International Monetary Arrangements for the 21st Century—Which Way?

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Abstract

This paper examines some competing views on currency regime choice by applying the dynamic multi-state Markov (MSM) model to the regime transitions of 166 countries from 1980 to 1999. The findings suggest that the bipolar view is valid only in the long run and for a reason quite different from what the proponents had imagined, namely, economic development rather than crisis-driven exits. The estimated steady-state probabilities even predict that a unipolar fixed exchange rate system could emerge in the long run. Despite some divergence, both *de jure* and *de facto* regime data corroborate the key findings.

Key words: The bipolar view, Regime transition, Crisis, Developmental stage, Markov model

JEL classification codes: F3, G2.

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1. Introduction

> "…….contingent policy rules to hit explicit exchange rate targets will no longer be viable in the twenty-first century……[Countries]….will be forced to choose between floating exchange rates on the one hand and monetary unification on the other." Eichengreen (1994), pp. 4-5.

The bipolar view, which became popular in the 1990s, considers all exchange rate regimes other than completely fixed and freely floating as unsustainable[1]. Advocates of the bipolar view argue that greater exposure to global capital markets makes intermediate exchange rate regimes such as adjustable peg, crawling peg and crawling band susceptible to speculative attacks. Countries will be forced to move to the corners, either to a fixed regime such as currency union, currency board or dollarization, or to a freely floating regime (Eichengreen, 1994; Obstfeld and Rogoff, 1995; Summers, 2000). The bipolar view is also consistent with the *impossible trinity doctrine*. This doctrine states that a country must give up one of the three goals: exchange rate stability, monetary independence and financial market integration, that is, a country cannot have all three simultaneously.

The proponents of the bipolar view claim that an intermediate regime will be hollowed out over time as a result of involuntary transitions, particularly for a crisis[2]. The view was rapidly adopted by the financial establishments as the "new conventional wisdom" (Frankel, 2003) after the Asian crisis in 1997-98 with a view to "reform financial architecture" so as to minimize the frequency and severity of crises in the future. As a result, as Eichengreen (1994) anticipated, the distribution of currency regimes will take a bipolar form in the 21st century. This paper, therefore, aims to examine the validity of the claim in a thorough empirical investigation.

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[1] This view is variously called, "the corners hypothesis", "the two poles view", "hollowing out hypothesis" and "the vanishing middle".

[2] As in the currency crisis models, an abandonment of an intermediate regime (pegs) happens when countries with intermediate regime experience excessive domestic credit growth, overvalued exchange rates, or weak economic growth and high unemployment.

Do crises lead to the disappearance of the intermediate regime? Even though the proponents of the bipolar view argue that crises produce an irreversible transition toward the poles, various case studies show that transitions occur not just away from an intermediate regime, but also toward it. Some transitions are hastily executed and some are highly deliberated, with or without the occurrence of crises. For example, a number of Asian countries adopted floating regimes during the time of crisis in 1997-98, but they reverted to a *de facto* intermediate regime after the crisis. Thailand and Korea are notable examples (Hernandez and Montiel, 2003). On the other hand, the currency union was adopted voluntarily by European countries in 1999 with preceding preparations done in steps, such as the Exchange Rate Mechanism (ERM) of the European Monetary System, and its predecessor, the Snake.

Therefore, both voluntary and involuntary transitions can happen toward the poles, which seem contradictory with the claim of the proponents of the bipolar view. It is therefore asked in this paper, is the bipolar view likely to be valid for crises, as mentioned by the proponents, or could it be valid for different reasons? To answer this question, the dynamics of currency regime transitions of 166 countries are studied for the period 1980-99 using both *de jure* and *de facto* data[3].

The paper examines whether the distribution of exchange rate regimes tends to converge to the polar extremes and identify factors that increase the likelihood of convergence. To this end, combined with transition intensities involving determinants of regime transitions under the multi-state Markov (MSM) model, this paper sets a testable approach as follows. *If the rates of transition from intermediate regimes to the poles are higher than the rates of reverse transition, and if capital integration and currency crises facilitate transition, it would suggest that the bipolar view is likely to be valid*. Although this approach points to a weaker definition of the

[3] Not all countries' regimes are available for all dates.

bipolar view as it allows some transitions toward the intermediate regime, it is helpful in exploring a broader scope of the view.

Two recent studies provide evidence against the bipolar view. Masson (2001) is the first study which cast a light on the hollowing out hypothesis directly and showed that there are non-zero transition probabilities to intermediate regimes, implying that the bipolar view is not correct strictly. However, it did not study the causes. In another study, Masson and Ruge-Murcia (2005) endogenize the exchange rate regime transitions to show that inflation and, to a lesser extent, output growth and trade openness can explain regime transitions, but not necessarily toward the bipolar direction.

Although significant contributions, it is not clear from these studies whether the view may gain some validity from a long run perspective and for the reasons mentioned by its proponents, the main one being crises. Our analysis departs from the above studies in two important ways. First, while the strict definition of the view (i.e. no transition toward intermediate regime) is not supported by data (Masson, 2001), this study proposes an alternative test involving a weaker definition of the view by allowing some transitions toward the intermediate regime. The proposed approach has made it possible to explore a broader scope of the view instead of its narrow scope under the strict rule. Second, and more importantly, this study tests the view by analyzing the effects of crisis and developmental stage directly on the regime transition dynamics, which was not done in earlier studies.

The primary antecedents of choosing explanatory variables, “crisis” and “developmental stage” are found in the literature of involuntary and voluntary regime choice models, such as the currency crisis models and optimum currency area (OCA) models, respectively (see Masson and Ruge-Murcia, 2005; Poirson, 2001). Developmental stage dummy is chosen to capture various

dynamics of development as well as to proxy capital integration since capital control dummy is not found significant to regime transitions. Moreover, when relatively more developed countries face crisis in an intermediate regime in the face of high capital mobility, they are likely to move to the corner and sustain it as long as they have more developed financial institutions (Hossain, 2009a). But this may not be the case for relatively less developed countries because they often revert to an intermediate regime from the corner after the crisis as they cannot comply with the conditions required to sustain a corner regime. These dynamics have been investigated in this paper, and within that context, it is found that the bipolar view is likely to be valid during later stages of development.

To analyze the dynamics of regime transition with the effects of relevant explanatory variables as a part of testing the hollowing out hypothesis, this study chooses to apply the multi-state Markov (MSM) model (see Appendix II for details). Particularly, this model has been chosen for some of its special features. First, as a statistical methodology, the MSM model has been widely used in the biomedical sciences to analyze transition between different states of diseases and death (an absorbing state) and it can predict the probability of death with the effect of a disease through estimating survival (or hazard) probabilities[4]. The MSM model is well suited since testing the hollowing out hypothesis requires an analysis of whether a polar extreme becomes an absorbing state over time with transition from the intermediate regime. Second, a continuous-time model is used because the duration of individual regime is a continuous time variable, which provides estimates of transition intensities (the instantaneous rate of transition) between exchange rate regimes as a non-linear function of the relevant explanatory variables assuming that transition happens instantaneously. This is a useful assumption required for testing the bipolar view as transition between currency regimes generally happens instantaneously with

[4] For details, see Kay (1986), Islam (1994), Marshall and Jones (1995).

the effect of crisis or for other reasons. Finally, the model can even be used to predict the expected time for hollowing out of intermediate regimes allowing for the effects of possible explicit causes. These features of this model make it an adequate framework for testing the hollowing out hypothesis[5].

