Crawford School of Public Policy

CAMA

Centre for Applied Macroeconomic Analysis

The gains from catch-up for China and the US: An empirical framework

---

CAMA Working Paper 7/2019
January 2019

Mardi Dungey
University of Tasmania
CFAP, University of Cambridge
Centre for Applied Macroeconomic Analysis, ANU

Denise R. Osborn
University of Manchester
University of Tasmania
Centre for Applied Macroeconomic Analysis, ANU

Abstract

As China becomes more closely entwined with the US, positive shocks in the US translate into positive outcomes for China, but the extent of gain for the US during the convergence process is less clear. We develop an empirical framework of two interacting open economies in which Chinese GDP per capita moves towards convergence and cointegration with the US, resulting in a time-varying structural VAR model. As a result, the impulse responses of the two countries to shocks are sensitive to the timing of the shock. The changing effects of US shocks are evident in the analysis, which shows that over the convergence process both the US and China unambiguously benefit from the catch-up process.

Keywords

China, SVAR, convergence, catch-up

JEL Classification

O11, O47, F63, F41

Address for correspondence:

(E) cama.admin@anu.edu.au

ISSN 2206-0332

The gains from catch-up for China and the US: An empirical framework*

Mardi Dungey*+^ and Denise R. Osborn&*^
* University of Tasmania
+ CFAP, University of Cambridge
^ CAMA, Australian National University
& University of Manchester

January 2019

Abstract

As China becomes more closely entwined with the US, positive shocks in the US translate into positive outcomes for China, but the extent of gain for the US during the convergence process is less clear. We develop an empirical framework of two interacting open economies in which Chinese GDP per capita moves towards convergence and cointegration with the US, resulting in a time-varying structural VAR model. As a result, the impulse responses of the two countries to shocks are sensitive to the timing of the shock. The changing effects of US shocks are evident in the analysis, which shows that over the convergence process both the US and China unambiguously benefit from the catch-up process.

JEL Categories: O11, O47, F63, F41

Keywords: China, SVAR, convergence, catch-up

*Mardi Dungey passed away in January 2019, shortly after this paper was completed. Both authors are grateful for comments from Ron Smith, Hashem Pesaran and seminar participants at Loughborough University, George Washington University and the University of the Balearic Islands. Author contact: denise.osborn@manchester.ac.uk.

1 Introduction

China is now the second largest economy in the world, behind only the US. It is well-recognised that trade has played a key role in China's "growth miracle", with its accession to the World Trade Organisation (WTO) in late 2001 a particular milestone (see, for example, Yao, 2014). It seems clear that China has benefited from increased economic interactions with the US and other developed economies, but it is less immediately evident whether the US has gained from the rise of China. One view is that the US has suffered from the increase in Chinese imports, with this seen particularly in declining manufacturing employment (Autor, Dorn and Hanson, 2013, Acemoglu, Autor, Dorn, Hanson and Price, 2016, Pierce and Schott, 2016). On the other hand, the recent analysis of Feenstra and Sasahara (2017) finds that this is outweighed by the associated increase in jobs (mainly in services) from higher US exports. Further, viewing China's accession to the WTO as a reduction in policy uncertainty, Handley and Limão (2017) conclude that this event improved the welfare of US consumers through reduced prices, again despite a decline in manufacturing employment.

The relationship between the US and China is of crucial importance for both countries. It is unsurprising that aggregate growth in China is relatively highly correlated with the US (Fidrmuc and Korhonen, 2016), but there is scant literature on the dynamic macroeconomic relationship between them. Although the structural VAR (SVAR) models of Pang and Siklos (2016) and Sun (2017) both find that China's growth responds to real US shocks, these papers consider only short-run interactions. A crucial issue for empirical models of China's interactions with the world economy is, however, how to represent China's extraordinary development over the last three decades in a framework that is coherent from both macroeconomic and econometric perspectives, including the long-run trajectory as well as short-run interactions.

This paper develops an SVAR (or, more precisely structural vector error-correction) model for China and the US which recognizes the time-dependent nature of the long-run relationship implied by China's development. Specifically, we use the literature on cross-country convergence, particularly Barro and Sala-i-Martin (1992), to define the long-run relationship between per capita Chinese and

US GDP. Building on the identification advances of Pagan and Pesaran (2008), Fisher, Huh and Pagan (2016) and Dungey and Osborn (2014), our approach effectively combines ideas drawn from the macroeconomic convergence literature, the time-varying generalization of cointegration ('asymptotic cointegration') suggested by Phillips and Sul (2007, 2009) and open economy SVAR identification.

The convergence literature hypothesizes that the mechanisms of international trade and finance (savings and investment), technology adoption, and innovation will eventually lead countries to reach a common long-run equilibrium in the level and/or growth of per capita output; see Islam (2003) for a review of the empirical convergence literature and Barro (2015) for recent results. Whether China might ultimately converge to reach US levels of per capita GDP is an open question[1], but its recent growth rate (around 10% pa over three decades since it opened to international influences at the end of the 1970s) is extraordinary. Nevertheless, per capita GDP of China in 2016 was only around 13 percent of the US value. Thus, despite the rapid growth in China, there remains considerable room for catch-up, particularly given that the US economy is expected to continue to grow in the intervening period to (potential) convergence. Our paper models the catch-up to date and projects this into the future.

As already noted, there have been few attempts to date to examine China and the US as interacting large open economies[2]. Pang and Siklos (2016) estimate a series of VAR models to examine this interdependence, finding significant spillovers from the US to China over their sample period of 1998-2014, but not vice versa. Using a similar time period (2001-2015), the US-China model of Sun (2017) yields results in broad agreement with those of Pang and Siklos (2016). Through the use of split samples, Kim, Lee and Park (2011) provide evidence of increased cross-country GDP spillovers for major East Asian countries with the US and G7 after the 1997/98 Asian financial crisis, while Bataa, Osborn and Sensier (2018) find increased correlations between China GDP growth and that of the US from

[1] Although not our focus, there is also a lively literature on regional convergence within China; Jarreau and Poncet (2012), Andersson, Edgerton and Opper (2013).

[2] A related strand of recent literature compares spillovers from China and the US on other economies, including Kim and Lee (2012) and Dungey and Vehbi (2015) for East Asia. In addition, interlinked models of the global economy have been used to focus on the role of China, for example McKibbin and Tang (2000) and applications of GVAR such as Cesa-Bianchi, Pesaran, Rebucci and Xu (2012).

around 2007. In an attempt to take account of change, Abeysinghe and Forbes (2005) incorporate time-variation in their SVAR covering Asian economies, the US and the rest of the OECD through the use of bilateral trade weights, finding that shocks originating in China generally have less than half the effect of those from the US on Asian economies. However, their sample period of 1978-1998 misses a large portion of the dramatic growth in the Chinese economy. Recent work by Dungey, Khan and Raghavan (2018) on updated data shows that the effect of China has increased, but also that the results are critically dependent on the identification assumption used for the decomposition of shocks.

This paper confronts change by combining advances in empirical modelling with theoretical frameworks in order to allow for bidirectionality in the relationship between China and the US in a data driven SVAR framework. Our results unambiguously show that as China converges towards the US, shocks originating in the technology leading country have increasing permanent impacts over time on both China and the US. Our estimates imply that a US shock in 1979 has own effects of 140% of the original shock at the 10 year horizon, but China accrues a benefit of only 20% of the shock. At the time of China's accession to the WTO, the effect on China is 70%, compared with 150% for the US. By the end of our sample (2016), our preferred specification (including a break for the WTO accession with faster convergence post-break) implies effects of 90% and 160% respectively, with the impact on China increasing to 110% at the 10 year horizon for a 2025 shock. Ultimately, when convergence has effectively been achieved, both countries experience permanent effects of 170% of an original shock sourced from the US. Hence, while China gains relatively more from convergence, the US also experiences substantial improvement due to the dynamic interactions between these economies. Consequently, our results imply that convergence boosts the gains to the technological leader from its own innovations.

The paper proceeds as follows. Section 2 gives the framework for convergence and Section 3 develops our methodology incorporating this into an empirically implementable dynamic specification, dealing particularly with issues of stationarity and estimating the rate of convergence. The data are described in Section 4. Section 5 covers our results, with sensitivity analysis for impulse responses due to shocks at different stages of the convergence process. Finally, Section 6 concludes.

2 Framework for Convergence

Consider the simple model in Barro and Sala-i-Martin (1992) which formalized the literature on convergence. Taking the standard Solow-Swan model (in capital intensive form so that we deal with capital per unit of labour and a Cobb-Douglas production function), the beta-convergence parameter so often estimated in the convergence literature comes from the dynamics in the convergence process, given by

$$\ln Y_t = (\ln Y_0)\, e^{-\beta t} + \ln(Y^*)(1 - e^{-\beta t}) \tag{1}$$

where Y_t is per capita output at t for a given economy, Y^* is the equilibrium steady state value, and Y_0 is the value at the base period. The convergence rate $\beta > 0$ can be expressed in terms of the underlying (constant) population growth rate, n, depreciation rate, δ, rate of time preference, ρ, the steady state growth rate of per capita output, capital and consumption, x where $\rho > n + (1 - \theta)x$ to satisfy transversality conditions and $\theta > 0$ is the intertemporal consumption substitution elasticity. Cross-country growth regressions investigated first by Barro (1991) subsequently concentrate on convergence via estimation of β. The Barro and Sala-i-Martin (1992) relationship between initial and final output per capita at time T for country i is given by

$$\frac{1}{T} \ln \frac{Y_{i,T}}{Y_{i,0}} = B - \frac{1 - e^{-\beta t}}{T} \ln(Y_{i,0}) + u_i$$

where u_i is a disturbance term and the constant is $B = x + (1 - e^{-\beta t})/T$. The most usual form seen in later analyses is

$$\Delta y_i = \alpha + \beta y_{i,0} + \gamma x_i + u_i$$

where Δy_i represents growth rate of country i, over the period in question, $y_i = \ln(Y_i)$ and x_i are relevant control variables. Subsequent conditioning on initial values of variables such as education and government expenditure resulted in estimates of the so-called conditional convergence rates of 2 to 3% across 98 countries that provides a useful a benchmark; see Barro and Sala-i-Martin (1992). A stream of later work addresses additional explanators, bias, alternative estimators and non-linear forms.

