Innovating in “lagging” cities: A comparative exploration of the dynamics of innovation in Chinese cities

by

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Abstract:

Innovation, proxied by patent applications, in China is highly territorialised. The lion’s share of the country’s innovation is concentrated in its richest city-regions. Less developed cities — defined as cities whose GDP per capita is below 75% national average— also innovate but innovate far less. And how they manage to do so is not sufficiently understood. This paper explores the processes of innovation in China’s more and less developed cities. We develop an econometric analysis involving 283 Chinese cities between 2003 and 2014 to address: (a) what are the socioeconomic and structural factors that govern processes of innovation in Chinese cities? And (b) how do these factors differ between more and less developed cities? The analysis indicates that China’s more and less developed cities innovate in markedly different ways. The innovation systems of China’s more developed cities are more complex, integrated and mature —leveraging knowledge from R&D activities, large human capital endowments and inter-city spillovers— than those that have emerged in the country’s less developed cities. Innovation in less developed cities also suffers from the lower capacity of these cities to generate knowledge synergies.

Keywords: China, innovation, R&D, inequality, lagging regions

JEL: O1, O31, O32, O38, O53

1. Introduction

Recent decades have seen China become an important participant in the global knowledge economy (OECD, 2009; Griffith and Miller, 2011; Fan, 2014; Woetzel et al., 2015; Rodríguez-Pose and Wilkie, 2016). Its economy is transforming from one based on low cost, low value added manufacturing activities to one increasingly reliant on the manufacturing of higher value added, more sophisticated goods and also on knowledge generation (Zhao and Yang, 2012; Leifner and Wei, 2014; Fu, 2015; McGilvray, 2016). The importance of innovation —proxied by the number of patent applications— in China is unlikely to wane. China has been, and remains, one of the world's fastest growing economies. There are signs, however, that growth is slowing as China completes its transition from a developing country to an emerging one (Gu et al., 2016; Eichengreen et al., 2017; World Bank, 2017). The extent to which this slowdown can be averted and the economy's growth rates can be maintained will depend on its capacity to cultivate innovation and unlock the productivity gains associated with doing so (Fan, 2014; Woetzel et al., 2015; Fu, 2015; Gu et al., 2016; Lewin et al. 2016).

There is, however, considerable variation in the extent to which cities have participated in and benefitted from the expansion of the country's knowledge economy. Innovation in China is highly territorialised. The lion's share of the country's innovative activity is concentrated in its more economically developed cities (e.g. Sun, 2000; Sun 2003; Li, 2009; Crescenzi et al., 2012; Fan et al., 2012; Leifner and Wei, 2014; Fu, 2015; Rodríguez-Pose and Wilkie, 2016; Wang and Li, 2016). This geographic polarisation is problematic, as innovation imbalances could entrench, if not exacerbate, already-pronounced disparities in wealth and economic performance (Howells, 2005; Fu, 2015; Liu and Lawell, 2015; Zhou and Song, 2016) and, eventually, lead to economic, social and political tensions that could ultimately result in phenomena similar to that of the revenge of 'the places that don't matter', as described by Rodríguez-Pose (2018).

These innovation imbalances can therefore not be ignored. There is a need for policy-makers to devise ways to bolster the innovative capacity of China's more developed, 'core' cities whilst also upgrading the innovative potential of its less developed ones. This implies developing a more nuanced understanding of the factors that drive and shape processes of innovation in China's more and less developed cities —measured at the prefecture-city level. It is this understanding that the research aims to provide. It is guided by two research questions. The first relates to identifying the factors that govern processes of innovation in China's cities. The second question is whether —and if so, how— the 'dynamics of innovation' differ between more and less developed cities. More developed cities are, for the purposes of the analysis, defined as those whose GDP per capita exceeds 75% of the national average. Less developed cities, those whose GDP per capita falls below this threshold.

The novelty of the paper is derived from the comparative perspective it adopts and the territorial unit of analysis it employs. An explicit focus on the differences in innovation capacities between China's more and less developed cities is, so far as we are aware, unique to this research. Underdeveloped environments in China can and do innovate. How they manage to do so, however, is not sufficiently understood; the presumption that they are distinctly 'un-innovative' coupled with a preoccupation with the success stories that are China's technological hubs has led to their neglect. This paper represents an effort to fill this void and sheds light on the insufficiently understood processes of innovation unfolding in China's economic periphery. Moreover, preceding research of this nature has been conducted almost exclusively at the province-level (e.g. Li et al., 2016). The research eschews this provincial-level focus for an urban one that concentrates on what has generally been considered the most innovative territorial unit (Glaeser, 2011) and renders it able to capture the oft-overlooked internal heterogeneity by which Chinese provinces are characterised. Accordingly, the inferences derived from the econometric analysis are more granular than those offered by existing research.

The contributions of the paper can therefore be summarised as follows: it offers insights into processes of innovation in China's more and less developed cities that previous research is yet to provide.[1] In doing so, the paper exposes the policy 'levers' that need be pulled to stimulate innovation across the spectrum of Chinese cities and, in doing so, provides policy-makers with a sense of how efforts to promote innovative dynamism in China's economically disadvantaged environments should differ from those undertaken in its more economically advanced ones.

The analysis, covering 283 Chinese cities between 2003 and 2014, reveals that China's more developed cities feature innovation systems that are more complex, integrated and, in turn, mature than those of their less developed counterparts. China's more developed cities mobilise knowledge inputs —the knowledge generated by local and extra-local R&D activities and human capital— with comparative efficiency. Their innovative capacities are underpinned by agglomeration externalities and their industrially-biased economic fabrics while those of their

[1] Fu (2015:8), for example, observes that "comprehensive and systematic analyses of China's overall strategy, drivers and outcomes are rare with very few exceptions".

less developed counterparts rely merely on the ready availability of physical infrastructure. Moreover, the country's more developed cities also reap the innovative benefits of a range of knowledge resource-related synergies that are yet to materialise or mature in its less developed cities. This suggests that while the innovation potential of more developed cities in China is affected by innovative processes that stress their dynamic and, especially, contextually-contingent nature, in less developed cities the availability of knowledge inputs is still fundamentally reliant on mechanisms anticipated by linear models of innovation.