Moreover, the hidden Markov model (HMM), an extension of the MSM model with misclassification, is introduced to increase the precision of the test of the bipolar view by considering probabilities of misclassification of regimes, as we observe a substantial amount of discrepancies between *de jure* and *de facto* regime classifications (as shown in Section 2).

To summarize the main results, this study finds that economic development significantly increases the likelihood of transition from an intermediate regime to a fixed or a floating regime, but crises do not. The analysis shows that less developed countries move from an intermediate regime in the face of crisis but most of them revert to an intermediate regime due to crisis in corner regimes, particularly in a floating regime. This rejects the claim that crises produce an irreversible transition toward the poles. However, crisis can be a factor of short-term regime dynamics, and hence, it cannot be an imperative to hollowing out of intermediate regime in the long run.

What would be the long run distribution of currency regimes? This is the question that is asked in the title of the paper. Since the current distribution of currency regimes may change in the future in the face of capital mobility or changing status of development, we estimate steady-state probabilities under the MSM to have an idea about the long run distribution of regimes. We

[5] The MSM differs from the Markov chain models used in earlier studies such as Masson (2001) and Masson and Ruge-Murcia (2005) in terms of its properties to estimate survival (hazard) probabilities. The estimation of survival probabilities of intermediate regimes is crucial for this study as it is necessary to estimate the expected time of hollowing out of intermediate regime for explicit causes.

find from the estimates that there is high probability for relatively developed countries to adopt a fixed regime in the long run.

The remainder of the article is divided into six sections. Section 2 discusses a number of technical issues related to testing the bipolar view, such as the divergence between *de jure* and *de facto* classifications and a snapshot of regime transitions over time. The empirical framework and results of the study are discussed in Sections 3 and 4, respectively. The application of the Hidden Markov Model to deal with the problem of regime misclassification and the prediction of hollowing out of intermediate regimes are presented in the next two sections (Sections 5 and 6). Section 7 concludes this paper.

2. Examining the bipolar view: related issues

Explaining the choice of a regime appears to be difficult in the beginning since the classification of a regime is problematic. Note that the IMF has traditionally offered a classification which is "*de jure*", that is, it is essentially based on what the countries report to the IMF. As a result, it does not reflect the actual regime when countries diverge from their officially announced regime for certain periods of time. This divergence potentially affects the analysis of historical trends in exchange rate regimes. However, based on the available *de facto* classification data sets, Hossain (2009b) analyzes divergence as a stochastic process of learning to a *de jure* regime, and argues that it would not affect the long-run distribution of exchange rate regimes.

To ensure the robustness of the empirical investigation of the bipolar view, this section provides a discussion on discrepancies between *de jure* and *de facto* regime classifications in the following subsection.

2.1 Divergence from de jure exchange rate regimes

In this section, the proportion of divergence is estimated between *de jure* and two *de facto* regime classifications proposed by Bubula and Ötker Robe, (2002) (henceforth *BOR de facto classification*) and Reinhart and Rogoff (2004) (henceforth RR)[6]. If the *de jure* and *de facto* regimes do not match for a specific year, it is considered divergent and the percentage of divergent cases is calculated with respect to the total number of observations.

Divergences are estimated within three broad categories of exchange rate regimes namely, fixed, intermediate and floating. A *fixed regime* consists of hard pegs such as formal dollarization, currency union and currency board arrangement; an *intermediate regime* consists of all soft pegs such as conventional fixed pegs (basket pegs with published or secret weights, single currency peg), crawling pegs, crawling bands and tightly managed floats; and a *floating regime* consists of managed floats without a predetermined range and free floats[7]. As the definition of *de jure* fixed regime is different from the above-mentioned one (because *de jure* fixed regime consists of conventional fixed regimes in addition to hard fixes)[8], the percentage of divergence from *de jure* fixed to other *de facto* regimes is not estimated. Hence the focus is primarily on the divergence between intermediate and floating regimes.

The estimated percentages of divergence are reported in Table 1 (Panel A) for the BOR classification (for the period 1990-99) and in Table 1 (Panel B) for the RR classification (for the periods 1980-89 and 1990-99). According to BOR, around 12 percent of *de jure* floaters in fact operated intermediate regimes. But, according to the RR classification, this percentage is around 40 percent for the 1980s and 50 percent for the 1990s. This divergence has increased over time,

[6] Some other notable *de facto* classifications are, Ghosh, Gulde, Ostry and Wolf (1997); Levy-Yeyati and Sturzenegger (2002); Kaminsky and Schmukler (2001). *De jure* classifications are published by the IMF.

[7] Note that the 'freely falling' category of the RR classification is lumped, in most cases, into the freely floating category, and sometimes it is placed under managed floating on the basis of other information gathered by Reinhart and Rogoff (2004).

[8] Until 1999, countries were obliged to report their exchange rate regime to the IMF according to three categories: fixed (both hard fixes and conventional pegs), limited flexible regimes (other soft pegs) and freely floating. From 1999, the IMF asks countries to report their exchange rate regimes according to eight categories to overcome the limitations of old coarse classification system.

perhaps due to high exchange rate volatility, crises and episodes of high inflation. On the other hand, the percentage of *de jure* intermediate that was floating in practice has decreased in the 1990s (using BOR, 26 percent in the 1980s and 18 percent in the 1990s; and 14 percent according to RR). These are perhaps the cases of inadvertent floating in the face of political or financial crises. From the trend in both types of divergence, it may be argued that the fear of floating has increased over time.

Another type of divergence, one that is particularly relevant to measurement error, is that among *de facto* classification schemes. The estimated proportion of the observed differences between *de facto* regimes is shown in Table 2. A total of 17 percent diverged cases are detected where a majority of these are associated with intermediate and floating regimes. To understand this divergence (or measurement error in *de facto* classification), we have studied the case of Malawi's exchange rate regime classification. Malawi's exchange rate regime was classified in 1990 as a *de jure* peg, intermediate by BOR, and floating by the RR classification. In fact, Malawi's official exchange rate was fixed to a basket of undisclosed currencies, which falls in the intermediate regime category (see Reinhart and Rogoff, 2004). It appears that the RR classification, relying on statistical tests, identifies the 'nontransparent multiple currency basket' as floating (or managed floating) because of frequent parity adjustments. However, it can be classified as a basket (i.e. intermediate regime) if the researcher uses other information as in the case of BOR. A basket peg is classified as fixed in *de jure* classification according to the IMF's old coarse classification system (until 1999).

It is therefore necessary to recognize the possibility that the proportion of divergence is slightly overestimated due to misclassification in *de facto* regime classifications. To deal with the

probability of misclassification in *de facto* classification systems, this study introduces the Hidden Markov model in Section 5.

To conclude, the findings in this section show that the divergence between *de jure* and *de facto* regime classifications and among the *de facto* classifications is not negligible. Thus, the *de jure* and two *de facto* classifications are used in the analysis for robustness of the results.

2.2 The bipolar view: A preliminary investigation

This subsection investigates the validity of the bipolar view in a snapshot. The percentages of alternative exchange rate regimes adopted by countries in 1980, 1990 and 1999 are shown in Figure 1. According to the *de facto* classifications, the percentage of countries in intermediate regimes remained almost the same in 1980 and in 1990, but it had declined in 1999. This finding is consistent with Fischer (2001)[9]. However, the *de jure* classification shows that the percentage of countries in intermediate regimes has slightly increased over time.

