

The impact of knowledge diffusion and learning capability on regional economic development in China

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Abstract

One of the guiding principles of regional policy during the reform era in China has been the assumption that imbalances of regional development will trigger off catching-up processes in the lagging regions. Serious doubts on this have been raised since the mid-nineties when the impression became stronger and stronger that there are increasing imbalances in particular between the interior and the coastal provinces. This has caused a policy shift in favour of government intervention especially supporting Western region development.

Under this light the tremendous importance of knowledge and technology for regional development becomes more and more recognized. In this paper we present an evolutionary growth model focusing on the inter-regional diffusion of knowledge. Using provincial data for the time period 1978-1998 we calculate the provincial learning capabilities, which are the main parameters of the model, and compare these results to a constructed measure of absorptive capability using data on the provinces level of education, infrastructural endowment and political environment.

Our results support evidence for the high relevance of the included factors of social capability for the regional growth process observed in the nineties. We conclude that government intervention in backward regions should focus on improving educational and infrastructural aspects as well as on establishing linkages to coastal provinces enabling knowledge transfer. Nevertheless, as this article presents our first modelling approach on this problem, there is still some room for improvement and extension of the model.

1 Introduction

For a country with the enormous size of China, roughly the same as Europe, and heavily varying geographic conditions it is only natural to expect also a large cultural and economic diversity across regions. Regionalism has a historic background in China going long back before the establishment of the communist Peoples Republic. Mainly for strategic reasons Mao Zedong followed the principle of a cellular economy in which every region could be economically independent of the other regions. Neglecting certain comparative advantages, this led to a parallel establishment of similar industrial structures in many regions, but had an equalizing impact on disparities in total output¹. After the chaos of the cultural revolution (1966-1975) and Mao's death a new period of reform and opening up to the outside world began in 1978, when the first farmers abandoned collective production and distributed the fields among their families. Since that time the Chinese economy is on a path of transition towards a market economy, which is now, by the year 2000, no way finished. While slowly allowing foreign investment in selected regions since the mid-eighties, the government explicitly followed a biased policy towards the coast, concentrating most of its investment in the coastal provinces and assuming, that the achieved wealth would later on more or less automatically 'trickle-down' to the central and western regions (see map 1 for an overview of the "three belts regional framework" adapted at this time). The FDI-driven and export oriented development approach had spectacular success in the coastal regions allowing for two-digit national GDP growth rates. In the mid-nineties evidence of the ongoing growth of the gap between coast and interior (see figure 1) made the central government realize the danger of a destabilisation and potential regional desintegration. For this reason the government abandoned its former strategy and made the reduction of regional disparities and the development of the Western regions a major policy goal².

¹ On the „third front“ policy under Maoism favoring remote interior provinces in the sixties and seventies, see the seminal study by Naughton (1988). Gore provides a useful survey of the long-run path dependencies resulting from the Maoist legacy in general (Gore 1999).

² See the summary Report on the Ninth Five Year Plan of the National Economy and Social Development and the 2010 Long-term Targets (Li Peng 1996).