The remainder of the paper is structured as follows: Section 2 examines the factors behind the concentration of innovation in more dynamic cities, often at the expense of less developed ones. Section 3 explores the geography of the Chinese knowledge economy before introducing the motivations for the questions that guide the research. Section 4 analyses the heterogeneity of China's more and less developed cities and proposes two hypotheses for empirical research. Section 5 outlines the methodology employed to test the research hypotheses. Section 6 presents and offers a more comprehensive discussion of the results of the econometric analysis. Section 7 concludes.

2. Innovating in more and less developed areas

Innovation is generally territorially concentrated in the most dynamic cities and regions. Innovative activity the world over has a well-documented tendency to concentrate in larger, more economically developed cities and regions (e.g. Feldman and Audretsch, 1999; Carlino et al., 2007; Mitra, 2007; Crescenzi et al., 2007; 2012; Liu and Sun, 2009; Fan et al., 2012). The metropolitan areas of San Jose, New York, San Francisco, Los Angeles and Boston drive innovation in the US, as do Toronto, Ottawa-Hull, Vancouver and Montreal in Canada (Breau et al., 2014: 361). London and the South East represents the innovation hub in the UK, while the capital cities of Paris, Tokyo and Mexico City dominate the innovative landscapes of France, Japan and Mexico, respectively. The same applies for India, where Bangalore, Chennai, Delhi, Hyderabad and Mumbai lead the way (Mitra, 2007), or China, with Beijing, Shanghai and Guangdong province in the same role (Wang and Li, 2016).

Why is innovation territorially concentrated? Large and dynamic cities have many advantages when it comes to innovation. Cities attract multinational enterprises (Goerzen et al., 2013). They host the most dynamic entrepreneurs and small- and medium-sized firms (Stam, 2009). They also house top universities, research institutes and a diversity of other public and private organisations (Florida, 2017). Hence, skilled workers, entrepreneurs and a diversity of firms and public organisations come together in more economically developed cities that tend to be well-endowed with the sorts of infrastructure and resources upon which the aforementioned actors rely (Glaeser, 1999; Florida, 2002; Acs et al., 2011; Bosma and Sternberg, 2014). The concentration and relative abundance of these public and private entities yields a similar concertation of R&D activities and investment that affords these places a facility for the generation of knowledge and ideas without which innovation is not possible (e.g. Grilliches, 1979; Audretsch and Feldman, 2004). Similarly, the ready availability of skills and human capital renders them capable of transforming this knowledge into more applied innovation (Vogel, 2015). All these actors invest in R&D functions and engage in other knowledge-generating innovative activities, meaning that innovation-inducing knowledge, ideas and information are not in short supply. They also draw on the large pools of skilled human capital and leverage them not only to generate new knowledge but also to apply it in productive ways (Lee et al, 2010; Moretti, 2012).

The spatial concentration of all these factors in dynamic cities facilitates the exchange and sharing of knowledge —in more formal, structured and deliberate ways and via informal, unplanned interactions— that spurs innovation (Storper and Venables, 2004). Efficiency enhancing "agglomeration economies" are, therefore, created (Duranton and Puga, 2004; Glaeser, 2010), facilitating the sharing and exchange of knowledge and other interactive processes at the genesis, diffusion and application of innovation (Gertler, 2003; Bathelt et al., 2004; Storper and Venables, 2004). Agglomeration economies, furthermore, afford economic actors the opportunity to collaborate and cooperate to combine competencies, knowledge bases and resources in their pursuit of technological progress (Narula and Santangelo, 2009).

Evidence of these mechanisms at work, and the existence of the agglomeration externalities they give rise to, have bred the perception that density and co-location are conducive to firm and individual productivity; the sharing and combination of knowledge and, ultimately, the cultivation of innovation; and economic dynamism, most generally. Large, densely-populated urban environments are regarded as the places where efficiency is maximised and economic performance optimised. Innovative cities are perceived as the drivers of regional or even national economic growth and have, accordingly, garnered much of the scholarly attention (Jacobs, 1969; Fujita and Thisse, 2002; Glaeser, 2011).

By contrast, cities in less economically developed territories have far less resources to devote to R&D and face far greater difficulties in attracting, cultivating and retaining innovative entrepreneurs and firms. Their inability to attract and retain these actors is both a cause and consequence of their greater human and physical capital deficiencies (Rodríguez-Pose, 1999; 2001). Moreover, their underlying economic fabrics are weaker and often dominated by more traditional, technologically less sophisticated sectors where the potential for innovation is scarce. Accordingly, economic actors operating in these environments have little incentive and/or opportunity to invest in R&D or engage in knowledge-intensive activities. This, in turn, curtails the innovative potential of the economy as a whole. Further limits are imposed by a characteristic scarcity of human, physical and financial capital that undermines both the generation and application of knowledge in these territories.

