustainability of the large US debt. During this period the dollar stops its strong depreciating trend and alternates between short-lasting appreciating and depreciating trends according to whether the bull convention dominates the bear one.

From January 2006 until December 2008, model 6 provides in the majority of times, the best explanatory power of the euro/dollar exchange rate. The accumulation of negative news concerning the US economy after January 2006 (larger US current account deficits, increasing fears about a possible burst of the US house price bubble, surge in oil prices) puts an end to the bull convention (model 1) shared by investors in the previous period. The start of the subprime crisis in June 2007 definitely led to the domination of the bear convention (model 6) in the market. The dollar starts a significant depreciating trend in this period.

The analysis of the econometric results shows that the euro/dollar market alternates between bull and bear periods. Model 1 provides a high explanatory power in periods of optimism while model 6 offers a high explanatory power in period of pessimism. Therefore, model 1 and model 6 can be assimilated respectively to a bull convention and to a bear convention. The model explains the euro/dollar dynamics by the switches between fundamentals considered in the bull and in the bear conventions. More precisely, the market

puts a large accent on the US and European productivity indices and dividend yields in times of optimism while in times of pessimism the market puts a large weight on the US and European external debt, oil prices and US house prices. This result provides evidence of the existence of a non-linear relationship between fundamentals and the euro/dollar dynamics. In other words, some fundamentals are important at some periods of time in the determination of exchange rate dynamics but less important at other periods of time.

The econometric analysis ends up with the same results as the macroeconomic analysis. Indeed, as in the macroeconomic analysis, the econometric analysis highlights 5 phases and three main conventions for the euro/dollar exchange rate between January 1995 and December 2008: a bull convention based on the new economy between January 1995 and December 2000 (with a bear subperiod between September 1997 and March 1999 due to the contagion effects of the Asian crisis); a bear convention based on the large US external debt, the fears about a possible house price bubble burst and the negative effect of the increase in oil prices on the US economy between January 2001 and December 2008; and a bull convention based on the spectacular recovery of the US economy from the stock market crash caused by the collapse of the internet convention (February 2003-December 2005). The econometric analysis thus validates empirically the macroeconomic analysis of market conventions. It validates also the theoretical model of conventions. As a result, the euro/dollar dynamics are driven by market conventions *i.e.* by time-varying fundamental models.

4.4 Assessing the predictive power of the convention model

We compare the predictive performances of the convention model with regards to four alternative models. The considered models are defined below:

- Model 1 assumes a linear structure and a symmetric world. Model 1 thus represents traditional models of exchange rate:

$$\begin{aligned} \Delta s_{t+k}^{Model1} = & \alpha_0 + \alpha_1 (pdy_t^{EU} - pdy_t^{US}) + \alpha_2 (divyield_t^{EU} - divyield_t^{US}) \\ & + \alpha_3 (niipgdp_t^{EU} - niipgdp_t^{US}) + \alpha_4 op_t + \beta_5 HPI_t^{US} + \varepsilon_{t+k} \end{aligned} \quad (26)$$

- Model 2 rests on a linear structure and an asymmetric world. By assuming an asymmetric world, the structure of model 2 is more realistic than the one of model 1:

$$\begin{aligned} \Delta s_{t+k}^{Model1} = & \alpha_0 + \alpha_1 pdy_t^{EU} + \alpha_2 pdy_t^{US} + \alpha_3 divyield_t^{EU} + \alpha_4 divyield_t^{US} \\ & + \alpha_5 niipgdp_t^{EU} + \alpha_6 niipgdp_t^{US} + \alpha_7 op_t + \alpha_8 HPI_t^{US} + \varepsilon_{t+k} \end{aligned} \quad (27)$$

- Model 3 relies on a non-linear structure and an asymmetric world. Model 3 is the convention model. Model 3 assumes that the dynamics between exchange rates and their fundamentals are nonlinear and asymmetric:

$$\Delta s_{t+k} = \begin{cases} \alpha_0 + \alpha_1 pdy_t^{EU} + \alpha_2 pdy_t^{US} + \alpha_3 divyield_t^{EU} + \alpha_4 divyield_t^{US} + \varepsilon_{t+k} & \text{if } \varepsilon_t < \eta_t \\ \beta_0 + \beta_1 niipgdp_t^{EU} + \beta_2 niipgdp_t^{US} + \beta_3 op_t + \beta_4 HPI_t^{US} + \eta_{t+k} & \text{if } \varepsilon_t > \eta_t \end{cases} \quad (28)$$

- Model 4 is the simple random random walk without drift:

$$s_{t+k}^{RW} = s_t + \varepsilon_{t+k} \quad \text{Where } \varepsilon_{t+k} \rightarrow iidN(0, \sigma_\varepsilon^2) \quad (29)$$

We first estimate in-sample the four models from January 1995 to December 1999. We then forecast out-of-sample the exchange rate of our respective models between January 2000 and December 2008. We use recursive forecasts⁷ based on OLS methods. Forecast horizons are 1 month, 3 months, 6 months, 1 year, 2 years and 5 years. Tables 5 shows the forecast errors of the models⁸.