Map 1: The three belts regional framework

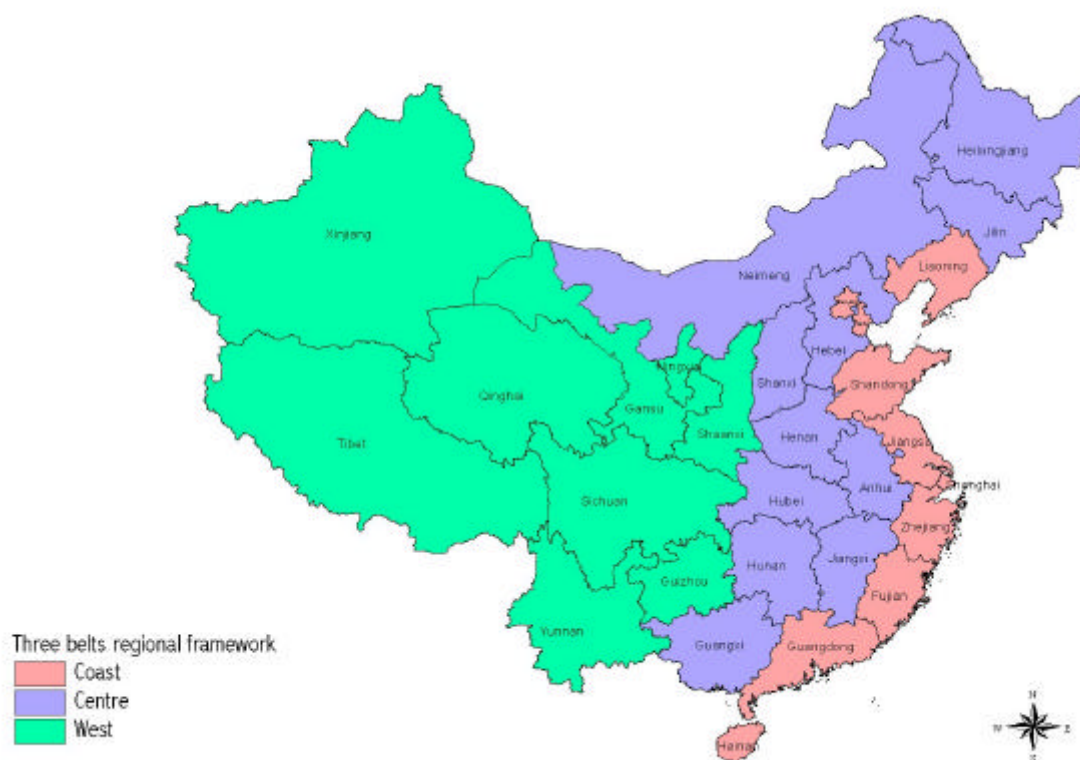
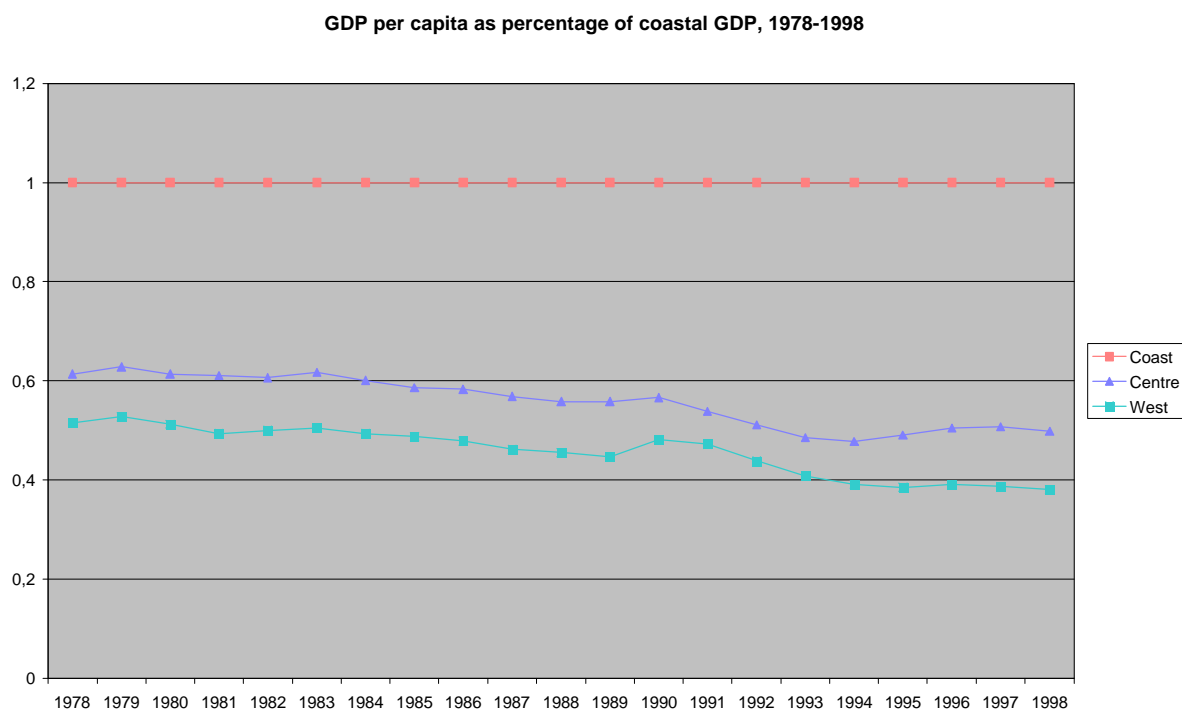
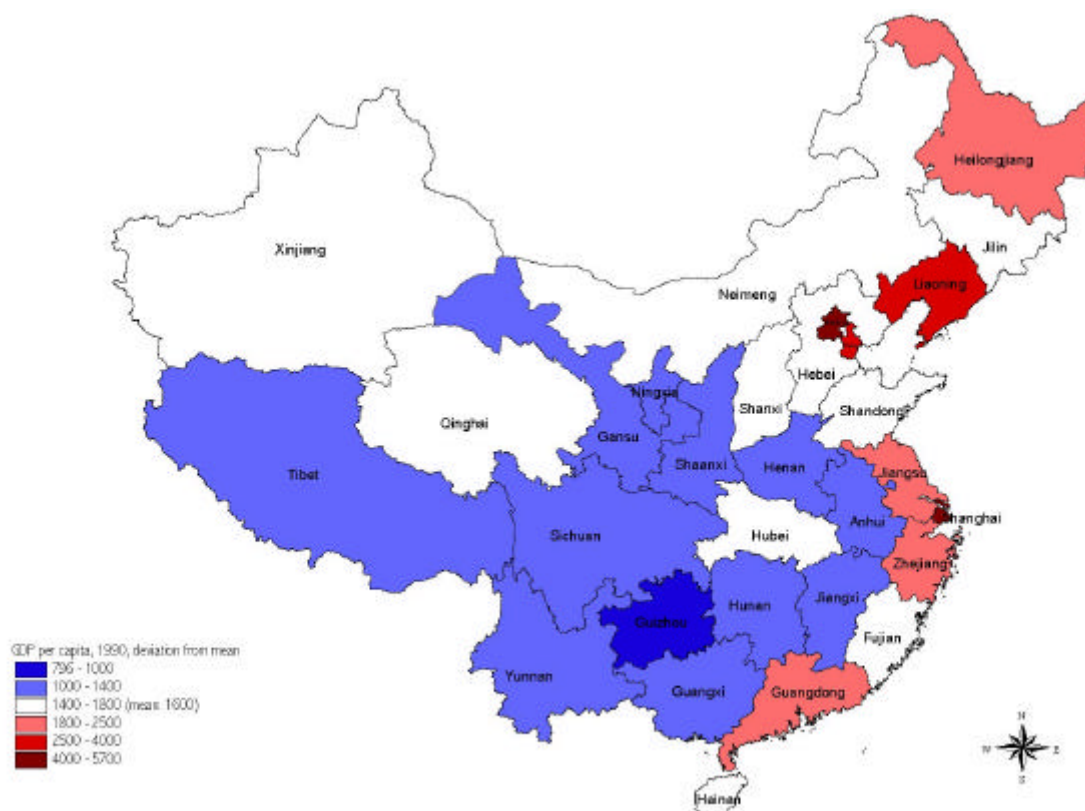


Figure 1: Divergence between coast and interior



Map 2: GDP per capita 1990, deviation from national mean



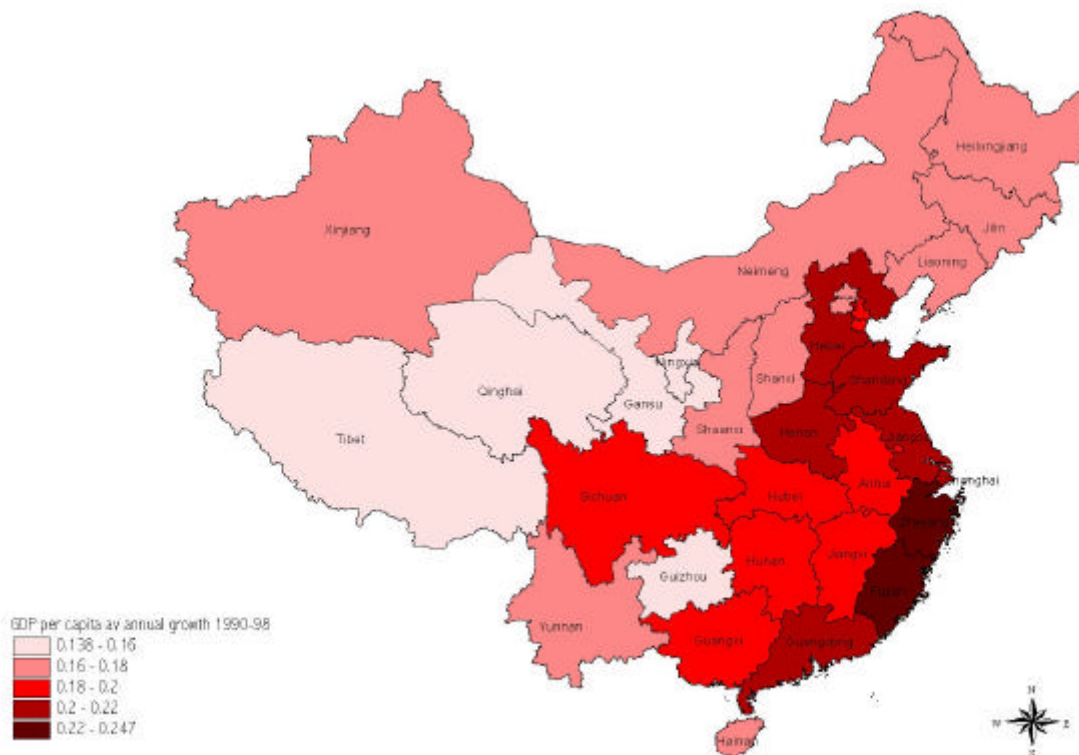
Maps 2 and 3 clearly illustrate the strong trend of divergence in the nineties between coastal and interior regions. In terms of GDP per capita in 1990 there is already an obvious disbalance in favor of some coastal provinces (Map 2), and this gap is getting significantly larger between 1990 and 1998 (Map 3). Numerous studies have pointed at the tremendous impact of foreign direct investment (FDI) on China's economic performance in the reform period. Map 4 shows the strong correlation between cumulative FDI for the last twenty years and the level of economic development. Some authors have argued that the success of China's economy can mainly be explained by a mere increase in factor inputs (mostly labor)³, but the evidence of the high impact of FDI and the rising disparities point at the high importance that knowledge (and its diffusion or 'non-diffusion') has played in recent regional economic development. Although the Chinese central government recently seems to have recognized the role of innovations and knowledge for economic growth and supports a large number of programs aiming at improving the national or regional innovation systems⁴, there remains the central question on the basic factors and conditions enabling a region to 'learn' and absorb the knowledge of more advanced neighbours. To investigate more into this point we introduce a regional spillover model to show that the ongoing trend of divergence between coast and interior can be explained – additionally to different levels of