Next, the percentage distribution of regimes between 1990 and 1999 according to the stages of development (developing, emerging and developed) is examined in Figure 2. This is to examine the implication of the stages of development on the choice of regimes. The definitions of developed and emerging countries follow those of the Morgan Stanley Capital International (MSCI) index and Emerging Markets Bond Index Plus (EMBI+) of J.P. Morgan (see Table A1 in Appendix I). The rest are then defined as developing countries. Figure 2 shows that the percentage of countries operating intermediate regimes is slowly declining over time irrespective of the stage of development. Only the *de jure* trend shows that the popularity of intermediate regimes among developing countries is not declining.

[9] Fischer (2001) observes that economies open to international capital flows have been and are in the process of moving away from intermediate regime, some towards harder pegs, more towards systems with greater exchange rate flexibility.

In summary, the snapshot analysis shows that intermediate regimes have been gradually hollowing out from the 1980s, but more rapidly in the 1990s. The stage of development appears somewhat irrelevant for the bipolar choice of regimes. However, it is not possible to understand clearly the dynamics of regime transition from the snapshot or any static analysis. Because, within the period covered, some countries shifted toward corner regimes while some shifted from the corner regimes to intermediate regimes. The snapshot analysis ignores this short-to-medium term dynamics and also causes of transitions are not known from the analysis. Therefore, it is necessary to analyze the dynamics of regime transition to have a clear idea about the bipolar view. The subsequent sections of this paper will, therefore, deal with dynamic models of exchange rate regime transitions.

3. Empirical framework

In this section, the basic analytical framework is discussed. The empirical framework for testing the bipolar view is based on the multi-state Markov model (the model is discussed in Appendix II). A diagram for displaying the transitions (λ_{ij}) among the regimes, fixed (1), intermediate (2) and floating (3) with the coefficients of covariates (β_{ij}) is shown in Figure 3. This figure shows that transitions can take place from fixed to intermediate (λ_{12}), fixed to floating (λ_{13}), intermediate to fixed (λ_{21}), intermediate to floating (λ_{23}), floating to fixed (λ_{31}) and floating to intermediate (λ_{32}) regimes. The model is analyzed under this framework because no absorbing state is found in the currency regime transition pattern for the period under consideration.

To identify the factors that may facilitate transitions toward the bipolar direction, variables suggested by the competing paradigms of regime choice can be considered as explanatory variables. The focus of this study is primarily on the variables that are suggested by the

proponents of the bipolar view. These proponents argue that capital integration will make intermediate regimes susceptible to speculative attacks and countries will therefore be forced to adopt a corner regime. Hence, according to them, capital integration and crises are the potential reasons for transition toward the bipolar direction. Since capital integration is not found significant in this study (see Table 3), developmental stage is considered, because emerging and developed economies have stronger links to global capital markets than developing economies. Moreover, stages of development could be deemed as an important factor for regime transition as macroeconomic fundamentals and financial sectors may behave differently in different stages of development for different currency regimes. This study also investigates the effects of some economic fundamentals on transitions.

With the effect of the aforementioned variables, the bipolar view is likely to be valid if the rate of transition from intermediate to fixed (λ_{21}) is significantly higher than the rate of reverse transition (λ_{12}), i.e. if $\lambda_{21}/\lambda_{12} > 1$ and if the rate of transition from intermediate to float (λ_{23}) is significantly higher than the rate of reverse transition (λ_{32}), i.e. if i.e. if $\lambda_{23}/\lambda_{32} > 1$. Support for either of the condition by data would imply a partial support to the bipolar view for the period under consideration.

4. Empirical results

The regime transition dynamics are analyzed by calculating the duration of an individual regime in years from the 1980s and 1990s[10]. The dependent variable is regime classification, which consists of fixed = 1, intermediate = 2 and floating = 3. A larger value of the dependent variable indicates that a more flexible regime is likely to be adopted for the country in the period under consideration.

[10] The duration of a regime is calculated by how many years (it is in most cases fractional value) a country continued with a specific currency regime. This gives rise to a continuous time MSM model.

Note that the transition between regimes can happen either voluntarily or involuntarily. For example, generally speaking, if transition happens as a result of economic development or capital mobility, it may be viewed as voluntary. On the other hand, if transition happens in a crisis, it may be viewed as involuntary. So the multi-state Markov model of exchange rate regime transitions involves explanatory variables representing both voluntary and involuntary elements.

The dynamics of regime transitions are explored in two stages. First, following the traditional approach, the effects of some macroeconomic fundamentals implied by the OCA and currency crisis models are assessed on the transitions. Generally, OCA models explain voluntary transitions while crisis models explain involuntary transitions. From the OCA perspective, literature suggests that while trade openness, the existence of a dominant trading partner, labor mobility and nominal flexibility explain a move toward a fixed regime, economic development, diversification of production and exports, and size of the economy explain a move toward a floating exchange rate regime (Poirson, 2001; Von Hagen and Zhou, 2005). On the other hand, as an involuntary choice model, the currency crisis models suggest a large number of endogenous variables such as inflation rate, growth rate of GDP, unemployment rate, fiscal deficit, level of reserves, growth of domestic credit etc. as the determinants of exchange rate regime choice. Although there is no consensus on the positive relationship between these macroeconomic fundamentals and the regime choice in existing literature (see Baxter and Stockman, 1989; Juhn and Mauro, 2002), this analysis is revived under the MSM model in order to shed additional insights into the choice of a polar regime. Second, transition intensities are estimated allowing for the effects of the stage of development (developing = 1, emerging = 2, developed = 3) and the role of currency crises (crisis = 1, no crisis = 0).

The crisis dummy is taken from Glick and Hutchison (2001) and other macroeconomic fundamentals such as terms of trade, openness, inflation, broad money growth and per capita GDP growth are taken from the International Financial Statistics (IFS) of the International Monetary Fund (IMF).

4.1 The effect of macroeconomic fundamentals on transitions

First we examine the transition dynamics considering explanatory variables suggested by OCA and crises literature. We consider only four variables, such as trade openness, inflation, per capita GDP and capital control (1 = control, 0 = open) as explanatory variables and do not consider other potential variables suggested by literature in order to avoid collinearity problem in the model. The estimates of parameters are reported in Table 3 for the 1990s.

Table 3 shows that trade openness and high inflation increase the probability of a flexible regime. This finding is consistent with many studies including Masson and Ruge-Murcia (2005). However, per capita GDP growth, a proxy for economic development, is not found to be significant to explain regime transitions. Traditionally, per capita GDP growth is used as a proxy of economic development, which is a rough indicator of economic development. The coefficient on capital control dummy is not significant on regime transition, indicating that the argument of the proponents of the bipolar view that capital integration may lead countries to abandon the intermediate regime is not supported by data. Therefore, rather than these macroeconomic fundamentals, exogenous structural features of an economy, such as developmental stage and crisis are used to explain regime transition dynamics in the following sub-section.

4.2 Regime transition dynamics

The dynamics of currency regime transition towards fixed and floating corner is examined by estimating the transition intensity rates $\hat{\lambda}_{21}$, $\hat{\lambda}_{12}$, $\hat{\lambda}_{23}$ and $\hat{\lambda}_{32}$ in Panel A of Tables 4 and 5

with the effect of developmental stage and crisis. Panel B of the tables 4 and 5 gives estimates of the coefficients of explanatory variables on regime transitions. The results are reported in Table 4 for the 1980s and in Table 5 for the 1990s.