Our analysis is based on (1). To be more precise, with y_t representing log per capita GDP in China at year t and $y^* = \ln(Y_t^*)$ relating to the US as the mature economy representative of the attainable long-run equilibrium of per capita GDP, (1) becomes

$$\begin{aligned} y_t &= y_0 e^{-\beta t} + y_t^*(1 - e^{-\beta t}) \\ &= y_t^* + (y_0 - y_t^*)e^{-\beta t} \end{aligned} \tag{2}$$

where the second line of (2) explicitly expresses the path in terms of y^* and the catch-up, $(y_0 - y_t^*)(1 - e^{-\beta t})$. Note that, as in Cameron (2005), the US economy is assumed to be innovating, but it is not experiencing growth due to catch up engendered by mechanisms such as learning from a more advanced economy. Therefore, y^* is evolving and is replaced by y_t^*.

However, (2) effectively represents a single snapshot of the catch-up relationship. To be employed in a time series context, y_0 is replaced by an appropriate measure of what Chinese per capita output would be at t in the absence of any international influences, based on its own internal (closed economy) growth rate. On the basis that China would have remained a centrally planned economy, a constant underlying internal growth rate g^I is assumed[3].

With this modification to (2), the long-run catch-up relationship of China to the US becomes

$$y_t = y_t^* + (y_t^I - y_t^*)e^{-\beta t}. \tag{3}$$

The relationship of (3) can also be expressed as

$$y_t = y_t^I e^{-\beta t} + y_t^*(1 - e^{-\beta t}), \tag{4}$$

which explicitly shows China's per capita output at t as a weighted sum of what it would be based on its internal growth rate (y_t^I) and US per capita output (y_t^*). As t increases, the weight on y_t^* increases or, from (3), the gap with the US narrows. Clearly, as $t \to \infty$,

$$y_t = y_t^*, \tag{5}$$

representing the convergence of China's per capita output with that of the US.

[3]Internal technological progress is embedded in the growth coefficient g^I.

3 Methodology

3.1 Background

A number of previous empirical studies of convergence undertaken in a time series context have employed cointegration methods. For example, Pesaran (2007) uses the cross-country differences between log per capita output for pairs of economies, on the basis that stationarity in these differences is a necessary, although not sufficient, condition for convergence. Although such an approach is valid for testing whether economies have converged, as used by Pesaran (2007), it does not capture the convergence process, by which we mean the process by which an under-developed economy gradually adopts world-leading technology so that its per capita output ultimately converges to (or towards) that of the leader. This latter situation is the one of interest for China, which over the past four decades has moved from essentially a closed under-developed economy to become the second largest economy in the world, behind only the US.

When examining transition towards ultimate convergence, Phillips and Sul (2009 pp.1164-1166) show that the use of cointegration and unit root approaches have many potential pitfalls, essentially because a developing economy on a convergence path has time-dependent properties which need to be appropriately taken into account. They emphasize that evidence of no cointegration, in the conventional linear sense, does not rule out the possibility that they are on a convergence path. That is, conventional (linear) cointegration tests are not designed for the situation where one or more economies are in transition even when (in a terminology suggested by Phillips and Sul (2007, p.1778)) they are *asympototically cointegrated*. Where the difference between two processes/economies can be expressed in terms of some common process (say technology for example), $X_{it} - X_{it} = (\delta_{it} - \delta_{jt})u_t$, if both loadings, δ_{it}, δ_{jt} converge asympototically to a common loading δ, then these series are asympotically cointegrated as $t \to \infty$, even though within samples (particularly where u_t is changing faster than the loading parameters) conventional cointegration tests will have low power to detect the relationship.

To avoid these difficulties, Phillips and Sul (2007) develop a panel log-t convergence test, applied to test for club convergence across groups of economies in Phillips and Sul (2009). Based on results over 1970-2003 compared with 1960-

1985, they find evidence that China (along with some other countries) has begun a process of transition to the developed country group; see Phillips and Sul (2009: Figure 8, p.1177). Carvalho and Harvey (2005) use a common trends representation, which also allows for short-term deviations, to elicit convergence groups within historical European data. Employing the framework of the previous section, our analysis develops an econometric model in order to capture such long-run convergence for China towards the US.

3.2 Convergence model

Our empirical model corresponding to the convergence relationship of (3) is

$$y_t = y_t^* + (y_t^I - y_t^*)e^{-\beta t} + gap_t, \qquad t = 0, 1, 2, ..., \tag{6}$$

where y_t^I is understood to be an expected value and

$$gap_t = (y_t - y_t^*) - (y_t^I - y_t^*)e^{-\beta t} \tag{7}$$

is a zero mean transitory (short memory process).[4] Convergence is assumed to take place over a period denoted as $t = 1, 2, ...$ Prior to the start of convergence,

$$y_t = y_t^I + gap_t, \qquad t \leq 0. \tag{8}$$

In a closed centrally planned economy, such as China in the 1960s and early 1970s, the internally generated y_t^I is deterministic and (8) describes a trend stationary process. Subsequently, (6) describes the movement towards convergence, which (if it continues) ultimately leads to the final regime given by

$$y_t \to y_t^* + gap_t, \qquad t \to \infty, \tag{9}$$

in which $E[y_\infty] \to E[y_\infty^*]$. It is easy to see that (6) satisfies the two definitions of convergence proposed by Bernard and Durlauf (1996), interpreted as catching up and equality of long-term forecasts. That is,

$$\lim_{k\to\infty} E[y_{t+k} - y_{t+k}^* \,|\Omega_t] = 0 \tag{10}$$

[4]Lee, Pesaran and Smith (1997) canvassed the different outcomes from alternative specifications of the stochastic component, and proposed that the resulting beta-convergence estimate was closer to 30% - although standard values of population growth and depreciation rates are inconsistent with this result indicating a violation of their assumed convexity conditions.

where Ω_t is the information set available at t, represented in this case by all X_τ for $\tau \leq t$ and $X_t = (y_t,\, y_t^*,\, y_t^I)'$.

Analogously to (4), the relationship given by (6) and (8) can be written as

$$y_t = w_t y_t^* + (1 - w_t) y_t^I + gap_t \tag{11}$$

with the weight w_t on the role of the US for China at time t being

$$w_t = \begin{cases} 0 & t < 0 \\ 1 - e^{-\beta t} & t \geq 0 \end{cases} . \tag{12}$$

Further insight can be gained from (11) by noting that it implies China's growth rate at t can be decomposed as

$$\begin{aligned} \Delta y_t &= [w_t y_t^* + (1 - w_t) y_t^I + gap_t] - [w_{t-1} y_{t-1}^* + (1 - w_{t-1}) y_{t-1}^I + gap_{t-1}] \\ &= w_t(\Delta y_t^* - \Delta y_t^I) + \Delta w_t (y_{t-1}^* - y_{t-1}^I) + \Delta y_t^I + \Delta gap_t. \end{aligned} \tag{13}$$

This decomposition clearly shows that changes in the weights on the US through the convergence process play a key role for China's growth over time.

Returning to (6), y_t is unrelated to y_t^* for $t \leq 0$, but (making the reasonable assumption that US $y_t^* \sim I(1)$), y_t and y_t^* are cointegrated with coefficients (1, -1) and zero intercept as $t \to \infty$. This is a case of asymptotic cointegration and conventional tests for linear cointegration between y_t and y_t^* are inappropriate. Nevertheless, convergence implies that gap_t of (7) does not contain any unit roots and hence examination of the properties of the computed gap series after estimation of β in (6) is informative. Indeed, such an examination plays a crucial role in our empirical analysis and leads us to favour a specification in which the rate of convergence β is subject to a structural break during our sample period; see Section 5.

The convergence model of (6) is also related to the concept of smooth transition cointegration, where the cointegrating coefficients vary according to a nonlinear smooth transition function; see Saikkonen and Choi (2004). However, their model differs from the specification of interest to us in that the variables involved in smooth transition cointegration are unit root processes, whereas y_t in (11) is initially a trend stationary process that moves towards a cointegrating relationship.

3.3 Dynamics

In our application, the technology embedded in y_t^* (US per capita GDP) is assumed to be driven by a unit root process, with permanent shocks denoted by ε_t^*. Through (11), these permanent US shocks play a progressively greater role for China as convergence proceeds.