Table 5: Comparative forecast performances of the convention model

Statistics	Horizon	1 month	3 months	6 months	1 year	2 years	5 years
	Model						
<i>RMSE</i>	Model 1	0,0569	0,0590	0,0591	0,0614	0,0672	0,0756
	Model 2	0,0565	0,0601	0,0603	0,0650	0,0827	0,2152
	Model 3	0,0573	0,0581	0,0576	0,0585	0,0607	0,0640
	Model 4	0,0306	0,2651	0,3511	0,4748	0,6216	0,7518
<i>MAE</i>	Model 1	0,0378	0,0416	0,0416	0,0452	0,0532	0,0588
	Model 2	0,0372	0,0435	0,0428	0,0478	0,0587	0,1175
	Model 3	0,0386	0,0399	0,0389	0,0406	0,0442	0,0462
	Model 4	0,0235	0,1126	0,1690	0,2838	0,4558	0,6227
<i>DoC</i>	Model 1	0,4481	0,4675	0,4740	0,3896	0,3442	0,3182
	Model 2	0,3961	0,4610	0,4286	0,4026	0,3961	0,3442
	Model 3	0,3052	0,3506	0,3506	0,2662	0,2403	0,2532
	Model 4	0,6111	0,5648	0,5185	0,4815	0,3704	0,2037

NB: *RMSE* stands for Root Mean Square Errors; *MAE* stands for Mean Absolute; *DoC* stands for the average percentage of right direction in the forecasts of future prices.

Table 5 shows that at short run horizons *i.e.* at 1 month, the random walk beats all the fundamental models. As long as the horizon increases - from 3 months to 5 years - fundamental models start to beat the random walk in term of exchange rate value forecasts (*RMSE* and *MAE*). The convention model (model 3) provides the best out-of-sample exchange rate value forecasts from 3 months to 5 years. The convention model provides however unsatisfying results concerning direction forecasts (*DoC*). Indeed, the random walk provides the best out-of-sample direction forecasts from 1 month until 1 year. This result is probably due to the momentum effect peculiar to the exchange rate dynamics at short/medium horizons. As long as the horizons extends, the momentum effect becomes weaker. Indeed, between 2 years and 5 years model 2 provides the best out-of-sample direction forecasts. We notice also that traditional models of exchange rate (model 1) provide the worst forecasts whatever horizon considered. Therefore, table 5 proves that to improve exchange rate forecasts one can rely on a model that assumes a nonlinear and asymmetric structure *i.e.* a structure close to the empirical stylised facts observed in the foreign exchange market. Indeed, the best predictions of future exchange rates values based on fundamental variables are offered by model 3 - the convention model (nonlinear and asymmetric structure). Traditional models of exchange rate (linear and symmetric structure) offer the worst forecasts in the period of analysis.

⁷ Recursive forecasts aim at estimating the model in-sample for a given period of time and forecasting the endogenous variable out-of-sample. We then estimate the model by adding one observation to the previous in-sample period (the initial date of the in-sample period remains the same). We iterate this procedure until the end of the sample period.

⁸ Forecasts series are computed in *Eviews* and *MATLAB*.

5. Conclusion

This paper provides an unorthodox way to model exchange rate dynamics based on conventions that prevail among market participants. The paper presents a theoretical model to describe the formation of conventions by agents in the market. The structure of the theoretical model borrows elements from the recent Imperfect Knowledge Economics approach by Frydman and Goldberg (2007). The simulated exchange rate from the theoretical convention model replicates several stylised facts highlighted empirically in the exchange rate dynamics. We test empirically the theoretical model on the euro/dollar exchange between January 1995 and December 2008. In a first step, we make use of a macroeconomic analysis to highlight the conventions that prevail on the euro/dollar exchange rate. In a second step, we build an econometric approach to find market conventions. We use a time-varying parameter model to find the most important fundamentals in the determination of the euro/dollar exchange rate. The macroeconomic analysis and the econometric approach end up with the same results. Both analyses show that the market tends to switch between periods of optimism and periods of pessimism. Moreover, switches between fundamentals associated to a bull and a bear convention explain the dynamics of the euro/dollar exchange rate. Finally, forecasting tests show that the convention model offers the best exchange rate forecasts at horizons higher than 1 month relative to traditional models of exchange rate and to the simple random walk.