Table 5 (panel A) shows that the rate of transition from intermediate to fixed regime, $\hat{\lambda}_{21}$, is statistically significant and higher than the rate of reverse transition, $\hat{\lambda}_{12}$[11]. Therefore, the "fixed corner" is satisfied in the 1990s (the insignificance of $\hat{\lambda}_{12}$ for *de facto* data implies that very few transitions occurred from hard fixes to intermediate regimes, but $\hat{\lambda}_{12}$ is significant in *de jure* data because some conventional pegs, which are classified as fixed in *de jure* classification, gave way to intermediate regimes). But, in the 1980s, as Table 4 shows, only *de jure* data satisfy the fixed corner. On the other hand, the estimated rate of transition from intermediate to floating regime is lower than the rate of reverse transition, $\hat{\lambda}_{23} < \hat{\lambda}_{32}$, implying that the "floating corner" is not satisfied by data in both the 1980s and 1990s. Both estimates, $\hat{\lambda}_{23}$ and $\hat{\lambda}_{32}$, are statistically significant, indicating that intermediate regimes are less likely to give way to floating regimes. These estimates also indicate that there are some transitions toward the intermediate regime from the polar extreme, which is not consistent with the predictions of the proponents of the bipolar view.

Now consider the coefficients of the explanatory variables (β_{ij}) on regime transitions from intermediate to fixed regime. The coefficient of developmental stage is negative and significant (according to *de jure* data, Table 4) in the 1980s while it is positive and significant in the 1990s on the transition from intermediate to fixed regime (all three data sets corroborate this, see Table 5). This implies that although less developed countries were involved with such transitions in the

[11] The rates of transition between fixed and intermediate regime are almost the same in BOR *de facto* classification.

1980s, the situation has changed in the 1990s as more developed countries adopted fixed regimes. Some examples of this trend are the creation of the European Monetary Union in 1999 as well as the adoption of currency boards in Argentina (1991) and Bulgaria (1997). On the other hand, the effect of crises is not significant on the observed transition from intermediate to fixed regime during the 1980s. But in the 1990s, crisis has positive and significant effects on both transitions and reverse transitions (both *de jure* and RR classification data satisfy this finding), indicating that crisis does not only produce transition toward a polar extreme. Therefore, the estimates of base-line transition intensities and the coefficients of explanatory variables together indicate that crisis may not be an important factor for the hollowing out of intermediate regime; rather it can be considered a factor of short-term regime transition dynamics.

Next, considering the transition from intermediate to floating regimes, the effect of developmental stage ($\hat{\beta}_{23}$) is mixed in the 1990s as it is positive and significant according to the RR classification, positive and insignificant according to BOR, and negative and significant according to *de jure* classification. The opposite sign for $\hat{\beta}_{23}$ in *de jure* and RR *de facto* classification indicates a discrepancy which means that certain less developed countries which officially claim to be floaters are, in fact, not. However, the positive and significant effect of developmental stage on the transition from intermediate to floating regime via the RR classification suggests that relatively advanced countries tend to adopt floating regimes. But the role of crisis on the transition from intermediate to floating regime is not strong as the coefficients are only marginally significant. These evidences suggest that there is high likelihood for hollowing out of intermediate regimes with the rise of the level of economic development over time.

Finally, considering the transition from floating to intermediate regime, the coefficient of the stage of development is negative and statistically significant (according to both BOR and *de jure* data), suggesting that less developed countries (indicated by negative sign of the coefficient, $\hat{\beta}_{32}$) were involved in such transition. Although the effect of crisis is insignificant on the transition in the 1980s, a robust positive and significant effect (all three data set corroborate this) of crisis in the 1990s implies that floating exchange rate regime is not a viable option for less developed countries as they often experience crises in it. This runs counter to the widely held opinion that intermediate regimes are the most susceptible to crises.

A noteworthy finding is that less developed countries often tend to switch to a more rigid regime at the advent of a crisis, implying that crisis cannot be an imperative toward hollowing out of intermediate regimes. This finding is also contrary to the predictions of the so-called first generation model (Krugman, 1979) and second generation model (Obstfeld, 1996) of currency crises[12]. Perhaps, the countries' tendency to adopt a fixed regime at the time of crisis is associated with the state of vulnerability of their financial sectors.

It should also be noted that despite a considerable amount of divergence among regime classifications (as shown in Section 2), the key results do not substantially vary. This indicates that the divergence characterized largely by short-term regime dynamics does not matter for long-term regime trends.

To sum up, estimates of transition intensities suggest that the "fixed corner" is satisfied, but the "floating corner" is not satisfied for the period under consideration, which rejects the bipolar view even under the weaker definition given in this study. However, by analyzing the

[12] In these models, crisis is usually resolved through a forced exit from the peg followed by a floating exchange rate regime normally characterized with exchange rate overshooting.

causes of transitions, it is found that the bipolar view will likely to be valid during later stages of development. When countries reach a high level of development, which is also correlated, *inter alia*, with high capital integration, they tend to switch to either a fixed or a floating regime and sustain it. Intermediate regimes remain viable for less developed countries, at least for the short run. The empirical findings reveal that support for the bipolar view is relatively weak in the 1980s compared to the 1990s, indicating a decade-dependency in the regime transitions process. It is worth noting, however, that the 1990s was marked by higher levels of economic development as many countries entered into the emerging category, increased capital market integration and global shocks that make intermediate regimes unsustainable to some extent. If this pattern continues, the validity of the bipolar view will be more pronounced in the foreseeable future.

5. Regime misclassification

In this section the Hidden Markov model is applied to the *de facto* regime classification data sets to obtain estimates of transition intensities controlling for the probability of misclassification. In the Hidden Markov model, the true regimes (or states) of the Markov chain are not observed. The observed regimes are governed by some probability distribution (the emission distribution) conditional on the unobserved regimes. For example, the observed states O_i are generated conditionally on the true states S_i according to a misclassification matrix $E = (e_{rs})_{n\times n}$, where $e_{rs} = \Pr (O(t) = s \mid S(t) = r)$, and is assumed to be independent of t[13].

To investigate the effect of explanatory variables z(t) for the probability of misclassification e_{rs} for each pair of states r and s, a logistic model can be used,

$$\text{Log} (e_{rs} /(1- e_{rs})) = \gamma^{T}_{rs} z(t).$$

[13] The quality of a diagnostic test (sensitivity and specificity) is often measured by probabilities that the true and observed states are equal, $\Pr (O_i (t) = r \mid S_i (t) = r)$.

Here a direct method is applied to calculate likelihoods in continuous time based on matrix products, following the method developed by Macdonald and Zucchini (1997) and Guttorp (1995).

The estimated misclassification probabilities are reported in Table 6. The sample period considered for the HMM is 1990-99. The estimates in Table 6 show that the probability for misclassifying a floating regime as an intermediate regime and vice-versa is around 0.04, which is slightly higher than the probability of misclassifying the other regime.

The estimated transition intensities and coefficients of covariates are reported in Table 7. The estimates from both BOR and RR classification show that the rate of transition from intermediate to fixed regime is higher than the rate of reverse transition. On the other hand, the rates of transition and reverse transition between intermediate and floating regimes are almost the same. These results are robust as both *de facto* classifications provide almost the same results (after correcting for the probability of misclassification in it).