Our assumption is that the US is the technology leader to which China adjusts, and hence the dynamic model for China incorporates adjustment to *gap* of (7). Allowing dynamics, and analogously to the relationship used by Dungey and Osborn (2014) when analyzing Euro area GDP in relation to that of the US, the specification employed for China's growth in year t (Δy_t) is

$$\Delta y_t = \delta + \phi_0 \Delta y_t^* + \sum_{i=1}^{p} \phi_{1i} \Delta y_{t-i}^* + \sum_{i=1}^{p} \phi_{2i} \Delta y_{t-i} + \alpha\, gap_{t-1} + \varepsilon_t. \qquad (14)$$

Note that US growth in t affects China in (14) and this term captures any contemporaneous correlation between growth in the two countries. In other words, contemporaneous causality is assumed to run from the US to China, in line with the assumption that the US is the leading economy. Since China is assumed to absorb US technology, and not vice versa, the adjustment to the convergence relationship of (6) is undertaken only by China. However, short-run feedback may be bilateral, with the US equation given by

$$\Delta y_t^* = \delta^* + \sum_{i=1}^{p} \phi_{1i}^* \Delta y_{t-i}^* + \sum_{i=1}^{p} \phi_{2i}^* \Delta y_{t-i} + \varepsilon_t^*. \qquad (15)$$

The specification of (15) is based on the result of Pagan and Pesaran (2008) that an equation giving rise to permanent shocks in a structural error-correction model (SVECM) should not include adjustment to the long-run relationship. Thus, in the bivariate model of (14) and (15), ε_t^* are permanent shocks and are uncorrelated with the China growth shocks, ε_t, while both are temporally uncorrelated (including zero cross-equation temporal shock correlations). That is for $u_t = (\varepsilon_t^*, \varepsilon_t)$, then $E[u_t u_t'] = \Sigma$ with Σ diagonal and $E[u_t u_s'] = 0$ for $s \neq t$.

The specification of (14) and (15) assumes constant coefficients for all short-run responses. The possibility of structural breaks or evolution of coefficients could also be introduced, although the relatively short sample of observations available points towards the use of a parsiminous specification. Nevertheless, in the application we show that incorporating one structural break in the long-run model to allow for China's increased trade and internal investment from 2002 improves the model[5]. In effect, our model is a conventional SVECM specification, except for the crucial difference that China adjusts in relation to the time-dependent convergence relationship of (6) that defines gap_{t-1} in (14).

3.4 Implications

The inclusion of the long-run convergence relationship has important implications for the model's properties. For their analyses, Pagan and Pesaran (2008) and others use a representation of the time-invariant SVECM in terms of the variables with permanent shocks and the error-correction terms, all of which are stationary in that context. The analogy in our case is to write the system of (14) and (15) in terms of Δy_t^* and gap_t.

Employing the decomposition of (13) and considering the special case of $p = 1$ for ease of exposition, a little messy algebra leads to the system which can be written in matrix notation as

$$\begin{bmatrix} 1 & 0 \\ w_t - \phi_0 & 1 \end{bmatrix} \begin{bmatrix} \Delta y_t^* \\ gap_t \end{bmatrix} = \begin{bmatrix} \widetilde{\delta}_t^* \\ \widetilde{\delta}_t \end{bmatrix} + \begin{bmatrix} \phi_1^* + w_{t-1}\phi_2^* & \phi_2^* \\ \phi_1 + w_{t-1}\phi_2 & 1 + \alpha + \phi_2 \end{bmatrix} \begin{bmatrix} \Delta y_{t-1}^* \\ gap_{t-1} \end{bmatrix}$$

$$+ \begin{bmatrix} 0 & -\phi_2^* \\ 0 & -\phi_2 \end{bmatrix} \begin{bmatrix} \Delta y_{t-2}^* \\ gap_{t-2} \end{bmatrix} + \begin{bmatrix} 0 & \phi_2^* \Delta w_{t-1} \\ -\Delta w_t & \phi_2 \Delta w_{t-1} \end{bmatrix} \begin{bmatrix} y_{t-1}^* \\ y_{t-2}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t^* \\ \varepsilon_t \end{bmatrix} \tag{16}$$

where the non-stochastic terms are

$$\begin{aligned} \widetilde{\delta}_t^* &= \delta^* + \phi_2^*[(1 - w_{t-1})\Delta y_{t-1}^I - \phi_2^* y_{t-2}^I \Delta w_{t-1}] \\ \widetilde{\delta}_t &= \delta + (\phi_2 - 1)\Delta y_t^I - \phi_2 w_{t-1} \Delta y_{t-1}^I + y_{t-1}^I \Delta w_t - \phi_2 y_{t-2}^I \Delta w_{t-1}. \end{aligned}$$

The expression of (16) makes clear a number of implications of (6). In a time invariant specification, the vector (16) $z_t = (\Delta y_t^*,\ gap_t)'$ is stationary. However, due to convergence, not only are the coefficients in the equation for the convergence term gap_t time-varying in (16), but so are those for Δy_t^*.

[5] Otherwise informal investigation of time-variation in the coefficients resulted in only modest improvements in the fit of estimated equations.

Two points may be noted in particular. Firstly, (16) implies that US growth depends on its own past per capita GDP level, since y^*_{t-2} appears in the equation for Δy^*_t when $\Delta w_{t-1} \neq 0$. This is one source of nonstationarity in Δy^*_t during China's convergence. Secondly, the other source is that both the nonstochastic $\widetilde{\delta}^*_t$ and the own lag 1 US coefficient $(\phi^*_1 + w_{t-1}\phi^*_2)$ vary with w_{t-1}, namely with the time-dependent US weight for China in (11). In particular, for $\phi^*_2 > 0$ (that is, when lagged China growth has a positive effect on that for the US), the own US lag 1 coefficient $\phi^*_1 + w_{t-1}\phi^*_2$ increases as convergence progresses.

An important implication of this discussion is that although the US is the leading economy in our model, with only China responding to the convergence gap of (7) and time-invariant coefficients in (14) and (15), both the US and China have time-varying responses shocks. This time-variation will, however, be gradual since it depends on the evolution of the weights in (11). Nevertheless, it raises the possibility that the US itself benefits from China's catch-up, namely when there is positive feedback from growth in China to that in the US.

Of course, the model implies that China's growth is not (statistically) stationary during the period of convergence. Nevertheless, a well-specified system should exhibit short memory properties both in the period before convergence starts, when $w_t = 0$ for $t \leq 0$, and once convergence is complete, when $w_t \to 1$ for $t \to \infty$. To be specific, for $t \leq 0$, $d_t = y_t - y^I_t$ and the system is the VAR

$$\begin{bmatrix} 1 & 0 \\ -\phi_0 & 1 \end{bmatrix} \begin{bmatrix} \Delta y^*_t \\ gap_t \end{bmatrix} = \begin{bmatrix} \delta^* + \phi^*_2 \Delta y^I_{t-1} \\ \delta - \Delta y^I_t + \phi^*_2 \Delta y^I_{t-1} \end{bmatrix}$$
$$+ \begin{bmatrix} \phi^*_1 & \phi^*_2 \\ \phi_1 & 1+\alpha+\phi_2 \end{bmatrix} \begin{bmatrix} \Delta y^*_{t-1} \\ gap_{t-1} \end{bmatrix} + \begin{bmatrix} 0 & -\phi^*_2 \\ 0 & -\phi_2 \end{bmatrix} \begin{bmatrix} \Delta y^*_{t-2} \\ gap_{t-2} \end{bmatrix} + \begin{bmatrix} \varepsilon^*_t \\ \varepsilon_t \end{bmatrix}. \qquad (17)$$

Provided that the coefficient matrices of the $VAR(2)$ of (17) satisfy the stationarity conditions, and if Δy^I_t is constant over time, the vector $z_t = (\Delta y^*_t,\ gap_t)'$ will be short memory. However, in line with the discussion above, stationarity of $gap_t = y_t - y^I_t$ implies that the level of China per capita GDP (y_t) in (17) is trend stationary, namely stationary around the nonstochastic trend defined by y^I_t, whereas stationarity of Δy^*_t implies $y^*_t \sim I(1)$.

At the other extreme, as $t \to \infty$ and with all $w_t = 1$ at the limit, the system becomes

$$\begin{bmatrix} 1 & 0 \\ 1-\phi_0 & 1 \end{bmatrix} \begin{bmatrix} \Delta y_t^* \\ gap_t \end{bmatrix} = \begin{bmatrix} \delta_t^* \\ \delta_t \end{bmatrix}$$

$$+ \begin{bmatrix} \phi_1^* + \phi_2^* & \phi_2^* \\ \phi_1 + \phi_2 & 1+\alpha+\phi_2 \end{bmatrix} \begin{bmatrix} \Delta y_{t-1}^* \\ gap_{t-1} \end{bmatrix} + \begin{bmatrix} 0 & -\phi_2^* \\ 0 & -\phi_2 \end{bmatrix} \begin{bmatrix} \Delta y_{t-2}^* \\ gap_{t-2} \end{bmatrix} + \begin{bmatrix} \varepsilon_t^* \\ \varepsilon_t \end{bmatrix} \tag{18}$$

in which cointegration applies, provided that the coefficients of (18) satisfy the vector stationarity conditions. Thus, once convergence is complete, $z_t = (\Delta y_t^*, gap_t)'$ is short memory, now with $gap_t = y_t - y_t^*$, and $y_t^*, y_t \sim I(1)$.

3.5 Empirical implementation

Assuming a series to be available for y_t^I, three possibilities are considered for estimation of the convergence parameter β over a sample period $t = 0, 1, ..., T$ in (6), written as

$$y_t - y_t^* = (y_t^I - y_t^*)e^{-\beta t} + gap_t, \tag{19}$$

namely:

1. Direct estimation of β in (19) by non-linear least squares, with gap_t estimated as the resulting residual series.

2. Taking a conventional linear approximation to the exponential term in (19) as $e^{-\beta t} \approx 1 - \beta t$, which (after some simple manipulation) yields

$$y_t - y_t^I = -\beta(y_t^I - y_t^*)t + \widetilde{v}_t \tag{20}$$

   where $\widetilde{v}_t$ is influenced by both the approximation error and gap_t. The convergence coefficient β is then estimated by OLS, with the residuals used as the empirical measure of gap.