³ see for example Krugman's famous article (Krugman 1994).

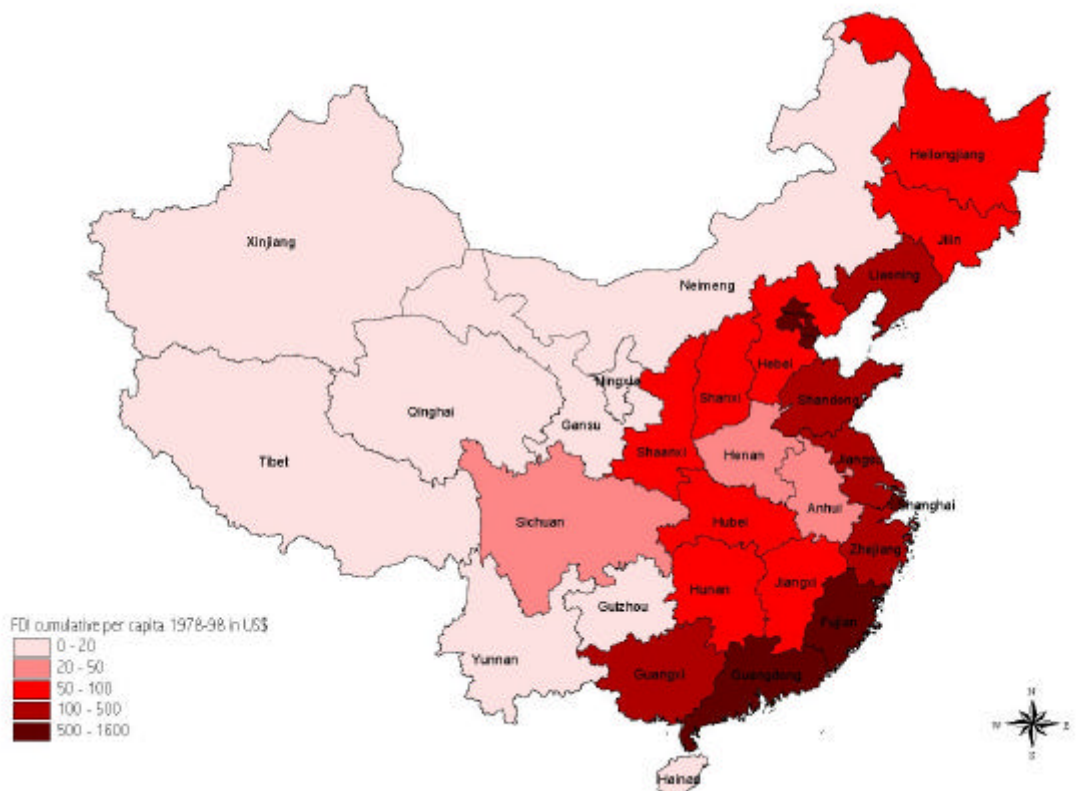
⁴ see for example the contributions to the conference HLSTI (2000) or the seminal work of Gu Shulin (1999) on the role of technological innovation in Chinese economic development.

exogenous knowledge input (FDI) - by differing regional absorptive capacities, which can be understood as the regions educational, infrastructural and regulative endowment.

Map 3: GDP per capita average annual growth, 1990-1998



Map 4: Cumulative foreign direct investment (FDI) in US\$ per capita, 1978-1998



2 The data

We use provincial data for the years 1978-1998 from the National Statistical Yearbooks of China (Zhongguo tongji ju, 1979-1999)⁵. All data used in this article and shown on the maps are at 1980 constant prices.

Many researchers have pointed at problems with the reliability of Chinese data⁶. We can only keep this caveat in mind and assume that by analysing regional disparities and not looking at absolute levels, we can at least observe quite reliable trends.

Recent results show that the level of regional aggregation plays a crucial role for the analysis of regional disparities in China (Herrmann-Pillath, Kirchert and Pan, 2001b). By analysing nation-wide data on the sub-provincial prefecture-level it is shown that more than 50% of inequality in GDP per capita is due to intra-provincial disparities and therefore lost in all conventional studies based on province data. It is also important to keep in mind that provinces in China are in terms of size and population comparable to large European countries. For this reason it would be the best approach to base our analysis of the impact of knowledge-diffusion on regional inequality on prefecture-level data, but unluckily all data on educational and infrastructural aspects, which are a major determinant of regional absorptive knowledge capability, are only available at the levels of provinces⁷. Although regional disparities in China can mainly be understood as a dichotomy between coast and interior (centre and west), as it is mentioned above, there are still considerable variations inside of these three belts (Herrmann-Pillath, Kirchert and Pan, 2001b). So instead of just using aggregate data of the three belts we base our first approach for a model analysing regional knowledge spillovers on province level data.

⁵ These data has been collected in a database at the ICCE (Institute for Comparative Research into Culture and Economic Systems) at university Witten-Herdecke and has been implemented in a GIS (Geographic Information System) to enable an easy visualization of the spatial distribution of the included statistical indicators.

⁶ See for example Dernberger (1996) or Fischer (2000). Fischer emphasizes, amongst other points, that the transition to the SNA system is not yet completed, that measurement of newly emerging sectors is very insufficient (like real estate business), and that there are serious limitations to the comparability of categories during the course of time. The well-known phenomena of statistical fake and secrecy add to these problems.

