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Abstract
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Keywords
Bayesian inference, China’s provinces, growth-cycles, multivariate-synchronization, panel Markov-switching.

JEL Codes
C1, C11, C15, C32, E32, E37.

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Growth-cycle phases in China’s provinces: A panel Markov-switching approach

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Abstract
This paper analyses features of 28 provincial growth-cycles in China’s economy from March 1989 to July 2009. We study the multivariate synchronization of provincial cycles and the selection of the number of cycles phases by means of panel Markov-switching models. We obtain evidence that growth-cycles in China and its provinces are characterized by distinct episodes of ‘growth-recession’, ‘normal-growth’ and ‘rapid-growth’. We find a demarcation between coastal and interior provinces in terms of level of ‘normal-growth’ and ‘rapid-growth’ rates. The results, also, show evidence supporting interior provinces catching up on coastal provinces proving efficient economic policy coordination to reduce the gap between the Chinese coastal and interior. However, in terms of concordance, coastal provinces have cycles that are more synchronized with the national cycle than the interior provinces. Thus, China’s national and subnational officials have to take further effective measures to achieve high degree of concordance between national and interior provinces. The geographic pattern of the national growth-recessions and rapid-growth periods have substantially changed over time. The number of provinces experiencing growth-recession at the middle of the nation’s growth-recession has reduced over time while the number of provinces in rapid-growth at the middle of the nation’s rapid-growth has increased over time.

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1. Introduction

There is a growing interest in studying features of regional business cycles. Altavilla (2004) analyses the euro area business cycles and found that euro area economies shared a similar business cycle, with some differences in the size and timing of recessions and expansions. Owyang et al. (2005) provided direct evidence on business cycles phases in U.S. states. They find differences in state-level business cycles, both in terms of the growth rates in the two phases and in the timing of the business cycles features. Wall (2007) did so for Japan regional business cycles. After considering changes in the Japanese economic activity, He found over the period 1976-2005 that occurrence and length of recessions in majority of regions have increased over time. Norman and Walker (2007) examine the nature and degree of co-movement among Australian states business cycles and Hall and McDermott (2007) establish New Zealand’s classical business cycles at region and national levels and determine some factors that influences co-movement between regions.

There is also a rich developing literature on the synchronization of cycles among Chinese provinces’ initiated by Tang (1998), Poncet and Barthélemy (2008), Gerlach-Kristen (2009) and Gatfaoui and Girardin (2014). Tang (1998) consider deseasonalized monthly data of industrial output and retail price index over the period from 1990 to 1995 to gauge the degree of economic integration of business cycles between 28 Chinese provinces. He uses a structural VAR and focus on the variance-covariance matrix of the structural shocks to identify a large group of correlated provinces including Liaoning, Jilin, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hunan, Guangdong, Guangxi, Yunnan, Gansu, Ningxia that accounted for 60.7 percent of national industrial output in 1994. Poncet and Barthélemy (2008), document the determinants of provincials business cycles’ fluctuations in China by considering quarterly data from March 1991 to January 2005. After emphasizing that early 1990s, cycles synchronization increased from a rather low level to a level comparable to that of the US at early 2000s, they stress on the importance of policy coordination between provinces to reduce low business cycles synchronization of interior provinces.

Gerlach-Kristen (2009) examines similarity between business and inflation cycles among Chinese provinces’ with annual GDP and inflation data for 28 provinces over the 1962-2003 period. She uses principal-component analysis to extract a common business cycle among provinces, and confirms
that there has been a synchronisation of both business and inflation cycles within China but nevertheless business cycles in North-western provinces are disconnected from the rest of the country. Gatfaoui and Girardin (2014) deal with the comovement of Chinese provincials business cycles considering deseasonalized monthly data of industrial production over the time horizon 1989-2009. They use the dating algorithm proposed by Artis et al. (2004) based on a Markov chain algorithm that allows for the identification of turning points. They find evidence of clusters of provinces with homogeneous and separate growth-cycle. At the national level they identify three mains recessions that are well diffused across the country. Their results, also, suggest that the timing and duration of recessions are characterized by province-specific variations.

These authors, very often, follow the literature on business cycle developed by Burns and Mitchell (1946) who assume that the business cycle can be characterized as distinct recession and expansion phases. However, within the literature on China business cycle characteristics, many studies appeared to favour three or four distinct regimes in Chinese economy. Examples include Girardin (2005), Langnana and Hongweib (2007), Liu and Zheng (2008). Their results support the three regimes classification in Chinese economy: low-growth, normal-growth and rapid-growth. Chengyong and Chunrong (2010) show that partitioning the Chinese business cycle phases in four regimes that are: contraction, recovery, expansion and recession; improves notably the explanation ability on economic growth structure of China. Thus, it is questionable to directly assume the number of business cycle phases.

The first aim of this article is to establish a comprehensive chronology of China’s growth-cycle phases at the provincial and national level after selecting the suitable number of phases for the different business cycles. This issue is important since it is a crucial step to explain which factors contribute or cause a given business cycle phase.

In identifying the mains features of regional business cycles, it is often common to check the synchronization of each business cycles. The different approaches proposed in the literature to measure the degree of synchronization are often based upon the phases of all states. Harding and Pagan (2002) assess the synchronicity of cycle by means of concordance index which describes the fraction of time the cycles spend in the same phase. However the degree of synchronization can changes over time and cannot be captured by the concordance index. Harding and Pagan (2002) consider a regression ap-
approach to deal with this issue. An extension of the notion of synchronization of cycles to the multivariate case appears in Harding and Pagan (2006). The test of multivariate non-synchronization is based on the method of moments estimation which advantage over the regression approach is that, there are no assumptions about which states are exogenous.

In this same vain, the second aim of our work is, to contribute to the literature on regional business cycles synchronization by proposing an alternative way based on panel Markov-switching model to select the degree of multivariate synchronization (Harding and Pagan (2006)) that are: strong multivariate non-synchronization, imperfect cycles synchronization with space-homogeneous transition and perfect multivariate synchronization.

There are many competing methods of estimation proposed in the literature of business cycles analysis such as the approach of trend/cycle decomposition known as a band-pass filter as well as the popular Markov-switching model of Hamilton (1989). We build on the approach proposed by Hamilton (1989) a panel Markov-switching model and provide a full Bayesian framework for the estimation. The advantage of our orientation towards panel Markov-switching model is to simultaneously test for both the number of business cycle phases (two, three or four-states switching model) and the type of multivariate cycles synchronization.

The remainder of the paper is structured into seven sections. Section 2 presents the panel Markov-switching model with three majors degree of synchronization among the time series and outlines the estimation procedure. In section 3, we first discuss the data and present the results of the model selection procedure. Then the selected model at hands, we start the analysis of the growth-cycles, the national regime dating and make comparison with benchmarks provided by some Institutions. In section 4, we then turn to the provincials regimes dating and highlight the relevant features characterizing asymmetry of the cycles and their phases. The evidence presented in this section is compared to the general context prevailing in some East Asian countries. Section 5 discusses the degree of persistence and concordance of the cycles. Section 6 moves to the study of the geographical pattern of Chinese national growth-cycle and section 7 provides conclusions.
2. A Bayesian Markov-Switching Model

2.1. The Model

The econometric approach used to identify classical business cycle and to date turning points is mostly based on Markov-switching autoregressive models (MS-AR). Popularized by Hamilton (1989), Markov-switching models distinguish growth-cycle phases shift as shift in the mean growth rate of a statistical model for economic output growth. The switching mechanism between various regimes is governed by a hidden state variable described by its transition probabilities matrix. The process is assumed to be stationary within each regime. The total process is then non-linear stationary due to the shift among regimes. Girardin (2005) used standard Markov-switching (MS-AR) methodology to assess growth-cycles features of east Asian countries documenting that this should be done with a model allowing discrete shift in the mean growth rate between three states: ‘growth recession’, ‘normal growth’ and a catching up phase. To analyse regional business cycles phases in advanced countries U.S. and Japan, Owyang et al. (2005) and Wall (2007) applied a Bayesian Markov-switching model with no lag structure where the mean growth rate switches between only two regimes expansion and recession. Markov-switching models can be complicated on various dimensions depending on the primary goal of the researchers. Kim and Nelson (1998) and Kim and Nelson (1999) employed Bayesian techniques to combine dynamic factor model and regime switching model, and allow for a structural break at an unknown change-point in a Markov-switching model. Hamilton and Owyang (2012) extended the Hamilton model’s of Frühwirth-Schnatter and Kaufmann (2008) and Kaufmann (2010) to characterize the clustering across states in terms of regional grouping designated as region-clusters. Billio et al. (2012, 2013) proposed a forecast combination scheme for predicting turning points of business cycles with a Panel Markov-switching model and used a Bayesian Panel Markov-switching vector autoregressive (PMS-VAR) to analyse interactions between Euro-zone and US booms and busts.