3. Approximating (19) as the multiplicative disturbance process

$$y_t^* - y_t = (y_t^* - y_t^I)e^{-\beta t + v_t}$$

and, after taking natural logarithms, estimate β by applying OLS to the regression[6]

$$\log(y_t^* - y_t) - \log(y_t^* - y_t^I) = -\beta t + v_t. \tag{21}$$

Empirical estimates of gap_t are then obtained by substituting the estimated β in (19)[7].

The second and third methods are convenient in requiring only OLS estimation and it is an empirical question as to how well these approximations work in practice compared to direct estimation. It should be noted that, while the linear approximation of (20) is widely used in empirical development analyses, the implied weight on the US, given by $\widehat{w}_t = \widehat{\beta}t$, can exceed unity when the t considered is sufficiently large. On the other hand, the implied US weights are based on (12) for the other two methods and hence cannot fall outside the admissable range $[0, 1]$.

As already mentioned, our empirical analysis finds evidence that the rate of convergence has changed during the sample period. Therefore, say an initial value β_0 applies over $t = 0, ..., t_1$ $(t_1 < T)$, with β_1 applying over $t_1 + 1, , , , T$. Assuming that the break date t_1 is known, (19) with β_1 replacing β cannot be used for estimation over the sub-sample from $t_1 + 1$ because the new convergence rate does not apply from $t = 0$. In the presence of a potential structural break, the modified specification

$$y_t = y_t^* + (y_t^I - y_t^*)e^{-(\gamma+\beta_1 t)} + gap_t, \qquad t = t_1 + 1, ...T \tag{22}$$

is employed, which takes account of the convergence achieved up to time t_1 through the parameter γ[8]. Approximations can be made to (22) analogous to (20) and (21)

[6] The identity $\log(a + b) = \log(a) + \log(1 + b/a)$ implies that

$$\log(y_t - y_t^*) = \log(y_t^I - y_t^*) - \beta t + \log\left[1 + \frac{gap_t}{e^{-\beta t}(y_t^I - y_t^*)}\right]$$

for which (21) provides an approximation when gap_t is small relative to $(y_t^I - y_t^*)e^{-\beta t}$.

[7] The log-t convergence test of Phillips and Sul (2007, 2009) employs a test regression similar to (21) in a non-parametric panel setting. Our focus, however, is parametric modelling.

[8] Formally, convergence achieved to the end of t_1 gives an exponential term $e^{-\beta_0 t_1}$ in (6). With β_1 applying for $t > t_1$, the post-break exponential term becomes $e^{-\beta_0 t_1 - \beta_1(t-t_1)}$. This restricted form is not enployed in (22) to recognize that (particularly with annual data) the break does not necessarily occur precisely at the end of period t_1.

discussed above.

4 Data

The data required for our exercise are the US and Chinese real per capita GDP figures in a common currency. We obtain these as the annual GDP/capita in US$ 2010 prices for US and China from the World Bank World Development Indicators database, with the sample period for our analysis being 1979 to 2016 after allowing for lags[9]. Although there is considerable debate in the literature about the quality of Chinese data, Sinclair (2012) shows that the extent of data revisions is comparable to those for the US. Similarly, Chow (2006) finds official China data to be at least reasonably accurate and are reliable for use in many macroeconomic analyses. Since our study primarily concerns long-run issues, we are confident that data limitations do not invalidate our findings.

Figure 1, which shows log per capita GDP for each of China and the US over 1979-2016, provides clear visual evidence that values for China are approaching (albeit still well below) those for the US. The extent of catch-up is remarkable: whereas China's per capita GDP was 1.1% of the US value in 1979, and still stood at only 3.9% in 2000, this rose to 13.2% in 2016. The challenge is to empirically model the time series relationship between these key international series.

4.1 China base period and internal growth rate

Implementation of our model also requires specification of y_t^I, namely the expected value of the internally generated log per capita GDP that would apply in China at t without catch-up. As already explained, a constant underlying internal growth rate g^I is assumed. To facilitate calculations of the series y_t^I, we assume $y_0^I = y_0$, where y_0 is the observed value of China per capita output for the base year from which convergence is assumed to take place over $t = 1, 2, ...$

To benchmark the value of g^I, note that China was essentially closed to international developments from 1950 until the late 1970s. During this period Maddison (2001) estimates that per capita GDP growth rate in China for 1950-1973 was

[9] The data were extracted on October 30, 2017. The IMF figures are in Geary-Khamis dollars (that is having equvialent PPP to US$ in 2010).

2.86%. However, during the same period there was population decline as the result of the famine associated with the Great Leap Forward from 1958, resulting in a population decline of 37%, or almost 40 million people between 1960 and 1962 according to the World Bank Development Indicators data (there are disputes around the estimates of population decline in this period but estimates generally range between 18 and 45 million people). This was followed by rapid population regrowth, which had already begun to slow before the imposition of the one-child policy in 1979. From 1979 onwards the population growth rates in the US and China have been remarkably similar, averaging around 1% per annum. This suggests that we do not need to adjust the internal rate of per capita growth for China (which would occur without catch-up) from 1979 for unusual changes in population. China's per capita GDP growth rate over 1950-1973, with a downwards adjustment to account for the large fluctuations in population experienced in the early 1960s, suggests 2% as the upper limit of plausible values for g^I. Our principal empirical analysis employs $g^I = 0.01$, but robustness analysis for other plausible values of g^I yield qualitively similar results (results not reported to conserve space). Of course $g^I = 0$ implies that China's underlying per capita GDP would have remained constant had the economy not been opened to international influences.

We generate the internal rate of growth using g^I from the base year (where $t = 0$) of 1979. A number of authors, including Andersson, Edgerton and Opper (2013), Brandt, Ma and Rawski (2014) and Yao (2014) date the reform period in China from the late 1970s. By the end of the decade Mao had died and the Cultural Revolution ended, the one child policy imposed, economic reform was beginning, and, arguably, early aspects of China's gradual opening to the international economy were taking place. This choice also avoids the worst of the OPEC and currency crises of the early 1970s and subsequent world stagflation, although it does incorporate the second oil price shock and subsequent US double-dip recession and problems associated with the monetary targeting regime in the early 1980s.

5 Results

This section details the performance of the framework in modelling the interactions between the Chinese and US economies via GDP per capita when emedded in a data-driven VAR model with the long-run relationships given by (6) in which China converges to the US. Specification tests support a VECM(1) structure, with $p = 1$ in (14) and (15), equivalent to a VAR(2) in the levels of the variables, with higher order lags not significant according to residual autocorrelation tests applied to the VECM(1).[10] For reasons of empirical tractability estimation is undertaken in two stages, with the convergence rate estimated in the first stage and the short-run dynamics in the second.

5.1 Convergence rates

Table 1 gives the estimates for β obtained employing each of the three methods discussed in Section 3.5, with the first column showing those obtained using data over the entire sample of 1979 to 2016. In the table, Exp is the underlying model of (6) in which β is estimated by non-linear least squares, while Linear refers to the conventional linear approximation given by (20) and Log Diff employs the linear form of (21). As discussed above, the assumed internal growth rate used to construct y^I for China is $g^I = 0.01$ (that is, 1%) from 1979 as the base year. Note that $\widehat{\beta}$ is expressed as a percentage in the table.

Table 1: Convergence rate estimates (%)

	1979-2016	1979-2001	2002-2016
Exp	2.00	1.74	3.21
Linear	1.55	1.52	1.70
Log Diff	2.07	1.76	3.18

The catch-up by China to the US implied by the estimates over 1979-2016, at 1.5-2%, may appear to be low, although it is to be recalled that these are measured in relation to an assumed internal rate of growth rather than a constant value. Indeed, we initially anticipated a higher rate of convergence, based on

[10] Recall the data are annual so this corresponds to the use of 4 (12) lags with quarterly (monthly) data.

evidence in papers such as Cameron (2005) and McQuinn and Whelan (2007). Sala-i-Martin (1996) notes that the 35 year convergence horizon implied by beta convergence estimates of 2% are not intuitively attractive, however, Barro (2015) provides evidence that 2% is consistent with a so-called 'iron law' of (conditional as opposed to unconditional) convergence. Phillips and Sul (2009) argue that there are many potential paths a country may take to convergence and describe three phases (Phillips and Sul, 2009, (pp.1159-1162): an initial phase (A), a phase 'beginning to turn the economy around' (B) and a catching-up and convergence phase (C), with (based on their analysis over 1953 to 2003) China expected to enter Phase C.

As discussed in section 3.4, the convergence model of (6) implies that the series *gap* is a zero mean short memory series. However, as seen in Figure 2, the *gap* estimates we obtain using the Exp and Log Diff convergence rate estimates (computed as in section 3.5) are unsatisfactory from this perspective. In particular, they exhibit an upward trend from around 2000 until the end sample. Consequently, China's actual per capita output growth in the latter part of the sample is substantially larger than implied by the model with a 1.5-2% annual catch-up to the US, suggesting that the rate of convergence may not be constant over our sample period of 1979 to 2016.

The estimates in Table 1 include the possibility of a structural break at the end of 2001 in equation (6), with this date selected due to China's accession to the WTO in December of that year[11]. Both Amiti, Dai, Feenstra and Romalis (2017) and Handley and Limão (2017) identify this event as an important break in the US-China relationship, while Yao (2014, p.961) estimates that 30% of China's GDP growth over 2002-2008 can be attributed to the growth of exports as a consequence of its WTO membership. Examining initially the direct non-linear estimates (Exp) obtained from (22), our results indicate that the rate of convergence of China to the US nearly doubles from around 1.7% per year until 2001 to 3.2% subsequently. The corresponding *gap* series are also included in Figure 2 and are much more (statistically) satisfactory than those that do not allow for a break. For both economic and statistical reasons our subsequent analysis therefore focuses primarily

[11]A contributing factor to any change in the rate of convergence around this period may be the slowdown in US productivity growth, dated by Syverson (2017) to apply from 2005.

on the break specification.