As the convention model offers promising results in the explanation and the prediction of the euro/dollar exchange rate dynamics, it could be interesting to extend the convention model to other exchange rates or even to other assets in order to assess the robustness of convention theory. As a matter of facts, Schulmeister (2009) shows that asset price dynamics in the foreign exchange market, stock markets and commodity markets exhibit the same patterns. All three markets tend to alternate between bull and bear periods.

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Appendix

A. Variables considered in the convention model

The period of analysis spans January 1995 to December 2008 on a monthly frequency. Data come from the following sources: *Thomson Datastream* and *US Federal Housing Finance Agency*.

Table A: Description of the series

Type of Variable	Name	Model Name	Source
Endogenous	euro/dollar exchange rate	s_t	<i>Datastream</i>
Exogenous	productivity	pdy_t	<i>Datastream</i>
Exogenous	dividend yield	$divyield_t$	<i>Datastream</i>
Exogenous	net external investment position	$niipgdp_t$	<i>Datastream</i>
Exogenous	oil prices (North Sea Brent)	op_t	<i>Datastream</i>
Exogenous	US house prices	HPI_t	<i>US Federal Housing Finance Agency</i>

NB: We do not consider the European house price index since house prices did not experience a bubble (only perhaps in the Spanish economy negligible at a European level).

A.1 Endogenous variable

The endogenous variable is the variation in the (log of) the nominal exchange rate s_t :

$$\Delta s_t = \log(S_t/S_{t-1})$$

With S_t , the euro/dollar nominal exchange rate (listed as 1 euro per S dollars). To reduce noise, we smooth this series with a Hodrick-Prescott filter (we considered $\lambda=1$).

A.2 Exogenous variables

- The industrial production (*INDPROD*) which plays the role of a proxy for GDP:

$$\Delta indprod_t = \log(INDPROD_t/INDPROD_{t-1})$$

With *INDPROD*, the monthly index of industrial production. This series is available in monthly frequency.

- The expected profits (*PROFIT^a*).

$$\Delta profit_t^a = \log(PROFIT_t^a / PROFIT_{t-1}^a) \quad \text{With } PROFIT_t^a = \frac{SPI_t}{PER_t}$$

With *SPI*, the stock price index (we consider respectively, the Eurostoxx for the euro zone and the S&P500 for the United States); and *PER*, defines the price earning ratio related to the respective stock indices. This series is available in monthly frequency.

- The external debt (*NIIPGDP*):

$$\Delta niipgdp_t = NIIPGDP_t - NIIPGDP_{t-1}$$

With *NIIPGDP*, the net international position over the GDP of the respective economic zone being available only in an annual frequency, the series was transformed in a monthly frequency through a Quadratic Match Average filter. For the building of the ECM model, we smoothed this series with a Hodrick-Prescott filter (we considered $\lambda=14400$).

- Oil prices (*OP*):

$$\Delta op_t = \log(OP_t/OP_{t-1})$$

With *OP*, the oil price as listed for the barrel of Brent of the North Sea. This series is available in monthly frequency.

- House prices in the United States (*HPI*).

$$\Delta HPI_t = \log(HPI_t/HPI_{t-1})$$

With *HPI*, the house price index IAS360 delivered by the US Federal Housing Finance Agency (formerly OFHEO). This series is available in monthly frequency.

A.3 Remarks

Concerning the euro zone, when data is not available before 1999, we compute an artificial euro zone composed by a weighted average of GDP in Germany (GDP_t^1), France (GDP_t^2) and Italy (GDP_t^3). Thus for the unavaible data x_t before 199, we compute them as:

$$x_t = \frac{GDP_t^1}{\sum_{i=1}^3 GDP_t^i} x_t^1 + \frac{GDP_t^2}{\sum_{i=1}^3 GDP_t^i} x_t^2 + \frac{GDP_t^3}{\sum_{i=1}^3 GDP_t^i} x_t^3$$

For the external debt, we rely partly on data by Lane and Milesi-Ferretti (2007). For sake of precisions, we compare the computed series with variables computed for the Area Wide Model of the euro zone (Fagan, Henry and Mestre (2001)).