In the following, since our aim is to date regime shifts between different growth regimes, we propose a simple Bayesian panel Markov-switching with no autoregressive component for each series of the panel. This can be seen as a generalization of the Bayesian Markov-switching model in Owyang et al. (2005) to a population of time series. We denote with \( X_{it}, i = 1, \ldots, N, t = 1, \ldots, T \), the observable process, that is the industrial output growth of the province \( i \) at time \( t \), with \( N \) the total number of units in the panel.
and $T$ the length of the series of the panel. We assume $X_{it}$, $i = 1, \ldots, N$, $t = 1, \ldots, T$, are conditionally normal with mean and variance depending on the latent process $S_{it}$, $t = 1, \ldots, T$. The evolution of industrial output growth is described by the following model

$$X_{it} = \sum_{k=1}^{K} \mathbb{1}_{\{k\}}(S_{it}) (\mu_{ik} + \sigma_{ik} \varepsilon_{it}), \quad \varepsilon_{it} \sim i.i.d. \mathcal{N}(0, 1), \quad t = 1, \ldots, T \quad (1)$$

for $i = 1, \ldots, N$, where $K$ is the number of regimes, and $\mathbb{1}_{\{E\}}(X)$ is the indicator function which takes value 1 if $X \in E$ and 0 otherwise. We assume $\text{Cov}(\varepsilon_{it}, \varepsilon_{jt}) = 0$, for all $i \neq j$. The parameters $\mu_{ik}$ and $\sigma_{ik}$ represent the mean growth rate and the output growth volatility, respectively, of the province $i$ in the state $S_{it} = k$. The latent process $S_{it}$, $t = 1, \ldots, T$ provides a description of the growth cycle of the $i$-th province, and each variable $S_{it}$ denotes the province-specific state of the economic activity. We assume that $S_{it}$ is a discrete valued Markov process (regime switching process), with values in the set $\{1, \ldots, K\}$, and with time-homogeneous transition probability

$$P(S_{it} = j_1 | S_{i(t-1)} = j_2, \ldots, S_{it-1} = j_{t-1}) = P(S_{it} = j_1 | S_{i(t-1)} = j_2) = p_{j_1, j_2} \quad (2)$$

The model in equation (1) is then considered under three different types assumptions, each assumption leading to different models and estimation procedures. The three assumptions naturally take into account different degrees of similarity between the growth-cycle dynamics of the provinces, that are: strong multivariate non-synchronization (Assumption 1), imperfect cycle synchronization with space-homogeneous transition (Assumption 2), and perfect synchronization (Assumption 3). To the three assumptions correspond the following different models.

From Harding and Pagan (2006), strong multivariate non-synchronization perfect synchronization between states occurs when states Under Assumption 1, the states of the economy are province-specific and independent across provinces, and their dynamics does not share any similarity. Otherwise stated, the process $S_{it}$ are independent across provinces and each
process has its own transition matrix which is

\[ \mathbb{P}(S_{it+1}|S_{it}) = P_i = \begin{pmatrix} p_{i,11} & \cdots & p_{i,1K} \\ \vdots & \ddots & \vdots \\ p_{i,K1} & \cdots & p_{i,KK} \end{pmatrix} \] (3)

The model implied by this assumption is denoted with \( M_1 \).

Under Assumption 2, the state of the economy are province-specific, and independent across provinces, but the state transition is the same across provinces. This assumption implies that the processes \( S_{it}, t = 1, \ldots, T \) are independent across provinces and follow the same transition matrix

\[ \mathbb{P}(S_{it+1}|S_{it}) = P = \begin{pmatrix} p_{11} & \cdots & p_{1K} \\ \vdots & \ddots & \vdots \\ p_{K1} & \cdots & p_{KK} \end{pmatrix} \] (4)

The model implied by this assumption is denoted with \( M_2 \).

The Assumption 3 translates into perfectly synchronized cycles. According to Harding and Pagan (2006), perfect synchronization between states occurs when states are identical, that is \( S_{it} = S_t, i = 1, \ldots, N \) with transition matrix

\[ \mathbb{P}(S_{t+1}|S_t) = P = \begin{pmatrix} p_{11} & \cdots & p_{1K} \\ \vdots & \ddots & \vdots \\ p_{K1} & \cdots & p_{KK} \end{pmatrix} \] (5)

The model implied by this assumption is denoted with \( M_3 \).

These three assumptions (and models) can be seen as an attempt to diagnose independence, imperfect synchronization and perfect synchronization in the underlying provincials growth-cycles. If the growth-cycles of the 28 provincial industrial growth-rate are synchronised then our panel Markov switching models based on Assumption 1 and Assumption 2 should be statistically identical.
2.2. Bayesian inference

In this paper we follow a Bayesian inference approach. One of the reasons of this choice, is that inference for latent variable models calls for simulation based methods, which can be naturally included in a Bayesian framework. Moreover, model selection and averaging can be easily performed in an elegant and efficient way within a Bayesian framework, overcoming difficulties of the frequency approach in dealing with model selection for non-nested models. In this paper we follow a data augmentation framework and introduce the allocation variables \( \xi_{it} = (\xi_{i1,t}, \ldots, \xi_{iK,t}) \), where \( \xi_{iK,t} = \mathbb{1}_{i(K)}(S_{it}) \) indicates the regime to which the current observation \( X_{it} \) belongs to. Note that in \( M_3 \), \( \xi_{it} = \xi_t \), for all \( i \). The data-augmentation framework applied to the three panel Markov-switching models, yields the following completed likelihood functions

\[
\mathcal{L}(X_{1:T}, S_{1:T} \mid \theta_1, M_1) = \prod_{i=1}^N \prod_{t=1}^T \prod_{l=1}^K (2\pi \sigma_{il}^2)^{-\frac{1}{2}} \exp \left\{ -\frac{\xi_{il,t}}{2\sigma_{il}^2} (\Delta X_{il})^2 \right\} (p_{il})^{\xi_{il,t} \xi_{il,t-1}} \\
\mathcal{L}(X_{1:T}, S_{1:T} \mid \theta_2, M_2) = \prod_{i=1}^N \prod_{t=1}^T \prod_{l=1}^K (2\pi \sigma_{il}^2)^{-\frac{1}{2}} \exp \left\{ -\frac{\xi_{il,t}}{2\sigma_{il}^2} (\Delta X_{il})^2 \right\} (p_{il})^{\xi_{il,t} \xi_{il,t-1}} \\
\mathcal{L}(X_{1:T}, S_{1:T} \mid \theta_3, M_3) = \prod_{i=1}^N \prod_{t=1}^T \prod_{l=1}^K (2\pi \sigma_{il}^2)^{-\frac{1}{2}} \exp \left\{ -\frac{\xi_{il,t}}{2\sigma_{il}^2} (\Delta X_{il})^2 \right\} (p_{il})^{\xi_{il,t} \xi_{il,t-1}}
\]

where \( \Delta X_{il} = X_{it} - \mu_{il} \), \( X_t = (X_{1t}, \ldots, X_{Nt}) \), \( X_{1:t} = (X_1, \ldots, X_t) \), \( S_t = (S_{1t}, \ldots, S_{Nt}) \) and \( S_{1:t} = (S_1, \ldots, S_t) \). The description of the model is completed by the elicitation of the prior distributions on the parameters. The parameter vector and the prior setting for the three models are described as follows. In \( M_1 \) the parameter vector is defined as \( \theta_1 = (\mu, \sigma, \mathbf{p}) \), where \( \mu = (\mu_{11}, \ldots, \mu_{1K}, \mu_{21}, \ldots, \mu_{NK}) \), \( \sigma = (\sigma_{11}, \ldots, \sigma_{1K}, \sigma_{21}, \ldots, \sigma_{NK}) \), \( \mathbf{p} = (p_{11}, \ldots, p_{N}) \) with \( p_i = (p_{i1}, \ldots, p_{i1K}, p_{i21}, \ldots, p_{iKK}) \), \( i = 1, \ldots, N \). We assume normal and inverted gamma priors for \( \mu_{ik} \) and \( \sigma_{ik} \) and independent Dirichlet prior distributions for the rows of the transition matrices \( P_i \), \( i = 1, \ldots, N \). In \( M_2 \) and \( M_3 \) the parameter vectors are defined as \( \theta_2 = \theta_3 = (\mu, \sigma, \mathbf{p}) \), where \( \mu, \sigma \) are defined as in \( M_1 \), and \( \mathbf{p} = (p_{11}, \ldots, p_{1K}, \ldots, p_{K1}, \ldots, p_{KK}) \).
To address the non-identifiability of the parameters (see among other Celeux (1998) and Frühwirth-Schnatter (2001, 2006) for review) that is, the resulting posterior distribution of the parameters of the Markov-switching model is invariant to permutations in the labelling of the parameters following exchangeable priors, we impose identification restrictions naturally related to the interpretation of the different states that are $\mu_{i1} \leq \mu_{i2} \leq \ldots \leq \mu_{iK}$ where $i \in \{1, \ldots, N\}$.

The joint posterior distribution of the parameters and the allocation variables are discussed in Appendix B. Since Bayesian estimator are not easily obtained from analytical calculation we follow a Markov chain Monte Carlo approach to posterior approximation. Samples from the posterior can be obtained by iterating a Gibbs sampling algorithm. The full conditional distributions of the Gibbs sampler are given in the Appendix together with the sampling procedure for the posterior of the allocation variables using a forward filtering backward sampling (see Frühwirth-Schnatter (2006)) algorithm for the proposed panel Markov-switching models. In order to generate 5000 draws from the posterior distributions, we run the Gibbs sampler, for 12000 iterations. Thereafter, we discard the first 2000 draws to avoid dependence from the initial condition and apply a thinning procedure with a factor of 2 samples, to reduce the dependence between consecutive Markov-chain draws.

3. The China Growth-Cycle

3.1. Data

The data used in this work are the monthly growth rates first difference of the logarithm of industrial production index of 28 provinces of China and the aggregate Chinese industrial production. All our series cover more than twenty years long sample, from March 1989 to July 2009. The provinces of Chongking, Tibet and Xinjiang are not included in our database because of data unavailability. one of the main hurdles, as discussed in Holz (2004a,b), when analysing cycle in output, is the unreliability of China’s economic data since the promotion of provincial-government officials partly is based on their capability to deliver good economic performance. Young (2000) underlines, another difficulty, that is the split between volume and prices which if not imperfect is sometimes not existent for firms often report similar numbers for the volume and the value of output in order to save time and resources. Also, Gatfaoui and Girardin (2014), put in evidence the seasonal effect of January and February for all provinces. Nevertheless, these limits
impact more on the trend and less on the cyclical component that characterises the behaviour of the growth-cycle. To deal with all these issues, we look at the data province by province and seasonally adjusted the database using the U.S Census Bureau’s X-12 procedure (Findley et al. (1998)).