Some comments are also in order about how the linear regressions of (20) and (21) perform in yielding estimates of β which provide good approximations to those of the non-linear rate regression of (6). It is clear that Linear, the linear approximation, results in poor estimates, which are not only always less than those from (6), but also apparently substantially under-state the speed-up in convergence after 2001. Put a different way, the conventional linear approximation provides little indication of a change in the rate of convergence after China joined the WTO. Although Figure 2 indicates that the time series pattern of the *gap* estimates from this approximation are broadly similar to those given by the non-linear break model, this is effectively a chance occurrence. On the other hand, the Log Diff approximation of (21), both without and with a break, leads to estimates that are relatively close to the corresponding ones from the underlying non-linear model and hence the *gap* estimates are very similar.

5.2 Impulse responses

Our focus on the debate about how the catch-up and opening of the Chinese economy affect the US leads us to focus first on the impact of US sourced shocks on both the US and Chinese economies. Using our preferred specification, namely the exponential form with break, we now analyze this problem in some detail. Recall from Section 3.4 that the impulse responses are time-varying depending on the point at which they are assessed reflecting the changing weights (see equation 16). Figures 3 and 4 present the impulse responses of unit shocks sourced from the US and China respectively on both the US and China for a 50 year horizon at five different potential impact points. These are chosen as the beginning of the sample, 1979, a point shortly post the WTO entry break-point in 2003, the end of the data sample in 2016, a projection to 2025, and a projection 150 years after the start of the process (namely 2129).

Bootstrapped confidence intervals for the 1979, 2003, 2016, and 2129 shock scenarios for the four sets of impulse responses are provided in Figure 5, with the 2025 shock omitted only for ease of representation. The confidence intervals are 1 standard deviation bands from 5000 draws using a naive bootstrap with size scaling $(T(T-Kp-1)^{-1})^{-1/2}$ where T is sample size, K the number of endogenous variables, and p the number of lags. Our draws are conditional on the estimated rates of convergence from the first stage estimation. Although there is a substantial literature on problems with coverage with the naive bootstrap, see for example Pesavento and Rossi (2006), Lütkepohl, Staszewska-Bystrova and Winker (2015, 2017), it does not propose a solution for VECM models of the form we have, and the problem with time-varying weights has not yet been considered. Consequently, we choose to remain with the relatively conservative naive bootstrap.

Figure 3 makes clear that the process of convergence means that the US shock implies different outcomes at different periods. Consider first the shock occuring in 1979. The effect of the shock on the US in the left-hand panel rises initially to a multiplier of just over 1.3, before declining a little and then resuming the general path towards the higher level of final output that would ultimately be achieved when convergence between the two is complete. A shock in 2003 indicates that the benefits to the US of this shock accrue earlier (eg in the first 20 years), because the Chinese GDP per capita is closer to convergence with that of the US and hence provides stronger feed-back to the US from the initial shock. This is evident in the continued increase in the short term impact of the US shock in both the 2016 and 2025 scenarios. The effects of being very close to complete convergence are evident in the 2129 impulse responses. Here the impact at 10 years is greater than the final impact, that is there is an overshooting of the long-run converged rate of growth in response to a temporary shock to technology from the US.

The Chinese responses to the US sourced shock are shown in the right-hand panel of Figure 3. A remarkable aspect is the change in the nature of the impulse responses in the years soon after the shock. The response in China to a US shock in 1979 initially results in an insignificant effect (with negative sign in years 3-6) for the first 9 years of the impulse (Figure 5). For a 2003 shock the inital dip has disappeared, and the impulse response is significantly positive after 5 years. The uncertainty about the initial response continues throughout the different time periods, as even in the 2129 scenario the first three years have (positive) insignificant responses, but thereafter are strongly positive and significant. What is most evident in the China responses of Figure 3 is the 'humped' response at around the 10 year mark, followed by convergence towards the common path. In the case of

China, as the scenarios progress through time, and China is closer to convergence with the US, the 'hump' is larger and the relative slope of the post-10 year path in the impulse response is lower.

A comparison of the responses to the 2003 shocks across the two panels reveals that considerable progress towards convergence has been made by early in the new millenium. With convergence largely achieved by 2129, both countries have almost identical long-run responses to the US shock (note the different vertical scales in the two panels of Figure 3).

While the US always accrues more benefit than the initial unit US shock as a permanent effect in each of the scenario years, China does not. In 1979 China had only accrued some 0.2 of the shock by the 10 year mark, compared with 1.4 times in the US. By the time of the break (the 2003 scenario) the unit shock to the US results in a 10 year horizon impact of 0.7 for China and 1.5 for the US. By the end of the sample period the Chinese response is 0.9, and by 2025 is 1.1, while for the US the effect is 1.6 (to 1 decimal place) for both shock periods. In the 2129 scenario, and due to convergence, they both receive an equivalent impact of the unit shock at 10 years, at 1.7 times the initial US shock. Thus, as convergence progresses, not only does the Chinese economy obtain an improved impact from a US originated shock, but the US also gains substantially. Both economies are unambiguously better off.

Although not our main interest in this paper, we also briefly examine the effects of Chinese generated shocks on the system. In our specification these are temporary shocks and so do not have long term impacts. Figure 4 provides the corresponding scenario analysis to Figure 3 focussing on China originated shocks. It is clear that the difference in outcomes is far less pronounced for the different timings of the shock (all negative values shown are insignificant, see Figure 5), and the outcomes reflect that there are no permanent effects from China in this model, as the US is the proxy for world technology developments. In the future China may become an equivalent source (or even main provider) of technological shocks, in which case the required framework becomes similar to that modelled with a world technology shock such as explored for the US and Euro Area in Dungey and Osborn (2014). However, this paper is concerned with modelling progress through the catch-up period.

5.3 Robustness to alternative specifications

We now present some robustness results in comparison to the non-linear exponential specification with convergence break aligned with China joining the WTO. Again we concentrate on the effects of US shocks on both economies where the shock originates at different times. Figure 6 contains eight panels, where the top row shows US responses and the bottom row the Chinese responses while each column represents periods when the shocks are applied; 1979, 2003, 2016 and 2129. (We do not include the 2025 scenario analyzed in Figures 3 and 4 to conserve space.) The figure shows the impulse responses formed by four different approaches, namely the three convergence rate estimation methods discussed in section 3.5, each without a break, and the preferred non-linear Exp model with a break (denoted Break in the figure). The Log Diff and Exp forms are very similar in each case, suggesting that a quick means of examining non-linear convergence through the log linearization suggested in equation (20) is a reasonable way to proceed; they can effectively be treated as the same outcome for analytical purposes in what follows. Similarly, had a convergence break been incorporated in the Log Diff form, this would result in very similar responses to those shown for the Break specification.

The alternative specifications of Linear, Log Diff/Exp and Break have at times quite different properties. First, the time to convergence of the Linear, Log Diff/Exp forms are clearly longer than the Break specification, which is a direct consequence of the higher post-break convergence rate estimate in Table 1. Second, in the 1979 scenario, when convergence is not well advanced, the effects of US shocks on China are negative in the Linear and Log Diff/Exp forms for a sustained period, which makes little economic sense. This period of negativity has become shorter for a 2003 shock, and all the models show a long term positive effect on China from the US shock (at around 50% of the initial shock). By 2016 the US shock on China has a higher long-term impact of almost 1:1 for three of the models, but the Break model shows the continued effect of the higher convergence rate in place after the WTO accession.

The most pronounced difference between the results is shown in the 2129 scenario in the final column of Figure 6. In this scenario the Break and Log Diff/Exp models converge to around 1.7 times the impact of the original shock, with this value common to both the US and China. The Linear model now displays its unattractive properties in not respecting the weighting conditions outlined in section 2[12]. This is evident in that the unit shock to the US now produces a linear model long-run response of 2.8 in the US and 6.6 in China. On the strength of the comparisons demonstrated in Figure 6 and associated analysis we prefer the Break model as specified in the text, consisting of the non-linear specification in exponential form as discussion in the body of the main results, but also note that the Log Diff model with a break would yield very similar results.

Although details are not shown, we have also verified that our substantive results are not sensitive to the assumption of China having an internal rate of growth of $g^I = 0.01$. For example,an assumption of $g^I = 0.02$ yields qualitatively very similar results to those presented in Figures 2 to 6.

6 Conclusion

This paper tackles the issue of the extent to which the US may or may not gain from the rapid development of China. More formally we examine whether two open economies both gain from convergence when one is rapidly developing and the other is operating at an already high per capita GDP. We develop an empirically driven, theoretically consistent, macroeconometric framework to examine this question using a SVAR model anchored by identification via convergence theory in which China is expected to catch up to the US in the long run. The concept of 'asymptotic cointegration', where two non-stationary series approach cointegration in the long run, is used to implement the convergence identification.

In this convergence framework, the SVAR becomes time-varying via the changing weights embodied in the long-run effect of the US on China. Consequently, and as explored analytically, impulse responses are sensitive to the point in time at which a shock is implemented. Empirical implementation uses annual GDP per capita for China and the US over 1979-2016, with our preferred specification

[12]The weights could be forced to be less than unity by using the Linear model estimate and then computing weights using the exponential formula, as effectively implemented for the Log Diff estimates. However, as shown in Table 1 and discussed above, the conventional linear specification is a poor approximation to the underlying non-linear model in this context.

including a break in the rate of convergence at the beginning of 2002 attributed to China's accession to the WTO. We also demonstrate that, in our context, a conventional linear approximation under-estimates the convergence rate compared with the underlying non-linear exponential specification, but that a log-difference linear approximation performs well.