B. Stationarity tests for the error correction models

Stationarity tests are based on three tests: the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP) test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. Results are presented in tables B.1 and B.2.

Table B.1: Stationarity tests on the endogenous variable

Variables	ADF	PP	KPSS
Δs	-8,91*** (0,00)	-9,67*** (0,00)	0,09*

NB: For the ADF test the Akaike criteria with 2 lags is considered; *p-values* are mentioned in parenthesis; stars denote a stationary series at a 1 % (***) , 5 % (**), 10 % (*) confidence level.

Table B.2: Stationarity tests on the exogenous variables

Bull State				Bear State			
Variables	ADF	PP	KPSS	Variables	ADF	PP	KPSS
Δpdy^{EU}	-2,59 (0,28)	-6,75*** (0,00)	0,08*	$\Delta niipgd^{EU}$	-5,33*** (0,00)	-47,43*** (0,00)	0,12
Δpdy^{US}	-3,39** (0,05)	-6,75*** (0,00)	0,07***	$\Delta niipgd^{US}$	-4,34*** (0,00)	-33,97*** (0,00)	0,12
$\Delta divyield^{EU}$	-10,75*** (0,00)	-55,18*** (0,00)	0,12	Δop	-9,73*** (0,00)	-9,82*** (0,00)	0,08**
$\Delta divyield^{US}$	-9,73*** (0,00)	-84,37*** (0,00)	0,21***	ΔHPI	-12,93*** (0,00)	-5,42*** (0,00)	0,31

NB: For the ADF test the Akaike criteria with 2 lags is considered; *p-values* are mentioned in parenthesis; stars denote a stationary series at a 1 % (***) , 5 % (**), 10 % (*) confidence level.

Stationarity tests validate the stationarity of the series considered on the fundamental models.

C. Estimation procedure for the ECM model

The estimation procedure of the ECM models follows three steps. The first step checks whether all series have the same order of integration. Table C.1 shows that all series are integrated of order one.

Table C.1: Integration order for the series

Variables	ADF	PP	KPSS
s_t	I(1)	I(1)	I(1)
pdy_t^{EU}	I(1)	I(1)	I(1)
pdy_t^{US}	I(1)	I(1)	I(1)
$divyield_t^{EU}$	I(1)	I(1)	I(1)
$divyield_t^{US}$	I(1)	I(1)	I(1)
$niipgd_t^{EU}$	I(1)	I(1)	I(1)
$nipgd_t^{US}$	I(1)	I(1)	I(1)
op_t	I(1)	I(1)	I(1)
HPI_t^{US}	I(1)	I(1)	I(1)

In a second step, we then look for the number of cointegrated vectors by applying Trace tests and Maximum Eigenvalue tests. Results available in table C.2 (column 4) validate the presence of at most one cointegrated vector between the exchange rate and its fundamentals. We therefore estimate a univariate error correction model.

Table C.2: Number of cointegrated vectors at a 5 % confidence level for the stock price index model

Model 1					
Data Trend	None	None	Linear	Linear	Quadratic
Type de Test	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	2	1	1	1	1
Max-Eigenvalue	1	2	1	1	2
Model 6					
Data Trend	None	None	Linear	Linear	Quadratic
Type de Test	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	5	3	1	1	0
Max-Eigenvalue	2	2	1	1	1

NB: Critical values are based on the tables of MacKinnon, Haug and Michelis (1999).

In a third step, we estimate the long run relationship by ordinary least squares (OLS). The long-run relationships are defined as follows:

$$s_t^{Model1} = \alpha_0 + \alpha_1 pdty_t^{EU} + \alpha_2 pdty_t^{US} + \alpha_3 divyield_t^{EU} + \alpha_4 divyield_t^{US} + \varepsilon_t$$

$$s_t^{Model6} = \beta_0 + \beta_1 niipgdp_t^{EU} + \beta_2 niipgdp_t^{US} + \beta_3 op_t + \beta_4 HPI_t^{US} + \eta_t$$

We then test for stationary residuals in the long run relationships. Table C.3 shows that residuals in the long run relationships are stationary. We can therefore estimate the error correction models for the respective models.