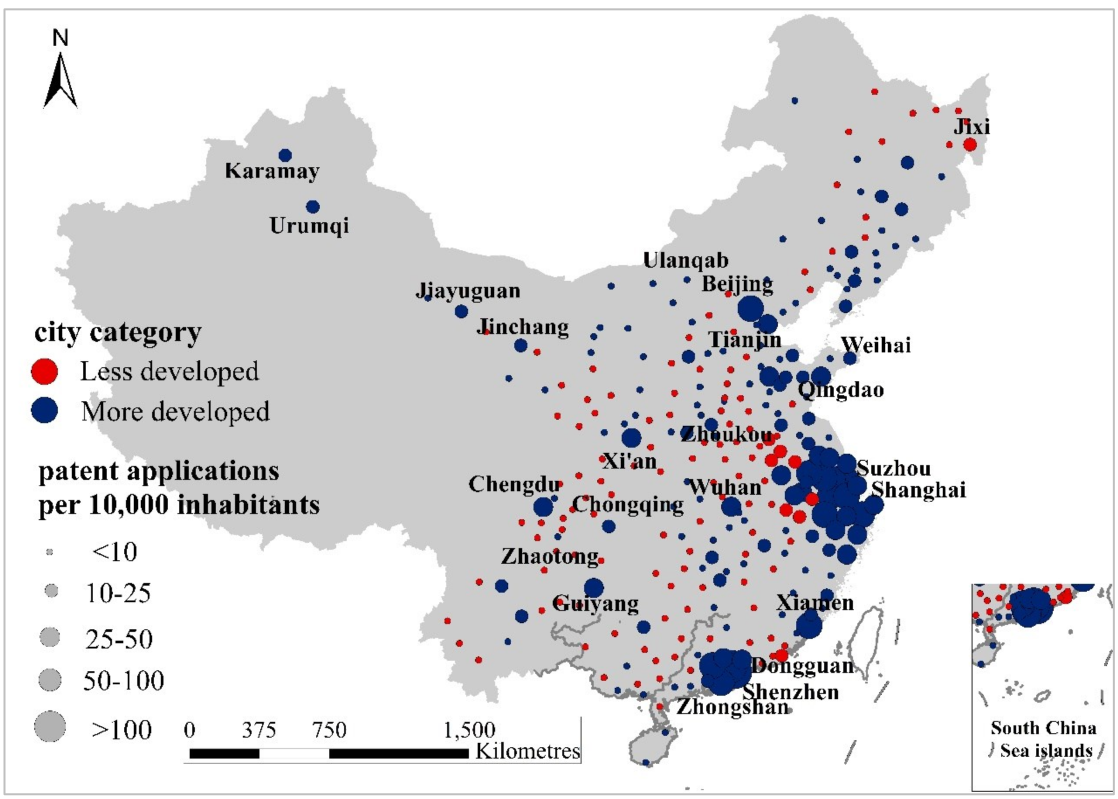
Finally, many less developed cities are burdened simply by geography. Economic peripherality often coincides with geographic isolation. Many less developed cities are situated beyond the spatial limits of knowledge spillovers emanating from more innovative territories and thus stifling opportunities to supplement locally-generated knowledge with that generated extra-locally (e.g. Moreno et al., 2005; Sonn and Storper, 2008; Rodríguez-Pose and Crescenzi, 2008). All of this renders less developed cities less likely to generate knowledge; less exposed to extra-local sources of it; and, ultimately, less able to apply it and transform it into tangible, applied innovation.

3. Innovation in Chinese cities

3.1. The territorialisation of innovation in China

China is no exception to the spatial polarisation of innovation. In 2014, the more developed cities and regions of China produced 77.6% of GDP and 88.7% of patent applications, while the less developed ones produced 22.4% of GDP and 11.3% of patent applications. Innovation was thus far more concentrated in China than GDP. The extent of the geographical polarisation of innovation across urban China is captured by Figure 1. It depicts the number of patent applications produced per capita by Chinese cities in 2014. Two related inferences are drawn from *Figure 1*.

Figure 1. Patent intensity, 2014



Source: Author's elaboration.

First, there is considerable intra-national variation in the innovative capacities of Chinese cities. Different cities have participated to different extents in the county's rise to innovative prominence. A handful of Chinese cities, most of which are situated in the country's more economically developed coastal provinces, stand out as especially innovative. Shenzhen, Zhongshan, Dongguan and Suzhou produced more than 120 patent applications per 10,000 inhabitants in 2014. In absolute terms, Beijing and Shanghai were responsible for over ten percent of the country's patent applications. At the other end of the spectrum, the interior cities of Zhoukou (0.45 patent applications per 10,000 inhabitants), Ulanqab (0.35) and Zhaotong (0.30), among others, struggled, in both absolute and relative terms, to keep pace with their more innovative counterparts.

The second inference relates to how China's innovative activities are spread across its more and less economically developed cities. China's less developed cities (marked by red dots in Figure 1) are far less innovative than their more developed counterparts. In 2014, 49 of the 50 (and 89 of the 100) most innovative cities in China (marked by blue dots) were classified as more economically developed. Six of these more developed cities —Beijing, Suzhou, Shanghai, Shenzhen, Chengdu and Hangzhou— produced over a quarter of China's total innovative output and, of the 19 cities that generated over half of the county's patent applications, all qualify as more developed. Moreover, almost half of China's more economically developed cities registered more than 10 patent applications per 10,000 inhabitants. Less than a tenth of its less developed ones, on the other hand, managed to do so and only one produced more than 20.

The implications of this innovation polarisation are significant. There are two of particular note. First, the socioeconomic divide between China's more and less developed cities will widen if the innovative capacities of its less developed ones are not upgraded and innovation remains a 'developed city phenomenon'. Innovation is a driver of economic growth and development (e.g.

Romer, 1990; Grossman and Helpman, 1994). The territorialisation of innovative activity, in China or otherwise, is therefore tantamount to the territorialisation of potential for economic growth (Howells, 2005). China's already more economically developed cities are, because of their more robust innovative capacities (Figure 1), also better positioned for the pursuit and achievement of competitiveness, economic growth and dynamism than their less developed counterparts. Spatial inequalities are inhibitors of economic growth and dynamism (e.g. Cingano, 2014; Ostry et al., 2014) and catalysts for social discontent, tensions and unrest (Rodríguez-Pose, 2018). These may become more and more pronounced as China's more developed cities leverage this innovative potential and outperform their lagging peers.

The second relates to the necessity of boosting the innovative capacities of China's less innovative, less economically developed cities for the achievement of more widespread economic growth. Consensus is beginning to form around the notion that "China needs to evolve…to an innovation leader to sustain GDP growth in the coming decade as other drivers of growth…decline" (Woetzel et al., 2015:ii). Established technological hubs will undoubtedly continue to contribute to this drive. Their innovative efforts thus far have not, however, proven enough to arrest the decline in the country's growth rate —more innovation, and the boost to productivity it provides, is needed. The latent innovation potential of the country's less economically developed cities will have to be tapped to generate knowledge and innovations at a rate and with a frequency sufficient to reignite economic growth. Shoring up the innovative capacity of China's less developed cities is thus necessary if pervasive spatial dipartites in economic performance are to be addressed and if a return to more robust economic growth is to be achieved. The design of the policies and strategies that will be relied upon to do so is predicated on the development of a robust understanding of the factors that shape the innovative capacities of these less developed cities.

