1 Panel Granger causality tests

In our daily language, “causal” means INUS condition (Mackie 1966), which stands for an insufficient but necessary part of a condition which is itself unnecessary but sufficient for the result. The causal in this paper is defined by (Granger 1969), A variable Y Granger causes another variable X if at time t, X_{t+1} can be better predicted by using past values of Y than by not doing so, all other information being used in either case (Triacca 2001).

Because panel data give us more variability, degree of freedom and efficiency, and also considering the time series for individual provincial region or city is relatively short, we introduce panel techniques to improve the validity of our Granger causality test.

The econometric methodology proceeds in four stages.

(1) Test the order integration of GDP per capita and built-up area by heterogeneous panel unit root tests developed by (Im, Pesaran et al. 2003) and (Maddala and Wu 1999).

(2) Conditional on that all variables are integrated of order one, we proceed to implement panel cointegration test developed by (Pedroni 1999; Pedroni 2004) to examine the long run relationship between the variables.

(3) Given the two variables are cointegrated, we use panel based VECM to evaluate the direction of both short run and long run causality.

(4) Considering the heterogeneous character in panel data, we also implement the heterogeneous panel causality test developed by (Hurlin 2007), but as the variables are integrated of order one, we could only run this test on the first difference of all variables, so it only test the causality at short run.

1.1 Heterogeneous panel unit root tests

For each cross-section in panel $i = 1,\ldots,N$, at time $t = 1,\ldots T$, we suppose that $Y_{i,t}$, is generated by the following AR(1) process:

$$Y_{i,t} = \rho_i Y_{i,t-1} + \delta_i Z_{i,t} + \varepsilon_{i,t}\,,\quad t = 1,\ldots,T\,,\quad i = 1,\ldots,N \tag{1}$$

where $Z_{i,t}$ represent the exogenous variables in the model, including any fixed effects or individual trends; T is the time span of the panel; ; N represents the number of cross-sections; ρ_i is the autoregressive coefficients, and error $\varepsilon_{i,t}$ are assumed to be mutually independent idiosyncratic disturbance. If $|\rho_i| < 1$, then $Y_{i,t}$ is said to be stationary. On the other hand, if $|\rho_i| = 1$, and then $Y_{i,t}$ contains a unit root.

The methods we apply is those allow ρ_i to vary freely across cross-sections, they are the IPS method developed by (Im, Pesaran et al. 2003), Fisher-ADF and Fisher-PP developed by (Maddala and Wu 1999).

1.2 Heterogeneous panel cointegration test

Once the existence of a panel unit root has been established, the issue arises whether there is a long-run equilibrium relationship, namely cointegration, between GDP per capita and built-up area. Given that all variables are integrated of order one, we test for cointegration by the method of (Pedroni 1999; Pedroni 2004). It allows for using panel data thereby overcoming the problem of small samples, and also allow for heterogeneity in the intercepts and slopes of the cointegrating equation.

1.3 Granger causality test based on panel VECM

Once we determined that the two variables are cointegrated, we perform a panel-based VECM to conduct Granger causality test, which could test both short run and long run causality. We do this using the two step procedures by (Engle and Granger 1987)

In the first step, we estimated the long run model specified in Eq. 2 to obtain the estimated residuals $\varepsilon_{i,t}$:

$$Y_{i,t} = \alpha_i + \delta_t + \gamma X_{i,t} + \varepsilon_{i,t} \quad (2)$$

where α_i and δ_t are fixed cross-section and trend effects respectively, we include them only when redundant fixed effects show they are necessary.

Next we estimate a Granger causality model used by (Narayan, Nielsen et al. 2008) with a dynamic error correction term based on (Holtz-Eakin, Newey et al. 1988):

$$\Delta Y_{i,t} = \theta_j + \sum_{k=1}^{K} \theta_{1k} \Delta Y_{i,t-k} + \sum_{k=1}^{K} \theta_{2k} \Delta X_{i,t-k} + \lambda ECT_{i,t-1} + u_{i,t} \quad (3)$$

where Δ denotes the first difference of the variable; K is the lag length; $ECT_{i,t}$ is the error correction term, namely the estimated residuals $\varepsilon_{i,t}$ in Eq. 2, $ECT_{i,t-1}$ is the error correction term with lag 1; $u_{i,t}$ is the residuals of the model. Using this specification, we can test for both short-run and long-run causality. The significance of causality results are determined by Wald F-test. In the short run X does not Granger cause Y if $\forall k = 1, \ldots K$, θ_{2k} =0. The presence of long run causality can be established if λ, the coefficient of error correction term $ECT_{i,t-1}$ equals to zero.