Our main results show that the gains to both the US and China from convergence are unambiguously positive. Convergence implies that both economies will ultimately have identical gains to a permanent US sourced shock, and we estimate these effects at a 10 year horizon would be about 170% of the magnitude of the shock. In contrast, at the beginning of the convergence process, a shock in 1979 has estimated effects of 140% for the US and only 20% for China. Therefore, both economies received far larger permanent effects from a technology shock after convergence than they could expect earlier in the convergence process. Convergence and catch-up does not just benefit the emerging country, but has a substantial positive impact for the high GDP per capita country. This is an important source of increased productivity enhancement for both players, and at aggregate level both are better off.

Caveats of course remain. Because the aggregate is better off does not mean that all individuals or industrial sectors will gain. As witnessed in recent years employment in US manufacturing has declined, while service export employment and consumer prices are reduced in response to the emergence of China. Internal redistribution of the gains from the convergence process remain an issue for policymakers. However, there is no doubt from our results that convergence ultimately benefits both of the countries involved. One could question of whether the US will continue to be the technological leader as implied in this paper. Accommodating counterfactuals for this type of question requires the development of a structural framework, which is not informed by the data in the way we propose here. Finally, whether Chinese institutional and political systems will support continued converengence has been questioned based on historical precedence. Brandt, Ma and Rawski (2014) provide a long-term perspective on growth, convergence and divergence in China as far back as the Song dynasty (10th century), comparing and contrasting conditions with those supporting the most recent growth, but are not able to be definitive on this question.

References

[1] Abeysinghe and Forbes, K. (2005) "Trade Linkages and Output-Multiplier Effects: A Structural VAR Approach with a Focus on Asia", *Review of International Economics*, 13(2), 356-375.

[2] Acemoglu, D., Autor, D., Dorn, D., Hanson, G. and Price, B. (2016) "Import Competition and the Great US Employment Sag of the 2000s", *Journal of Labor Economics*, 34:S1, S141-S198.

[3] Amiti, M., Dai, M., Feenstra, R. and Romalis, J. (2017) "How did China's WTO Entry Benefit Consumers?", NBER Working Paper 23487.

[4] Andersson, F., Edgerton, D. and Opper, S. (2013) "A Matter of Time: Revisiting Growth Convergence in China", *World Development*, 45, 239-251.

[5] Autor, D.H., Dorn, D. and Hanson, G.H. (2013) "The China Syndrome: Local Labor Market Effects of Import Competition in the United States", *American Economic Review,* 103(6), 2121-2168.

[6] Bataa, E., Osborn, D.R. and Sensier, M. (2018) "China's Increasing Global Influence: Changes in International Growth Linkages", *Economic Modelling*, forthcoming.

[7] Barro, R.J. (1991) "Economic Growth in a Cross Section of Countries", *The Quarterly Journal of Economics*, 106(2), 407-443.

[8] Barro, R.J. (2015) "Convergence and Modernisation", *The Economic Journal*, 125(585), 911-942.

[9] Barro, R.J. and Sala-i-Martin, X. (1992) "Convergence", *Journal of Political Economy*, 100(2), 223-251.

[10] Bernard, A.B. and Durlauf, S.N. (1996) "Interpreting Tests of the Convergence Hypothesis", *Journal of Econometrics*, 71, 161-173.

[11] Brandt, L., Ma, D. and Rawski, T.G. (2014) "From Divergence to Convergence: Reevaluating the History behind China's Economic Boom", *Journal of Economic Literature*, 52(1), 45-123.

[12] Cameron, G. (2005) "The Sun Also Rises: Productivity Convergence between Japan and the USA", *Journal of Economic Growth*, 10(4), 387-408.

[13] Carvalho V. and Harvey A. (2005) "Convergence in the Trends and Cycles of Euro-Zone Income", *Journal of Applied Econometrics*, 20, 275-289.

[14] Cesa-Bianchi, A., Pesaran, M.H., Rebucci, A. and Xu, T. (2012) "China's Emergence in the World Economy and Business Cycles in Latin America", *Economia (The Journal of LACEA)*, 12(2), 1-70.

[15] Chow, G. (2006) "Are Chinese Official Statistics Reliable?", *CESInfo Economic Studies*, 52(2), 396-414.

[16] Dungey, M., and Vehbi, T. (2015) "The Influences of International Output Shocks from the US and China on ASEAN Economies", *Journal of Asian Economics*, 39, 59-71.

[17] Dungey, M., Khan, F. and Raghavan, M. (2018) "International Trade and the Transmission of Shocks: The Case of ASEAN-4 and NIE-4 Economies", *Economic Modelling*, 72, 109-121.

[18] Dungey, M. and Osborn, D.R. (2014) "Modelling Large Open Economies with International Linkages: The USA and Euro Area", *Journal of Applied Econometrics*, 29(3), 377-393.

[19] Feenstra, R.C. and Sasahara, A. (2017) "The 'China Shock', Exports and U.S. Employment: A Global Input-Output Analysis", National Bureau of Economic Research Working Paper Series No. 24022.

[20] Fidrmuc, J. and Korhonen, I. (2016) "Meta-analysis of Chinese Business Cycle Correlation", *Pacific Economic Review*, available in early-view.

[21] Fisher, L.A., Huh, H-S., and Pagan, A.R. (2016) "Econometric Methods for Modelling Systems with a Mixture of I(1) and I(0) Variables", *Journal of Applied Econometrics*, 31(5), 892-911.

[22] Handley, K. and Limão, N. (2017) "Policy Uncertainty, Trade, and Welfare: Theory and Evidence for China and the United States", *American Economic Review*, 107(9), 2731-2783.

[23] Islam, N. (2003) "What have we Learnt from the Convergence Debate?", *Journal of Economic Surveys*, 17(3), 309-362.

[24] Jarreau, J. and Poncet, S. (2012) "Export Sophistication and Economic Growth: Evidence from China", *Journal of Development Economics*, 97(2), 281-292.

[25] Kim, S. and Lee J.-W. (2012) "Real and Financial Integration in East Asia", *Review of International Economics,* 20(2), 332-349.

[26] Kim, S. and Lee, J.-W. and Park, C.-Y. (2011) "Emerging Asia: Decoupling or Recoupling", *The World Economy*, 34(1), 23-53.

[27] Lee, K., Pesaran, M.H. and Smith, R. (1997) "Growth and Convergence in a Multi-Country Empircial Stochastic Solow Model", Journal of Applied Econometrics, 12, 357-392.

[28] Lütkepohl, H., Staszewska-Bystrova, A. and Winker, P. (2015) "Confidence Bands for Impulse Responses: Bonferroni Versus Wald", *Oxford Bulletin of Economics and Statistics*, 77(6), 800-821.

[29] Lütkepohl, H., Staszewska-Bystrova, A. and Winker, P. (2017) "Calculating Joint Confidence Bands for Impulse Response Functions using Highest Density Regions" *Empirical Economics*, forthcoming.

[30] McKibbin, W.J. and Tang, K.K. (2000) "Trade and Financial Reform in China: Impacts on the World Economy", *The World Economy*, 23(8), 979-1003.

[31] McQuinn, K. and Whelan, K. (2007) "Conditional Convergence and the Dynamics of the Capital-Output Ratio", *Journal of Economic Growth*, 12(2), 159-184.

[32] Maddison, A. (2001) *The World Economy: A Millenial Perspective*, OECD, Paris.

[33] Pagan, A.R. and Pesaran, M.H. (2008) "Econometric Analysis of Structural Systems with Permanent and Transitory Shocks", *Journal of Economic Dynamics and Control*, 32(10), 3376-3395.

[34] Pang, K. and Siklos, P.L. (2016) "Macroeconomic Consequences of the Real-Financial Nexus: Imbalances and Spillovers between Chinese and the US", *Journal of International Money and Finance*, 65, 195-212.

[35] Pesaran, M.H. (2007) "A Pair-Wise Approach to Testing for Output and Growth Convergence", *Journal of Econometrics*, 138(1), 312-355.

[36] Pesavento, E. and Rossi, B. (2006) "Small-Sample Confidence Intervals for Multivariate Impulse Response Functions at Long Horizons", *Journal of Applied Econometrics*, 21(8), 1135-1155.

[37] Phillips, P.C.B. and Sul, D. (2007) "Transition Modelling and Econometric Convergence Tests", *Econometrica*, 75(6), 1771-1855.

[38] Phillips, P.C.B. and Sul, D. (2009) "Economic Transition and Growth", *Journal of Applied Econometrics*, 24(7), 1153-1185.

[39] Pierce, J.R. and Schott, P.K. (2016) "The Surprisingly Swift Decline of US Manufacturing Employment", *American Economic Review*, 106(7), 1632-1662.

[40] Saikkonen, P. and Choi, I. (2004) "Cointegrating Smooth Transition Regressions", *Econometric Theory*, 20(2), 301-340.

[41] Sala-i-Martin, X.X. (1996) "The Classical Approach to Convergence Analysis", *The Economic Journal*, 106(437), 1019-1036.

[42] Sinclair, T.M. (2012) "Characteristics and Implications of China Macroeconomic Data Revisions", Working Paper IIEP-WP-2012-09, George Washington University.

[43] Sun, W. (2017) "Business Cycle Synchronization and Monetary Policy Coordination between the US and China: Evidence from a Structural VAR Model", *The Chinese Economy*, 50(1), 3-20.

[44] Syverson, C. (2017) "Challenges to Mismeasurement Explanations for the US Productivity Slowdown", *Journal of Economic Perspectives*, 31(2), 165-186.