3.2 Innovating in the 'core' and 'periphery': Do China's less economically developed cities differ from their more dynamic counterparts?

Given these stark differences, the capacities to generate innovation in China's more and less developed cities differ considerably. China's more developed cities direct more resources to R&D functions than their less developed counterparts. Their more robust financial commitments to the generation of "new economic knowledge" (Audretsch and Feldman, 2004: 2716) are anticipated to lend them a greater capacity to do so. This indispensable 'input' (e.g. Grilliches, 1979; Audretsch and Feldman, 2004) to processes of innovation is more abundant in China's more developed cities than it is in its less developed ones. Skilled human capital is, like the aforementioned 'new economic knowledge', more readily available in these cities as well. Their facility for the mobilisation and productive application of this knowledge in innovative processes is, in turn, greater. China's more developed cities are also, on balance, more densely populated and density is conducive to the diffusion, sharing and exchange of knowledge, ideas and innovation, and to the emergence of other innovation-enhancing, agglomeration-induced externalities.

Conversely, China's less developed cities suffer from more than comparative underinvestment in R&D and a relative dearth of human capital both, of which impair their capacity to generate and absorb knowledge. Their underlying economic fabrics, in which manufacturing activity features less prominently, are not especially amenable to innovative activity. They are also, as is characteristic of less developed cities, both more sparsely populated and more geographically isolated. While many of China's more developed cities are clustered on the country's east coast, its less developed ones are scattered across the country and without immediately proximate neighbours (Figure 1). The scope for the realisation of benefit from local and extra-local knowledge spillovers is therefore more limited.

That China's more economically developed cities host a disproportionate amount of the country's innovative activity is, in that respect, what prevailing theories would predict. However, as much as innovation in China is a 'developed city phenomenon', it is nonetheless occurring, albeit with less intensity and frequency, in the country's less developed cities (Figure 1).

That said, it cannot be assumed that the factors and forces behind the innovativeness of China's innovation-prone, more developed cities are identical to those which shape processes of innovation in its less developed ones. Innovation, as Crescenzi and Rodríguez-Pose (2012: 22) note, "display very differentiated territorial processes in different contexts" in accordance with their socioeconomic, institutional and political factors, characteristics, features and attributes. That is, territories that direct different amounts of resources to R&D, are differentially endowed with human capital, or host different types of firms, sectors and industries will generate innovation in different ways. Contextual similarities between China's more and less developed cities are few. It is therefore unlikely that innovative processes in China's less economically developed cities will resemble those unfolding in their more developed counterparts.

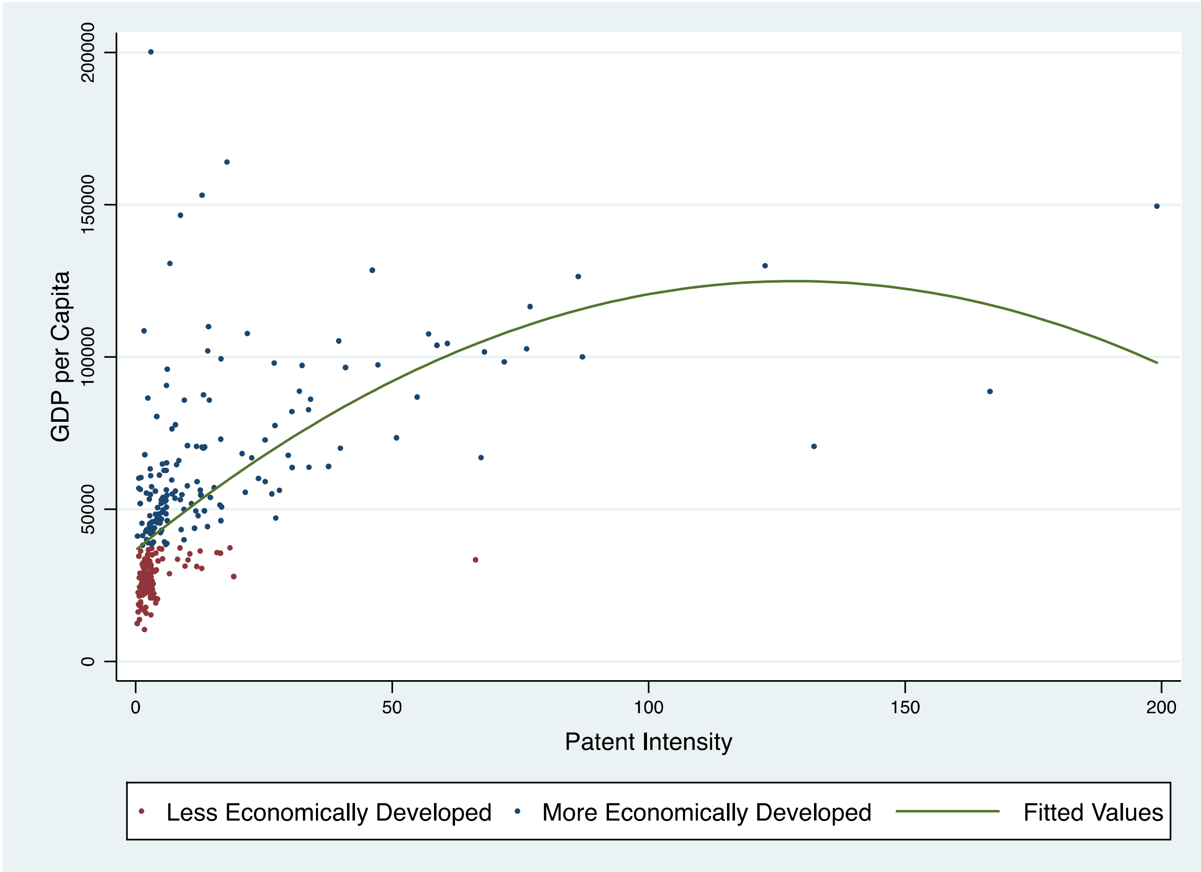
It is from this hypothesis that the paper's research questions are derived. The overarching aim of the paper is to contrast the innovative processes hosted by China's more economically advanced cities with those occurring in their less economically developed neighbours with a view to discern how they differ. Two more specific questions guide the analysis: (a) what are the socioeconomic and structural factors that govern processes of innovation in China's cities? and (b) how do these factors differ between more and less developed cities?