1.4 Hurlin heterogeneous panel Granger causality test

The inappropriate assumption of causal homogeneity in the above Granger causality test based on panel VECM, and many other panel causality test methods, could be inappropriate in panel context. (Hurlin and Venet 2003) explicitly addressed the heterogeneity character of causal processes from variable X to variable Y within a panel framework by four basic hypothesises. The first one is Homogenous Non Causality (HNC) hypothesis, which means there is no causality relationship from X to Y in any individual. The second is Homogenous Causality (HC) hypothesis, which implies every individual has a causality relationship. The third is Heterogenous Non Causality (HENC) hypotheses, which implies a subgroup of individuals has no causality relationship. And the fourth is Heterogenous Causality (HEC) hypothesis, which assumes a subgroup of individuals has causality relationship.

In this paper, we will test the Homogenous Non Causality (HNC) hypothesis by the methods developed in (Hurlin 2007). As the method requires variables to be stationary, we only carry this test between the first differences of GDP per capita and built-up area, which means the short run relationship between GDP per capita and built-up area.

For each individual $i = 1, \ldots, N$ at time $t = 1, \ldots T$,

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t}$$

where $\beta_i = \left(\beta_i^{(1)}, \ldots, \beta_i^{(K)}\right)'$; individual effects α_i are assumed to be fixed; K is the lag length; coefficients $\gamma_i^{(k)}$ and $\beta_i^{(k)}$ are constants, and could vary among individuals.

The null hypothesis of HNC is $H_0 : \beta_i^{(k)} = 0 \quad \forall k = 1, \ldots K$, $\forall i = 1, \ldots, N$. The alternative hypothesis is $H_1 : \begin{cases} \beta_i^{(k)} = 0 & \forall k = 1, \ldots, K \quad \forall i = 1, \ldots, N_1 \\ \beta_i^{(k)} \neq 0 & \exists k = 1, \ldots, K \quad \forall i = N_1 + 1, N_1 + 2, \ldots, N \end{cases}$.

We define F_i^b as the Fischer statistic for the *i*-th individual:

$$F_i^b = \frac{\left(RSS_{2,i} - RSS_{1,i}\right)/K}{RSS_{1,i}/(N - 2K - 1)}$$

where $RSS_{2,i}$ stands for the sum of squared residuals from restricted model $\left(\beta_i^{(k)} = 0\right)$, $RSS_{1,i}$ stands for the sum of squared residuals from unrestricted model.

Then individual Wald statistic for the *i*-th individual is $W_{i,T} = KF_i^b$. If individual residuals $\varepsilon_{i,t}$ are independently distributed across groups, then $W_{i,T}$ are identically and independently distributed with finite second order moment as T tends to infinity, and therefore by Lindberg-Levy central limit theorem under the HNC null hypothesis, the average Wald statistic $W_{N,T}^{HNC}$, defined as $W_{N,T}^{HNC} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T}$, sequentially converges in distribution. Let $Z_{N,T}^{HNC}$ be the corresponding standardized statistic,

$$Z_{N,T}^{HNC} = \sqrt{\frac{N}{2K}}\left(W_{N,T}^{HNC} - K\right) \xrightarrow[T, N \to \infty]{d} N(0,1)$$

If the value of $Z_{N,T}^{HNC}$ is superior to the normal corresponding critical value for a given level, then the HNC hypothesis is rejected.