⁷ A detailed description of the prefecture-level dataset for the years 1993 and 1998 is given in Herrmann-Pillath, Kirchert and Pan (2001b). A large number of maps and further information on GIS for China can be found under www.uni-wh.de/socialsciencechina/ .

3 The model

The model used here is a slightly modified form of a general diffusion and spillover simulation-model introduced by Caniels (1999)⁸, which combines a number of ideas from economic and geographic theory by integrating space as an explaining factor into a general technology gap model⁹. The idea underlying the technology gap approach is that a technological difference between countries opens up the possibility for countries at a lower level of economic and technological development to catch up by imitating the more productive technologies of the leader country (Fagerberg 1988). The catching up process is conditional upon some specific factors, referred to as social capability and technological congruence (Abramowitz 1986). Social capability describes all the factors facilitating the imitation of a new technology, or the implementation of technology spillovers. These are education, infrastructure, an appropriate financial system, labour market relations etc. (Fagerberg, Verspagen, von Tunzelmann 1994). The second factor determining the potential for catching up is technological congruence. This means to which extent the backward country is able to apply the technical features of the new knowledge. These basic concepts are reflected in the modelling approach.

We look at n regions with total output Q_i and knowledge stock K_i ($i = 1, \dots, n$). Like in other catching up literature it is assumed that knowledge is the only factor influencing output. The growth rate of output is proportional to the growth rate of knowledge:

$$\frac{\dot{Q}_i}{Q_i} = b \frac{\dot{K}_i}{K_i} \quad (1)$$

The growth rate of the knowledge stock in region i is determined by three factors, the growth of output via a Verdoorn effect, knowledge-spillovers S_i received from the other regions and an exogenous rate of knowledge-growth r_i :¹⁰

$$\frac{\dot{K}_i}{K_i} = l \frac{\dot{Q}_i}{Q_i} + a S_i + d_i r_i \quad (2)$$

$$\text{with } S_i = \sum_{\substack{j=1 \\ j \neq i}}^n S_{ij} \text{ and } S_{ij} = \frac{d_i}{g_{ij}} e^{-\left(\frac{G_{ij}}{d_i} - m\right)^2}, \quad G_{ij} = \ln\left(\frac{K_j}{K_i}\right).$$

l determines the impact of the Verdoorn effect on total knowledge growth. a influences the size of the contribution of spillovers to knowledge growth¹¹. g_{ij} is the geographic

⁸ For a short version see also Caniels and Verspagen (1999)

⁹ For a short general survey see Caniels (1999) pp.26ff and Verspagen (1992)

¹⁰ Note that our version of equation (2) slightly differs from the original one, taking a as a scale variable for spillovers only and including d_i as factor of r_i .

distance between regions i and j . d_i is the parameter reflecting the social capability or of region i to adapt new knowledge. G_{ij} , defined by the logarithm of the quotient of the knowledge stocks of regions j and i , is the technology or knowledge gap between these regions. m_j is a parameter influencing at which level of the knowledge gaps maximum spillovers between regions will occur.

To explain some of the basic characteristics of the model we illustrate the case when there are only two regions. We assume that region one is the leader and region two the technologically backward region. If the other parameters d_i and m_j are equal (and larger than zero) there will be positive spillovers between both regions, but the spillover received by the lagging region two will be higher than the one received by the advanced region one, which is the basic principle of technology gap literature. In contrast to other models an important feature of this model is, that it is possible for the leading region to learn from the backward region, taking account of the possibility that a backward region could have developed complementary knowledge. From equation (2) it is easy to see that the spillovers S_i are a monotone rising function of d_i , meaning that the higher the social capability of a region, the more spillovers it will receive. On the other hand the amount of spillovers S_{ij} between two regions is reduced when the geographic distance g_{ij} grows. The impact of the exogenous knowledge input r_i is also influenced by the regional absorptive capability d_i . So even if a region has a very high level of exogenous knowledge input, it is possible that only a small proportion will be absorbed, if d_i is small.

For a more detailed explanation of the advanced characteristics of the model and a discussion of the different parameters behaviour in numerous long-run simulations see Caniels (1999).

The original model is designed as a simulation model and so far real data has not been used to estimate it. Our idea is to make an estimation of the model taking account of the specific framework of regional development on the level of provinces in China in the reform period between 1978 and 1998. Putting in data for the 30 provinces in the model we can numerically solve the resulting complex equation system for the 30 regional social capabilities d_i ($i = 1, \dots, 30$). These results can be compared to a constructed measure of absorptive capability consisting of a number of infrastructural, educational and regulative indicators.

The hypothesis we want to test for with the model is

The rising disparities and diverging growth rates in GDP per capita between coastal and interior provinces in China since 1990 are strongly related to the social capability for new knowledge or high 'communicative' distance to other regions with high levels of exogenous knowledge input.

To use the available data for the estimation of the model we have to make some specific adaptations and assumptions.

¹¹ In our further application α takes only the role of a technical parameter shifting the scales of other parameters inside of S_i , because we estimate d_i .

1. To prevent a distortion of the results by random or exogenous fluctuations in the data, we select only two base years and make a 'one step' estimation of the model in contrast to annual calculations¹². Since inter-regional disparities have started to rise dramatically since 1990 in China, while the trend in inter-provincial output inequality from 1978-1990 shows relative stability, we select 1990 as the base and 1998 as the final year of our estimation, but take also account of the previous period 1978-1990.
2. The provincial average annual growth rates of GDP per capita for 1978-1990 (*gr7890*) and for 1990-1998 (*gr9098*) are calculated and used to fit equation (1) and (2). *gr9098* is put in the left side of equations (1) and (2) and *gr7890* is used in the right side of equation (2) to attribute for the Verdoorn-effect.
3. A big problem is given by the estimation of the knowledge stock. In it's basic form, the model assumes only one form of homogenous knowledge, which is the only production factor for total output¹³. For fitting the model with real data we do not need absolute initial levels of the knowledge stock, but only estimates of the knowledge gaps G_{ij} . For this reason we simply assume in this first approach that the knowledge gaps between regions are equal to the gaps in GDP per capita in 1990 and $b = 1$.
4. The distance g_{ij} is a key-parameter of the model reflecting the economic distance between two regions, which means that the lower the distance, the higher the probability that knowledge from one region to the other will spill over. There are many methodologies for calculating such kind of distances alternative to just taking the geographical distance between two regions¹⁴. To start with a simple model we just use the basic method of taking the geographic distance reflected by the shortest path between two regions. If two regions are neighbours their distance will be set to one, if there is a path between the two regions with only one other region in between, the distance will be two, and so on¹⁵. The resulting table of distances is shown in Appendix A.
5. Usually the exogenous knowledge input r_i could probably best be reflected by using data on R&D expenditure. It is well known that FDI have played the major role in building up new knowledge in the Chinese transition economy of the mid-eighties. For this reason we exclusively use cumulative provincial FDI per capita

¹² That means we use the discrete time versions of equations (1) and (2) and consider only one iteration of the model.