4. Descriptive statistics

Prior to proceeding with the econometric analysis, we consider the heterogeneity of Chinese cities and assess how the county's more economically developed cities differ from their less developed counterparts. The taxonomic analysis of the descriptive statistics and figures that follows also facilitates the establishment of a cursory understanding of the links between the innovative capacity of China's more and less developed cities and a series of socioeconomic factors and territorial characteristics.

Figure 2 plots patent intensity against GDP per capita. It visualises the key difference between the two types of cities: China's more developed cities are more innovative than their less developed counterparts.

Figure 2. Patent applications per 10,000 inhabitants and GDP per capita, 2014



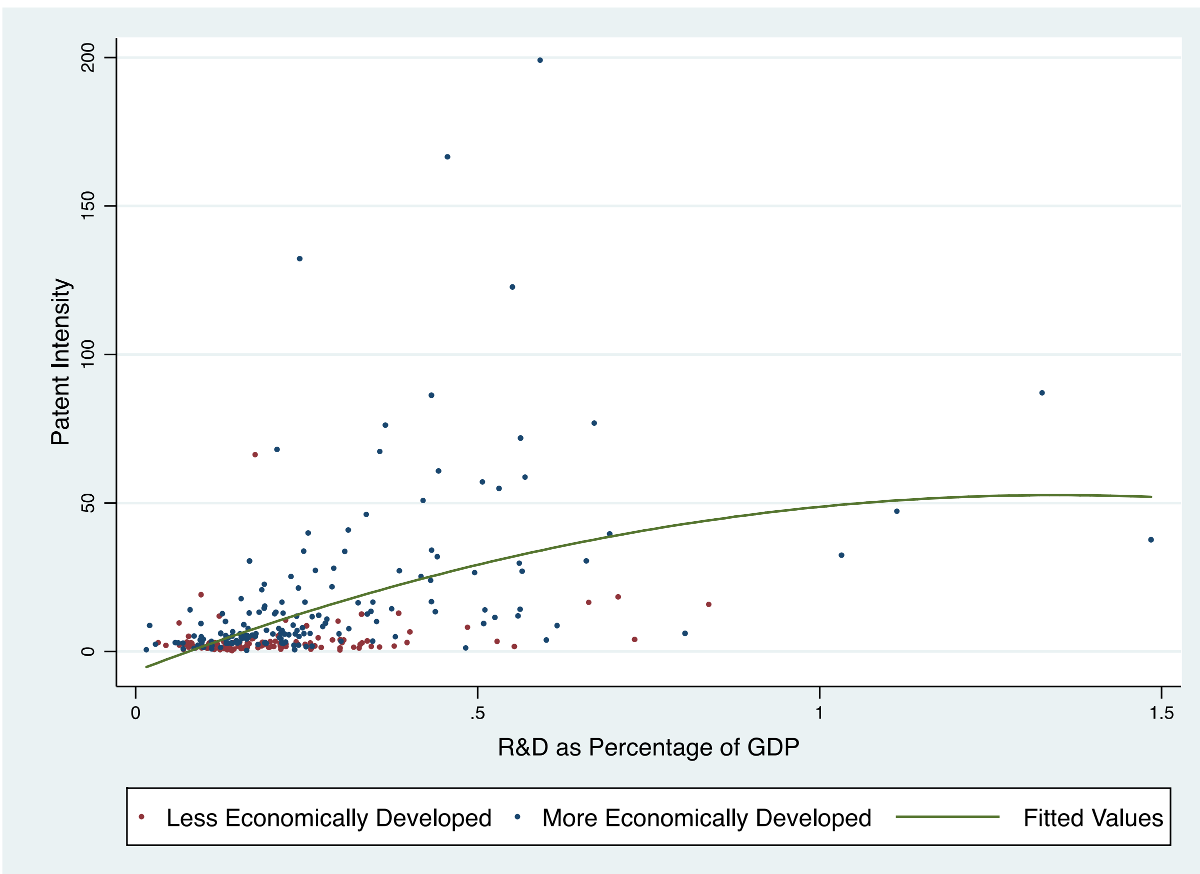
Source: Authors' elaboration

There is some variation in the innovative capacities of China's more economically developed cities. This variation is itself indicative of the intra-national variation in urban innovative capacities flagged in *Section 3*. Less developed cities, on the other hand, are similarly 'innovation averse' and there are next to no 'outliers'. The virtual absence of outliers shows the difficulties less developed cities face cultivating higher-value added, knowledge intensive activities.

Figures 3 through 6 adopt a slightly different perspective. They, however, yield similar conclusions.

Figure 3 depicts R&D expenditure as a percentage of GDP against innovative capacity, proxied by patent intensity. Two key inferences emerge. The first is that China's more developed cities channel more resources to knowledge generating activities than their less developed counterparts.