However, the convergence result cannot be achieved for any time dimension T. Under the assumption that each individual residual residuals $\varepsilon_{i,t}$ are independently and normally distributed with $E\left(\varepsilon_{i,t}\right) = 0$ and finite heterogeneous variances $E\left(\varepsilon_{i,t}^2\right) = \sigma_{i,t}^2$, and they are independently distributed across groups, then For a fixed time dimension T, with $T > 5 + 2K$, the approximated standardized statistic $\tilde{Z}_{N,T}^{HNC}$ converges in distribution:

$$\tilde{Z}_{N,T}^{HNC} = \sqrt{\frac{N}{2K} \times \frac{T-2K-5}{T-2K-3}} \times \left[\frac{T-K-3}{T-2K-1} W_{N,T}^{HNC} - K \right] \to N(0,1)$$

If the value of $\tilde{Z}_{N,T}^{HNC}$ is superior to the normal corresponding critical value for a given level, then the HNC hypothesis is rejected under finite sample.

2 Results of correlation analysis between city size and growth rate

The correlation analysis between normalized growth rate and city size

Initial X in 1997	Y'= $\frac{Y_{2006}-Y_{1997}}{Y_{1997}}$		
	GDP per capita	Built-up area	Population
Built-up area	7.62E-05 (0.48)	8.95E-05 (0.41)	-2.39E05 (0.79)
Population	6.07E-05 (0.27)	7.78E-05 (0.16)	-5.59E-05 (0.23)

Not significantly correlated.

The correlation analysis between marginal growth rate and city size

Initial X in 1997	Y'= $\frac{Y_{2006}-Y_{1997}}{Y_{1997}} / \frac{X_{2006}-X_{1997}}{X_{1997}}$		
	GDP per capita	Built-up area	Population
Built-up area	-0.00(0.63)	-	-0.00 (0.56)
Population	-0.01(0.89)	0.00(0.27)	-

Note: significant level in parenthesis.

Not significantly correlated, either.

3 Cities included in each data panel

The 174 Chinese cities in panel U1 are:

Anqing, Anshan, Anyang, Baiyin, Baoding, Baoji, Baotou, Beihai, Bengbu, Cangzhou, Changchun, Changde, Changsha, Changzhi, Changzhou, Chaoyang, Chenzhou, Chifeng, Dalian, Daqing, Datong, Dezhou, Dongchuan, Dongying, Ezhou, Fuoshan, Fushun, Fuxin, Fuyang, Fuzhou, Guangyuan, Guangzhou, Guilin, Guiyang, Haikou, Handan, Hangzhou, Hanzhong, Harbin, Hebi, Hefei, Hegang, Heihe, Hengshui, Hengyang, Huaibei, Huainan, Huaiyin, Huangshi, Huhehaote, Huizhou, Huzhou, Island of Hulu, Jiamusi, Jiaozuo, Jiaxing, Jiayuguan, Jilin, Jinan, Jinchang, Jingdezhen, Jinhua, Jining, Jingzhou, Jinzhou, Jiujiang, Jixi, Kaifeng, Kelamayi, Langfang, Leshan, Lianyungang, Liaoyang, Liaoyuan, Liupanshui, Liuzhou, Longyan, Luohe, Luoyang, Luzhou, Maoming, Meizhou, Mianyang, Mudanjiang, Nanchang, Nanchong, Nanjing, Nanning, Nanping, Nantong, Nanyang, Neijiang, Ningbo, Panjin, Panzhihua, Pingdingshan, Pingxiang, Putian, Qingdao, Qinhuangdao, Qiqihar, Qitaihe, Quanzhou, Qujing, Quzhou, Rizhao, Sanmenxia, Sanming, Sanya, Shanghai, Shangqiu, Shantou, Shaoguan, Shaoxing, Shaoyang, Shenyang, Shijiazhuang, Shizuishan, Shuangyanshan, Shuozhou, Siping, Suining, Suzhou, Taiyuan, Tangshan, Tianjin, Tianshui, Tieling, Tongchuan, Tongling, Weifang, Weinan, Wenzhou, Wuhai, Wuhan, Wuhu, Wulumuqi, Wuxi, Wuzhou, Xiamen, Xi'an, Xiangfan, Xiangtan, Xianyang, Xingtai, Xining, Xinxiang, Xinyu, Xuchang, Yan'an, Yangquan, Yantai, Yibin, Yichang, Yichun, Yinchuan, Yingkou, Yingtan, Yongzhou, Yueyang, Zaozhuang, Zhangjiajie, Zhangjiakou, Zhangzhou, Zhanjiang, Zhaoqing, Zhengzhou, Zhenjiang, Zhongshan, Zhoushan, Zhuzhou, Zibo, Zigong, and Zunyi.