¹³ Usually this is done with patenting or R&D-data (see for example Verspagen and Schoenmakers 2000). For a developing country like China patenting data might not be very adequate to estimate the knowledge stock in the above sense. Expenditure on R&D is also a relatively questionable indicator, which is not available at firm level in China. A good approximation for China could probably be obtained through employment data showing the educational composition of the total workforce of a region. Unluckily such data is not completely available for the time period under consideration.

¹⁴ For example the calculation of hub-and-spoke distances.

¹⁵ To extend the model, we are currently developing a method taking flight-time weighted with frequency of airplane connections as a measure of communicative distance between provinces.

data for the complete time period 1978-1998 (*fdi7898*). Data for FDI in 1978-1990 is included to account for a temporal shift in the effect of accumulation of knowledge on growth. The parameter r_i is normalized by setting the value of the maximum province to 1 and calculating the respective values of the other provinces as the proportions to the leader.

6. The parameter l expresses the intensity of the Verdoorn-effect. We follow the simulations in the original model and assume $l = 0.1$.
7. The parameter a determines the impact of spillovers for the growth of knowledge. Because in our application of the model we want to get an estimate of d_i ($i=1, \dots, n$), a has mainly a scale effect and varying it does not change the general outcome of the model. For this reason we simply assume $a = 0.05$.
8. The parameters m_i ($i=1, \dots, n$) are positive and influence the catching-up potential of backward regions. For the sake of simplicity we want to restrict ourselves in this article to assume $m_i = 1$ ($i=1, \dots, n$)¹⁶.

¹⁶ It shall only be noted here that the parameters m_i (or even m_{ij}) can also be interpreted as the congruence of knowledge between two regions. There could be a situation with two regions with a relatively large knowledge stock, but no or only very few spillovers happening between them, because their knowledge or technologies are incompatible (i.e. very different regional specialization). It could be a possible extension of the model to further investigate into this direction.

4 Results

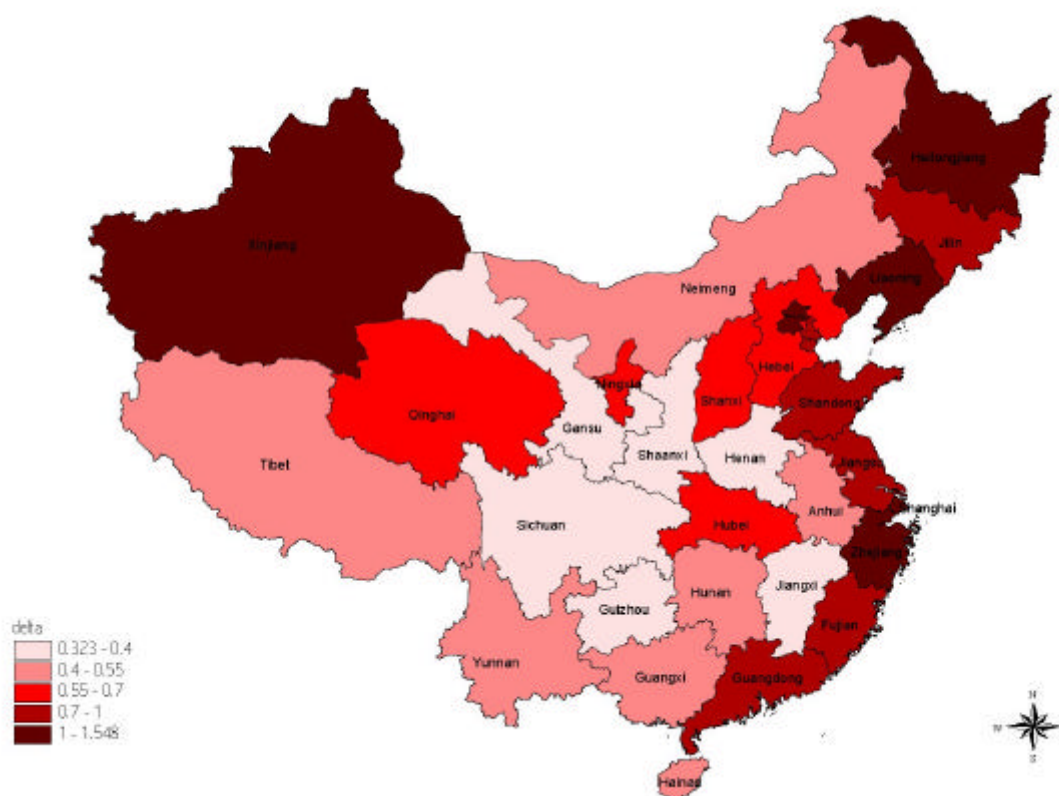
Putting the data and assumed parameter values in equations (1) and (2) we get a complex system of 30 equations with the 30 unknown variables d_1, \dots, d_{30} . We have solved this system numerically using the Newton method in Mathematica 4.0. The results are shown in table 1 and map 5.

Table 1: Learning capabilities for the provinces as results of the model estimation

| Coast | d_i | Centre | d_i | West | d_i |
|--------------|-------|---------------|-------|-------------|-------|
| Beijing | 1.548 | Anhui | 0.412 | Gansu | 0.332 |
| Fujian | 0.708 | Guangxi | 0.440 | Guizhou | 0.329 |
| Guangdong | 0.789 | Hebei | 0.570 | Ningxia | 0.605 |
| Hainan | 0.416 | Heilongjiang | 1.412 | Qinghai | 0.679 |
| Jiangsu | 0.881 | Henan | 0.383 | Shaanxi | 0.323 |
| Liaoning | 1.231 | Hubei | 0.657 | Sichuan | 0.370 |
| Shandong | 0.798 | Hunan | 0.471 | Tibet | 0.445 |
| Shanghai | 1.212 | Jiangxi | 0.399 | Xinjiang | 1.067 |
| Tianjin | 0.910 | Jilin | 0.777 | Yunnan | 0.542 |
| Zhejiang | 1.110 | Neimeng | 0.455 | | |
| | | Shanxi | 0.604 | | |

The results for d_i under the current model assumptions show that apart from having a high level of knowledge input in the form of FDI, a high absorptive knowledge capability is an important determinant for high levels of growth in the time period under consideration (see map 3). A number of alternative model runs and calculations show that this result is robust to variations in the parameters α , β and most importantly the normalization of $\max r_i$.