Turning to the effects of developmental stage and crisis on transitions, the effects of higher levels of development (indicated by the positive sign of the coefficient of developmental stage) and currency crisis are significant to the transition from intermediate to floating regime. Nonetheless, crisis has significant effect also on the transitions from floating to intermediate regime, and intermediate to fixed regime. This suggests that the effect of crisis is not very strong for the reinforcement of the bipolar view. This set of findings confirms the commonly held belief that less developed countries may find it advantageous to operate intermediate regimes while the floating regime is better suited for more developed nations. Considering transition intensities and the effect of developmental stage, it may be concluded the bipolar view is likely to be valid in the long run.

The findings in this section using the HMM support the findings of the previous section strongly.

6. Predictions for hollowing out

Since the probabilities of adopting regimes may change over time as a result of various events, such as capital mobility or crises in the future, current distribution of regimes may not be the same as the long run one. Therefore, we ask: what would be the long run distribution of exchange rate regimes? This section explores answer of this question by estimating the long-run probability distribution (also known as invariant or steady-state distribution) of regimes under the MSM. The estimates are reported in Table 8.

Table 8 (Panels A and B) shows that intermediate regimes will not be hollowing out completely with or without crisis situation in the long run. However, according to *de facto* data, the long run probability of adopting an intermediate regime is found to be very low among emerging and developed countries. Even there is a high probability of hollowing out of floating regime with the emergence of a unipolar fixed exchange rate regime in later stages of development.

The estimated steady-state probabilities are found to be low for both intermediate and floating regimes, indicating that an intermediate regime is not viable for relatively advanced countries. This is because intermediate regime does not bring much benefits such as anti-inflationary or safe-guards against liability dollarization. Therefore, the findings in this section are supportive of the bipolar view in the long run under a weaker definition given in the Introduction section, and of the unipolar fixed system, in general.

7. Conclusion

This study examines the bipolar view of currency regime choice in the context of crisis and developmental stage. While the strict definition of the view (i.e. no transition toward intermediate regime) is not supported by data, this study proposes an alternative test involving a looser definition of the view by allowing some transitions toward the intermediate regime. The proposed approach has made it possible to explore a broader scope of the view.

This study finds that economic development significantly increases the likelihood of transition from an intermediate regime to a fixed or a floating regime, but crises do not. The analysis shows that less developed countries move from an intermediate regime in the face of crisis but most of them revert to an intermediate regime due to crises in corner regimes, particularly in a floating regime. This rejects the claim of the proponents that the bipolar view will be valid in the long run with irreversible transitions toward the poles for a crisis in intermediate regimes. However, our findings suggest that the bipolar view is valid only in the long run under a weaker definition and for a reason quite different from what the proponents imagined, namely, economic development rather than crisis-driven exits.

The findings of this study suggest that an irreversible transition toward the poles occurs both voluntarily and involuntarily when countries have achieved economic development and integrated with global capital markets. The MSM model prediction shows that intermediate regimes disappear more rapidly in the emerging and developed stages than the developing stage. This finding is reasonable because when institutions are built and a good policy track is established in the emerging and developed stages, an intermediate regime may not be suitable as the economy will no longer require the benefits of an intermediate regime like anti-inflationary credibility or safeguards against liability dollarization.

The estimates of long-run probabilities suggest that a unipolar fixed exchange rate system might emerge in the long run as there is a high probability for adopting fixed regime among relatively developed countries. This prediction comes from recent trends of countries adopting currency union, currency boards and dollarization.

It is thus reasonable to argue that the looser definition that is taken in this study does not contradict much with the spirit of the original view. Hence, if we take a nuanced view of the way policies tend to work, a looser definition of the bipolar view might be appropriate.

The MSM model used in this study could not give an estimate of survivorship function of intermediate regime due to the absence of an absorbing polar extreme in the data for the period under consideration. Therefore, we could not predict the estimated time of hollowing out of intermediate regime. However, the MSM model can be effectively applied if an absorbing regime emerges over time, and more importantly, the model can be applied to many other similar situations of economic analysis.

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Table 1

Divergence between *de jure* and *de facto* exchange rate regime classifications

A. *De jure* vs. BOR *de facto* (1990-1999)

Divergence from\to *De jure*	*De facto* Fixed	Intermediate	Float	Total observations
Intermediate	1 (0.20%)	336 (81.20%)	77 (18.60%)	414 (100%)
Float	1 (0.20%)	109 (12.09%)	315 (74.10%)	425 (100%)

B. *De jure* vs. RR *de facto* (1980-1989, 1990-99)

Divergence from\to	*De facto*						Total observations	
De jure	Fixed		Intermediate		Float			
	1980-89	1990-99	1980-89	1990-99	1980-89	1990-99	1980-89	1990-99
Intermediate	0	2	219	327	78	55	297	384
	(0.0%)	(0.50%)	(73.74%)	(85.20%)	(26.26%)	(14.30%)	(100%)	(100%)
Float	0	1	52	182	77	174	129	357
	(0.0%)	(0.30%)	(40.31%)	(50.30%)	(59.69)	(48.10%)	(100%)	(100%)

Notes: 1. Estimates are based on total number of observations. Row percentages are reported.
2. Underline indicates consensus (consistent) regime.

Table 2

Observed difference between BOR and RR *de facto* classification (1990-1999)

BOR *de facto*	*RR de facto* Fixed	Intermediate	Float	Total observations
Fixed	225 (97.40%)	4 (1.70%)	2 (0.90%)	231 (100%)
Intermediate	2 (0.30%)	646 (90.50%)	66 9.20%	714 (100%)
Float	4 (1.10%)	154 (44.0%)	187 (53.40%)	345 (100%)
Total observations	231	804	255	1290

Note: Row percentages are calculated. Total diverged cases are (off diagonal cases): 232 (17% of total cases). Underline indicates consensus (consistent) regime

Table 3
Estimated coefficients of macroeconomic fundamentals on regime transition in 1990-99

A. D*e jure* classification

	De jure classification				*BOR de facto classification*				*RR de facto classification*			
Transition parameters	Trade openness	Per capita GDP growth	Inflation	Capital control	Trade openness	Per capita GDP growth	Inflation	Capital control	Trade openness	Per capita GDP growth	Inflation	Capital control
Fixed to inter.	-0.48 (0.51)	-0.82 (2.91)	1.82 (1.09)	0.27 (0.71)	-0.40 (0.51)	-0.30 (2.98)	-1.07 (3.40)	-0.18 (1.52)	-0.72 (0.55)*	-0.54 (2.98)	0.19 (1.81)	-0.05 (1.4)
Fixed to float	-1.62 (0.60)*	0.18 (1.96)	1.86 (0.89)*	0.53 (0.72)	-1.08 (0.55)*	-0.30 (2.56)	0.77 (1.40)	-0.20 (1.47)	-1.27 (0.56)*	1.34 (0.88)*	1.70 (0.96)*	-0.06 (0.8)
Inter. to fixed	0.10 (0.54)	-0.89 (8.3)	0.20 (4.03)	0.04 (0.80)	0.15 (0.33)	-0.97 (6.2)	-0.59 (2.09)	-0.11 (0.98)	0.0004 (0.37)	-1.60 (6.48)	-0.72 (1.88)	0.01 (0.62)
Inter. to float	-1.77 (0.85)*	0.70 (6.01)	0.97 (1.33)	0.52 (0.51)	-1.21 (0.99)*	-0.76 (6.21)	0.61 (1.34)	0.66 (0.38)*	-0.94 (0.62)*	-0.57 (6.11)	-0.10 (1.39)	0.30 (0.77)
Float to fixed	-0.002 (1.09)	-0.75 (6.1)	0.55 (5.05)	-0.06 (1.18)	0.17 (0.99)	-1.22 (5.7)	2.13 (1.81)	0.15 (1.38)	0.34 (0.82)	-2.84 (4.84)	0.64 (1.83)	0.03 (1.33)
Float to inter.	-0.03 (0.49)	-2.65 (2.47)	0.24 (1.16)	0.39 (0.38)	-0.08 (0.43)	0.14 (2.45)	0.66 (0.75)	0.42 (0.38)	0.17 (0.42)	1.67 (2.67)	-0.22 (0.99)	0.06 (0.59)

Notes: Log-likelihoods: RR: -232.70; BOR: -363.77; *De jure*: -446.17
-Standard errors are in parentheses; ***,**,* indicates significance at 1, 5, 10 percent levels, respectively.

