Efficiency Convergence in the Greater China Region*

Chun Kwok LEI**

Faculty of Business Administration, University of Macau
Email: henrylei@umac.mo

Abstract:

This study is organized to estimate the efficiency level of the economies in the Greater China region which is composed by the provincial economies in the Mainland, Hong Kong, Macau and Taiwan. Employing the stochastic frontier approach, the technical efficiency level of these economies is estimated and decomposed. In addition, panel unit root tests are also conducted to assess if stochastic convergence has been achieved. Evidences suggest that the average technical efficiency level of the Greater China region has reached 0.95. Tianjin is the most efficient economy in the sample whereas Taiwan is the most efficient external Chinese economy. The least efficient economies in the sample and on the Mainland side are Hong Kong and Beijing respectively. The inner region is found to perform slightly better than the central and coastal regions and external Chinese economies in terms of technical efficiency. For the efficiency determinants, when the capital stock per labor is a negative and significant factor to efficiency, labor productivity, service output ratio, fiscal decentralization and trade openness are found to be efficiency contributors with various magnitudes. The panel unit tests have confirmed the presence of stochastic convergence across economies in the Greater China region as well as among the provincial economies on the Mainland side, coastal and inner regions and the external Chinese economies. Nevertheless, divergence of technical efficiency with enlarged disparities is also observed for the central region. Rationalization on investment projects, structural transformation toward service-oriented productions and training and vocational training programs, meanwhile, are policies which could be implemented to enhance efficiency improvements.

Key words: Stochastic Frontier Approach, Technical Efficiency, Stochastic Convergence

---

* This article is based on a paper presented at the Joint East Asian Studies Conference held in University of Nottingham, U.K., 5th-7th September 2013.

** Chun Kwok LEI is an Assistant Professor in Department of Finance and Business Economics, Faculty of Business Administration, University of Macau.

1. INTRODUCTION

Since the beginning of the economic reforms, China has been growing continuously at an average rate of approximately 9% per annum. It does not only contribute to increase the real per capita gross domestic products (GDP) by 14.7 folds (China Statistical Yearbook 2012), but also allows the country to catch up with the external Chinese economies, namely Hong Kong, Macau and Taiwan in terms of per capita income. As shown in Lei and Yao (2008), the initially poorer provinces on the Mainland side were able to grow faster than the initially richer Special Administrative Regions (SARs which composes of Hong Kong and Macau) to achieve convergence of per capita income. Similar conclusion was made in Lei and Tam (2010) in which the stochastic convergence technique was adopted. Lei and Tam (2013) has extended the sample to cover Taiwan in the discussion. It indicated that the per capita income gap between Mainland, Hong Kong, Macau and Taiwan has been declining and stochastic income convergence was achieved in the Greater China region (composing of the Chinese provinces, Hong Kong, Macau and Taiwan). In line with the process of income convergence, whether the efficiency level of these economies has converged or not has not been thoughtfully studied. With reference to the Solow (1957) growth model, input growth and productivity improvement were the driving forces to economic growth. Productivity improvement, meanwhile, was attributed to technical efficiency (TE) improvement and technological progress (TP). The aforesaid rapid income growth on the Mainland side and the consequent convergence in per capita income with the external Chinese economies (namely Hong Kong, Macau and Taiwan), therefore, does not necessary imply efficiency growth made by the Chinese provinces. It could probably be driven by input growth with the persistence of a significant efficiency gap. In fact, similar doubt has been raised in Mas, Maudos and Perez (1998) and the scenario of convergence of TE for Spanish regions was examined and affirmed. The importance of TE improvement and convergence is that it allows an economy to produce more to approach to its frontier or full capacity output, given the same amount of inputs and same level of technology. To investigate if the TE of the provincial economies on the Mainland side has been improving and catching up with the external Chinese economies, this paper pools up 32 Chinese municipalities, provinces[1] and external Chinese economies to firstly estimate their TE level and determinants. Then the hypothesis of convergence of TE among economies in the Greater China region is examined. Apart from employing the popular Battese and Coelli (1995)'s time variation model (BC model hereafter) for TE estimation, the Greene (2005)'s fixed effect model (G model hereafter) and the Wang and Ho (2010)'s transformation model (WH model hereafter) are also employed. Then the contributions of the a series of factors, including the capital stock per capita, labor productivity, openness ratio and fiscal decentralization are

---

[1] All the Chinese provinces and municipalities are included except Chongqing and Tibet due to data shortages.

addressed. To examine if the TE of these Chinese economies has been converging, the notion of stochastic convergence used in Pedroni and Yao (2006), Nagayasu and Liu (2008) and Lei and Tam (2010) is advocated. The panel unit root tests introduced in Levin, Lin and Chu (2002) (LLC test hereafter), Im, Pesaran and Shin (2003) (IPS test hereafter) and Maddala and Wu (1999) (MW test hereafter) are then performed.

The remaining part of this paper is organized as follows: Section 2 is the literature review. Section 3 describes the methodology and data employed. Section 4 reports and discusses the results of the empirical estimations. Section 5 examines the efficiency convergence hypothesis. The last section concludes and discusses the implications.

2. LITERATURE REVIEW

The stochastic frontier approach (SFA) is a regression based technique to estimate TE introduced in Aigner, Lovell and Schmidt (1977)[2] and Meeusen and van den Broeck (1977)[3]. In the analyses, the formulation of a production function is required and the full capacity output is called the frontier output with its scale determined by the available input factors and technology. If the actual output falls behind the frontier output, then there is technical inefficiency in the production process. Technological progress is achieved if an improvement on production frontier over time is recorded. Economic growth is determined jointly by growth in input factors, TE improvement and technological progress. The sum of the latter two mechanisms is called growth in total factor productivity (TFP) which is critical to economic growth.

Given their straight forward specifications, Battese and Coelli (1992 & 1995)[4] have become popular and important empirical models under the SFA. When the former specification assumed time-invariant performance with its appropriateness being criticized, the latter was introduced with a revised assumption of time-variant performance. In this model, the production of region i at time t (Y_{it}) was written as an exponential function of a vector of factor inputs x_{it} and a vector of unknown parameters β. The error term was written as the difference between an independent and identically distributed random error V_{it} $N(0, \sigma^2_v)$ and an independent and identically distributed non-negative truncations U_i $N(m_{it}, \sigma^2)$. The i.i.d. truncations was said to be explained by a vector of explanatory variables z_{it} associated with technical inefficiency with a vector of unknown parameters δ in $m_{it}= z_{it}\delta$, such that $U_{it}=z_{it}\delta+W_{it}$ where W_{it} was defined by the truncation of the normal distribution with zero mean and variance σ_u^2. TE was specified as $TE_{it}=\exp(-U_{it})= (-z_{it}\delta-W_{it})$.

---

[2] Aigner, Lovell and Schmidt (1977).

[3] Meeusen and van den Broeck (1977).

[4] Battese and Coelli (1995).