In general the provinces with above average performance in the nineties also show a high learning capability (Fujian, Guangdong, Zhejiang, Jiangsu, Shanghai, Tianjin, Shandong) and the most backward provinces also have the lowest d_i (Gansu, Guizhou, Shaanxi). But there is a small number of provinces contradicting this general trend. Most obvious is Heilongjiang province in the northeastern corner of China showing the second highest d_i but a below average growth in the nineties. A similar phenomenon can be observed for Jilin, Liaoning (both in the northeast), Xinjiang, Qinghai and Ningxia (in the west). The problem for these unexpected results is clearly given by our methodology of calculating the inter-regional distances g_{ij} . Geographically relatively remote provinces like Heilongjiang, Jilin and Liaoning in the northeast or Qinghai, Xinjiang and Ningxia in the west have very high distances calculated with the shortest-path method and therefore the model overestimates the learning capabilities of these regions, which would be needed to receive the respective level of spillovers from advanced regions. We currently work on solving this problem by implementing a more realistic way to calculate the 'economic' or 'communicative' distance between the provinces.

Map 5: Learning capabilities d_i for the provinces as results of the model estimation

In the following we want to compare the results of the model estimation to a constructed measure of absorptive capability (MAC). To construct such a combined measure reflecting the regional learning capabilities we concentrate on infrastructure, education and the local political environment. A lot more indicators could be included, but the selection is restricted by the availability of data for the base year 1990¹⁷.

Table 2 shows the composition of the MAC. The first two indicators in the category development of science and technology (population shares of university graduates and highschool or university graduates in 1990) are selected to roughly estimate the composition and quantity of the human capital stock and reflect the educational level of the province. This is refined by the population share of scientists and engineers working in the province. Furthermore we include input and output of science and technology as cumulative government expenditures on R&D and the total number of certified patents for the time periods 1990-1997. To measure the development of infrastructure we have chosen five indicators. The total length of railways and roads per sqkm are included as a general measure of the transport capability of the province. Additionally we measure the transport time from the provincial capital to the closest export harbour or international airport, the number of long distance telephone lines and the total turnover volume of freight traffic. For the third part of the measure, the political environment of the provinces, we have so far only selected one indicator, the share of employment in state

¹⁷ The MAC does not follow a recognized procedure for measuring the social capability of a region. It represents a first attempt to show on the base of existing data how the model parameter d_i could possibly interpreted.

owned enterprises (SOE)¹⁸. It is not easy to obtain any data on this political part, but it is especially important in China, as provincial governments have gained a very high level of autonomy and independence of the central government during the reform era and province level policies can have a very high impact on a provinces development path. In the future we hope to be able to add some qualitative indicators based on detailed provincial case-studies.

All of the indicators are normalized within $[0,1]$, where 1 always reflects the value of the indicators maximum among all provinces. Within each group the indicators have equal weight and the groups themselves are weighted in the following way: Development of Science and Technology (0.4), Infrastructure (0.4), Political environment (0.2).

Table 2: Selection of indicators for the construction of a combined measure of absorptive capability

| Development of Science and Technology | Infrastructure | Political Environment |
|--|--|--|
| Number of persons with university degree per 1000 population, 1990 | Total length of railways per sqkm | Share of employment in SOE to total employment |
| Number of persons with high school or university per 1000 population, 1990 | Total length of all roads per sqkm | |
| Expenditure od R&D institutions per capita, 1990-1997 | Number of long distance telephone lines per 1000 population | |
| Number of scientists and engineers per thousand persons, 1990 | Average transport time to closest export harbour or international airport* | |
| Number of patent applications certified, 1990-1997 | Turnover volume of freight traffic (water, railway, road) per capita | |

* If the province has an export harbour or international airport the indicator is set to one, otherwise we divide the province with the shortest transport time by the actual transport time

Table 3 and map 6 show the resulting values of the MAC. We can observe very strong imbalances in the measure. Beijing being the leading province in mostly all selected indicators shows a value of 0.966 and only the other province level municipalities Shanghai and Tianjin and the northeastern province Liaoning have a MAC above 0.5. In the coast we find that Fujian as the fastest growing province in the nineties shows a relatively low MAC and Zhejiang and Jiangsu also have a low level of absorptive capability if compared to their growth performance in the observed time period (see map 3). If we look at the sub-provincial level we find that these three provinces all have a relatively strong spatial concentration of economic activity (coastal cities in Fujian, the south of Jiangsu, northeast of Zhejiang). The infrastructural and educational level in these regions is probably much higher than the provincial average what leads to an underestimation of the real learning capabilities.

If we look at the central provinces we find smaller disparities than expected to the coast as Hebei, Hunan and Heilongjiang show the same level of the MAC as other coastal

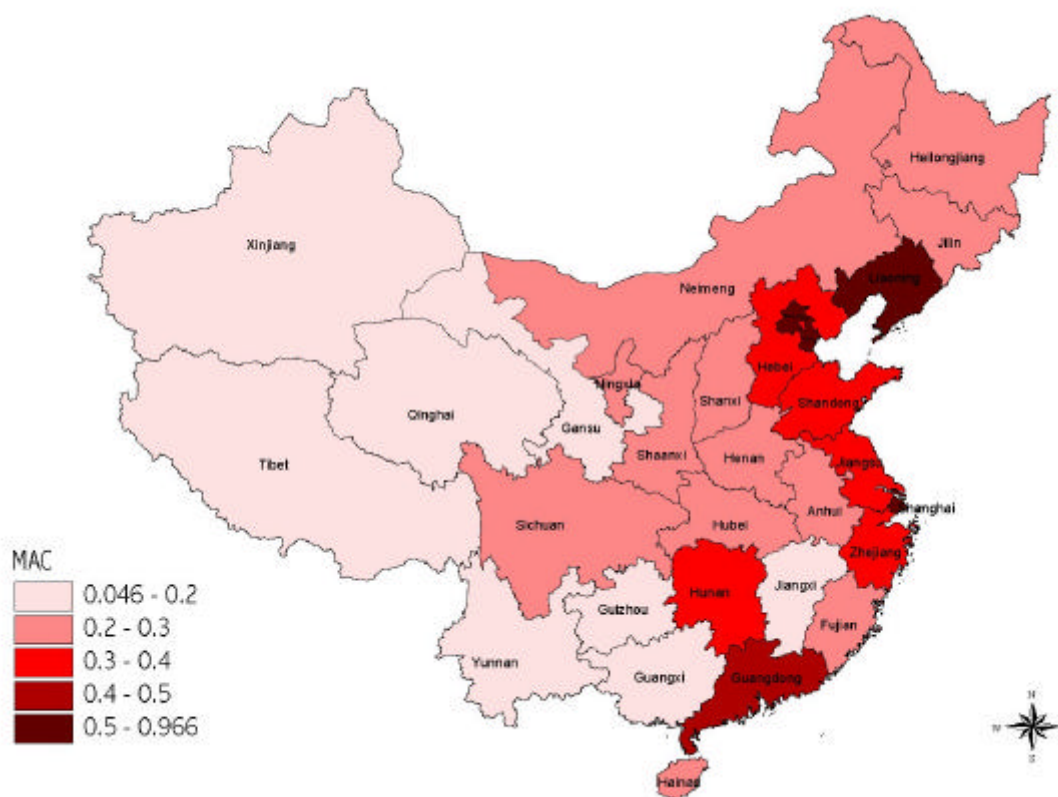
¹⁸ Because we assume a negative correlation on absorptive knowledge capability we take $1 - (\text{share of employment in SOE})$ as the actual indicator.

provinces. Inside of the centre the distribution of the MAC is relatively homogenous, only Jiangxi and Guangxi taking values below 0.2. Moving to the west we find a relatively large gap to the central and coastal provinces. With the exceptions of Shaanxi, which has a long tradition in scientific research, Sichuan, with the highly developed provincial capital Chengdu, and the small minority province Ningxia, the other provinces low level of MAC reflects their very underdeveloped infrastructure and strong deficits in education and research.