3.2. Model Selection for Province’s Growth-Cycles

With regime switching dynamics, the selection of the best model is a difficult task. When the number of regimes is the same in the models being compared, standard testing procedures can be applied. This is not our case because we want to select simultaneously the number of regimes (two, three or four-states switching model) as well as the type of synchronization driven the data generating process. Nevertheless, in a fully Bayesian framework, the decision concerning the model selection can be based on the log marginal likelihood if the prior distribution of the regime dependent parameters of interest are proper (see Gelfand and Dey (1994), Frühwirth-Schnatter (2006) for details). In this case, Bayes factors are properly defined.

In Table 1, we present the value of the log marginal likelihood and the standard Bayesian information criterion (BIC) for different number of regimes of the model in equation (1) taking into account the synchronization assumptions on the provincial hidden states and transitions matrices mentioned in equation (3), (4) and (5).

On the whole, for all the proposed models (see Table 1), the log of marginal likelihood and the BIC shows the relevance of a third regime in growth-cycle dynamics for the panel of provinces of China. These stylized fact has been found at national level for many east Asian countries: China, Japan, South Corea, Taiwan, etc., (see Girardin, 2005; Wang and Theobald, 2008).

As far as synchronization is directly taken into account by the models, the estimation presented in Table 1 reveals a second important fact: the similarities between the independence models and the imperfect synchronization models. The difference between the values of the log of marginal likelihood of model 1(independence) and model 2 (imperfect synchronization), irrespective of the number of state $K$, is very small. This could be attributed to the fact that the transitions probabilities are not significantly different under the independence and imperfect synchronization models.

\[\text{source: CEIC database}\]
Model 1: Strong non-synchronization
Model 2: Imperfect cycle synchronisation
Model 3: Perfect synchronisation

Log of marginal likelihood

| K=2         | -5.4606e+03 | -5.3810e+03 | -2.5973e+04 |
| K=3         | -4.8188e+03 | -4.8093e+03 | -2.5577e+04 |
| K=4         | -5.2670e+03 | -5.1116e+03 | -2.1054e+04 |

BIC

| K=2         | 1.1770e+04 | 1.1411e+04 | 5.2595e+04 |
| K=3         | 1.5551e+04 | 1.0608e+04 | 5.2144e+04 |
| K=4         | 1.3722e+04 | 1.1565e+04 | 4.3449e+04 |

Table 1: China provinces industrial output growth rate, modelled by different panel Markov-switching models with different number of state K; log of marginal likelihoods and BIC

From the Table 1, both the log of marginal likelihood and the BIC favour the imperfect synchronization with three states model to the independence and the perfect synchronization models.

3.3. Analysis of the Growth-Cycles

3.3.1. National and Provinces Level Growth-Cycles

We examine the three regimes panel Markov-switching model with imperfect synchronization for Chinese provincial industrial output growth rate. We refer to the first regime as growth-recession, the second regime as normal-growth and the third regime as rapid-growth.

At the national-level, the mean growth-recession rate is positive (see Table 2, row 2 and column 2). The least volatile regime is normal-growth and the most volatile regime is growth-recession (see table 2, row 2 and column 6; row 2 and column 5). The province-level monthly growth rates in the three regimes, are presented in Table 2. Substantial difference are manifest between coastal and interior provinces.

Asymmetric features of slow declines, quick recoveries and acceleration with high growth

The estimators of the mean growth-recession rates are smaller in absolute value than the absolute value of the mean normal-growth rates. This shows the asymmetric feature of slow declines and quick rise of growth. The estimators of the mean rapid-growth rates are almost twice larger than
<table>
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<th>$\mu_{i2}$</th>
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<td>0.1007</td>
<td>0.6674</td>
<td>1.4107</td>
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<td>0.9599</td>
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</tr>
<tr>
<td>Interior Provinces</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANHUI</td>
<td>0.3348</td>
<td>0.9554</td>
<td>1.6744</td>
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<td>1.3844</td>
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<td>0.2991</td>
<td>0.4623</td>
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<td>0.7461</td>
<td>1.4332</td>
<td>0.6214</td>
<td>0.6866</td>
<td>0.4571</td>
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<td>HEILONGJIANG</td>
<td>0.2708</td>
<td>0.9361</td>
<td>1.5084</td>
<td>0.3975</td>
<td>0.3378</td>
<td>0.6646</td>
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<td>0.7604</td>
<td>1.5778</td>
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<td>0.3917</td>
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<td>1.6416</td>
<td>0.5233</td>
<td>0.3476</td>
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<td>HUNAN</td>
<td>0.4325</td>
<td>1.0215</td>
<td>1.5623</td>
<td>0.4017</td>
<td>0.3266</td>
<td>0.3285</td>
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<td>JIANGXI</td>
<td>0.2448</td>
<td>0.8064</td>
<td>1.6870</td>
<td>0.5746</td>
<td>0.3993</td>
<td>0.3143</td>
</tr>
<tr>
<td>JILIN</td>
<td>0.2610</td>
<td>0.7200</td>
<td>1.6867</td>
<td>0.8074</td>
<td>0.9395</td>
<td>0.5221</td>
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<tr>
<td>NEIMONGGU</td>
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<td>0.7043</td>
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<td>0.4418</td>
<td>0.3105</td>
<td>0.4302</td>
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<tr>
<td>NINGXIA</td>
<td>0.0678</td>
<td>0.6716</td>
<td>1.3381</td>
<td>0.7231</td>
<td>0.6011</td>
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<td>QINGHAI</td>
<td>0.2891</td>
<td>0.7887</td>
<td>1.5385</td>
<td>0.4550</td>
<td>0.2908</td>
<td>0.4189</td>
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<tr>
<td>SHAANXI</td>
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<td>0.5832</td>
<td>1.6042</td>
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<td>SHANXI</td>
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<td>0.5356</td>
<td>1.5995</td>
<td>0.6705</td>
<td>0.7839</td>
<td>0.5466</td>
</tr>
<tr>
<td>SICHUAN</td>
<td>-0.4637</td>
<td>0.9349</td>
<td>1.6598</td>
<td>0.6884</td>
<td>0.4594</td>
<td>0.3488</td>
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<td>YUNNAN</td>
<td>-0.5047</td>
<td>0.6985</td>
<td>1.5580</td>
<td>0.6691</td>
<td>0.8056</td>
<td>0.4933</td>
</tr>
</tbody>
</table>

Note: All estimated value are significant at the 5% level. $\mu_{i1}$, $\mu_{i2}$ and $\mu_{i3}$ denote respectively the province specific mean growth rate in slowdown, normal-growth and catching-up regime. $\sigma_{i1}$, $\sigma_{i2}$ and $\sigma_{i3}$ denote respectively province specific volatility in slowdown, normal-growth and catching-up regime.

Table 2: Estimation of the Panel Markov-switching model of Imperfect synchronization with 3 regimes for China provinces.
the value of the mean normal-growth rates. Although rapid-growth rates differ across China, the regime features accelerated growth in China and its provinces.

**Difference in the absolute growth rate between coastal and interior provinces**

The mean growth rates in the normal-growth and rapid-growth regime imply clear separation between coastal and interior provinces. Coastal provinces exhibit monthly normal-growth rate higher than 1% (expected Zhejiang) while the interior provinces exhibit monthly normal-growth rate less than 1% (expected Hunan).

In addition, coastal provinces have monthly rapid-growth rate higher than 2% apart from Guangxi, Hebei, Shandong and Shanghai while the interior provinces have monthly rapid-growth rate less than 1.7%. With the exception of Beijing, Jiangsu and Shanghai in the coastal provinces and Guizhou, Ningxia, Shaanxi, Shanxi and Sichuan in the interior provinces which experienced negative monthly growth rates all the other provinces are characterized by positive industrial output growth rate in the slowdown regime.

**Difference in the expected mean growth rate between coastal and interior provinces**

The expected mean growth rates across provinces also imply clear separation between coastal and interior provinces. Figure 1 reported the expected mean growth rates over the sample period 1989.M3-2009.M6. The interior provinces display higher expected mean growth rate compared to the coastal ones. This high expected growth of interior provinces can be one factor of catching-up on the coastal provinces.

The evidence of catching-up of interior provinces on coastal ones, supports in some sense, the conclusion of Girardin and Kholodilin (2011) who analyse the gap between the Chinese coastal and interior counties using unconditional and conditional $\beta$-convergence of real per-capita income. They identify two groups of counties exhibiting the possibility of different convergence regimes, or clubs of convergence. The first group of counties is composed of interior provinces with high growth and the second group of counties located mainly in coastal regions with slower growth. They point out that: the Chinese administration which took office after 2002, has pursued policies to redress the provincials disparities with the aim of creating a harmonious society. The project called ”10,000 Businesses Going West” encouraging about 10,000 foreign firms and Chinese companies based in
eastern areas to invest in the interior regions of China can be cited as one example of such policy.

Figure 1: Heat map of expected mean growth over the sample period 1989.M3-2009.M6. Provinces on the Y-axis are ordered in two groups: coastal provinces from Beijing to Zhejiang and interior provinces from Anhui to Yunnan.

3.4. National Regime Dating

Even though, the statistical models based on two regime do not capture some stylized facts of Chinese provinces growth-cycles, we start by comparing (see Table 3) the dating of the two regime panel Markov-switching model with two benchmarks, one given by the Organisation for Economic Co-operation and Development (OECD) and another given by The Conference Board (TCB).

Similarity between our two regime panel Markov-switching model and the OECD turning points

There are differences between the OECD and the TCB national cycles and turning points. According to Ozyildirim and Wu (2012), the TCB has industrial value added (or industrial GDP) as one of its coincident indicators while the OECD used only industrial value added as its only coincident indicator. The dating of the recessions and expansions based on the smoothed probabilities from the two regime panel Markov-switching
model presented in Table 3 is much more similar to the dating of the OECD than the one of the TCB.