[45] Yao, Y. (2014) "The Chinese Growth Miracle", *Handbook of Economic Growth*, *Volume 2B*, Chapter 7 (pp.943-1031), Elsevier.

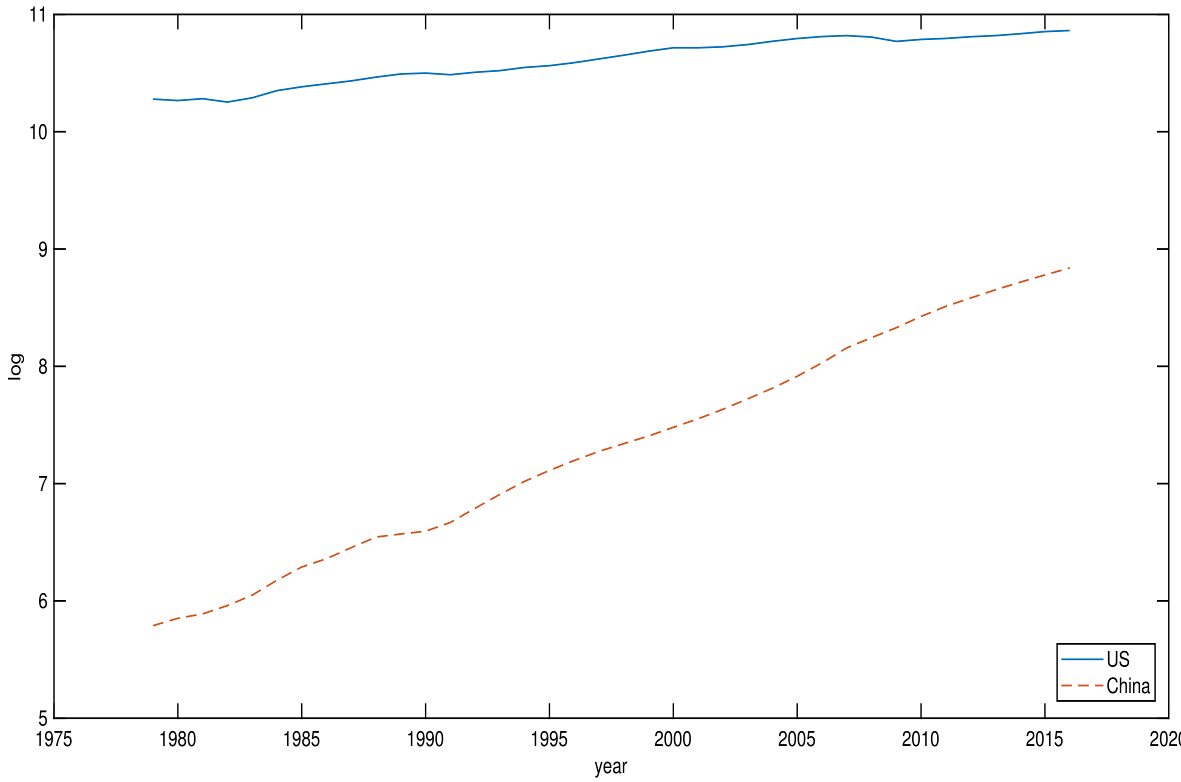

Figure 1: Log per capita GDP for the US and China for 1979 to 2016. Source data is from World Development Indicators.

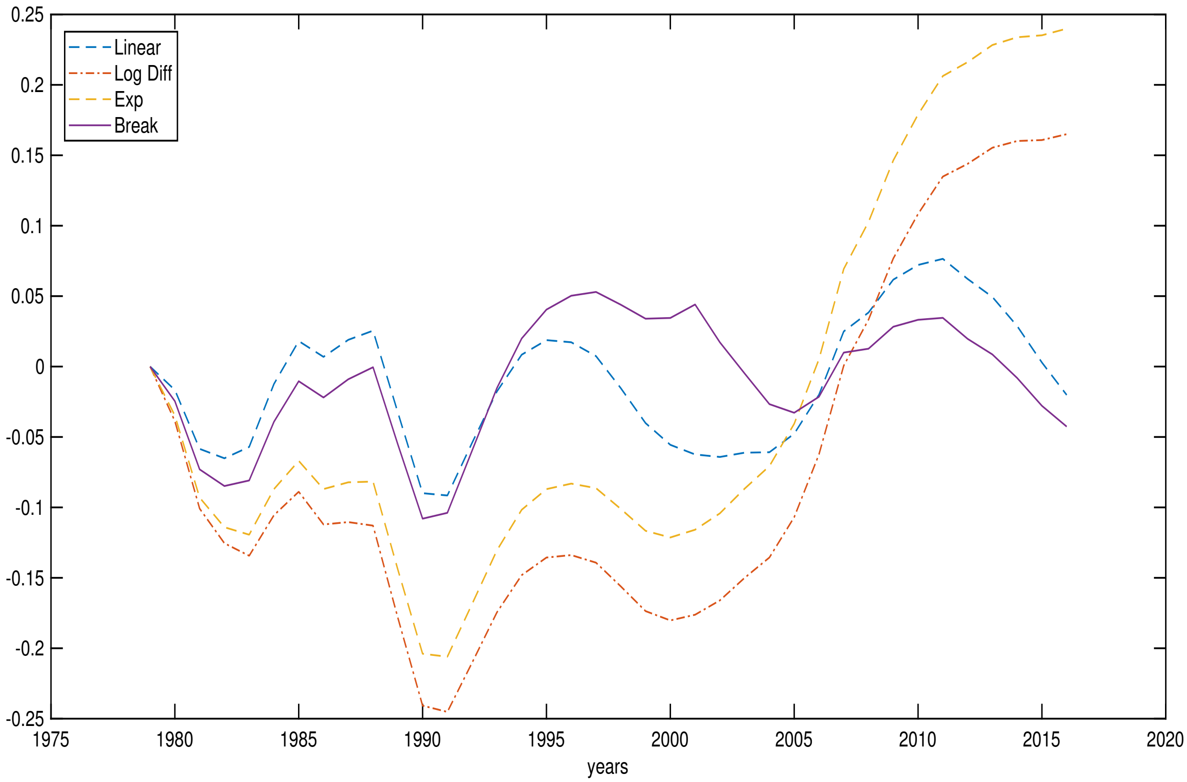

Figure 2: Estimated gaps for each specification: Linear represents equation (20), Log Diff is for equation (21), Exp is the non-linear form of equation (6) and Break is the non-linear form of (22) with a break in 2002.

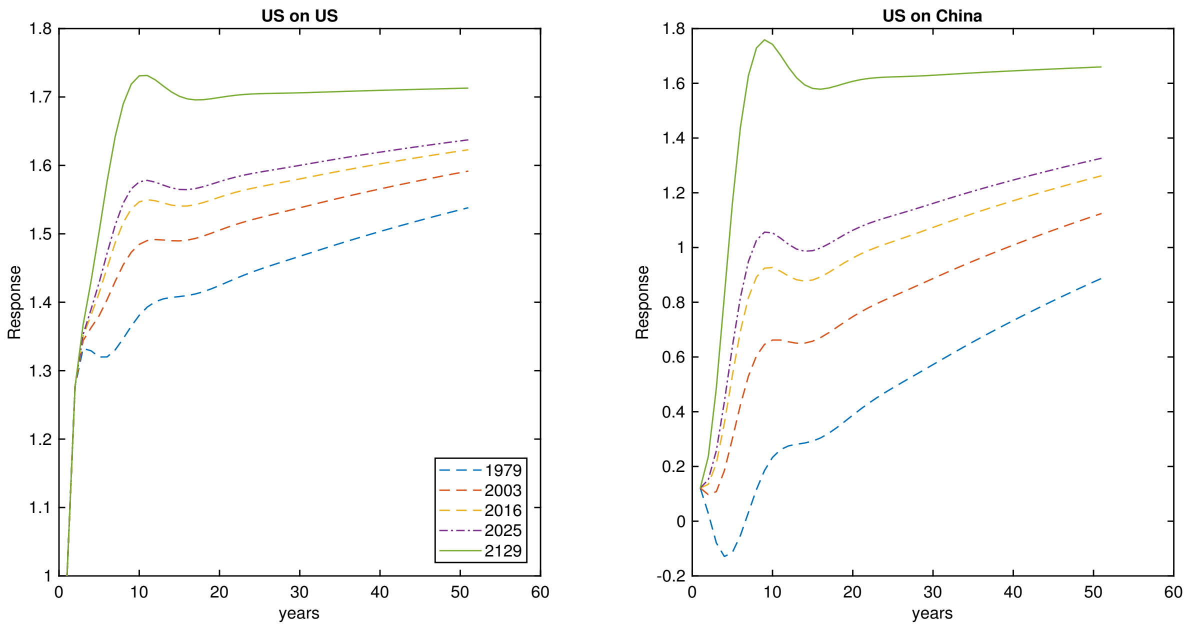

Figure 3: Impulse response functions for US sourced shocks implemented at different times. Effects are shown for US and China per capita GDP.