Greene (2005) indicated that the BC model was suffered from the drawbacks of heterogeneity in panel data analyses and the differences of the sampling entities were not adequately modeled. It could lead to biased results in which the estimated TE was the sum of inefficiency and individual heterogeneity rather than pure TE. Then the "true fixed-effect" model was introduced which has applied the fixed effect in panel data analyses in order to segregate regional heterogeneity from the estimated technical inefficiency. However, as stated in Wang and Ho (2010), there was an "incidental parameter" problem inherited in the G model. It referred to the exceptionally large value of the fixed effect parameter in panel data analyses or a large number of sampling entities which carried either no or un-interpretable economic meaning. Eventually, the role of the other determinants in the model could be distorted. Then the "first-difference" and "within" transformation procedures were introduced in which either the first lag or the mean was subtracted from the vectors to obtain the transformed series. In such a way the time-invariant individual effect could be separated from the estimated TE.

Wu (1995; 2000) have advocated the BC model to estimate parametrically the TE of Chinese provinces. Human capital, openness to international trade, household registration system (*hukou system*), the size of the government were found as significant determinants to TE. In Ao and Fulginiti (2003), the BC model was used to estimate the TFP of 30 Chinese provinces and the agriculture output and openness ratio were found to be statistically significant in explaining TE. Similar applications have been performed in Yu (2008) and Zhou, Li and Li (2012) to estimate the TE of Chinese provinces. In these studies, the coastal Chinese provinces were found to be more efficient than the central and inner counterparts. Human capital, the degree of urbanization (Yu (2008)) and the exposure to FDI (Yu (2008); Zhou, Li and Li (2012)) were efficiency determinants. In contrast, the size of government was found to be adversely related to efficiency (Yu (2008)).

In Lei (2013), the BC, G and WH models were employed to estimate the TE of Chinese cities and SARs which have once organized regional or international mega sports or other events. The findings showed that the mean TE estimated by the WH model was the lowest. Furthermore, the G model tended to overstate the magnitude of the efficiency determinants. In addition, TE estimated by the BC model tended to be distorted by regional heterogeneity. Investment to GDP ratio was found to be a significant contributor to TE. The service sector's output to GDP ratio, meanwhile, has posted a negative impact on efficiency when structural transformation toward service-oriented production was policies rather than market driven.

To test for convergence, parametric and non-parametric techniques are both available in the literature. The former method employs ordinary least square (OLS) estimations to examine if the initially poorer or less efficient economies could grow or improve faster than the initially richer or more efficient economies. β-convergence is achieved if the initial income[5] or efficiency level[6] is statistically significant and negative to its growth pace. For the non-parametric approach, Carlino and Mills (1993) has introduced the stochastic convergence framework to test for convergence. If the logarithm of the ratio of per capita income, labor productivity, TFP or capital to labor ratio of one region to the group mean is stationary without a unit root, then the external shocks are only transitory. The concerned economies could have achieved stochastic convergence in terms of income, efficiency or productivity with declined disparities among the group members.

This framework has been employed in a wide array of researches, for instance Carlino and Mills (1993), Lowey and Papell (1996), Li and Papell (1999) and Galvão and Gomes (2008) to examine if regional incomes have been converging towards the national mean, or if the national income across a group of countries have been converging towards the group mean. Herrerias and Monfort (2013) discussed the stochastic convergence across Chinese provinces by means of labor productivity, capital to labor ratio and TFP and the unit root test with structural break has revealed convergence. Comparing with the regression based β-convergence test, the non-parametric approach can avoid mis-specification and estimation error.

In line with the development of the panel based estimation techniques, the lack of power of the univariate test[7] in the near unit root and short sample cases was recognized as the drawback. The panel based unit root tests were regarded as the alternative method with better explanatory power. In Pedroni and Yao (2006) and Lei and Tam (2010), the LLC, IPS and MW tests were implemented to examine if stochastic income convergence has been achieved. In the former research, divergence was observed between Chinese provinces since the beginning of the economic reforms until the 1997. In the latter paper, the unit root null has been rejected which implied the presence of stochastic income convergence between Chinese provinces, Hong Kong, Macau and Taiwan from 1982 to 2007 with reduced income disparities.

3. METHODOLOGY AND DATA

3.1 Methodology

---

[5] β-convergence analyses on per capita income could be found in Jian, Sachs and Warner (1996), Chen and Fleisher (1996), Raiser (1998) and Démurger (2001). The estimation results exhibited that the initially poorer Chinese provinces could grow faster than the initially richer one in both the Pre- and early Post-reform periods to bring about a declined income gap, which is also known as unconditional income convergence.

[6] In Maudos, Pastor and Serrano (1998), β-convergence test on technical efficiency was conducted for a group of OECD countries. In Nissan and Niroomand (2012), convergence of technical efficiency was examined for a group of countries with different income level. The methodology adopted was developed from the β-convergence test to regress the initial efficiency level on its growth pace.

[7] Which can be found in Yao and Zhang (2001) and Zhang, Liu and Yao (2001) in which the univariate Augmented Dicky Fuller test for unit root was used.

The parametric based SFA approach is preferred to the non-parametric alternative given the modeled inefficiency estimations and its implications. It is then employed as the basis of the analyses. TE is estimated by the BC, G and WH models for comparison purpose. The BC model carries the following specification:

$$Y_{it}=f(x_{it};\beta)\exp(V_{it}-U_{it}) \quad (1)$$

where Y_{it} is the real GDP of province i at time t in logarithm; x_{it} is a vector of factor inputs and β is a vector of coefficients to be estimated. The V_{it} are assumed to be independent and identically distributed random errors $N(0,\sigma_V^2)$, U_{it} are assumed to be non-negative random variables which are independent and identically distributed and are truncated at zero with $N(\mu_{it},\sigma_U^2)$ distribution.

$$\mu_{it}=z_{it}\delta \text{ and } U_{it}=z_{it}\delta+W_{it} \quad (2)$$

where z_{it} is a vector of variables which can affect the efficiency of a province and δ is a vector of parameters to be estimated, W_{it} is defined by the truncation of the normal distribution with zero mean and variance σ_U^2.

The estimated TE of province i at time t is:

$$TE_{it}=\exp(-U_{it})=\frac{Y_{it}}{Y_{it}^*}=\frac{F(x_{it};\beta)\exp(V_{it}-U_{it})}{F(x_{it};\beta)\exp(V_{it})}=\exp(-z_{it}\delta-W_{it})^{8} \quad (3)$$

When the BC model cannot differentiate individual heterogeneity from inefficiency, the G model is also adopted with an intention to segregate the observed individual heterogeneity from inefficiency. With individual heterogeneity, Equation (1) can be rewritten as:

$$Y_{it}=\alpha_i+X_{it}\beta+V_{it}-U_{it} \quad (4)$$

where α_i is the fixed effect to reflect province i's unobservable heterogeneity. In Greene (2005), maximum likelihood estimations have been undertaken based on Equation (4). This model, however, is subject to the drawbacks of incidental parameter and biased estimation results. Consequently, the first-difference and within-transformation methods were introduced in Wang and Ho (2010) to segregate the regional heterogeneities from the estimated efficiency. In the later transformation, the sample mean is deducted from each panel to remove the time-invariant individual effect. Equation (4) is then transformed into:

$$y_{it}=x_{it}\beta+V_{it}-U_{it} \quad (5)$$

where the small letters refer to transformed variables in which the sample mean has been subtracted from each individual observation[9].