<table>
<thead>
<tr>
<th>Chronology from Model 2 with 2 regimes</th>
<th>Chronology by OECD ²</th>
<th>Chronology by TCB ³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recession</td>
<td>Expansion</td>
<td>Recession</td>
</tr>
<tr>
<td>2004M06-2005M02</td>
<td>2004M03-2005M01</td>
<td>2000M02-2002M02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2008M04-2009M09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2009M01-2011M02</td>
</tr>
</tbody>
</table>

Table 3: Chinese National Growth-Cycle chronology based on panel Markov-switching with imperfect synchronization. Data: growth rate of index of industrial production. Sample period: March 1989 to July 2009 (monthly information). Reference chronology based on the OECD composite index is added for comparison purpose.

Comparability between our three regime panel Markov-switching model and the OECD turning points

The statistical model which best replicate the stylized facts of Chinese provincials growth-cycle according to subsection 3.2 is the three regime panel Markov-switching with imperfect synchronization. Thus, we provide, a dating of provincials turning points based on this model. Over the period 1989Q1-2009Q2, the regimes are quite stable at the national level. The results in Table 4 underline three episodes of growth-recession, four episodes rapid-growth, and fives episodes of normal-growth. The three episodes of Chinese growth-recessions are within the dates given by OECD for recessions of Chinese reference cycle. In addition, our normal-growth periods

²The OECD Composite leading indicators (CLI) system is based on the growth cycle approach. The business cycles and turning points are measured and identified in the deviations from trend in industrial output (see Nilsson and Brunet (2006)).

³The Conference Board built its China leading economic index (LEI) and coincident economic index (CEI) constructed following the NBER approach (see Guo et al. (2009))
overlap between the OECD recessions dates and expansion dates. Furthermore, our episodes of the rapids-growth start and end within OECD expansion periods.

<table>
<thead>
<tr>
<th>Growth-Recession</th>
<th>Normal-Growth</th>
<th>Rapid-Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1994Q2-1994Q3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2004Q3-2006Q2</td>
<td>2006Q3-2007Q1</td>
</tr>
<tr>
<td></td>
<td>2007Q2-2008Q1</td>
<td></td>
</tr>
<tr>
<td>2008Q2-2008Q4</td>
<td></td>
<td>2009Q1-2009Q2</td>
</tr>
</tbody>
</table>


**National Rapids-Growth periods, Eight-year, Tenth-year plans and government stimulus**

The first wave of national rapid growth started in the third quarter of 1991 and ended in the fourth quarter of 1993. It coincides with the Eight Five-year plan (1991-1995) that marked the beginning of renewed economic reform.

The second wave of national rapid growth which cover the period 2002Q3-2004Q2 started after December 2001: entry of China into the World Trade Organization (WTO). It strongly overlaps with the Tenth Five-year plan (2001-2005) which contributes to news reforms in term of financial liberalization and engagement in international integration.

Early 2009 has started the fourth wave of rapid growth as a result of a very sizeable government stimulus and a target of 8% growth in GDP in 2009 (Tisdell (2009)) in order to come out rapidly from the global financial crisis of 2008.
National Growth-Recessions periods, political crisis, the East Asian crisis and tight monetary policy

The first wave of national growth-recession of 1989Q1-1990Q1, follows the period 1988-1989 of turbulence leading to the Tienanmen political crisis. As we saw in Table 4, the second wave of growth-recession 1994Q1-1997Q2 started before the East Asian crisis of 1997-1998. During the financial crisis of 2008, occurred the third wave of growth-recession of 2008Q2-2008Q4. Liu (2009) points out that switch of the national economy to recession around the financial crisis of 2008 was largely due to a “significant slowdown in external demand and a tight monetary policy to contain inflation in the first three quarters of 2008”.

4. Dating the Provincials growth-cycles

4.1. Province-level regime dating

Our Bayesian panel Markov switching models as a generalization of Markov switching model in Owyang et al. (2005) deliver for each province the estimated monthly smoothed probabilities that the provinces are in a growth-recession, normal-growth or rapid-growth.

Figure 2 which is composed of three heat maps of the smoothed probabilities of the three different regimes for each province highlights the difference between coastal provinces and interior provinces. The smoothed probabilities at each period are either close to 0 (blue color on the heat maps of figure 2) or to 1 (red color on the same heat maps). This shows that at any point in time, the decision regarding whether this province is in its growth-recession, normal-growth or rapid-growth is straightforward. In addition, the three regimes are very stable. All the provinces present long-lasting normal-growth and rapid-growth compared to growth-recessions.

4.2. Evidence Supporting catching up or structural changes of interior provinces

High probabilities of being in rapid-growth for provinces in the interior

The third map of Figure 2c of rapid-growth probability shows the move over time of the growth center from the coastal provinces to the interior provinces. In fact, rapid-growth was centred in the coastal region during the period 1990-1993, period known in China history for introduction of further economic reforms and opening up. From 2002 to early 2007, the growth center tends to move to the interior provinces which started experiencing an economic revival as they were having very high level of rapid-growth probabilities.
Figure 2: Heat map of monthly smoothed probabilities of China provinces; 1989.M3-2009.M6. (2a) growth-recession regime, (2b) normal-growth regime and (2c) rapid-growth regime. The blue (red) colour represents low (high) smoothed probabilities. Provinces on the Y-axis are ordered in two groups: coastal provinces from Beijing to Zhejiang and interior provinces from Anhui to Yunnan.
Figure 2: Heat map of monthly smoothed probabilities of China provinces; 1989.M3-2009.M6. (2a) growth-recession regime, (2b) normal-growth regime and (2c) rapid-growth regime. The blue (red) colour represents low (high) smoothed probabilities. Provinces on the Y-axis are ordered in two groups: coastal provinces from Beijing to Zhejiang and interior provinces from Anhui to Yunnan (continued).

Provinces specific variations in the timing and length of phases episodes

The dating of the national and province-level regimes are based on the monthly smoothed probabilities (see Krolzig (2003)). We convert our monthly in the quarterly regimes(see Owyang et al. (2005)) and construct tables 5 and 6 that explain how the provinces’ growth-cycle relate to each other and to that of the national economy. With a black bar we indicate if the province was in growth-recession in a month within a quarter over the sample period. With a green bar we indicate if the province was in rapid-growth in the months composing a quarter over the sample period. Further, gray background and respectively orange background are added to indicate when the national economy was in a growth-recession and respectively in a rapid-growth.

A first lesson to draw from the results of Tables 5 and 6 is the evidence of province specific variations in the timing and length of growth-recessions, normal-growth and rapid-growth episodes. Many provinces experienced the growth-recession of 1989Q1-1990Q1 compared to the growth-recessions of 1993Q3-1997Q2 and 2008Q2-2008Q4. Even during nationals normals-growth and rapid-growth, there are many provinces with idiosyncratic growth-recessions.
Table 5: Chinese Provinces growth recession (black bar), normal growth (white color) and rapid growth (green bar) by quarter: 1989Q1-1999Q4. Chinese national growth-recession indicated by gray background, normal-growth by white background and rapid-growth by orange background.
Move of the growth center from the coastal to the interior provinces

A second lesson drawn from Tables 5 and 6 is the move of the growth center from the coastal to the interior provinces. After the long national growth-recession of 1989-1990 six of the coastal provinces (Guangdong, Guangxi, Hainan, Jiangsu, Shanghai, Zhejiang) started enjoying rapid-growth when six of the interior provinces (Guizhou, Heilongjiang, Hubei, Hunan, Neimonggu and Qinghai) still remained in growth-recession. During the long-lasting national rapid-growth of early 1991 to early 1994, the majority of the coastal provinces were experiencing rapid-growth while the interior provinces were normal-growth (Gansu, Hunan, Neimonggu, Qinghai and Shanxi) and growth-recession (Guizhou and Heilongjiang). Ten years after the beginning of the national rapid-growth of early 1991 another two nationals rapids-growth took place from 2002 to early 2007 characterizing by a change in favour of interior provinces. During the two nationals rapids-growth of 2002 to early 2007 and the one of 2009, the majority of the interior provinces were experiencing rapid-growth while the coastal provinces were switching between growth-recession, normal-growth and rapid-growth.

Evolution of the number of provinces in each regime and economic policy coordination

Early 1990s, the number of provinces in growth-recession reach a maximum as result of bouts of serious inflation. From Figure 3, in the periods 1991M01-1993M03, and 2002M06–2007M12, the number of provinces experiencing a rapid-growth exceeds the number of provinces in normal-growth and growth-recession. Its demonstrates the ability of Chinese local and regional policy-makers to effectively restore macroeconomic stability through bold pilot experiments such as a combination of traditional monetary (exchange rate reform) and fiscal policies, decentralization policies including fiscal reforms in 1994.

In fact, Poncet and Barthélemy (2008) who documented business cycles’ fluctuations in Chinese provinces, indicate that stabilization of output fluctuations can be achieved in China by promoting coordinating fiscal and economic policies in the provinces.

Rapid growth and structural changes

Analysis of Figure 3 reveals a long ”soft landing” period from early 1993 to early 2002 characterized by many provinces in normal-growth. This suggests that the result of Zheng et al. (2010) about evidence of structural break around 1992-1993 of Chinese national business cycle should be extended to
Table 6: Chinese Provinces growth recession (black bar), normal growth (white color) and rapid growth (green bar) by quarter: 2000Q1-2009Q2. Chinese national growth-recession indicated by gray background, normal-growth by white background and rapid-growth by orange background.

Figure 3: Evolution over time (monthly information) of the number of provinces in each regime; black color: represents the number of provinces in recession is growth-recession, green color: the number of provinces in normal-growth and blue color: the number of provinces in rapid-growth.