Figure 3. R&D expenditure as a percentage of GDP and patent intensity, 2014

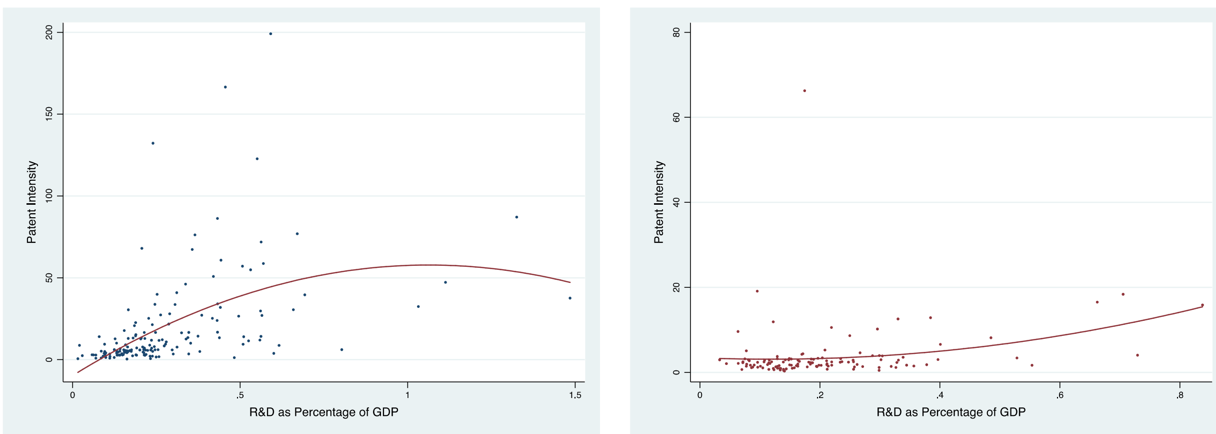


Source: Authors' elaboration

Second, Figure 3 reveals a positive relationship between R&D expenditure and patent intensity. Chinese cities investing more in knowledge generating functions are more innovative than those that opt not, or are unable, to do so. Deeper analysis, however, reveals that this positive relationship is driven by the country's more developed cities that both invest more in R&D and transform it into innovative output more efficiently than their less dynamic counterparts (Figure 4A and 4B).

Figure 4. R&D expenditure as a percentage of GDP and patent intensity in China's more and less developed cities, 2014

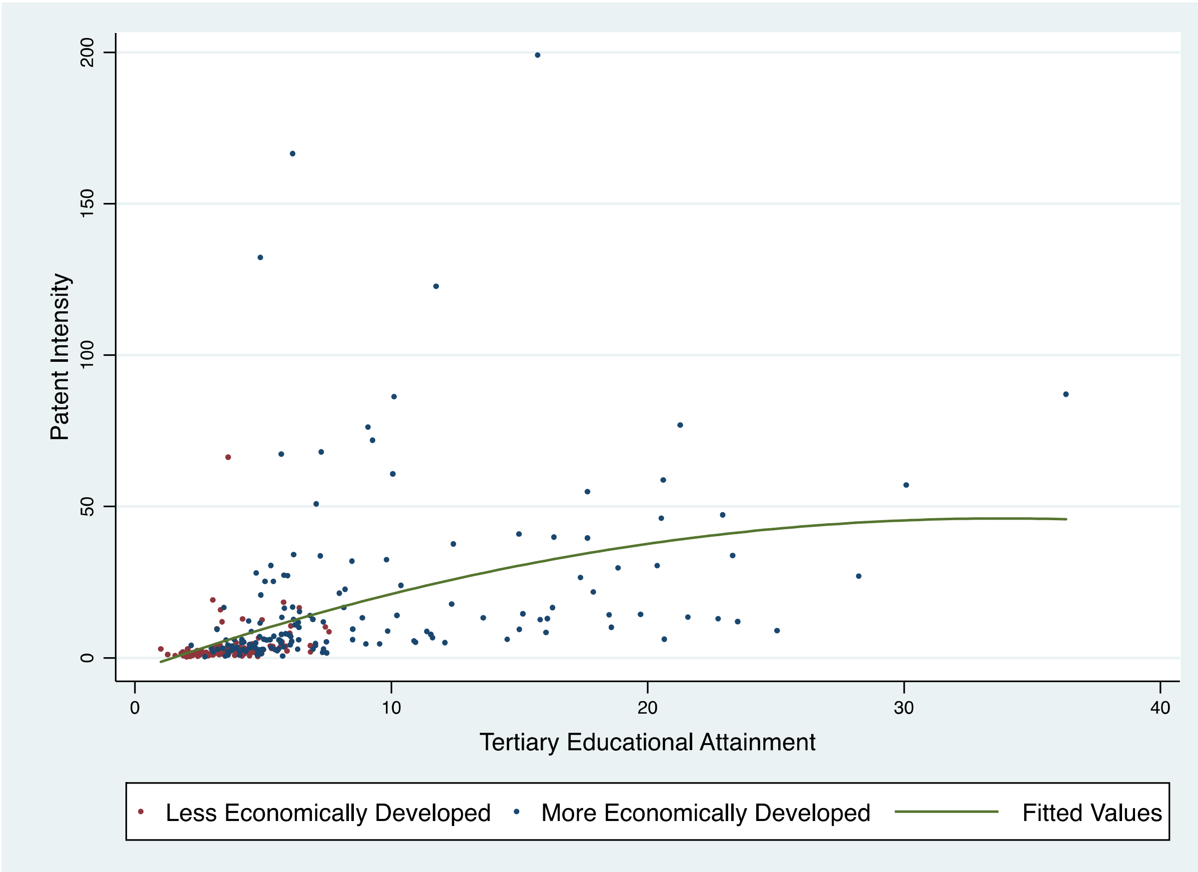
A. More developed cities B. Less developed cities



Source: Authors' elaboration

Similar conclusions are reached about the relationship between the availability of human capital and the innovative capacity of Chinese cities. Figure 5 reveals a positive correlation between tertiary educational attainment and patent intensity.