---

[8] The full specification of TE_{it} can be found in Battese and Coelli (1995)

The Translog production function is widely employed to estimate TE, but it is subject to criticisms. In Movshuk (2004), a comparison was made between Translog and Cobb-Douglas production functions on their goodness of fit. The problem of multicollinearity was found to be serious under the Translog specification. It could lead to over-rejection (on the explanatory variables) and a large estimated coefficient. The Cobb-Douglas type production function is therefore adopted in the estimation with the following specification:

$$Log(RGDP_{it}) = \beta_0 + \beta_1 \log(K_{it}) + \beta_2 \log(N_{it}) + \beta_3 \log(H_{it}) + \beta_4 t + \beta_5 Coastal_{it} + (V_{it} - U_{it}) \quad (6)$$

where *RGDP* is real gross domestic product, *K* and *N* are the capital stock and labor, *H* is a proxy of human capital measured as the ratio of enrollment in higher education institutes to population, *t* is the time trend, *Coastal* is the coastal dummy variable and the value of 1 is given to the coastal[10] provinces, SARs and Taiwan.

In the technical inefficiency equation, it is specified as:

$$U_{it} = \delta_0 + \delta_1 \log OPEN_{it} + \delta_2 \log Service_{it} + \delta_3 \log k_{it} + \delta_4 \log y_{it} + \delta_5 Decentral_{it} \quad (7)$$

where *OPEN* is the ratio of the sum of exports and imports to GDP, *Service* is the ratio of tertiary sector output to GDP, *k* and *y* are the capital stock per labor and real GDP per labor (or labor productivity), *Decentral* is the fiscal decentralization index which is the ratio of per capita government expenditure in real term for a sampling economy to the national level. These factors have been addressed in Wu (1995, 2000), Ao and Fulginiti (2003), Yu (2008) and Lei (2013) and were found to be significant determinants. As this study pools up the provincial and external Chinese economies with diversified geographical and economic scale, ownership structure and administrative framework, some potential determinants, including highway and railway, household registration system, ownership structure, urban location, have become inapplicable. In light of the stochastic convergence test, the standard LLC, IPS and MW tests are performed. When the procedures are well documented in Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003) and Maddala and Wu (1999), the steps are not described here.

3.2 Data

This study covers 32 economies consisting of the Chinese provinces, municipalities, SARs (Hong Kong and Macau) and Taiwan[11]. The sampling period starts from 1989 to 2010 as earlier

---

[9] Please see Wang and Ho (2010) p. 289 for the detailed specification of the model.

[10] Coastal region composes of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan.

[11] The statistics for Mainland China's economies are extracted from National Statistical Bureau's *China Compendium of Statistics 1949-2008* and *Yearbook of Statistics,* various issues. The statistics for Hong Kong and Macau are obtained from the Hong Kong and Macao Governments' Official Publications: *Hong Kong Annual*

statistics are not available for Macau. Year 2000 is used as the base year and all the nominal figures have been converted to real value.

To measure the capital stock, the procedure suggested in Kohli (1978) is applied. The capital-to-output ratio is assumed to be in steady-state at which the growth in capital equals the growth in output. The initial real output is assumed to be the average real output of the first five year of the available official statistics. This assumption is applied to measure the average investment to output ratio and output growth for the approximation of the steady states for these economies. For the depreciation rate, Zhang (2008)'s measurement[12] is adopted at 9.6% per annum. The initial capital stock is composed as:

$$\frac{K}{Y}\left(\frac{\Delta Y}{Y}+\theta\right)=\frac{I}{Y} \tag{8}$$ [13]

where K is initial capital stock, θ is depreciation, Y is output and I/Y is the ratio of gross fixed capital formation (GFCF) to GDP.

After obtaining the initial capital stock, the accumulated domestic capital stock is measured as:

$$K_{it}=K_{i,t-1}(1-\theta)+\Delta K_{it} \tag{9}$$

where K_{it} is the capital stock for economy i at time t, θ is depreciation, ΔK_{it} is the GFCF made by economy i at time t.

4. ESTIMATION RESULTS AND INTERPRETATIONS

The Wald test is firstly conducted to examine the statistical significance of the Cobb-Douglas production function and the results are summarized in Table 1.

Table 1: Wald Tests for Parameters in the Production Function and Technical Inefficiency Estimation

Hypotheses	F-statistic	Probability	Conclusion
$\beta_0 \dots \beta_5 = 0$	240480.10	0.00	Reject null
$\beta_1 = 0$	5422.96	0.00	Reject null

Digest of Statistics and *Yearbook of Statistics of Macao*. The statistics for Taiwan are extracted from *National Statistics*, republic of Taiwan.

[12] In Zhang (2008), the average duration of life for capital facilities such as construction and installation, purchases on equipment and instruments and other investments were assumed to be 45 years, 20 years and 25 years respectively, implying rates of depreciation at 6.9%, 14.9% and 12.1% accordingly. Given the average share of these capital facilities in total investment, 9.6% was worked out as the weighted depreciation rate for fixed capital formation for the Chinese provinces.

[13] The specification can be found in Ha and Leung (2001).

$\beta_2 = 0$	98.88	0.00	Reject null
$\beta_3 = 0$	6.76	0.00	Reject null
$\beta_4 = 0$	178.26	0.00	Reject null
$\beta_5 = 0$	60.67	0.00	Reject null
$\delta_0 = \delta_2 = ... = \delta_5 = 0$	85728.12	0.00	Reject null
$\delta_1 = 0$	39.37	0.00	Reject null
$\delta_2 = 0$	59.21	0.00	Reject null
$\delta_3 = 0$	8.17	0.00	Reject null
$\delta_4 = 0$	12.63	0.00	Reject null
$\delta_5 = 0$	6.30	0.01	Reject null

Author's calculation based on Equation (6).

In Table 1, rows 3 to 5 indicate that all the input factors, including capital, labor and human capital are significant output determinants. Row 6 suggests that there exists technological progress in the sampling years. Row 7 reveals that the growth disciplines of the coastal provinces, SARs and Taiwan are different from the rest of the provinces in China. Row 8 shows that there is technical inefficiency for the sampling Chinese economies. Rows 9 to 13 exhibit that the openness ratio, service sector output ratio, capital per labor, output per labor and decentralization index are all influential to TE.