4.3. Asymmetry of episodes of growth-recession, normal-growth and rapid-growth

To deeply analyse the business cycle, Burns and Mitchell (1946) suggested to consider among others the durations, the amplitudes and the steepness of the cycle and its phases. The gain in period of expansion and the loss in period of recession measured by the amplitude (Harding

4Let $S_{it}$ denotes the province-specific state of the economic activity for series $X_{it}$. $S_{it}$ takes value 1 if province $i$ is in growth-recession. It takes value 2 or 3 if province $i$ is in normal or rapid-growth. The amplitude $AMP_{i,k}$ and the steepness $STEEP_{i,k}$ of the phase $k$ of serie $i$ are:

$$AMP_{i,k} = \frac{\sum_{t=1}^{T} 1_{(k)}(S_{i,t}\Delta X_{i,t})}{\sum_{t=1}^{T} 1_{(k)}(1-S_{i,t+1})S_{i,t}}, \quad STEEP_{i,k} = \frac{\sum_{t=1}^{T} 1_{(k)}(S_{i,t}\Delta X_{i,t})}{\sum_{t=1}^{T} 1_{(k)}(S_{i,t})},$$

where $T$ is the sample size.

Amplitude and steepness of Chinese national economy

At national level, the gains of production during normal-growth 35% and rapid-growth 36% are largely higher than the gain of 11% during slowdown (see Table 7, third row). Accordingly to the figures presented in the last row of Table 7, the severities of switching from one phase to another phase are very slow.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
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<td>-0.073</td>
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<td>-0.061</td>
<td>-0.065</td>
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<td>-0.053</td>
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<td>Recess -Recovery Expansion</td>
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<td>0.016</td>
<td>0.022</td>
<td>0.012</td>
<td>0.015</td>
<td>0.014</td>
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</tr>
<tr>
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<td>0.065</td>
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<td>0.013</td>
<td>0.048</td>
<td>0.068</td>
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<tr>
<td>Rapid-Growth</td>
<td>0.3601</td>
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<td>0.583</td>
<td>1.011</td>
<td>0.496</td>
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<td>0.389</td>
<td>1.140</td>
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<tr>
<td>Steepness</td>
<td>0.0059</td>
<td>0.017</td>
<td>0.020</td>
<td>0.018</td>
<td>0.018</td>
<td>0.010</td>
<td>0.022</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Table 7: Amplitudes and steepness of Chinese National growth-cycle phases. Features from East Asian countries in Calderón and Fuentes (2014) from the World Bank are added for comparison purpose.

Calderón and Fuentes (2014) from the World Bank analyse changes in business cycles features of 71 countries which include countries in Eastern Asia but exclude China. Over specific time horizon, East Asian countries were experiencing moderate loss around 6% in recession while China appears to gain about 11% of production during its growth-recessions. The amplitudes of expansion in Korea Rep. and Taiwan are of magnitude of 101.1% and 114.0% respectively compared to that of China around 36% in rapid-growth. Furthermore, recessions in East Asian countries highlighted in Table 7 are deeper than the growth-recession in China.
Amplitude and steepness of provincials cycles

We find evidence of asymmetries across the phases of the cycle, especially among interior provinces. The amplitudes are on average about twice larger for rapid-growth than for normal-growth among interior provinces. There is greater variability in the amplitude of growth-recessions (see Table 8). Height provinces tend to experience deeper recessions: the average amplitudes drop in industrial activity are negatives. These provinces includes four in the coastal: Beijing, Hainan, Jiangsu and Shangai and four in the interior: Guizhou, Shanxi, Sichuan and Yunnan. The others remaining provinces tend to experience slowdown: the average amplitudes of industrial activity are positives.

Rapid-growth and normals-growth are often stronger in the interior than the coastal. For instance, Anhui, Hunan, and Neimonggu have amplitudes of 113.84%, 136.26% and 141.51% in rapid growth. Helongjiang and Qinhai have strong gains in normal-growth approaching 167.12% and 126.65% respectively. In general, the phases have very low steepness suggesting that the motion from one phase to another one is slow.

5. Persistence and Concordance of the Growth-Cycles

At both the national and provincials levels we observe from Table 9 that the duration is much shorter for growth-recession than normal and rapid-growth.

The expected normal-growth duration is slightly longer than the expected rapid-growth duration for 20 provinces: 9 in the coastal provinces and 11 in the interior provinces. This suggests that the baseline regime for these provinces is normal-growth. There are 8 provinces with rapid-growth as baseline regimes. These provinces include: Beijing, Fujian and Guangxi in the coastal and Anhui, Gansu, Guizhou, Jiangxi and Ningxia in the interior.

According to Table 9, all the three regimes are persistent. In fact, either at the national or provincial levels, the probability of staying in the same regime is extremely high compared to the probability to switch to the other regimes.

We are also interested in how the cyclical patterns of provincials and national activity compare. To achieve this, we consider the degree of concordance following Harding and Pagan (2002) based on our model 2 of imperfect cycle synchronization with homogeneous transition of three regimes(see
<table>
<thead>
<tr>
<th>Province</th>
<th>Growth-Rcession</th>
<th>Normal-Growth</th>
<th>Rapid-Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average amplitude</td>
<td>Steepness</td>
<td>Average amplitude</td>
</tr>
<tr>
<td>Coastal Provinces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEIJING</td>
<td>-0.0088</td>
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<td>0.1645</td>
</tr>
<tr>
<td>FUJIAN</td>
<td>0.2420</td>
<td>0.0022</td>
<td>0.4151</td>
</tr>
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<td>GUANGDONG</td>
<td>0.1849</td>
<td>0.0059</td>
<td>0.4702</td>
</tr>
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<td>GUANGXI</td>
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<td>0.2168</td>
</tr>
<tr>
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<td>-0.0003</td>
<td>0.1860</td>
</tr>
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<td>0.0315</td>
<td>0.0010</td>
<td>0.2554</td>
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<td>JIANGSU</td>
<td>-0.0341</td>
<td>-0.0007</td>
<td>0.1779</td>
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<td>0.0684</td>
<td>0.0007</td>
<td>0.2746</td>
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<tr>
<td>SHANDONG</td>
<td>0.0106</td>
<td>0.0002</td>
<td>0.2461</td>
</tr>
<tr>
<td>SHANGHAI</td>
<td>-0.0502</td>
<td>-0.0072</td>
<td>0.4354</td>
</tr>
<tr>
<td>TIANJING</td>
<td>0.0962</td>
<td>0.0017</td>
<td>0.5870</td>
</tr>
<tr>
<td>ZHEJIANG</td>
<td>0.0056</td>
<td>0.0006</td>
<td>0.1043</td>
</tr>
</tbody>
</table>

| Interior Provinces  |                   |               |               |         |                   |           |
| ANHUI           | 0.0385            | 0.0032       | 0.3023       | 0.0032  | 1.1384           | 0.0084    |
| GANSU           | 0.0335            | 0.0008       | 0.3982       | 0.0027  | 0.7528           | 0.0139    |
| GUIZHOU         | -0.0209           | -0.0005      | 0.1046       | 0.0009  | 0.1227           | 0.0015    |
| HEILONGJIANG   | 0.1587            | 0.0026       | 1.6712       | 0.0095  | 0.1059           | 0.0176    |
| HENAN           | 0.0101            | 0.0006       | 0.2573       | 0.0025  | 0.6598           | 0.0053    |
| HUBEI           | 0.0097            | 0.0004       | 0.1425       | 0.0013  | 0.3629           | 0.0033    |
| HUNAN           | 0.1213            | 0.0022       | 0.5293       | 0.0051  | 1.3626           | 0.0227    |
| JIANGXI         | 0.0139            | 0.0006       | 0.1958       | 0.0020  | 0.7050           | 0.0056    |
| JILIN           | 0.0079            | 0.0007       | 0.1933       | 0.0012  | 0.2240           | 0.0034    |
| NEIMONGGU       | 0.0176            | 0.0004       | 0.7450       | 0.0070  | 1.4151           | 0.0142    |
| NINGXIA         | 0.1317            | 0.0120       | 0.1544       | 0.0013  | 0.3653           | 0.0033    |
| QINGHAI         | 0.0958            | 0.0029       | 1.2665       | 0.0080  | 0.8115           | 0.0156    |
| SHAANXI         | 0.0140            | 0.0017       | 0.2136       | 0.0014  | 0.4751           | 0.0054    |
| SHANXI          | -0.0652           | -0.0038      | 0.0918       | 0.0006  | 0.2049           | 0.0023    |
| SICHUAN         | -0.0602           | -0.0016      | 0.1669       | 0.0019  | 0.9617           | 0.0083    |
| YUNNAN          | -0.0409           | -0.0020      | 0.0615       | 0.0007  | 0.2652           | 0.0019    |

Table 8: Basic features Chinese National and provincials Growth-Cycles(monthly information). Amplitude and steepness based on panel Markov-switching with imperfect synchronization.
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Note: Prob. Staying is probability of staying in the same regime N-G denotes normal-growth and R-G is rapid-growth. Exp. Duration is the expected duration (monthly information).

Table 9: Persistence of Province-level Growth-Recession, Normal-Growth and Rapid-Growth
Let $S_{it}$ denotes the province-specific state of the economic activity for series $X_{it}$. $S_{it}$ takes value 1 if province $i$ is in growth-recession. It takes value 2 or 3 if province $i$ is in normal or rapid-growth. The degree of concordance between provincials and national cycle is then

$$C_{i,China} = \frac{1}{T} \sum_{t=1}^{T} \left[ \mathbb{1}_{\{1\}} (S_{i,t}S_{China,t}) + \mathbb{1}_{\{2\}} (S_{i,t}S_{China,t}) + \mathbb{1}_{\{3\}} (S_{i,t}S_{China,t}) \right]$$

where $T$ is the sample size and $C_{i,CHINA}$ measures the proportion of time province $i$ is in the same phase with the nation.

Figure 4: Concordance index between provincials and National growth-cycles over the period 1989.M3-2009.M6. Provinces on the Y-axis are ordered in two groups: coastal provinces from Liaoning to Guangdong and interior provinces from Neimonggu to Jiangxi.