Figure 5. Tertiary educational attainment and GDP per capita, 2014



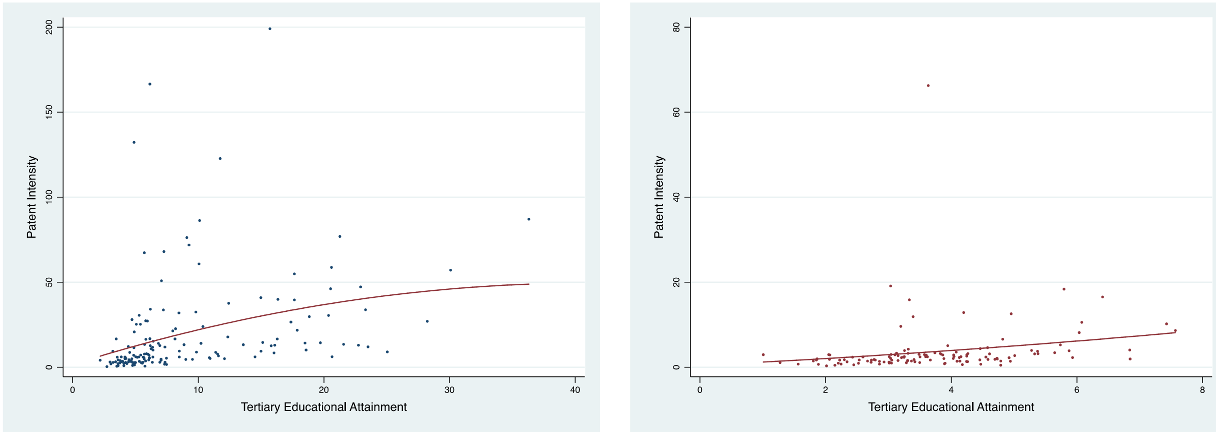
Source: Authors' elaboration

Once again, however, the positive relationship is a function of the strength of the relationship in the country's more developed cities where skilled human capital is more abundant (Figure 6A). Skills endowments seem also to increase patenting propensity in China's less dynamic regions. It is, however, made apparent by Figures 6A and 6B that China's more developed cities mobilise their deeper pools of human capital with greater efficiency than their less developed counterparts.

Figure 6. Tertiary education attainment and patent intensity in China's more and less developed cities, 2014

A. More developed cities

B. Less developed cities



Source: Authors' elaboration

These observations provide hint to why China's more developed cities are more innovative than their less developed counterparts. Based on this discussion, we propose the two hypotheses:

Hypothesis 1: The socioeconomic and structural factors that govern processes of innovation in China's more and less developed cities differ significantly.

Hypothesis 2: The efficiency in absorbing knowledge and transferring innovation inputs into outputs is higher in China's more developed cities than in its less developed ones.

The econometric exercise that follows facilitates the testing of these hypotheses and to assess whether these differences manifest themselves in the way different types of Chinese cities generate innovation.

5. Methodology

5.1. The model

A 'modified knowledge production function' (e.g. Ó hUallacháin and Leslie, 2007; Crescenzi et al., 2007, 2012) within which innovative capacity is anticipated to be a function of: investment in R&D; exposure to knowledge spillovers emanating from neighbouring cities; the availability of skilled human capital; and a vector of 'structural' factors is employed to model the innovative capacity of China's more and less developed cities.

The model is specified as follows:

$$y_{i,t} = \beta_1 R\&D_{i,t} + \beta_2 WR\&D_{i,t} + \beta_3 HumanK_{i,t} + Structural_{i,t}'\delta + \phi_t + \lambda_{I} + \varepsilon_{i,t} \qquad (1)$$

Where:

y	represents innovative performance proxied by patent intensity;
R&D	represents local investment in R&D;
WR&D	is a spatially lagged variable that reflects the average R&D expenditure of neighbouring cities;
HumanK	represents availability of skilled human capital
Structural	is a vector of structural factors;
i,t	represent city and time, respectively

5.2. The variables

5.2.1. The dependent variable

The dependent variable is patent applications per 10,000 inhabitants. Patent statistics capture and quantify the development and introduction of applied innovations and technological developments. It is for this reason that researchers undertaking econometric analyses of this nature rely on patent intensity as a proxy for innovative capacity. Patent intensity is by no means a perfect proxy for a territory's innovative capacity. Its limitations are, however, well understood,[2] and, importantly, do not impair one's capacity to draw the sorts of inferences the research sets out to provide.

5.2.2. The independent variables

Knowledge inputs:

Innovation involves the application of knowledge; "new economic knowledge" is the key 'input' to processes, the 'outputs' of which are more tangible, applied and commercially viable innovations (Audretsch and Feldman, 2004: 2716). This knowledge is generated by, embodied in, and drawn from a diversity of activities and sources. We consider three:

[2] The most prominent criticism levelled against the use of patent applications as a proxy for innovation is that patent statistics – for reasons relating to the (i) patentability (or lack thereof) of certain inventions and innovations, and (ii) variability in the propensities of different firms, sectors and industries to apply for patents – do not capture all of the innovations introduced by, and in turn, the innovative capacity of an economy and are, in that respect, somewhat biased (e.g. Desrochers, 1998). The case for their employment is presented by Trajtenberg (1990: 183) who asserts that patent statistics are "the only observable manifestation of inventive activity with a well-grounded claim for universality".

R&D expenditure, expressed as a percentage of GDP, is included in the model to capture extent to which public and private actors in cities are engaging in generating the essential and economically useful knowledge that spurs innovation. Audretsch and Feldman (2004: 2716) observe that "the greatest source generating new economic knowledge is generally considered to be R&D".

Economically useful knowledge is also embodied in human capital (e.g. Audretsch, 1998; Dachs, 2009; Rupietta and Backes-Gellner, 2019). This is not, however, the only avenue through which educated workers contribute to innovative processes. Skilled, educated workforces facilitate the identification, absorption and mobilisation of knowledge, locally generated or otherwise (e.g. Griffith et al., 2004; Dachs, 2009). The second 'knowledge input' considered is therefore **tertiary educational attainment.** The inclusion of this variable permits the formulation of inferences relating to the extent to which the depth of a city's pool of skilled workers shapes its innovative capacity, both directly (i.e. as an input) and indirectly (i.e. as a facilitator of the absorption of other sources of knowledge).