Table 2: Maximum Likelihood Estimates for the BC and G models

Variable	Parameter	BC Model		G Model	
		Estimated value	t-statistic	Estimated value	t-statistic
Production Function Estimation					
Constant	β_0	-0.48	-6.95**	-0.47	-6.95**
$LogK_{it}$	β_1	0.80	71.56**	0.81	75.13**
$LogL_{it}$	β_2	0.25	8.27**	0.22	7.57**
$LogH_{it}$	β_3	-0.01	-1.43	-0.02	-2.48**
t	β_4	0.002	6.54**	0.001	6.23**
Coast	β_5	0.17	11.03**	0.19	11.42**
Technical Inefficiency Estimation					
Constant	δ_0	-7.68	-4.44**	-7.86	-4.65**
$LogOpen_{it}$	δ_1	0.07	0.22	0.15	0.87
$LogService_{it}$	δ_2	-0.43	-2.94**	-0.22	-2.65**

$Logk_{it}$	δ_3	0.53	4.88**	0.31	5.19**
$Logy_{it}$	δ_4	-0.40	-3.49**	-0.25	-3.85**
$Decentral_{it}$	δ_5	0.006	0.32	0.01	1.07
	σ^2	0.0005	4.69	0.0004	5.92
Mean TE		0.972		0.975	

The above estimated values are generated by the STATA codes developed in Wang and Ho (2010). **: At 5% level significance.

Table 2 shows the estimation results obtained from the BC and G models which are similar and consistent. In the production function estimation, capital and labor are found to be significant inputs, with the former carrying stronger magnitude given its bigger estimated coefficient and t-statistics. It reveals the dominant role of capital in the production process whereas labor inputs can only play an accommodating role. Human capital, in contrast, is found to be either insignificant or with a negligible estimated coefficient. It suggests that the ratio of enrollment in higher education institutes to population is not a good proxy in the analyses on Greater China. The finding here deviates from that of Yu (2008) in which capital stock was found to be negatively related to output while labor and human capital were significant and positive determinants. It may be attributed to the Translog production function and the longer sampling period (1974-2004) adopted in Yu (2008). In contrast, it matches the estimation result exhibited in the parametric model in Zhou, Li and Li (2010) in which capital and labor inputs were positive and significant growth determinants, whereas human capital was a negative determinant with weak magnitude. The significant time trend observed here confirms the presence of technological progress. Its small estimated coefficient, however, implies a weak progress which is consistent with the result in Yu (2008). Lastly, the strongly significant and positive coastal dummy reflects that the municipalities and coastal provinces in the Mainland together with Hong Kong, Macau and Taiwan can enjoy higher level of RGDP, with a production discipline different from the other Chinese economies.

The technical inefficiency estimations are shown in the second half of Table 2. As the available literatures[14] have placed their focus on spatial factors, such as the influences of geographical location and rural-urban division which is departed from our core interest, direct comparison on the estimation results is hard to conduct. In general, the BC and G models have provided us with very similar conclusion. Output per labor and service sector output share are the most important determinants to TE. Economies with higher output per labor or more productivity labor and bigger service sector tend to attain higher TE. Capital stock per labor, meanwhile, is found to be negatively related to TE or positively related to inefficiency. It reflects that

[14] Including Shiu and Heshmati (2006), Yu (2008), Zhou, Li and Li (2010), etc.

economies which require more capital input per labor in the production process are less efficient. This finding does not contradict with that of Zhou, Li and Li (2010) which showed that if more infrastructure investment was required in the production process, then efficiency level tended to deteriorate. Trade openness, to our surprise, is an insignificant factor which violates the conventional expectation that trade tends to enhance efficiency. The decentralization index is also found to be insignificant. It is different from the estimation results derived from the WH model which are discussed below.

For the estimated TE, the mean value which is measured as the average efficiency for the 32 sampling economies over the period of 1989 to 2010 are 0.972 and 0.975 for the BC and G model. It indicates that economies in the Greater China region are highly efficient with output approaching to 97% of the frontier level. Nevertheless, with reference to Wang and Ho (2010) and confirmed in Lei (2013), TE estimated by the BC and G models is based by regional heterogeneity with an over-stated value. The WH model in "with-transformation" is then advocated to re-estimate the TE for the purpose of segregating regional heterogeneity from the true TE.

Table 3: Maximum Likelihood Estimates for the WH model

Variable	Parameter	WH Model	
		Estimated value	t-statistic
	Production Function Estimation		
Constant	β_0	-0.68	-14.51**
$LogK_{it}$	β_1	0.79	65.52**
$LogL_{it}$	β_2	0.29	8.75**
$LogH_{it}$	β_3	-0.003	-0.23
t	β_4	0.001	3.26**
Coast	β_5	0.21	12.45**
	Technical Inefficiency Estimation		
Constant	δ_0	4.55	4.31**
$LogOpen_{it}$	δ_1	-0.03	-4.45**
$LogService_{it}$	δ_2	-0.17	-4.78**
$Logk_{it}$	δ_3	0.23	6.65**
$Logy_{it}$	δ_4	-0.19	-6.34**
$Decentral_{it}$	δ_5	-0.007	-5.85**
	σ^2	0.001	18.32**
Mean TE		0.949	

The above estimated values are generated by the STATA codes developed in Wang and Ho (2010). **: At 5% level significance.

The estimation result shown in Table 3 affirms the previously reported findings. In the production function estimation, capital and labor inputs are significant contributors and weak technological progress is still exhibited. The human capital proxy, meanwhile, remains to be statistically insignificant as enrollment in the higher education cannot accurately address the level and quality of human resources in the Greater China region. In light of the technical inefficiency estimation, on the top of the direct and significant correlations between labor productivity, service sector output ratio and TE and the negative link between capital per labor and TE, it has also exhibited results deviated from the other models. After segregating the individual effects from TE, the real impacts of trade openness and fiscal decentralization can be revealed in the estimation. The observed positive and significant linkages comply with the conventional belief that trade and fiscal autonomy tend to strengthen TE. Higher involvement in international trade provides incentives for an economy to constantly improve itself for better international competitiveness, and hence to achieve higher TE. It contradicts to the result in Zhou, Li and Li (2010) in which the trade to regional GDP ratio had a negative correlation with TE, but affirms the finding in Yu (2008) where external linkages in the form of FDI to regional GDP ratio was positively linked up with TE. When the process of "learning by exporting" is time consuming, trade openness can only play an accommodating role in efficiency enhancement. Fiscal decentralization and the associated abundance in fiscal spending and flexibility in the implementation of public projects may allow the authorities to make more timely and adequate interventions to strike for better TE. When this is mainly the municipalities and Special Economic Zones (SEZs) in the coastal region of China to entitle to higher extent of fiscal decentralization, our finding does not conflict with the positive urban and coastal dummies observed in Yu (2008) and Zhou, Li and Li (2010). In the meantime, an economy may also expose itself to the risk of "over-spending"[15] if the authority has higher autonomy on public spending. For this reason, the estimated coefficient for fiscal decentralization is small relative to the other key efficiency determinants, implying that higher fiscal spending cannot dominate and guarantee high efficiency.

As a whole, the estimated coefficients of the efficiency determinants and the mean TE composed by the WH model are slightly smaller than those estimated by the BC and G model. It is consistent with the remarks made in Wang and Ho (2010) which indicated the dummy-variable G model had a tendency to bring about biased results[16]. When the estimated TE stays

[15] Which is bad for TE when the government over-spends as found in Lei (2013).