Table 4

A. Estimated rates of transition intensities, 1980-89

Transition intensities	RR *de facto* (N = 1103)	*De jure* (N = 1091)
Fixed to inter. (λ_{12})	0.04 (0.015)***	0.03 (0.01)***
Fixed to float (λ_{13})	0.01 (0.012)	0.01 (0.006)
Inter. to fixed (λ_{21})	0.003 (0.005)	0.04 (0.02)**
Inter. to float (λ_{23})	0.04 (0.005)***	0.05 (0.015)***
Float to fixed (λ_{31})	0.001 (0.010)	0.01 (0.02)
Float to inter. (λ_{32})	0.05 (0.021)*	0.08 (0.03)***

B. Estimated coefficients of developmental stage and crisis on transition intensities

	Developmental stage		Currency crisis	
	De jure	RR *de facto*	*De jure*	RR *de facto*
Fixed to inter. (β_{12})	-0.30 (0.46)	-0.26 (0.98)	-0.91 (1.18)	2.33 (1.05)**
Fixed to float (β_{13})	0.58 (0.43)	0.71 (1.37)	1.48 (0.74)**	-0.06 (5.15)
Inter. to fixed (β_{21})	-1.52 (0.54)**	0.51 (0.85)	-0.004 (0.77)	0.114 (2.42)
Inter. to float (β_{23})	-0.34 (0.44)	-0.07 (0.27)	0.13 (0.89)	1.13 (0.47)***
Float to fixed (β_{31})	0.73 (1.38)	0.18 (2.3)	-0.95 (2.91)	1.55 (3.53)
Float to inter. (β_{32})	-0.89 (0.50)*	-0.16 (0.42)	-0.14 (1.03)	-0.08 (0.81)
Log-likelihood	*De jure*: -240.91; RR *de facto*: -173.57			

Notes: Standard errors are in parentheses; ***,**,* indicates significance at 1, 5, 10 percent levels, respectively.

Table 5

A. Estimated rates of transition intensities, 1990-99

Transition intensities	*De jure* (N= 1573)	BOR *de facto* (N=1616)	RR *de facto* (N= 1282)
Fixed to inter. (λ_{12})	0.028(0.008)***	0.017 (.012)	0.017 (0.016)
Fixed to float (λ_{13})	0.041 (0.009)***	0.016 (.011)	0.03(0.016)***
Inter. to fixed (λ_{21})	0.058 (0.015)***	0.013 (0.004)***	0.026 (.007)**
Inter. to float (λ_{23})	0.084 (0.017)***	0.09 (0.011)***	0.033 (0.007)***
Float to fixed (λ_{31})	0.02 (0.008)***	0.006 (0.007)	0.03 (0.013)***
Float to inter. (λ_{32})	0.11 (0.019)***	0.125 (0.022)***	0.08 (0.026)***

B. Estimated coefficients of developmental stage and crisis on transition intensities, 1990-99

	Developmental stage			Currency crisis		
	De jure	BOR *de facto*	RR *de facto*	*De jure*	BOR *de facto*	RR *de facto*
Fixed to inter. (β_{12})	1.15 (0.38)***	-0.38 (1.33)	2.02 (0.73)***	1.85 (0.84)**	-0.24 (3.62)	3.77 (1.45)**
Fixed to float (β_{13})	0.33 (0.40)	-0.60 (1.51)	0.41 (0.59)	1.43 (0.72)**	0.37 (2.68)	3.37 (0.77)***
Inter. to fixed (β_{21})	0.61 (0.25)**	1.12 (0.31)***	1.06 (0.29)***	1.11 (0.66)*	0.15 (1.04)	1.54 (0.92)*
Inter. to float (β_{23})	-0.67 (0.32)**	0.02 (0.17)	0.55 (0.24)**	1.33 (0.66)*	-0.21 (0.57)	0.78 (.60)
Float to fixed (β_{31})	0.36 (0.42)	0.34 (0.71)	-0.01 (0.45)	0.45 (1.05)	1.05 (1.52)	0.19 (1.72)
Float to inter. (β_{32})	-0.32 (0.22)+	-0.53 (0.23)**	-0.20 (0.29)	0.59 (0.019)***	0.70 (0.36)**	1.14 (0.53)**
Log-likelihood	*De jure*: -506.49; BOR *de facto*: -490.52; RR *de facto*: -286.31					

Notes: Standard errors are in parentheses. ***, **, * represent significance at 1, 5, 10 percent levels, respectively. Significance is tested by the Wald Test Statistic Z = $\hat{\beta} / S.E.(\hat{\beta})$

Table 6

Estimated probabilities of errors in *de facto* classification of regimes, 1990-99

		Classification probabilities		
		Observed regime		
BOR *de facto* classification		Fixed	Intermediate	Float
True regime	Fixed	0.99 (0.17)	0.00 (0.26)	0.003(0.14)
	Intermediate	0.03 (0.005)	0.93 (0.01)	0.04 (0.006)
	Float	0.01 (0.003)	0.03 (0.01)	0.96 (0.02)
RR de facto classification				
True regime	Fixed	0.99 (0.25)	00 (0.25)	0.01 (0.25)
	Intermediate	0.04 (0.01)	0.92 (0.01)	0.04 (0.005)
	Float	0.01 (0.001)	0.04 (0.01)	0.96 (0.025)

Standard errors are in parentheses

Table 7

A. The estimates of transition intensities using the hidden Markov model, 1990-99

Estimated transition intensities	BOR *de facto*	RR *de facto*
Fixed to inter. (λ_{12})	0.03 (0.03)	0.03 (3.50)
Fixed to float (λ_{13})	0.06 (0.02)***	0.09 (0.01)***
Inter. to fixed (λ_{21})	0.05 (0.00)***	0.06 (0.0)***
Inter. to float (λ_{23})	0.10 (0.01)***	0.08 (0.0)***
Float to fixed (λ_{31})	0.04 (0.00)***	0.06 (0.0)***
Float to inter. (λ_{32})	0.10 (0.01)***	0.13 (0.0)***

B. Coefficients of developmental stage and currency crisis on transition intensities, 1990-99

	Developmental stage		Currency crisis	
	BOR *de facto*	RR *de facto*	BOR *de facto*	RR *de facto*
Fixed to Inter. (β_{12})	-3.42 (290.68)	0.63 (20.74)	-1.58 (235.56)	1.50 (81.99)
Fixed to float (β_{13})	0.65 (5.55)	0.24 (3.84)	2.46 (11.38)	-5.09 (255.96)
Inter. to fixed (β_{21})	-0.28 (0.38)	-0.32 (0.31)	1.99 (0.43)***	0.99 (0.49)**
Inter. to float (β_{23})	0.35 (0.22) *	0.71 (0.22)***	1.89 (0.38)***	0.66 (0.60)
Float to fixed (β_{31})	0.56 (0.537)	1.47 (1.59)	1.72 (0.96)*	3.41 (2.58)
Float to inter. (β_{32})	-0.20 (0.397)	-0.05 (0.39)	2.22 (0.67)***	1.93 (0.67)***
Log-likelihood	BOR *de facto*: -839.96 RR *de facto*: -646.48			