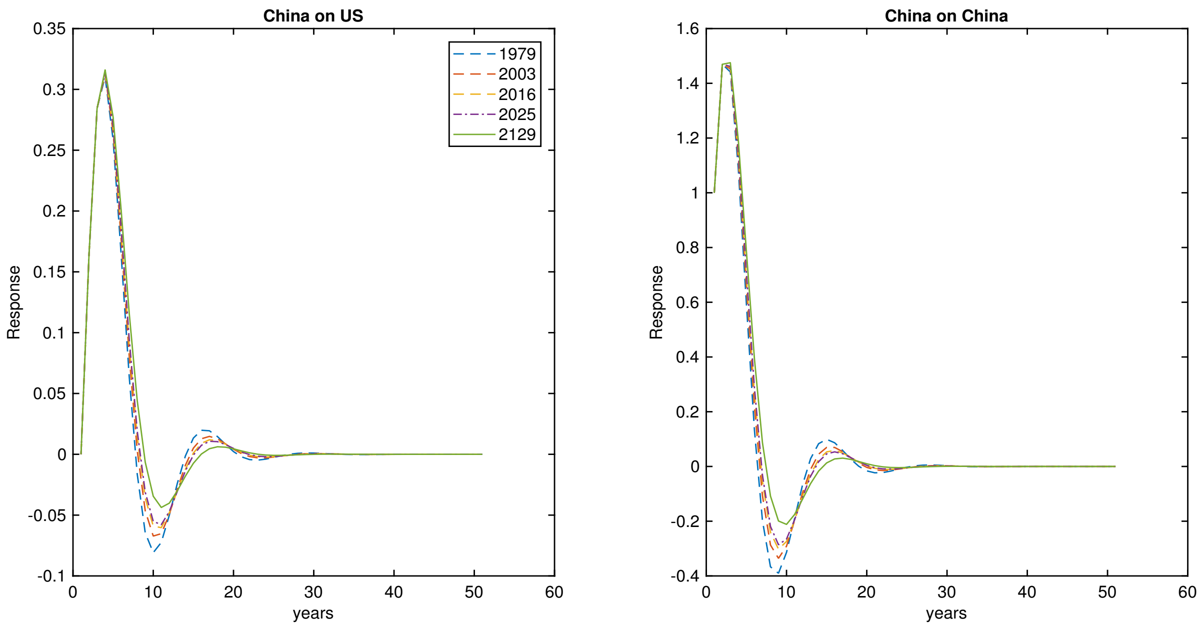

Figure 4: Impulse response functions for Chinese sourced shocks implemented at different times. Effects are shown for US and China per capita GDP.

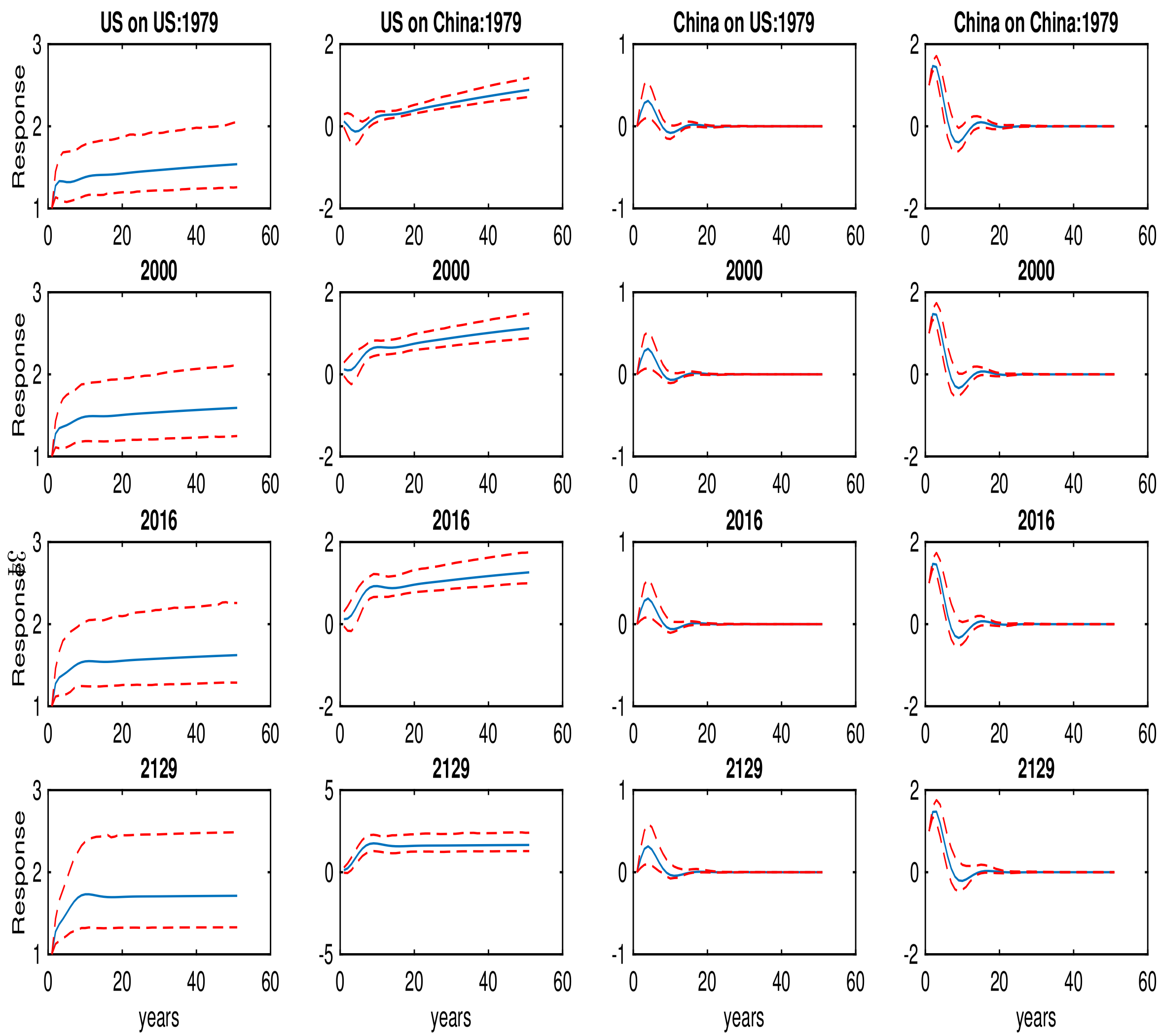

Figure 5: Impulse response functions with bootstrapped 1 standard deviation confidence bands obtained by naive bootstrap of 5000 draws; see text for further discussion.

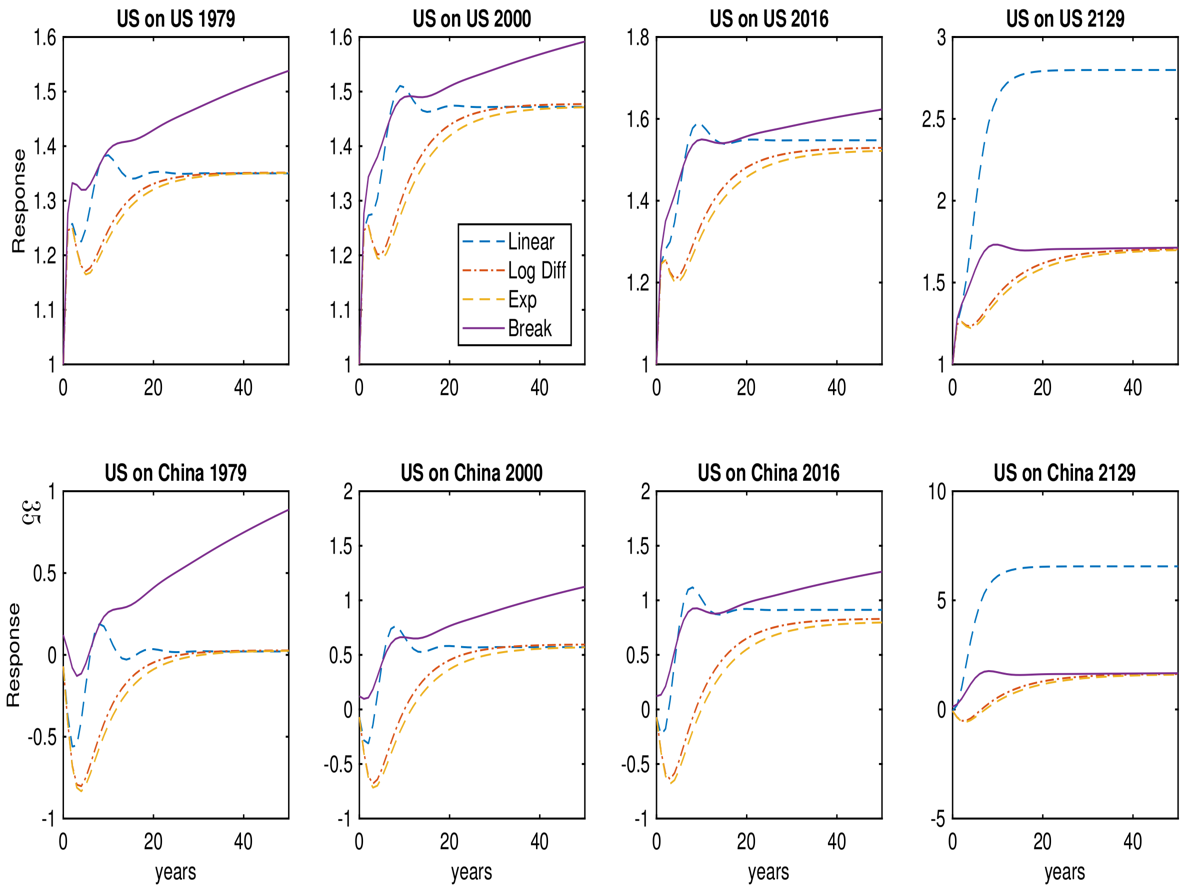

Figure 6: Comparison of impulse responses from US sourced shocks using different model specifications. Linear represents equation (20), Log Diff is for equation (21), Exp is the non-linear form of equation (6) and Break is the non-linear form of (22) with a break in 2002.