[16] Please see Wang and Ho (2010), p. 296 for the details.

at around 95%, it indicates that economies in the Greater China region are highly efficient with output level very close to the frontier level.

Table 4: Estimated TE (WH model) for the Chinese Economies for the Period of 1989-2010

Provinces	Maximum	Minimum	Average	Growth 1990-2000*	Growth 2001-2010**
Beijing	0.889	0.849	0.870	0.218	0.217†
Tianjin	0.989	0.985	0.988	0.020	-0.037†
Hebei	0.963	0.929	0.949	-0.098	-0.206†
Shanxi	0.981	0.967	0.977	0.023	-0.131†
Inner Mongolia	0.971	0.935	0.960	-0.032	-0.334†
Liaoning	0.934	0.878	0.918	-0.063	-0.521†
Jilin	0.903	0.787	0.871	-0.114	-1.230†
Heilongjiang	0.974	0.964	0.970	-0.028	-0.070†
Shanghai	0.963	0.926	0.942	0.047	0.109
Jiangsu	0.977	0.955	0.967	-0.080	0.026
Zhejiang	0.965	0.934	0.956	-0.031	-0.129†
Anhui	0.975	0.942	0.962	-0.057	-0.195†
Fujian	0.985	0.959	0.976	-0.065	0.130
Jiangxi	0.982	0.947	0.971	0.078	-0.141†
Shandong	0.981	0.960	0.972	0.048	-0.051†
Henan	0.980	0.957	0.971	0.114	-0.216†
Hubei	0.990	0.976	0.986	-0.018	-0.061†
Hunan	0.976	0.958	0.967	0.089	-0.007†
Guangdong	0.972	0.935	0.964	0.096	-0.114†
Guangxi	0.935	0.889	0.914	0.249	-0.188†
Hainan	0.931	0.872	0.902	-0.373	0.553
Sichuan	0.978	0.958	0.970	0.072	-0.049†
Guizhou	0.978	0.950	0.969	0.006	-0.117†
Yunnan	0.984	0.962	0.975	0.064	-0.030†
Shaanxi	0.983	0.958	0.975	0.103	0.038†
Gansu	0.973	0.940	0.963	0.013	0.005†
Qinghai	0.987	0.962	0.980	0.001	-0.010†
Ningxia	0.979	0.961	0.970	0.008	-0.068†
Xinjiang	0.980	0.956	0.971	-0.130	0.126
Hong Kong	0.849	0.728	0.785	-1.051	0.358
Macau	0.922	0.843	0.894	0.484	0.073†
Taiwan	0.976	0.959	0.969	0.040	-0.092†

Author's estimation; *: Average growth rate 1990-2000; **: Average growth rate 2001-2010; †: Slowed down in growth rate.

Table 4 summarizes the TE estimated by the WH model for the sampling Chinese economies. In 2010, the most efficient economy on the Mainland side was Tianjin with an index of 0.9854, followed by Fujian's 0.9847. The third rank was held by Shaanxi at 0.9816. For the external Chinese economies, Taiwan was the most efficient economy with an index of 0.9612, followed by Macau's 0.9023. Hong Kong's TE could only stay at 0.7624 which was the lowest in the

Greater China region. As shown, almost all the sampling economies have achieved TE level of over 90% which suggests that the actual output stays at over 90% of the frontier level. The TE estimated by the WH model has out-performed those shown in Yu (2008) and Zhou, Li and Li (2010) with differentiable efficiency ranking. For instance, Tianjin, Fujian and Shaanxi have just got the 8th, 11th and 23rd rank (Yu (2008)) and 27th, 17th and 14th rank (Zhou, Li and Li (2010)) with average efficiency level at 0.452, 0.411, 0.245 and 0.284, 0.601, 0.623 respectively, which are very much departed from the 0.9 level in this study. The differences in sampling period (from pre-reform to early post-reform period versus the most recent 2 decades), estimation model (Translog versus Cobb-Douglas) and transformation method (no transformation versus within transformation), especially the diversified sampling period are factors attributed to the huge deviations between these studies. Nevertheless, the average TE of the sampling economies which stays at 0.949, is very close to the 0.93 level stated in Zhou, Li and Li (2010). As shown in Table 4, TE is independent of income such that municipalities, provinces or SARs with higher per capita RGDP, for example Hong Kong and Macau, do not necessary attain higher TE. When the sampling period is divided into 2 sub-periods, the average growth rate of TE for the period of 2001-2010 is lagged behind by that of 1990-2000. Out of the 32 sampling Chinese economies, 26 of them face either a slowdown in efficiency growth or even deteriorated efficiency.

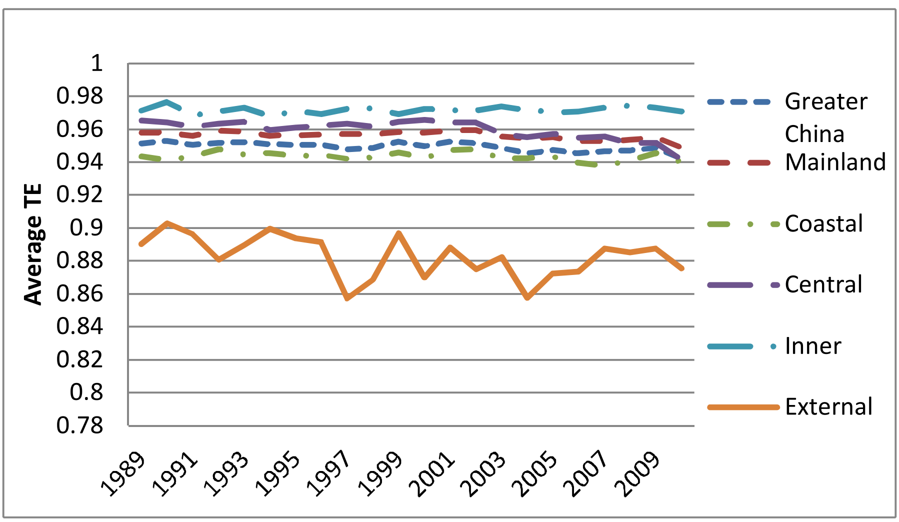

Figure 1: Estimated TE by Geographical Division

When the provinces and municipalities on the Mainland side are grouped into geographical regions[17], as shown in Figure 1, the inner region is the most efficient region with an average efficiency level[18] at 0.970. The second and third ranks are held by the central and coastal regions, with their efficiency level stating at 0.959 and 0.943 respectively. The average efficient level for the external economies, meanwhile, is recorded at 0.883. It indicates that external economies of China are less efficient than the municipalities and provinces on the Mainland side which matches the finding in Lei (2013).