The 135 Chinese cities in panel U2 are:
Anshan, Anyang, Baiyin, Baoding, Baoji, Beijing, Bengbu, Benxi, Cangzhou, Changsha, Changzhou, Chaoyang, Chengde, Chengdu, Chenzhou, Chifeng, Chuzhou, Dalian, Daqing, Datong, Dezhou, Ezhou, Fushun, Fuxin, Fuzhou, Guangyuan, Guangzhou, Guilin, Guiyang, Handan, Hangzhou, Hanzhong, Hebi, Hefei, Hegang, Heihe, Hengyang, Huaibei, Huainan, Huangshi, Jiamusi, Jiaozuo, Jiaxing, Jiayuguan, Jilin, Jinan, Jingdezhen, Jinhua, Jiujiang, Jixi, Kaifeng, Kunming, Leshan, Lianyungang, Liaoyuan, Liupanshui, Liuzhou, Longyan, Luohe, Luoyang, Luzhou, Ma'anshan, Maoming, Mianyang, Mudanjiang, Nanjing, Nanning, Nanyang, Neijiang, Ningbo, Panjin, Panzhihua, Pingdingshan, Putian, Qingdao, Qinzhou, Quanzhou, Quzhou, Rizhao, Sanmenxia, Sanming, Shanghai, Shangqiu, Shantou, Shaoguan, Shaoxing, Shaoyang, Shenyang, Shenzhen, Shijiazhuang, Shizuishan, Shuozhou, Siping, Suining, Suzhou, Taiyuan, Tangshan, Tianjin, Tieling, Tongchuan, Tongling, Weifang, Weihai, Weinan, Wenzhou, Wuhai, Wuhu, Wulumuqi, Wuxi, Xiamen, Xi'an, Xiangfan, Xianyang, Xiaogan, Xingtai, Xining, Xinxiang, Xinyu, Xuchang, Xuzhou, Yangquan, Yangzhou, Yantai, Yibin, Yichang, Yichun, Yinchuan, Yingtan, Zaozhuang, Zhangjiakou, Zhangzhou, Zhengzhou, Zhenjiang, Zhuzhou, and Zunyi.

The U3 panel consists of 121 Chinese cities appear in both U1 and U2 panel. They are:
Anshan, Anyang, Baiyin, Baoding, Baoji, Bengbu, Cangzhou, Changsha, Changzhou, Chaoyang, Chenzhou, Chifeng, Dalian, Daqing, Datong, Dezhou, Ezhou, Fushun, Fuxin, Fuzhou, Guangyuan, Guangzhou, Guilin, Guiyang, Handan, Hangzhou, Hanzhong, Hebi, Hefei, Hegang, Heihe, Hengyang, Huaibei, Huainan, Jiamusi, Jiaozuo, Jiaxing, Jiayuguan, Jilin, Jinan, Jingdezhen, Jinhua, Jiujiang, Jixi, Kaifeng, Leshan, Lianyungang, Liaoyuan, liupanshui, Liuzhou, Longyan, Luohe, Luoyang, Luzhou, Maoming, Mianyang, Mudanjiang, Nanjing, Nanning, Nanyang, Neijiang, Ningbo, Panjin, Panzhihua, Pingdingshan, Putian, Qingdao, Quanzhou, Quzhou, Rizhao, Sanmenxia, Sanming, Shanghai, Shangqiu, Shantou, Shaoguan, Shaoxing, Shaoyang, Shenyang, Shijiazhuang, Shizuishan, Shuozhou, Siping, Suining, Suzhou, Taiyuan, Tangshan, Tianjin, Tieling, Tongchuan,

Tongling, Weifang, Weinan, Wenzhou, Wuhai, Wuhu, Wulumuqi, Wuxi, Xiamen, Xi'an, Xiangfan, Xianyang, Xingtai, Xining, Xinxiang, Xinyu, Xuchang, Yangquan, Yantai, Yibin, Yichang, Yichun, Yinchuan, Yingtan, Zaozhuang, Zhangjiakou, Zhangzhou, Zhengzhou, Zhenjiang, Zhuzhou, and Zunyi.

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