***,**,* indicates significance at 1, 5, 10 percent levels, respectively.

Table 8

Steady-state probability distribution of exchange rate regimes

A. Without crisis

	BOR De facto data			*RR De facto data*		
	Fixed	Intermediate	Float	Fixed	Intermediate	Float
Developing	0.13	0.52	0.36	0.33	0.57	0.10
Emerging	0.30	0.34	0.36	0.60	0.28	0.12
Developed	0.52	0.18	0.30	0.81	0.09	0.10

B. With crisis

	BOR De facto data			*RR De facto data*		
	Fixed	Intermediate	Float	Fixed	Intermediate	Float
Developing	0.25	0.58	0.17	0.49	0.19	0.32
Emerging	0.52	0.33	0.15	0.81	0.09	0.10
Developed	0.76	0.14	0.10	0.95	0.02	0.02

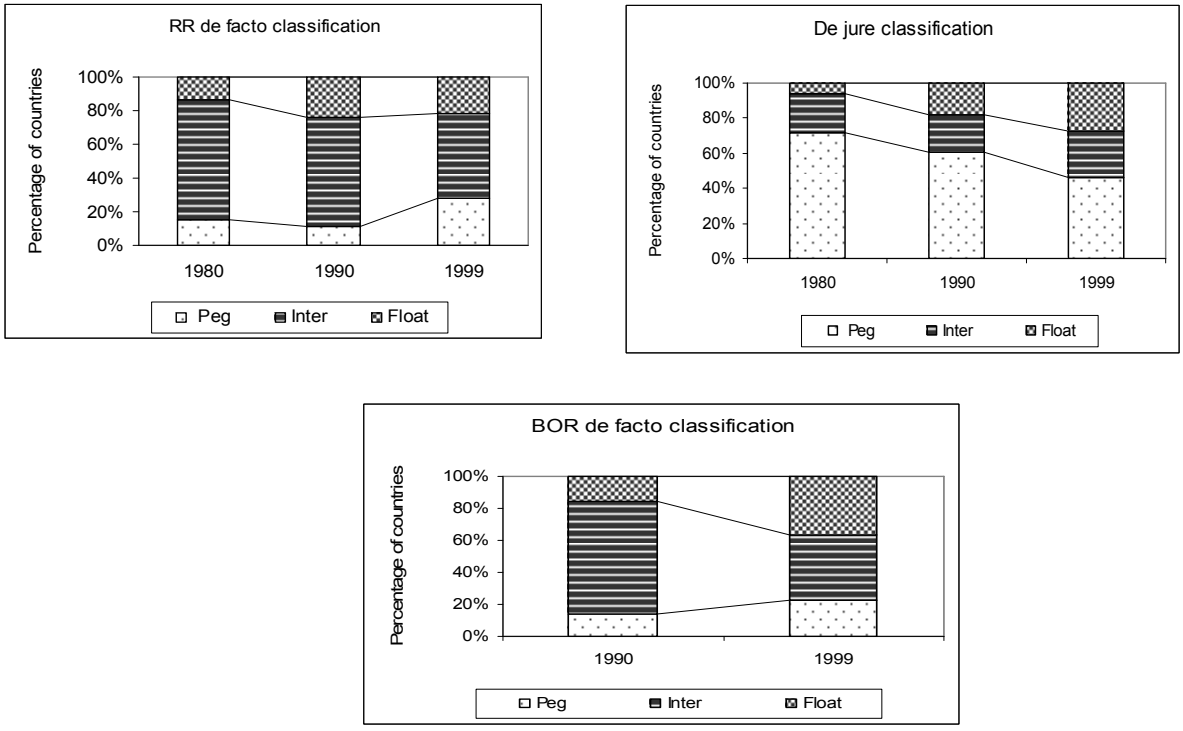

FIGURE 1

Percentage distribution of countries adopted alternative regimes in 1980, 1990 and 1999

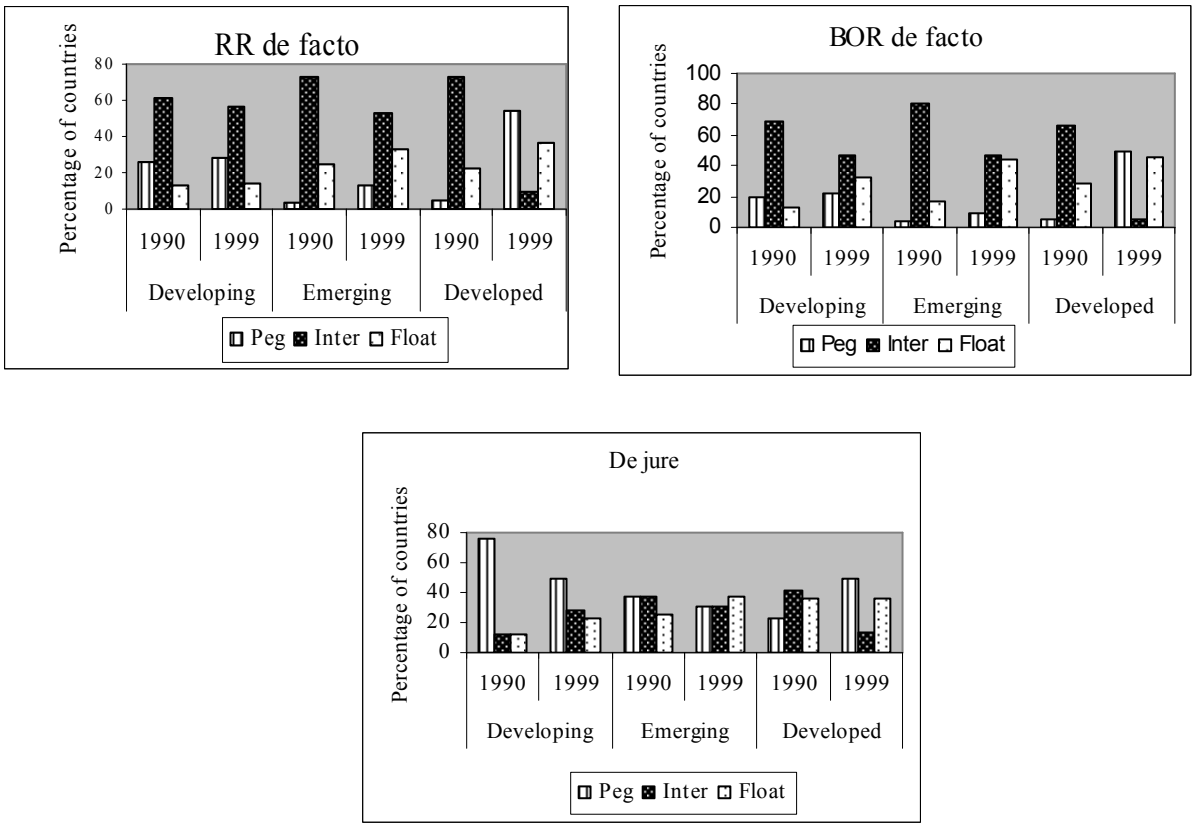

FIGURE 2
Percentage distribution of countries adopted alternative regime in 1990 and 1999 according to their developmental stage.