Graph 4 shows the degree of concordance of industrial activity amongst provinces with national industrial production. We already know based on the model selection steps in section 3.2 that the best model is the three regime model with imperfect cycles synchronization. However, we want to answer the question: which provincial cycles are similar with the national cycle? It appears that even by introducing three regimes classification, coastal provinces cycles are more in synch with the national cycle than the interior provinces.
6. The Geography of National Growth-Recessions and Rapid-growth

Over the period we considered, there are three national growth-recessions against four national rapid-growth with distinct geographic patterns. The national growth-recession and rapid-growth geographic patterns have considerably changed over time. The number of provinces being in growth-recession at the middle of national growth-recessions has decreased over time and the number of provinces in rapid-growth at the middle of the national rapid-growth has increased over time. The third episode of national rapid-growth which started 2006Q3 and ended the first quarter of 2007 and the third one which started early 2009 seem to have the same pattern.

6.1. The 1989Q1-1990Q1 national growth-recession

The first map in Figure 5a highlights in gray color a total of 19 provinces spread in both coastal and interior regions which experienced the growth-recession that start at the beginning of 1989. The rest of the provinces were in normal-growth. Two quarters after the 1989Q1-1990Q1 national growth-recession (Figure 5b, provinces coloured in gray) 6 provinces including 4 in the interior regions were still in growth-recession and one province in the coastal region (Guangdong) entered in rapid-growth (Figure 5b, provinces coloured in green). Indeed, the period of 1988-1989 was a turbulence period characterized by one of the most severe cycles which gave room to a Tiananmen political crisis. In particular, the year 1989 marked the end of one era of cautiously managed economic reform. After the year 1989, reforms restarted with a very different configuration.

6.2. The 1994Q3-1997Q2 national growth-recession

The geographic pattern of the 1994Q4-1995Q2 national growth-recession is particularly distinct from the one of 1989Q1-1990Q1. As we can see on Figure 5c, the 1994Q4-1995Q2 national growth-recession is experienced by few provinces. These provinces include 7 coastal ones: Beijing, Fujian, Guangxi, Hainan, Jiangsu, Shandong, Tianjing and only 3 of the interior ones: Gansu, Hunan, and Yunnan. During the period from May 1993 to March 1994, before the occurrence of the second growth-recession, the rapidly accelerating growth phase presented an high inflation rate. In response to rising inflation, the government adopted a fiscal tightening policy. Moreover, two quarters after the end of this national growth-recession (Figure 5d), the interior provinces in number of 5 switched into rapid-growth: Anhui, Guizhou, Henan, Hubei, and Yunnan. In 1994, occurred
the decentralization policies including fiscal reforms and the exchange rate reform when the two separate foreign exchange rates for the Yuan were unified into one official exchange rate. This caused the depreciation of the exchange rate from 5.3 to 8.7 Yuan to the dollar. Even tough the exchange rate reform has a complete success, it seems that in the short term, this adjustment stimulated the increase of exports but at the same time was responsible for a continued rise in inflation.

Figure 5: National growth-recession 1989Q1-1990Q1, 1994Q3-1997Q2 and 2008Q2-2008Q4. Growth-recession is indicated by gray colour, normal-growth by white color and rapid-growth by green colour. The provinces of Chongking, Tibet and Xinjiang which are not coloured in yellow are not included in our database because of data unavailability.
6.3. The 2008Q2-2008Q4 national growth-recession

At the beginning national growth-recession of 2008Q2-2008Q4 (Figure 5e), a total of 9 provinces were in growth-recession. A number of 4 provinces in the coastal regions: Beijing, Fujian, Guangdong, and Shangai and 4 in the interior provinces: Guizhou, Henan, Ningxia and Shanxi. At the same period, Anhui, Hunan, Neimonggu, and Sichuan in the interior provinces and Guanxi from coastal provinces were in rapid-growth. Chinese economy was exposed to the sudden collapse of global trade due to its openness. In 2008, interest rate and reserve requirement was reduced and limit on credit growth removed. The government, also, stopped the policy of letting the Yuan appreciate against the US dollar and took the decision to spend 16% GDP in investment. As result, bank lending experienced an extraordinary expansion and early 2009 economic recovery started at national level as well as provincial level. At the end of the national growth-recession of 2008Q2-2008Q4 (Figure 5f), 13 provinces mainly in the interior provinces have switched into or continued with rapid-growth.

6.4. The 1991Q3-1993Q4 national rapid-growth

The national rapid-growth of 1991Q2-1994Q1, started in coastal provinces (Guangdong, Shangai and Zhejiang) at least two quarters before. As figure 6a shows, 7 provinces were still in growth-recession and the others in normal-growth. At the middle of the national rapid-growth of 1991Q2-1994Q1, the rapid-growth reached almost all provinces from the coastal and at least half in the interior (see Figure 6b). Indeed, between 1989 and 1991, after the Tienanmen Square political crisis, started a period of conservative ascendency. In adequacy the decisions known as the Southern tour lectures, of president Deng Xiaoping in 1992, an acceleration in growth in the Southern region occurred; the economic reforms adopted to ensure transition from a planned to a market economy was reaffirmed and started vigorously. Once the rapid-growth ended at the national level, it ended fairly quickly across the provinces. Although there were 12 states still in rapid-growth at the end (1994Q1) (located in the coastal and the interior), this was reduced to only three by the next two quarter (Figure 6c).

6.5. The 2002Q2-2004Q2 national rapid-growth

The second national rapid-growth, which began in the first quarter of 2002, started in parts of the country well before that. As Figure 6d shows, there were 11 provinces, including much of the interior provinces, that were
Figure 6: National rapid-growth 1991Q3-1993Q4, 2002Q2-2004Q2. Growth-recession is indicated by gray colour, normal-growth by white color and rapid-growth by green colour. The provinces of Chongking, Tibet and Xinjiang which are not coloured in yellow are not included in our database because of data unavailability.
in rapid-growth at the first quarter of 20002. By the middle of this national rapid-growth (see Figure 6e), the rapid-growth had spread throughout the interior provinces in number of 13 out of 16 and only four provinces Hainan, Hebei, Jiangsu, and Liaoning that are from the coastal was in rapid-growth. At the end of this national rapid-growth, there were 18 provinces that were still in rapid growth (Figure 6f). The group of provinces concerned with this is composed by 14 provinces in the interior regions and only four in the coastal regions.

7. Conclusion

The analysis of evolution of provincials business cycles in China has been neglected compared to the study of the Chinese national business cycle. This article paid attention to this neglected part by studying the features of provincials growth-cycles in China. Our analysis is based on a panel of monthly growth rate of national and provincials industrial production indexes over two decades covering March 1989 to July 2009. The statistical model is built within a panel Markov-switching framework with regime-dependent mean denoting the equilibrium growth rate and regime-dependent error variance. The modelling approach used allows us to simultaneously select both the number of cycle and the type of synchronization. The results show evidence supporting a three regimes classification in the Chinese economy both at national and provincial levels. The mean growth rate of the industrial activity is positive in the second regime of ‘normal-growth’ and is twice smaller than the mean growth rate of ‘rapid-growth’. Chinese growth-recession rate at national level is positive. Height provinces out of 28 present negative growth-recession rate. The estimation procedure considers three types of synchronization of cycles: strong multivariate non-synchronization, imperfect synchronization and multivariate perfect synchronization. Provincials and national cycles are imperfectly synchronized. Results stress the asymmetries across the phases of the cycle, especially among interior provinces. On average, the amplitudes are about twice larger for rapid-growth than for normal-growth among interior provinces. Height provinces tend to experience deeper recessions. These provinces includes four in the coastal: Beijing, Hainan, Jiangsu and Shangai and four in the interior: Guizhou, Shanxi, Sichuan and Yunnan. A further examination of concordance between provinces cycles and national cycle reveals that more interior provinces exhibit similar cycles comparing with the national cycle than the coastal provinces. Overall, the interior provinces cycles are more
in synchronized with the national cycle while the coastal provinces cycle are less synchronized with the national cycle. There is evidence of provinces specifics variations in the timing and the length of the three phases of the cycles. The provincials growth-recessions and rapid-growth episodes are often associated with respectively nationals growth-recession and rapid-growth. All the regimes exhibit persistence although growth-recessions are shorter than normal-growth and rapid-growth. However, the times of occurrence of their regime’s differ and are not in phase with regimes at the national level. Since coastal provinces have been subject to preferential policies by early of the 1990’s as consequence from early 1990 to the end of 1994, many coastal provinces started enjoying the first wave of rapid-growth. After 2002, almost all the interior provinces were in rapid-growth while many provinces on the coast were in normal-growth. This move of the growth center from the coastal to the interior can be seen as evidence of catching up effects between interior and coastal provinces. China’s reforms might have induced a catching effect of growth-cycles between interior and coastal provinces. This can be seen as the benefit of the decentralization. However, this should be nuanced with results of Girardin and Kholodilin (2011) suggesting the possibility of two convergences regimes or clubs of convergence composed respectively of poor counties belonging to interior provinces and counties in the coastal provinces. The first group according to these authors converge with high growth rate and the second group fail to converge with slower growth.

For the investors, it is important to know the provinces which are experiencing an economic growth (rapid-growth). For the Chinese policy makers, it is important to know which provinces are in recession, growth or rapid-growth in order to design more uniform policies across the provinces. Indeed, Poncelet and Barthélemy (2008) indicate that stabilization of output fluctuations can be achieved in China by promoting further coordinating fiscal and economic policies in the provinces in order to obtain higher synchronization of interior and coastal cycles.

Acknowledgement

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References


A. Models elicitation

The general panel Markov switching model presented in this paper allows switching in both means and volatilities. It can be written as:

\[ X_{it} = \sum_{k=1}^{K} \mathbb{1}_{\{k\}}(S_{it})(\mu_{ik} + \sigma_{ik} \varepsilon_{it}), \quad \varepsilon_{it} \sim \mathcal{N}(0, 1) \]

with \( i = 1, \ldots, N \) where \( N \) is the number of series in the panel and \( t = 1, \ldots, T \), \( T \) being the length of the series of the panel. The total number of regimes is assumed to be equal to \( K \). The indicator function \( \mathbb{1}_{\{E\}}(X) \) takes value 1 if \( X \in E \) and 0 otherwise.