Our estimation result suggests that provinces which are further departed from the coastal line could enjoy relatively higher level of efficiency. It is different from Yu (2008)'s findings in which the coastal region had the highest efficiency, followed by the central and inner regions. It is believed that the efficiency level of the coastal region could have been adversely affected by the Global Financial Crisis led slump in export performance. Consequently the inner region which has less reliance on exportation could out-perform both the coastal and central regions to gain its first rank in terms of TE. Besides, the coastal region has successfully maintained an abundant stock of investment, but the output level generated is disproportionate to the available capital stocks. It is likely that there is a relatively large gap between the actual and frontier output in the coastal region, leading to a degraded TE. Notwithstanding their inferior position on endowments and attractiveness to investors, provinces in the inner region of China can better utilize the obtained inputs with output closer to the frontier level, and hence higher TE could be reached.

5. CONVERGENCE OF TECHNICAL EFFICIENCY

Table 5: The Standard Deviation of the Estimated TE (by WH model)

Year	Greater China	Mainland	Coastal	Central	Inner	External
1989	0.040	0.032	0.042	0.024	0.006	0.066
1990	0.040	0.034	0.040	0.031	0.006	0.067
1991	0.039	0.030	0.035	0.029	0.013	0.076
1992	0.044	0.029	0.035	0.029	0.010	0.101
1993	0.043	0.031	0.036	0.032	0.008	0.096
1994	0.038	0.031	0.037	0.031	0.011	0.068
1995	0.039	0.030	0.036	0.030	0.009	0.073
1996	0.041	0.031	0.037	0.031	0.008	0.083

[17] Coastal region has been defined in the previous section; Central region composes of Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; Inner region composes of Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. Greater China refers to all the 32 sampling economies while the Mainland consists of all the municipalities and provinces in China excluding Chongqing and Tibet.

[18] The average of all the provinces in the region over the sampling period of 1989-2010.

1997	0.052	0.031	0.038	0.028	0.007	0.122
1998	0.047	0.032	0.040	0.029	0.007	0.094
1999	0.039	0.030	0.035	0.031	0.007	0.075
2000	0.050	0.032	0.039	0.029	0.008	0.116
2001	0.041	0.028	0.033	0.030	0.006	0.087
2002	0.045	0.028	0.031	0.030	0.007	0.105
2003	0.042	0.029	0.032	0.031	0.007	0.088
2004	0.052	0.032	0.038	0.032	0.004	0.121
2005	0.047	0.032	0.035	0.036	0.007	0.107
2006	0.051	0.035	0.039	0.038	0.010	0.120
2007	0.047	0.036	0.036	0.044	0.012	0.104
2008	0.048	0.038	0.037	0.049	0.006	0.098
2009	0.047	0.038	0.033	0.056	0.009	0.089
2010	0.052	0.042	0.038	0.060	0.007	0.102

Author's calculation

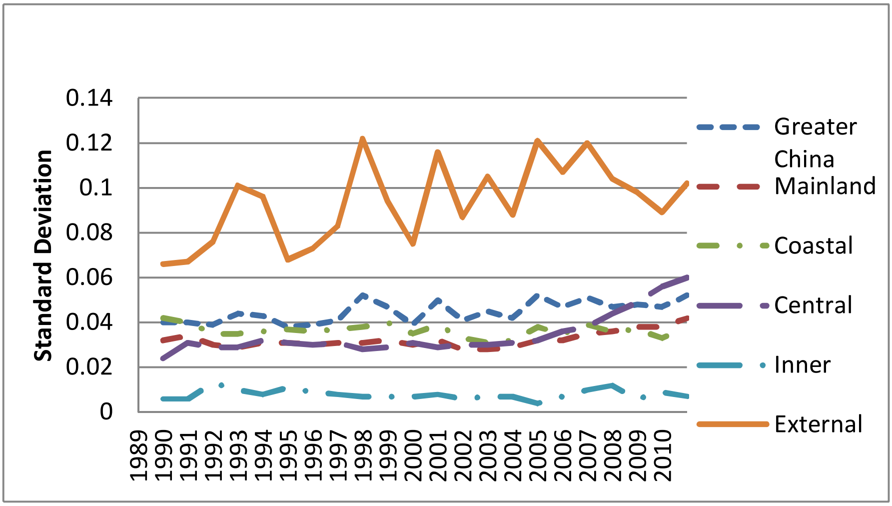

Figure 2: The Standard Deviation of TE by Geographical Division

Table 5 summarizes the standard deviation of the estimated TE by various groupings over the sampling period and their trends are shown in Figure 2. On the Greater China level, the standard deviation moves moderately without validate fluctuations. It exhibits no obvious sign of divergence across the 32 Chinese economies. Similar conclusion can also be drawn for the economies on the Mainland side as well as the coastal and inner regions in which the starting and ending value of their standard deviation state at similar level. In contrast, apart from their relatively larger standard deviation, volatile fluctuations are also observed for the external Chinese economies. It reflects that the TE of Hong Kong, Macau and Taiwan have been fluctuating with differentiable patterns. Nevertheless, there is still no explicit evidence to confirm divergence of TE between them. For the central region, its standard deviation is the highest on the Mainland side and has been increasing from 0.02 to 0.06 with a seemingly diverging trend since year 2005. To further address the issue of TE convergence, the stochastic convergence analyses based on panel unit root tests are then performed.

Before the panel unit root tests can be conducted, the cross-section dependence test (CD test) developed in Pesaran (2004)[19] is firstly run to examine if the residuals from the Augmented Dickey-Fuller test on TE are cross-section independent. The result shows that the null hypothesis of no cross-section dependence cannot be rejected. It is then proceeded to conduct the LLC, IPS and MW tests in which cross-sectional independence are assumed.

Table 6: Panel Unit Root Test for the Estimated TE

Testing method/Groups	LLC		IPS		MW	
	Statistic	P value	Statistic	P value	Statistic	P value
Greater China	-4.81	0.00	-7.75	0.00	219.79	0.00
Mainland	-3.90	0.00	-6.84	0.00	193.63	0.00
Coastal	-2.19	0.01	-4.46	0.00	78.64	0.00
Central	0.76	0.78	-0.85	0.20	37.50	0.01
Inner	-8.67	0.00	-6.73	0.00	77.48	0.00
External	-4.62	0.00	-4.06	0.00	26.17	0.00

The tests are made based on the standard LLC, IPS and MW procedures; Greater China, Mainland, Coastal, Central, Inner and External are the geographical divides defined before.

As shown in Table 6, the tests reject the unit root null hypothesis for almost all the groups at 5% level, with the exception of the central region. The stationary distribution pattern of the ratios provides evidence to support the presence of stochastic convergence of TE between economies in the Greater China region, on the Mainland side, within the coastal and inner regions and among the external Chinese economies. This finding is consistent to those exhibited in Herrerias and Monfort (2013) in which stochastic convergence was observed across Chinese provinces in terms of labor productivity and total factor productivity. It implies that the efficiency gap within these groups tends to decline. In contrast, there is no evidence to support stochastic convergence of TE between provinces in the central region. Given their adjacency to the coastal region, some of the provinces in the central region may be affected by the shocks faced exactly by the coastal region which are more trade related. Meanwhile, the rest of provinces may have closer linkages with the inner region which is less open. As a result, it has brought about diversified efficiency performance to different provinces in the central region, and hence enlarged efficiency gap is exhibited in the test.