Table C.3: Critical Values for Augmented Dickey Fuller cointegration test

Tables	Confidence Level	1 %	5 %	10 %	T-Stat Model 1	T-Stat Model 6
Engle and Yoo (1987)	T = 330, N = 4	- 4,70	- 4,18	- 3,89	-5,36	-4,35
Phillips and Oulliaris (1990)	without constant, without trend	- 4,67	- 4,13	- 3,81	-5,38	-4,35
	with constant, without trend	- 5,07	- 4,45	- 4,16	-5,38	-4,35
	with constant, with trend	- 5,36	- 4,74	- 4,46	-5,36	-4,34
McKinnon (1991)	with constant, without trend	- 5,02	- 4,46	- 4,16	-5,38	-4,35
	with constant, with trend	- 5,33	- 4,76	- 4,47	-5,36	-4,34

D. Principles of the Kalman Filter

State-space models deal with dynamic time series models that involve unobserved variables (Kim and Nelson (1998)). The basic tool to estimate standard state-space model is the Kalman filter. The Kalman filter is a recursive procedure for computing the estimator of the unobserved component or the state vector at time t , based on all available information at time t . State-space models are composed by two equations: a measurement equation and a state equation (or transition equation).

D.1 Measurement equation:

The measurement equation describes the relation between observed variables (exogenous fundamentals) and unobserved state variables:

$$y_t = \beta_{0t} + \beta_{1t}x_{1t} + \beta_{2t}x_{2t} + \dots + \beta_{18t}x_{18t} + \beta_{19t}x_{19t} + \beta_{20t}x_{20t} + \varepsilon_t$$

$$y_t = \begin{bmatrix} 1 & x_{1t} & x_{2t} & \cdot & \cdot & \cdot & x_{18t} & x_{19t} & x_{20t} \end{bmatrix} \begin{bmatrix} \beta_{0t} \\ \beta_{1t} \\ \beta_{2t} \\ \cdot \\ \cdot \\ \cdot \\ \beta_{18t} \\ \beta_{19t} \\ \beta_{20t} \end{bmatrix} + \varepsilon_t$$

$$y_t = x_t \beta_t + \varepsilon_t$$

With y_t , the endogenous variable (the exchange rate); x_t , the exogenous variables (the fundamentals); $\varepsilon_t \rightarrow iidN(0, R)$; $y_t = tdceuro-dollar_t$; $x_{1t} = indprod_t^{EU}$; $x_{2t} = indprod_t^{US}$; $x_{3t} = pdty_t^{EU}$; $x_{4t} = pdty_t^{US}$; $x_{5t} = niipgdp_t^{EU}$; $x_{6t} = niipgdp_t^{US}$; $x_{7t} = employ_t^{EU}$; $x_{8t} = employ_t^{US}$; $x_{9t} = op_t$; $x_{10t} = hpi_t^{US}$; $x_{11t} = sp_t^{EU}$; $x_{12t} = sp_t^{US}$; $x_{13t} = exp\ profit_t^{EU}$; $x_{14t} = exp\ profit_t^{US}$; $x_{15t} = divyield_t^{EU}$; $x_{16t} = divyield_t^{US}$; $x_{17t} = st\ int\ rate_t^{EU}$; $x_{18t} = st\ int\ rate_t^{US}$; $x_{19t} = lg\ int\ rate_t^{EU}$; $x_{20t} = lg\ int\ rate_t^{US}$.

D.2 State equations:

The state equations (or transition equations) define the dynamics of the state variables.

$$\beta_{it} = \beta_{it-1} + v_{it}$$

With $v_{it} \rightarrow iidN(0, Q)$, $i = 0$ to 20

$$\begin{bmatrix} \beta_{0t} \\ \beta_{1t} \\ \beta_{2t} \\ \cdot \\ \cdot \\ \cdot \\ \beta_{19t} \\ \beta_{20t} \\ \beta_{21t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \cdot & \cdot & \cdot & 0 & 0 & 0 \\ 0 & 1 & 0 & \cdot & \cdot & \cdot & 0 & 0 & 0 \\ 0 & 0 & 1 & \cdot & \cdot & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \cdot & \cdot & \cdot & 1 & 0 & 0 \\ 0 & 0 & 0 & \cdot & \cdot & \cdot & 0 & 1 & 0 \\ 0 & 0 & 0 & \cdot & \cdot & \cdot & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \beta_{0t-1} \\ \beta_{1t-1} \\ \beta_{2t-1} \\ \cdot \\ \cdot \\ \cdot \\ \beta_{19t-1} \\ \beta_{20t-1} \\ \beta_{21t-1} \end{bmatrix} + \begin{bmatrix} \nu_{0t} \\ \nu_{1t} \\ \nu_{2t} \\ \cdot \\ \cdot \\ \cdot \\ \nu_{19t} \\ \nu_{20t} \\ \nu_{21t} \end{bmatrix}$$

D.3 Description of the filter

The Kalman filter is a recursive procedure for computing the optimal estimate of the unobserved-state vector β_t , $t = 1, 2, \dots, T$, based on the appropriate information set, assuming that F , R and Q are known. The Kalman filter provides a minimum mean squared error estimate of β_t given the appropriate information set. Depending upon the information set used, we have the basic filter and the smoothing filter. The basic filter refers to an estimate of β_t based on information available up to time t . The smoothing filter is an estimate of β_t based on all the available information in the sample through time T .