A.1. Model 1: heterogeneous states with heterogeneous transition mechanism

We assume \( S_{it} \) is a Markov chain with transition matrix:

\[ \mathbb{P}(S_{it}|S_{i,t-1}) = P_i \]

with \( i \in \{1, \ldots, N\} \). The transition matrices of the latent process for unit \( i \) can be written as:

\[ P_i = \begin{pmatrix} p_{i,11} & \cdots & p_{i,1K} \\ \vdots & \ddots & \vdots \\ p_{i,K1} & \cdots & p_{i,KK} \end{pmatrix} \]  

(A.1)

where \( P_{i,kl} \) represents the conditional probability that unit \( i \) moves from the latent regime \( l \) at time \( t-1 \) to the latent regime \( k \) at time \( t \). So then, \( P_{i,kl} \geq 0 \), \( P_{i,kl} = \mathbb{P}(S_{it} = k|S_{i,t-1} = l) \) and

\[ \sum_{l=1}^{K} P_{i,kl} = 1, \quad \forall i \in \{1, \ldots, N\}, \quad \forall k \in \{1, \ldots, K\} \]  

(A.2)

A.2. Model 2: heterogeneous states with homogeneous transition mechanism

Model 2 is presented as follows:

\[ X_{it} = \sum_{k=1}^{K} \mathbb{1}_{\{k\}}(S_{it})(\mu_{ik} + \sigma_{ik} \varepsilon_{it}), \quad \varepsilon_{it} \sim \mathcal{N}(0, 1) \]
with transition matrix: $\mathbb{P}(S_{it}|S_{i,t-1}) = P, \forall i \in \{1, \ldots, N\}, \forall t \in \{1, \ldots, T\}$

$$
\mathbb{P}(S_{it+1}|S_{it}) = P = \begin{pmatrix}
p_{11} & \cdots & p_{1K} \\
\vdots & \ddots & \vdots \\
p_{K1} & \cdots & p_{KK}
\end{pmatrix}
$$

(A.3)

A.3. Model 3: homogeneous states with homogeneous transition mechanism

Model 3 is presented as follows:

$$X_{it} = \sum_{k=1}^{K} 1_{\{k\}}(S_t)(\mu_k + \sigma_k \varepsilon_{it}), \quad \varepsilon_{it} \sim \mathcal{N}(0, 1)$$

with transition matrix: $\mathbb{P}(S_{t}|S_{t-1}) = P, \forall i \in \{1, \ldots, N\}, \forall t \in \{1, \ldots, T\}$

$$
\mathbb{P}(S_{t+1}|S_t) = P = \begin{pmatrix}
p_{11} & \cdots & p_{1K} \\
\vdots & \ddots & \vdots \\
p_{K1} & \cdots & p_{KK}
\end{pmatrix}
$$

(A.4)

B. Complete data Bayesian inference

B.1. Prior elicitation

A variety of priors can be used to estimate the panel Markov-switching model. For the three models proposed, we assume conjugate independent priors for the parameters. Table B.10 summarizes the different priors.

B.2. Posterior simulation

B.2.1. Model 1 of independence: imperfect cycle synchronization with space-heterogeneous transition

The posterior distribution of the unit specific mean growth rate of model 1 is proportional to the product of likelihood in (6) and the prior in table
Model 1: Strong multivariate non-synchronization

- \( \mu_{ik} \sim \mathcal{N}(m_{ik}, \tau_{ik}^2) \)
- \( \sigma_{ik}^2 \sim \mathcal{IG}(\alpha_{ik}, \beta_{ik}) \)
- \((p_{i,k1}, \ldots, p_{i,kK}) \sim \mathcal{Dir}(\delta_{i1}, \ldots, \delta_{iK})\)

Model 2: Imperfect synchronization

- \( \mu_k \sim \mathcal{N}(m_k, \tau_k^2) \)
- \( \sigma_k^2 \sim \mathcal{IG}(\alpha_k, \beta_k) \)
- \((p_{k1}, \ldots, p_{kK}) \sim \mathcal{Dir}(\delta_1, \ldots, \delta_K)\)

Model 3: Perfect synchronization

- \( \mu_{ik} \sim \mathcal{N}(m_{ik}, \tau_{ik}^2) \)
- \( \sigma_{ik}^2 \sim \mathcal{IG}(\alpha_{ik}, \beta_{ik}) \)
- \((p_{i,k1}, \ldots, p_{i,kK}) \sim \mathcal{Dir}(\delta_{i1}, \ldots, \delta_{iK})\)

Note: \( i \in \{1, \ldots, N\} \) and \( k \in \{1, \ldots, K\} \).

Table B.10: Conjugate priors: normal distribution for the means growth rate; Inverse Gamma distribution for the volatilities of the growth rate; Dirichlet distribution for the transitions probabilities of the regimes.

B.10 (see column 1 and row 2).

\[
\begin{align*}
 f(\mu_d|X_{1:T}, S_{1:T}, \theta_{1-\mu_d}) \propto & \exp\left\{-\frac{1}{2\tau_{id}}(\mu_d - m_d)^2\right\} \prod_{t=1}^{T} \exp\left\{-\frac{\xi_{i,t}}{2\sigma_{i,t}^2}(X_{it} - \mu_d)^2\right\} \\
 & \propto \exp\left\{-\frac{1}{2} \mu_d^2 \left(\frac{1}{\tau_{id}^2} + \frac{T_d}{\sigma_{d}^2}\right) - \mu_d \left(\frac{m_d}{\tau_{id}} + \frac{\sum_{t\in T_d} X_{it}}{\sigma_{d}^2}\right)\right\} \\
 & \propto \mathcal{N}(\overline{m}_{id}, \tau_{id}^2)
\end{align*}
\]

with \( \overline{m}_{id} = \frac{m_d}{\tau_{id}} + \frac{1}{\sigma_{d}^2} \sum_{t\in T_d} X_{it} \) and \( \tau_{d}^2 = \left(\frac{1}{\tau_{id}^2} + \frac{T_d}{\sigma_{d}^2}\right)^{-1} \).

We defined \( T_d = \{t = 1, \ldots, T|S_{it} = l\} \), \( \overline{T_d} = \text{card}(T_d) \), \( X_{1:t} = (X_1, \ldots, X_t) \), \( S_t = (S_{1t}, \ldots, S_{Nt}) \) and \( S_{1:t} = (S_1, \ldots, S_t) \). The notation \( \theta_{1-\mu_d} \) refer to the parameter in \( \theta_1 \) without \( \mu_d \).

The posterior distribution of the unit specific volatilities of model 1 is proportional to the product of likelihood in (6) and the prior in table B.10 (see column 1 and row 3).
The posterior distribution of each $l$-th row of the transition matrix $(p_{i,l1}, \ldots, p_{i,lK})$ of model 1 is proportional to the product of likelihood in (6) and the prior in table B.10 (see column 1 and last row).

$$f((p_{i,l1}, \ldots, p_{i,lK})|X_{1:T}, S_{1:T}, \theta_{1-l}) \propto \left( \frac{1}{\sigma_{i,l}^2} \right)^{(\alpha_{i,l}+1)} \exp\left\{ -\frac{\beta_{i,l}}{\sigma_{i,l}^2} \prod_{t \in T_{il}} \frac{1}{\sigma_{i,l}^2} \exp\left\{ -\sum_{t \in T_{il}} \frac{1}{2\sigma_{i,l}^2} (X_{il} - \mu_{il})^2 \right\} \right\}$$

$$\times \left( \frac{1}{\sigma_{i,l}^2} \right)^{(\alpha_{i,l}+T_{il}+1)} \exp\left\{ -\frac{1}{\sigma_{i,l}^2} \left[ \beta_{il} + \frac{1}{2} \sum_{t \in T_{il}} (X_{il} - \mu_{il})^2 \right] \right\}$$

$$\times IG(\alpha_{il} + T_{il}, \beta_{il} + \frac{1}{2} \sum_{t \in T_{il}} (X_{il} - \mu_{il})^2)$$

where $T_{il} = \text{card}\{t \in \{1, \ldots, T\}|S_{it} = l \text{ and } S_{i(l-1)} = k\}$.

B.2.2. Model 2 of imperfect synchronization: imperfect cycle synchronization with space-homogeneous transition

The posterior distribution of the unit specific mean growth rate of model 2 is proportional to the product of likelihood in (7) and the prior in table B.10 (see column 2 and row 2). It can be derived directly from the one of model 1 since the are almost of the same structure:

$$f((\mu_{i1}, \ldots, \mu_{iK})|X_{1:T}, S_{1:T}, \theta_{1-(\mu_{i1}, \ldots, \mu_{iK})}) \propto \left( \prod_{k=1}^{K} p_{i1,ik}^{(\delta_{ik} - 1)} \right) \prod_{i=1}^{K} \prod_{k=1}^{K} p_{i1,ik}^{(\xi_{i,l'}, i, k, i, -1)}$$

$$\times \prod_{k=1}^{K} \delta_{ik}^{d_{i-1}} \sum_{t=1}^{T} \xi_{i,l', i, k, i, -1}$$

$$\propto Dir(\delta_{il} + T_{il}, \ldots, \delta_{iK} + T_{iK})$$

where $T_{il} = \text{card}\{t \in \{1, \ldots, T\}|S_{it} = l \text{ and } S_{i(l-1)} = k\}$.