[19] The CD test procedures are well documented in Pesaran (2004) and are not reported here.

6. CONCLUSION AND DISCUSSION

6.1 Conclusion

This study is organized to estimate the TE of the Greater China region with 32 Chinese economies, including the Chinese provinces and municipalities, SARs and Taiwan for the period of 1989-2010 as well as to track the major efficiency determinants. Adopting the SFA framework and the models advanced in Battese and Coelli (1995), Greene (2005) and Wang and Ho (2010), TE which is defined as the deviation of actual output from the frontier output is estimated and decomposed. The results indicate that Tianjin and Beijing are the most and least efficient economies on the Mainland side with average TE at 0.988 and 0.870 respectively. For the external economies, Taiwan is the most efficient entity with average TE at 0.969 followed by Macau's 0.894. Hong Kong, meanwhile, is the least efficient economy with average TE at 0.785. When the TE on the regional level is reviewed, the inner region is more efficient than the central and coastal regions and the external Chinese economies. Apart from the slowdown in TE improvement, there is also a tendency for the estimated TE to increase with the distance to the coastal line. It is probably attributed to the Global Financial Crisis which has posted certain adverse impacts to the relatively more open and export-oriented provinces in the coastal and central regions. For provinces in the inner region, they are not fully exposed to such external shocks and can strike to produce at a level closer to their frontier output, leading to slightly higher TE. For the relatively lower TE faced by the external economies, especially for Hong Kong and Macau, an intuitive explanation is that the massive investment together with the over-concentrated production structure faced by the SARs, specializing in financial services/real estate transactions and gaming services respectively is an obstacle to efficient allocation of resources. As a result, their output is departed from the frontier output, leading to a relatively low efficiency level.

As for the determinants of TE, the WH model is able to deliver more robust results than the other models. Capital stock per labor and labor productivity are significant determinants observed. When more capital inputs are required in the production process, it tends to discount efficiency. In contrast, the presence of more productive labor force improves directly the TE. Simultaneously service sector output ratio is also found to be highly significant with strong magnitude. It affirms that structural transformation toward service production contributes to efficiency improvement. Nevertheless, the service sector would have to arrive to certain scale before it can strengthen efficiency as increase in service sector output is observed as a statistically insignificant factor. The decentralization index, which measures the additional government expenditure relative to the group mean, is significant with limited magnitude. Although trade contributes to strengthen TE, it can only be regarded as a secondary factor relative to the other vital efficiency determinants.

In light of the convergence issue, the standard deviations and the stochastic convergence tests provide evidences to support convergence of TE for the Greater China region across 32 economies, on the Mainland side, within the coastal and inner regions and across the external

Chinese economies with the exception of the central region. This finding matches the conclusion drawn in Herrerias and Monfort (2013). It implies that in line with the process of income convergence across economies in the Greater China region as observed in Lei and Tam (2009; 2013), the TE of these economies has been converging simultaneously with reduced disparities. The correlation of such is consistent with the trend as observed in Mas, Maudos, Perez (1998) in which efficiency convergence in the form of lower TFP gap coincided with income convergence across different Spanish regions. In general, there is no contradiction between the evolution of income gap and efficiency gap in the Greater China region in which both has been declining in line with the economic reforms. Nevertheless, regional diversification on efficiency level remains to be at-risk despite the presence of convergence on the national level, especially for the central region whose enlarged efficiency gap is somehow caused by the interactions of the spill-over effects from both the coastal and inner regions.

6.2 Discussion

Despite the presence of a satisfactory level of TE and the tendency of stochastic convergence of TE across different regions and economies in China, the performance of the Greater China economy is not free from any uncertainties, reflected by the relatively lower level of TE attained by the coastal region, as well as the divergence of TE found among provinces in the central region. It implies that there is a risk for the coastal region to be outperformed and left behind by the other geographical regions, leading to enlarged efficiency gap over time if the current trend of development sustains. When the "over-investment" led disproportionate level of output is a cause to the low TE for the coastal region which has also been indicated in Herrerias and Monfort (2013), rationalization on investment projects must be stressed for economies in the coastal region with high autonomy and stronger fiscal strength, as well as Hong Kong and Macau. The perception of suppressing consumption for more investment to strike for higher economic growth which is deep-rooted on the Mainland side should be overhauled or the problem of low level of efficiency may persist. Besides, transitional supports could be provided to export-oriented sectors which have been hit by the Global Financial Crisis to lessen the distortions they faced.

As indicated in the empirical findings, structural transformation toward service oriented production tends to improve efficiency and therefore should be encouraged and to be regarded as a long-term development strategy. In addition, training and vocational training programs, which aim to strengthen the quality of human capital, remain to be effective policies with regard to efficiency improvement. Enhancement in administrative autonomy, meanwhile, may also help to tackle the sluggish improvement in TE.

As a whole, this study provides us with useful hints on how to sustain TE improvements. Nevertheless, when it is organized to pool up economies in the Greater China region with diversified background for an integrated study, further exploration for a more adequate common measurement or proxy for various efficiency determinants, such as human capital is desirable, or measurement error and biased result may arise.

REFERENCES

[1] Aigner D.J., Lovell C.A.K. and Schmidt P., 1977, Formulation and estimation of stochastic frontier production function models, *Journal of Econometrics*, 6, 21-37.

[2] Ao X. and Fulginiti L., 2003, Productivity growth in China: evidence from Chinese provinces, available at: http://econpapers.repec.org/paper/wpawuwpdc/0502024.htm.

[3] Battese G.E. and Coelli T.J., 1992, Frontier production functions, TE and panel data: with application to paddy farmers in India, *The Journal of Productivity Analysis*, 3, 153-169.

[4] Battese G.E. and Coelli T.J., 1995, A model for technical inefficiency effects in a stochastic frontier production function for panel data, *Empirical Economics*, 20, 325-332.

[5] Carlino, G.A., Mills, L.O., 1993, Are U.S. regional incomes converging?, *Journal of Monetary Economics*, 32, 335-346.

[6] Chen J. and Fleisher B.M., 1996, Regional income inequality and economic growth in China, *Journal of Comparative Economics*, 22, 141-164.

[7] Cheng Y.S. and Li S.K., 2006, Income inequality and efficiency: a decomposition approach and applications to China, *Economics Letters*, 91, 8-14.

[8] Coelli T.J., 1996, A guide to FRONTIER 4.1: a computer program for stochastic frontier production and cost estimation. Centre for Efficiency and Productivity Analysis, *Working Paper No. 96/07*, Department of Economics, University of New England, Armidale, New South Wales, Australia.

[9] Démurger, S., 2001, Infrastructure development and economic growth: an explanation for regional disparities in China?, *Journal of Comparative Economics*, 29, 95-117

[10] Galvão A.F. Jr., Gomes, F.A., 2007, Convergence or divergence in Latin America? a time series analysis, *Applied Economics*, 39, 1353-1360.