The basic Kalman filter is described by the two steps: the prediction step and the updating step.

D.3.1 The prediction equations:

The prediction equations form at the beginning of time t , an optimal predictor of y_t based on all the available information up to time $t-1$ ($y_{t/t-1}$). To do this, we need to calculate $\beta_{t/t-1}$. The prediction equations are defined below:

1/ The estimate of β_t conditional on information up to time $t-1$

$$\beta_{t/t-1} = F\beta_{t-1/t-1}$$

2/ The covariance matrix of β_t conditional on information up to time $t-1$

$$P_{t/t-1} = FP_{t-1/t-1}F' + Q$$

Where Q is the covariance of shocks to β_t

3/ The prediction error

$$\eta_{t/t-1} = y_t - y_{t/t-1} = y_t - x_t\beta_{t/t-1}$$

4/ The conditional variance of the prediction error

$$f_{t/t-1} = x_t P_{t/t-1} x_t' + R$$

Where R is the variance of ε_t

D.3.2 The updating equations:

Once y_t is realized at the end of time t , the prediction error $\eta_{t/t-1}$ can be calculated. This prediction error contains new information about β_t beyond that contained in $\beta_{t/t-1}$. Thus after observing y_t , a more accurate inference can be made of β_t i.e. $\beta_{t/t}$. An inference of β_t based on information up to time t , may be of the following form: $\beta_{t/t} = \beta_{t/t-1} + K_t \eta_{t/t-1}$ where K_t is the weight assigned to new information about β_t contained in the prediction error. The updating equations are defined below:

5/ The estimate of β_t conditional on information up to time t

$$\beta_{t/t} = \beta_{t/t-1} + K_t \eta_{t/t-1}$$

6/ The covariance matrix of β_t conditional on information up to time t

$$P_{t/t} = P_{t/t-1} - K_t x_t P_{t/t-1}$$

Where K_t is the Kalman gain : $K_t = P_{t/t-1} x_t' f_{t/t-1}^{-1}$

The Kalman filter is a recursive procedure for computing the optimal estimate of the unobserved state vector β_t , $t = 1, 2, \dots, T$, based on the appropriate information set, assuming that R and Q are known. The parameters to be estimated are the following ones :

$$\theta = (\beta_{0t}, \beta_{1t}, \beta_{2t}, \beta_{3t}, \beta_{4t}, \beta_{5t}, \beta_{6t}, \beta_{7t}, \beta_{8t}, \beta_{9t}, \beta_{10t}, \\ \beta_{11t}, \beta_{12t}, \beta_{13t}, \beta_{14t}, \beta_{15t}, \beta_{16t}, \beta_{17t}, \beta_{18t}, \beta_{19t}, \beta_{20t}, \beta_{21t}, \sigma_{\varepsilon}^2, \\ \sigma_{v0t}^2, \sigma_{v1t}^2, \sigma_{v2t}^2, \sigma_{v3t}^2, \sigma_{v4t}^2, \sigma_{v5t}^2, \sigma_{v6t}^2, \sigma_{v7t}^2, \sigma_{v8t}^2, \sigma_{v9t}^2, \sigma_{v10t}^2, \\ \sigma_{v11t}^2, \sigma_{v12t}^2, \sigma_{v13t}^2, \sigma_{v14t}^2, \sigma_{v15t}^2, \sigma_{v16t}^2, \sigma_{v17t}^2, \sigma_{v18t}^2, \sigma_{v19t}^2, \sigma_{v20t}^2, \sigma_{v21t}^2)$$

The parameters can be estimated by maximising the following log likelihood function with respect to the parameters of the model:

$$\ln L = -\frac{1}{2} \sum_{t=1}^T \ln(2\pi f_{t/t-1}) - \frac{1}{2} \sum_{t=1}^T \eta_{t/t-1}' f_{t/t-1}^{-1} \eta_{t/t-1}$$

Where $f_{t/t-1}$ and $\eta_{t/t-1}$ are provided by the Kalman filter.