The posterior distribution of the unit specific volatilities of model 2 is proportional to the product of likelihood in (7) and the prior in table B.10 (see column 2 and row 3). Similarly, it can be derived directly from the one of model 1 because the are almost of the same structure:

$$f(\tau_{i1}, \ldots, \tau_{iK})|X_{1:T}, S_{1:T}, \theta_{2-\tau_{i1}} \propto \mathcal{N}(\mu_{il}, \tau_{il}^2)$$

with $\mu_{il} = \tau_{il}^2 (\frac{\mu_{il}}{\tau_{il}^2} + \frac{1}{\sigma_{il}^2} \sum_{t \in T_{il}} X_{ilt})$ and $\tau_{il}^2 = (\frac{1}{\tau_{il}^2} + \frac{T_{il}}{\sigma_{il}^2})^{-1}$. The posterior distribution of the unit specific volatilities of model 2 is proportional to the product of likelihood in (7) and the prior in table B.10 (see column 2 and row 3). Similarly, it can be derived directly from the one of model 1 because the are almost of the same structure:
The posterior distribution of each $l$-th row of the transition matrix $(p_{l1}, \ldots, p_{lK})$ of model 1 is proportional to the product of likelihood in (7) and the prior in table B.10 (see column 2 and last row).

\[
f(p_{l1}, \ldots, p_{lK} | X_{1:T}, S_{1:T}, \theta_{2-2}) \propto \prod_{k=1}^{K} p_{lk}^{(\delta_k - 1)} \prod_{i=1}^{T} \prod_{k=1}^{K} p_{lk}^{\xi_k \xi_{k, it-1}} \prod_{k=1}^{K} (\delta_k - 1 + \sum_{i=1}^{T} \sum_{k=1}^{K} \xi_{k, it-1}) \propto \text{Dir}(\delta_1 + \sum_{i=1}^{N} T_{i,l1}, \ldots, \delta_K + \sum_{i=1}^{N} T_{i,lK})
\]

B.2.3 Model 3 of perfect synchronization

The posterior distribution of the mean growth rate of model 3 is proportional to the product of likelihood in (8) and the prior in table B.10 (see column 3 and row 2).

\[
f(\mu | X_{1:T}, S_{1:T}, \theta_{3-\mu}) \propto \exp\{-\frac{1}{2\tau^2} (\mu - m)^2\} \prod_{i=1}^{N} \prod_{t=1}^{T} \exp\{-\frac{\xi_{it} (X_{it} - \mu)^2}{2\sigma_i^2}\} \propto \mathcal{N}(m, \tau_i^2)
\]

with $m = \frac{\bar{m} \sigma^2 + \frac{1}{\tau^2} \sum_{i=1}^{N} \sum_{t \in T_i} X_{it}}{\frac{1}{\tau^2} + \frac{1}{\sigma^2}}$ and $\tau_i^2 = \left(\frac{1}{\tau^2} + \frac{1}{\sigma^2} N T_i\right)^{-1}$.

The posterior distribution of the volatilities of model 3 is proportional to the product of likelihood in (8) and the prior in table B.10 (see column 3 and row 3).

\[
f(\sigma^2 | X_{1:T}, S_{1:T}, \theta_{3-\sigma}) \propto \left(\frac{1}{\sigma_i^2}\right)^{(\alpha_i + 1)} \exp\left\{-\frac{\beta_i}{\sigma_i^2} \right\} \prod_{i=1}^{N} \prod_{t \in T_i} \frac{1}{\sigma_i^2} \exp\left\{\sum_{i=1}^{N} \sum_{t \in T_i} \frac{-1}{2\sigma_i^2} (X_{it} - \mu_i)^2\right\} \propto \mathcal{IG}(\alpha_i + NT_i, \beta_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{t \in T_i} (X_{it} - \mu_i)^2)
\]

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The posterior distribution of each $l$-th row of the transition matrix $(p_{l1}, \ldots, p_{lK})$ of model 3 is proportional to the product of likelihood in (8) and the prior in table B.10 (see column 3 and last row). It can be derived directly from the one of model 2 because they are almost of the same structure:

$$f((p_{l1}, \ldots, p_{lK})|X_{1:T}, S_{1:T}, \theta_3) \propto \prod_{k=1}^{K} p_{lk}^{(\delta_k-1)} \prod_{t=1}^{T} \prod_{i=1}^{N} \prod_{k=1}^{K} p_{lk} \xi_{l,t,k-1} \prod_{k=1}^{K} \delta_{k-1}^{-1+N} \sum_{t=1}^{T} \xi_{l,t,k-1} \propto \text{Dir}((\delta_1 + NT_{l1}, \ldots, \delta_K + NT_{lK})$$

**B.3. Forward filtering backward sampling algorithm**

The forward filtering backward sampling algorithm also known as multi-move Gibbs sampling of hidden Markov chain has been proposed independently for Markov-switching autoregressive model (Chib (1996), Krolzig (1997), Kim and Nelson (1998), Kim and Nelson (1999)).

**B.3.1. Model 1 of independence**

By means of dynamic factorization, the full conditional distribution of the whole path of the unit specific hidden state is:

$$P(S_{i,1:T}|X_{1:T}, \theta_1) = P(S_{i,T}|X_{1:T}, \theta_1) \prod_{t=1}^{T-1} P(S_{i,t+1:T}|S_{i,t}, X_{1:T}, \theta_1)$$

The second term of the RHS can be written as follows:

$$P(S_{i,t}|S_{i,t+1:T}, X_{1:T}, \theta_1) \propto P(S_{i,t+1}|S_{i,t})P(S_{i,t}|X_{1:t}, \theta_1)$$

The second term of the RHS represents the transition probability. By dividing by the normalizing constant we have the following probability mass
function:
\[
P(S_{i,t} = k|S_{i,t+1:T}, X_{1:T}, \theta_1) = \frac{P(S_{i,t+1}|S_{i,t} = k)P(S_{i,t} = k|X_{1:t}, \theta_1)}{\sum_{i=1}^{K} P(S_{i,t+1}|S_{i,t} = l)P(S_{i,t} = l|X_{1:t}, \theta_1)}
\]

(B.1)

where \(P(S_{i,t} = k|X_{1:t}, \theta_1)\) is calculated by Hamilton filter algorithm.

Firstly, the multi-move algorithm assumes that, by forward recursion \(t = 1, \ldots, T\) the unit specific filtered state probability distribution \(P(S_{i,t} = k|X_{1:t}, \theta_1)\) are stored. Secondly, the filtered state \(S_{i,T}\) is drawn conditional on \(X_{1:T}\) and \(\theta_1\). At a third position, given \(S_{i,T}\) and based on (B.1), the sampling of the unit specific smoothed state \(S_{i,t}\) for \(t = T - 1, \ldots, 1\) is implemented by backward recursion. The algorithm of the filtering consists of two steps of forward recursion \(t = 1, \ldots, T\):

**Prediction step** We calculate the probability for \(i = 1, \ldots, N\) and \(l = 1, \ldots, K\)

\[
P(S_{it} = l|X_{1:t-1}, \theta_1) = \sum_{k=1}^{K} P(S_{it} = l|S_{it-1} = k)P(S_{it-1} = k|X_{1:t-1}, \theta_1)
= \sum_{k=1}^{K} p_{i,kl} P(S_{it-1} = k|X_{1:t-1}, \theta_1)
\]

(B.2)

where \(p_{i,kl}\) is the transition probability of unit \(i\). We initialize for \(t = 1\), \(P(S_{i,0} = k|X_0, \theta_1)\) to be equal to the ergodic probabilities.

**Update step** We calculate the probability for \(i = 1, \ldots, N\) and \(l = 1, \ldots, K\)

\[
P(S_{it} = l|X_{1:t}, \theta_1) = \frac{P(S_{it} = l|X_{1:t-1}, \theta_1)f(X_{it}|S_{it} = l, X_{1:t-1}, \theta_1)}{\sum_{k=1}^{K} P(S_{it} = k|X_{1:t-1}, \theta_1)f(X_{it}|S_{it} = k, X_{1:t-1}, \theta_1)}
\]

(B.3)

The algorithm of the smoothing consists of one step of backward recursion \(t = T - 1, \ldots, 1\):

**Smoothing step** We store the filtered states. We calculate the probability for \(i = 1, \ldots, N\) and \(l = 1, \ldots, K\)
\[ \mathbb{P}(S_t = l|X_{1:T}, \theta_1) = \sum_{k=1}^{K} \mathbb{P}(S_t = l, S_{t+1} = k|X_{1:T}, \theta_1) \]
\[ = \sum_{k=1}^{K} \mathbb{P}(S_t = l|S_{t+1} = k, X_{1:T}, \theta_1) \mathbb{P}(S_{t+1} = k|X_{1:T}, \theta_1) \]
\[ = \sum_{k=1}^{K} p_{i,k} \mathbb{P}(S_t = l|X_{1:t}, \theta_1) \mathbb{P}(S_{t+1} = k|X_{1:T}, \theta_1) \]
\[ \sum_{j=1}^{K} p_{i,j} \mathbb{P}(S_t = j|X_{1:t}, \theta_1) \]  
(B.4)

**B.3.2. Model 2 of imperfect synchronization**

The procedure remains typically the same like the case of independence model describes in the above subsection except that in (B.1), (B.2) and (B.4) the unit specific transition probabilities \( \mathbb{P}(S_t|S_{t-1}) \) are identical for all unit that is \( \mathbb{P}(S_t|S_{t-1}) = P \) exactly like in (4).

**B.3.3. Model 3 of perfect synchronization**

The procedure remains typically the same like the case of imperfect synchronization model describes in the above subsection except that (B.3) of updating step becomes:

\[ \mathbb{P}(S_t = l|X_{1:t}, \theta_3) = \frac{\mathbb{P}(S_t = l|X_{1:t-1}, \theta_3) \prod_{i=1}^{N} f(X_{it}|S_t = l, X_{1:t-1,-i}, \theta_3)}{\sum_{k=1}^{K} \mathbb{P}(S_t = k|X_{1:t-1}, \theta_3) \prod_{i=1}^{N} f(X_{it}|S_t = k, X_{1:t-1,-i}, \theta_3)} \]  
(B.5)