[11] Greene, W., 2005, Reconsidering heterogeneity in panel data estimation of the stochastic frontier model, *Journal of Econometrics*, 126, 269-303.

[12] Ha J. and Leung C., 2001, Estimating Hong Kong's output gap and its impact on inflation, *Hong Kong Monetary Authority Research Memoranda*, Economic Research Division, Research Department, Hong Kong Monetary Authority.

[13] Herrerias M.J. and Monfort J.O., 2013, Testing stochastic convergence across Chinese provinces, 1952-2008, *Regional Studies*, 47, 1-17.

[14] Hong Kong SAR Government, *Hong Kong Monthly Digest of Statistics*, various issues. Census and Statistics Department, Hong Kong SAR Government, available at http://www.info.gov.hk/censtatd/eng/hkstat/index.html

[15] Im, K.S., Pesaran, M.H., and Shin, Y., 2003, Testing for unit roots in heterogeneous panels, *Journal of Econometrics*, 115, 53-74.

[16] Jian, T., Sachs, J.D., Warner, A.M., 1996, Trends in regional inequality in China, *China Economic* Review, 7, 1-21.

[17] Kim S. and Han G., 2001, A decomposition of total factor productivity growth in Korean manufacturing industries: a stochastic frontier approach, *Journal of Productivity Analysis*, 16, 269-281.

[18] Kohli U., 1978, A gross national product function and the derived demand for imports and supply of exports, *Canadian Journal of Economics*, 11, 167-182.

[19] Lei, C.K., 2013, Can Chinese cities achieve higher TE after hosting mega events?, *International Journal of China Studies*, 4, 85-110.

[20] Lei C.K. and Tam P.S., 2010, A panel data approach to the income convergence among mainland China, Hong Kong and Macao, *Journal of the Asia-Pacific Economy*, 15, 42-435.

[21] Lei C.K. and Tam P.S., 2013, Stochastic convergence of the greater China economies: a panel unit root approach, In *China's Development and Harmonisation: Towards a Balance with Nature, Society and the International Community*, eds., Wu B., Yao, S. and Chan J., 152-168, Routledge, London.

[22] Lei C.K. and Yao S., 2008, On income convergence among China, Hong Kong and Macau, *The World Economy*, 31, 345-366.

[23] Levin, A., Lin, C.-F., and Chu, C.-S. J., 2002, Unit root tests in panel data: asymptotic and finite-sample properties, *Journal of Econometrics*, 108:1-24.

[24] Li K.W., 2003, China's capital and productivity measurement using financial resources, *Center Discussion Paper*, no. 851, Yale University.

[25] Li Q., Papell D., 1999, Convergence of international output: time series evidence for 16 OECD countries, *International Review of Economics and Finance*, 8, 267-280.

[26] Loewy M.B. and Papell D.H., 1996, Are US regional incomes converging? Some further evidence, *Journal of Monetary Economics*, 38, 587-598.

[27] Macau SAR Government, *Yearbook of Statistics of Macau*, various issues. Statistics and Census Services, Macau SAR government. Also available at http://www.dsec.gov.mo

[28] Maddala, G.S., Wu, S., 1999, A comparative study of unit root tests with panel data and a new simple test, *Oxford Bulletin of Economics and Statistics*, 61, 631-652.

[29] Mas M., Maudos J., Perez F. and Uriel E., 1998, Public capital, productivity efficiency and convergence in the Spanish regions (1964-93), *Review of Income and Wealth*, 44, 383-396.

[30] Maudos J., Pastor J.M. and Serrano L., 1998, Convergence in OECD countries: technical change, efficiency and productivity, *Instituto Valenciano de Investigaciones Economicas (IVIE) Working Papers*, WP-EC 98-21.

[31] Meeusen W. and van den Broeck J., 1977, Efficiency estimation from Cobb-Douglas production functions with composed error, *International Economic Review*, 18, 435-444.

[32] Movshuk O., 2004, Restructuring, productivity and technical efficiency in China's iron and steel industry, 1988-2000, *Journal of Asian Economics*, 15, 135-151.

[33] Nagayasu J. and Liu Y., 2008, Relative prices and wages in China: evidence from a panel of provincial data, *Journal of Economic Integration*, 23, 183-203.

[34] National Statistical Bureau of China (NSB), 2010, *China Compendium of Statistics 1949-2008*. China Statistics Press, Beijing

[35] National Statistical Bureau of China (NSB), *Statistical Yearbook of China*, various issues. China Statistics Press, Beijing.

[36] National Statistics, Republic of China, available at http://www.stat.gov.tw.

[37] Nissan E. and Niroomand F., 2010, Convergence-divergence of technological efficiency and productivity across world regions, *Modern Economy*, 3, 690-694.

[38] Pedroni, P. and Yao, J.Y., 2006, Regional income divergence in China, *Journal of Asian Economics*, 17, 294-315.

[39] Pesaran, M.H., 2004, General diagnostic tests for cross section dependence in panels, *Cambridge Working Paper in Economics 0435*, University of Cambridge.

[40] Raiser, M., 1998, Subsidizing inequality: economic reforms, fiscal transfers and convergence across Chinese provinces, *Journal of Development Studies*, 34, 1-26.

[41] Shiu A. and Heshmati A., 2006, Technical change and total factor productivity growth for Chinese provinces: a panel data analysis, Discussion Paper no. 2133, Institute for the Study of Labor.

[42] Solow R.M., 1957, Technical change and the aggregate production function, *Review of Economics and* Statistics, 39,312-320.

[43] Wang, H. J. and Ho, C.W., 2010, Estimating fixed-effect panel stochastic frontier models by model transformation, *Journal of Econometrics*, 157, 286-296.

[44] Wang, H. J., 2012, Manual of Hung-Jen Wang's Stata codes, available at http://homepage.ntu.edu.tw/wangh

[45] Wu Y., 1995, Productivity growth, technological progress and technical efficiency change in China: a three-sector analysis, *Journal of Comparative Economics*, 21, 207-229.

[46] Wu Y., 2000, Productivity, growth and economic integration in southern China region, *Asian Economic Journal*, 1, 39-54.

[47] Yao S. and Zhang Z., 2001, On regional inequality and diverging clubs: a case study of contemporary China, *Journal of Comparative Economics*, 29, 466-484.

[48] Yu Y., 2008, A stochastic frontier approach to measuring regional TE in China, *Munich Personal RePEc Archive (MPRA), paper no. 18171.*

[49] Zhang J., 2008, Estimation of China's provincial capital stock (1952-2004) with applications, *Journal of Chinese Economic and Business Studies*, 6, 177-196.

[50] Zhang Z., Liu A. and Yao S., 2001, Convergence of China's regional incomes 1952-1997, *China Economic Review*, 12, 243-258.

[51] Zhou X., Li. K.W. and Li Q., 2012, An analysis on technical efficiency in post-reform China, *China Economic Review*, 22, 3