Table 3: Combined measure of absorptive capability (MAC)

| Coast | MAC | Centre | MAC | West | MAC |
|-----------|-------|--------------|-------|----------|-------|
| Beijing | 0.966 | Hebei | 0.342 | Sichuan | 0.239 |
| Tianjin | 0.520 | Shanxi | 0.270 | Guizhou | 0.153 |
| Liaoning | 0.504 | Neimenggu | 0.260 | Yunnan | 0.151 |
| Shanghai | 0.543 | Jilin | 0.262 | Tibet | 0.046 |
| Jiangsu | 0.339 | Heilongjiang | 0.297 | Shaanxi | 0.243 |
| Zhejiang | 0.339 | Anhui | 0.209 | Gansu | 0.191 |
| Fujian | 0.271 | Jiangxi | 0.188 | Qinghai | 0.138 |
| Shandong | 0.334 | Henan | 0.254 | Ningxia | 0.225 |
| Guangdong | 0.406 | Hubei | 0.261 | Xinjiang | 0.195 |
| Hainan | 0.237 | Hunan | 0.306 | | |
| | | Guangxi | 0.181 | | |

Map 6: Combined measure of absorptive capability (MAC)



When we check for the correlation of the results of our model estimation to our constructed measure (MAC), we find again that there is still need to further develop the model, as there are some significant outliers (see figure 2). If we exclude the mentioned cases which are problematic because our selection of g_{ij} , we get a much more satisfying

result (see figure 3), showing that another method to calculate the distance parameter g_{ij} will probably improve the validity of the model.

Figure 2: Linear Regression for all 30 provinces with the estimated model parameters d_i as independent and the constructed measure of absorptive capability (MAC) as dependent variable

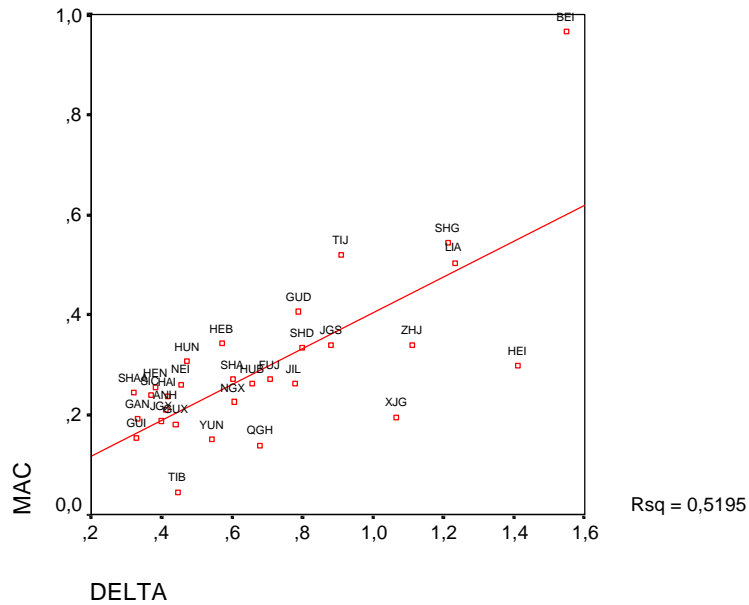
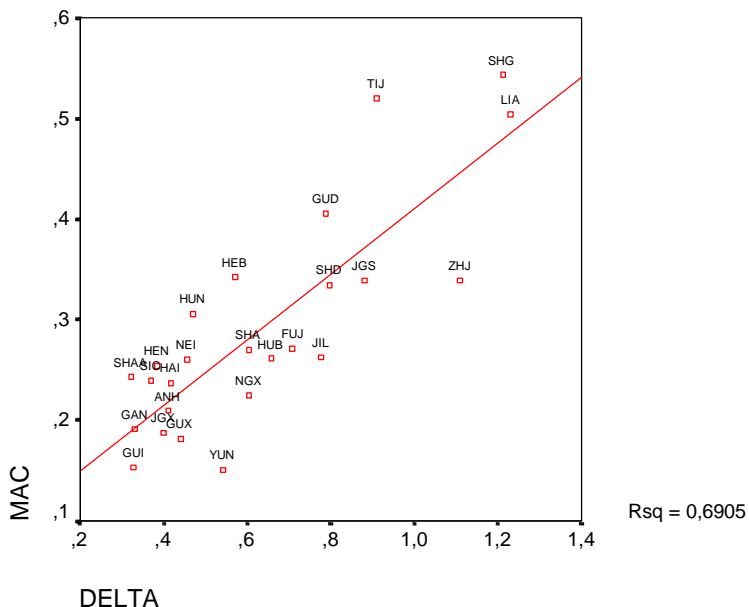


Figure 3: Linear Regression for all 30 provinces with the estimated model parameters d_i as independent and the constructed measure of absorptive capability (MAC) as dependent variable (excluding Beijing, Heilongjiang, Qinghai, Tibet and Xinjiang)



5 Conclusion

This article has presented a first approach using a technology gap model to investigate into the process of spatial knowledge diffusion in China. Based on the availability of data we have constructed a measure reflecting regional absorptive capabilities and compared it to the estimates of the corresponding model parameters.

Our results confirm that geographic distance and the social capabilities of provinces, here reflected by the level of science and technology, infrastructure and political environment, play a major role in explaining provincial growth paths and the general trend of divergence between coastal and interior provinces.

In the future we want to extend our model further. Especially the calculation of inter-provincial distances and the construction of the measure of absorptive capability shall be improved. As the main purpose of this article is to introduce the idea of applying this general type of simulation-model to a real world situation, in future there remains much work to be done discussing more specific details of provincial development in China in the light of this modelling approach.