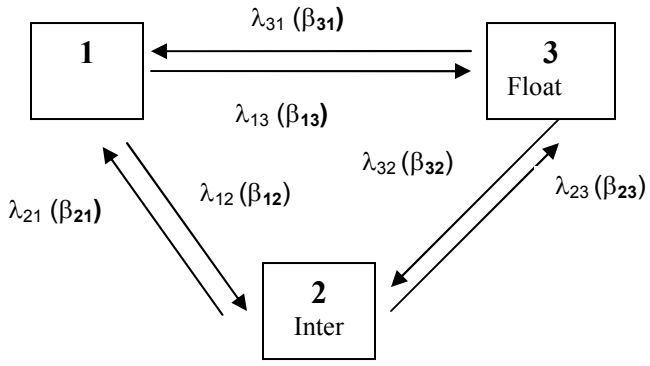

FIGURE 3
Transitions within the regimes of the MSM model

APPENDIX I

Table A1
List of emerging and developed countries

Emerging Countries (31)	Developed Countries (22)
Argentina, Brazil, Bulgaria, Chile, China, Colombia, Czech Republic, Ecuador, Egypt, Greece, Hungary, India, Indonesia, Israel, Jordan, Korea, Malaysia, Mexico, Morocco, Pakistan, Panama, Peru, Philippines, Poland, Qatar, Russian Federation, Sri Lanka, South Africa, Thailand, Turkey and Venezuela	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Hong Kong, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and United States.

Note: This list is based on the *Morgan Stanley Capital International* (MSCI) index and *Emerging Markets Bond Index Plus* (EMBI+) of J.P. Morgan

APPENDIX II

The multi-state Markov model

The multi-state Markov model (MSM) is used in this paper to analyze the exchange rate regime transition dynamics. Note that as the underlying economic structure such as parameters and variance change over time, the nature of the optimal exchange rate regime is expected to vary correspondingly, leading to an evolution of exchange rate regime. Therefore, the new equilibrium position of the economy leads to an evolution of an exchange rate regime. This can be true in a crisis situation when some countries change their regime and again return to the previous regime after the crisis. This gives rise to a Markov model, which assumes that the probability of transition to an alternative regime depends only on the current regime irrespective of past history. Masson (2001) argues that although the Markov assumption appears to be somewhat restrictive, as a first approximation, it would seem to be an adequate framework for examining exchange rate regime transitions as "it supposes that a typical currency will face the same likelihood that some shock will push it to an alternative regime" (p. 573).

The multi-state Markov model assumes continuous time Markov chain and explicitly takes the duration of a regime into account. The model is specified as

(1) $$\pi_{ij}(t \mid z) = \lambda_{ij} e^{\beta_{ij} Z}, \text{ (i, j = 1, 2, 3)}$$

where λ_{ij} represents baseline parameters (transition intensities), Z denotes the vector of explanatory variables and β_{ij} denotes the coefficients of explanatory variables on the transition from regime *i* to *j*. The transition intensities, λ_{ij}, can be defined as

(2) $$\lambda_{ij} = \lim_{\Delta t \to 0} \frac{\Pr\{transition\ from\ state\ i \to j\ in (t, t + \Delta t] \mid state\ i\ at\ time\ t\}}{\Delta t}.$$

Both time-dependent and time-invariant parameters can be estimated by the model. The estimated parameters are obtained from the partial likelihood function and that the estimates are less likely to suffer from omitted variable bias and multicollinearity. The Newton-Raphson iterative optimization algorithm can be used for non-linear estimation of the coefficients. Since this model assumes a continuous time Markov chain, it provides estimates of transition intensities (instantaneous rate of transition). Using the Kolmogorov forward differential equation (Eq. 3), transition probabilities can be estimated from transition intensities.

The MSM model considers that countries often make transitions and reverse transitions among three exchange regimes— fixed (1), intermediate (2) and floating (3), either voluntarily or involuntarily. It is assumed that there is no absorbing state (a state of no return) in the exchange rate regime transition process. The transition intensity matrix is defined as,

$$\Gamma = \begin{pmatrix} -(\lambda_{12} + \lambda_{13}) & \lambda_{12} & \lambda_{13} \\ \lambda_{21} & -(\lambda_{21} + \lambda_{23}) & \lambda_{23} \\ \lambda_{31} & \lambda_{32} & -(\lambda_{31} + \lambda_{32}) \end{pmatrix}.$$

The elements of the matrix Γ, λ_{ij}'s are defined in (2). Assume that the transition intensities i.e. instantaneous rate of transition are independent of time and the intensities follow the property $\lambda_{ii} = -\sum_{i \neq j} \lambda_{ij}$; i, j = 1, 2, 3, that is, *row sum is zero*.

The relationship between the transition probability matrix **P**(t) and the transition intensity matrix Γ can be established with the Kolmogorov forward differential equation

$$\frac{\partial \mathbf{P(t)}}{\partial \mathbf{t}} = \mathbf{P(t)}\Gamma \,, \tag{3}$$

where the (i,j)th element of the matrix **P**(t), p_{ij} (i,j = 1, 2, 3) represents the probability of transition from state i to j in a time interval t. Thus the transition probability matrix **P**(t) can be expressed as

$$\mathbf{P}(t) = \begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix}.$$

The Likelihood function

A general method for evaluating the likelihood for a multi-state Markov model in continuous time, applicable to any form of transition is discussed here (for details, see Kalbfleisch and Lawless, 1985; Kay, 1986). The likelihood is calculated from the transition probability matrix **P**(t). The likelihood function is the product of all individual contributions and the total contribution of an individual country to the likelihood function is the result of the product of the contribution from each observed transition.

For a country *k*, the likelihood function is formulated as:

$$L(\theta) = \prod_k \left[P_{k11}(t \mid z)\right]^{s_{11}} \left[P_{k12}(t \mid z)\right]^{s_{12}} \left[P_{k13}(t \mid z)\right]^{s_{13}} \left[P_{k21}(t \mid z)\right]^{s_{21}} \left[P_{k22}(t \mid z)\right]^{s_{22}} \left[P_{k23}(t \mid z)\right]^{s_{23}} \left[P_{k31}(t \mid z)\right]^{s_{32}} \left[P_{k32}(t \mid z)\right]^{s_{32}} \left[P_{k33}(t \mid z)\right]^{s_{33}} \tag{4}$$

where $\theta = (\lambda, \beta)$, $\lambda = (\lambda_{ij})$ and $\beta = (\beta_{ij})$ for $i, j = 1, 2, 3$. The variable s_{ij} takes the value 1 if transition occurs and 0 if otherwise. For example, if at time t, a country is in state 1 (fixed regime), at time $t+1$, the country can be in either of the states 1 (fixed), 2 (intermediate) or 3 (float). Therefore, $s_{11+} s_{12} + s_{13} = 1$, and so on. The log-likelihood function can be calculated by taking the log of the likelihood function.

The maximum likelihood estimates of $\theta = (\lambda,\beta)$ can be obtained by maximizing the log likelihood, and applying any of the iterative procedures such as the quasi-Newton algorithm or Nelder-Mead simplex-based algorithm. The MSM model is estimated in this paper using the "msm" package of **R** software.