Appendix

Geographic distances g_{ij} calculated with the shortest path method

| | Bei | Tian | Heb | Shan | Nei | Liao | Jil | Hei | Shg | Jgs | Zhe | Anh | Fuj | Jgx | Shd | Hen | Hub | Hun | Gud | Gux | Hai | Sic | Gui | Yun | Tib | Shaa | Gan | Qing | Ning | Xin | |
|--------------|-----|------|-----|------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|------|------|-----|---|
| Beijing | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 4 | 4 | 3 | 4 | 3 | 5 | 4 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 4 | 5 | 5 | 5 | 3 | 4 | 5 | 4 | 5 | |
| Tianjin | 1 | 0 | 1 | 2 | 2 | 2 | 3 | 4 | 4 | 3 | 4 | 3 | 5 | 4 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 4 | 5 | 5 | 5 | 3 | 4 | 5 | 4 | 5 | |
| Hebei | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 3 | 3 | 2 | 3 | 2 | 4 | 3 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 3 | 4 | 4 | 4 | 2 | 3 | 4 | 3 | 4 | |
| Shanxi | 2 | 2 | 1 | 0 | 1 | 2 | 3 | 4 | 4 | 3 | 3 | 2 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 4 | 5 | 2 | 3 | 3 | 3 | 1 | 2 | 3 | 2 | 3 | |
| Neimenggu | 2 | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 4 | 3 | 4 | 3 | 5 | 4 | 2 | 2 | 2 | 3 | 4 | 4 | 5 | 2 | 3 | 3 | 3 | 1 | 1 | 2 | 1 | 1 | |
| Liaoning | 2 | 2 | 1 | 2 | 1 | 0 | 1 | 2 | 4 | 3 | 4 | 3 | 5 | 4 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 4 | 5 | 5 | 5 | 3 | 4 | 5 | 4 | 5 | |
| Jilin | 3 | 3 | 2 | 3 | 1 | 1 | 0 | 1 | 5 | 4 | 5 | 4 | 6 | 5 | 3 | 3 | 4 | 5 | 6 | 6 | 7 | 5 | 6 | 6 | 6 | 4 | 5 | 5 | 5 | 5 | |
| Heilongjiang | 4 | 4 | 3 | 4 | 1 | 2 | 1 | 0 | 6 | 5 | 6 | 5 | 7 | 6 | 4 | 4 | 5 | 6 | 7 | 7 | 8 | 6 | 7 | 7 | 7 | 5 | 6 | 6 | 6 | 6 | |
| Shanghai | 4 | 4 | 3 | 4 | 4 | 4 | 5 | 6 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 5 | 5 | 6 | |
| Jiangsu | 3 | 3 | 2 | 3 | 3 | 3 | 4 | 5 | 1 | 0 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 3 | 3 | 4 | 5 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 5 | |
| Zhejiang | 4 | 4 | 3 | 3 | 4 | 4 | 5 | 6 | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | 5 | |
| Anhui | 3 | 3 | 2 | 2 | 3 | 3 | 4 | 5 | 2 | 1 | 1 | 0 | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 4 | |
| Fujian | 5 | 5 | 4 | 4 | 5 | 5 | 6 | 7 | 2 | 2 | 1 | 2 | 0 | 1 | 3 | 3 | 2 | 2 | 1 | 2 | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | 5 | |
| Jiangxi | 4 | 4 | 3 | 3 | 4 | 4 | 5 | 6 | 2 | 2 | 1 | 1 | 1 | 0 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 4 | |
| Shandong | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 4 | 2 | 1 | 2 | 2 | 3 | 2 | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 3 | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 4 | |
| Henan | 2 | 2 | 1 | 1 | 2 | 2 | 3 | 4 | 3 | 2 | 2 | 1 | 3 | 2 | 1 | 0 | 1 | 2 | 3 | 3 | 4 | 2 | 3 | 3 | 3 | 1 | 2 | 3 | 2 | 3 | |
| Hubei | 3 | 3 | 2 | 2 | 2 | 3 | 4 | 5 | 3 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 0 | 1 | 2 | 2 | 3 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | |
| Hunan | 4 | 4 | 3 | 3 | 3 | 4 | 5 | 6 | 3 | 3 | 2 | 2 | 2 | 1 | 3 | 2 | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | |
| Guangdong | 5 | 5 | 4 | 4 | 4 | 5 | 6 | 7 | 3 | 3 | 2 | 2 | 1 | 1 | 4 | 3 | 2 | 1 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | |
| Guangxi | 5 | 5 | 4 | 4 | 4 | 5 | 6 | 7 | 4 | 4 | 3 | 3 | 2 | 2 | 4 | 3 | 2 | 1 | 1 | 0 | 2 | 2 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 4 | |
| Hainan | 6 | 6 | 5 | 5 | 5 | 6 | 7 | 8 | 4 | 5 | 3 | 3 | 2 | 2 | 5 | 4 | 3 | 2 | 1 | 2 | 0 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | |
| Sichuan** | 4 | 4 | 3 | 2 | 2 | 4 | 5 | 6 | 4 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 1 | 1 | 2 | 2 | 4 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| Guizhou | 5 | 5 | 4 | 3 | 3 | 5 | 6 | 7 | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | 2 | 1 | 2 | 1 | 3 | 1 | 0 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | |
| Yunnan | 5 | 5 | 4 | 3 | 3 | 5 | 6 | 7 | 5 | 4 | 4 | 3 | 3 | 3 | 4 | 3 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 0 | 1 | 2 | 2 | 2 | 3 | 3 | |
| Tibet | 5 | 5 | 4 | 3 | 3 | 5 | 6 | 7 | 5 | 4 | 4 | 3 | 4 | 3 | 4 | 3 | 2 | 2 | 3 | 2 | 4 | 1 | 2 | 1 | 0 | 2 | 2 | 1 | 3 | 1 | |
| Shaanxi | 3 | 3 | 2 | 1 | 1 | 3 | 4 | 5 | 4 | 3 | 3 | 2 | 3 | 2 | 2 | 1 | 1 | 2 | 3 | 3 | 4 | 1 | 2 | 2 | 2 | 0 | 1 | 2 | 1 | 2 | |
| Gansu | 4 | 4 | 3 | 2 | 1 | 4 | 5 | 6 | 5 | 4 | 4 | 3 | 4 | 3 | 3 | 2 | 2 | 2 | 3 | 3 | 4 | 1 | 2 | 2 | 2 | 1 | 0 | 1 | 1 | 1 | |
| Qinghai | 5 | 5 | 4 | 3 | 2 | 5 | 6 | 7 | 5 | 4 | 4 | 3 | 4 | 3 | 4 | 3 | 2 | 2 | 3 | 3 | 4 | 1 | 2 | 2 | 1 | 2 | 1 | 0 | 2 | 1 | |
| Ningxia | 4 | 4 | 3 | 2 | 1 | 4 | 5 | 6 | 5 | 4 | 4 | 3 | 4 | 3 | 4 | 2 | 2 | 3 | 4 | 4 | 5 | 2 | 3 | 3 | 3 | 1 | 1 | 2 | 0 | 2 | |
| Xinjiang | 5 | 5 | 4 | 3 | 1 | 5 | 5 | 6 | 6 | 5 | 5 | 4 | 5 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 5 | 2 | 3 | 3 | 1 | 2 | 1 | 1 | 2 | 0 | |

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