Finally, territories are, through various mechanisms and channels, exposed to knowledge that is generated beyond their borders (Audretsch and Feldman, 2004:2718; Feldman and Kogler, 2010:401). This extra-locally sourced knowledge is an important knowledge input to innovative processes (e.g. Bathelt et al., 2004; Sonn and Storper, 2008; Rodríguez-Pose and Crescenzi, 2008; Grillitsch and Nilsson, 2015). To neglect these knowledge flows would be to overlook a potentially powerful catalyst for innovation. A **spatially lagged R&D** variable is included in the analysis to explore if, and how, a city's innovative potential is conditioned by its exposure to inter-city R&D knowledge flows.

Structural factors:

Innovative processes are shaped by a multitude of other territorial characteristics, features and attributes (Doloreux and Parto, 2005; Edquist and Chaminade, 2006; Buesa et al., 2010; Crescenzi and Rodríguez-Pose, 2012). The relationships between a set of preeminent structural influences and factors and the innovative capacity of Chinese cities are probed via the inclusion of five additional controls:

1. Externalities associated with the agglomeration of economic actors and activities are a catalyst for innovation (e.g. Carlino and Kerr, 2014). The importance of these externalities, and of co-location more generally, to the generation of innovative output is often examined in empirical analyses via the inclusion of measures of density (Ke, 2010). **Employment density** (e.g. Carlino et al., 2007) is used to assess the link between agglomeration and innovation.

2. Territorial innovative capacities are not free from influence from their demographic compositions (e.g. Poot, 2008); younger populations are anticipated to be more innovative (e.g. Crescenzi et al., 2007). Following Crescenzi et al., (2007; 2012), **the percentage of the population aged 15-24** is incorporated as an indicator of the youthfulness of a city's population.

3. A city's propensity to patent has been also linked to the size of the population (e.g. Bettencourt et al., 2007). **Population size** is, accordingly, added to the model to explore whether having a larger population is supportive of, or detrimental to, a city's innovative potential;

4. Cities, as Capello et al., (2012:152) note, may also realise "benefit from a favourable industrial mix [that supports] innovation". We explore the extent to which a city's innovative capacity is a function of its economic fabric, and more specifically, of the types of activities it hosts, via the inclusion of **employment in manufacturing as a percentage of total employment**.

5. Finally, a well-developed stock of physical infrastructure may be a boon to innovative capacity (e.g. Agrawal, 2017). An **infrastructure density** variable is, therefore, included to assess how an urban environment's innovative potential is affected by the ready availability (or lack thereof) of physical infrastructure.

5.3. Data sources

Patent data at prefecture-city level stem from the State Intellectual Property Office of the P.R.C. (http://www.sipo.gov.cn/). Human capital data are drawn from the 2000 and 2010 China Population Census. Data for the years 2003-2009 and 2011-2014 are predicted using linear interpolation. All other city-level data, including R&D, population size, density, manufacturing employment, GDP, and GDP per capita stem from the China City Statistical Yearbooks. All financial data are measured using 2003 prices, based on the consumer price index published by the China City Statistical Yearbook. After omitting the far-western provinces —that lack full sets of data and have virtually no measured innovation— the dataset includes 283 Chinese prefecture-cities covering the period 2003-2014. The correlations among the main variables are included in Table A1 in the Appendix.

6. Results and analysis

The model is estimated using a panel data regression approach with time and city fixed effects. Robust standard errors are clustered by city. The analysis considers a sample of 283 Chinese cities between 2003 and 2014. The cities included in the sample are listed in Table A2 in the Appendix. The estimation results are presented in Tables 1 through 3, each of which builds on the previous. Table 1 summarises the results of the first, most basic iteration of the model. Table 2 summarises iterations of the model to which a series of interaction terms are added. Table 3 presents the results of a set of estimations that include a spatially-lagged R&D variable.

The full sample specifications (Table 1, Specifications 1-4) provide a baseline against which the results for more developed and less developed city specifications can be implicitly compared. They are, in that that respect, the most suitable point of departure.

Table 1. Full sample, more & less developed cities estimations, without interaction terms

Dependent variable: Patent intensity	All cities (1)	(2)	(3)	(4)	More developed cities (5)	(6)	(7)	(8)	Less developed cities (9)	(10)	(11)	(12)
R&D expenditure (% of GDP)	1.666***	1.263**	1.082**	1.086**	7.903***	6.773***	5.889***	5.722***	0.230	0.334**	0.330**	0.326**
	(0.539)	(0.588)	(0.510)	(0.492)	(2.380)	(2.523)	(2.167)	(2.066)	(0.209)	(0.139)	(0.139)	(0.134)
Tertiary education attainment	3.210***	3.079**	3.165***	3.137***	2.369***	2.493***	2.752***	2.694***	0.873*	0.943**	0.906**	0.885**
	(0.547)	(0.510)	(0.498)	(0.499)	(0.594)	(0.549)	(0.547)	(0.552)	(0.487)	(0.437)	(0.438)	(0.432)
Employment density		0.995**	0.874*	0.868*		1.175**	1.029**	1.029**		-0.0194	-0.0239	-0.0386
		(0.435)	(0.451)	(0.453)		(0.460)	(0.489)	(0.490)		(0.0285)	(0.0295)	(0.0382)
Share of the population aged 15-24		-1.262	-1.058	-0.761		-2.076	-1.807	-1.230		-0.0810	-0.0827	-0.0722
		(0.869)	(0.830)	(0.735)		(1.440)	(1.431)	(1.330)		(0.0795)	(0.0778)	(0.0784)
Population		-0.0220	-0.0205	-0.0145		-0.0192	-0.0183	-0.0148		-0.0163**	-0.0158**	-0.0162**
		(0.0251)	(0.0256)	(0.0201)		(0.0298)	(0.0309)	(0.0258)		(0.00641)	(0.00633)	(0.00638)
Employment in industry/manufacturing			0.0899**	0.105*			0.150**	0.182**			-0.00114	-0.00143
			(0.0450)	(0.0543)			(0.0687)	(0.0817)			(0.0142)	(0.0140)
Infrastructure density				-0.0955				-0.150				0.0568**
				(0.152)				(0.161)				(0.028)
Constant	-11.69***	15.47	8.437	1.189	-19.95***	18.35	7.474	-3.372	-1.688	6.131*	6.063	5.974
	(2.512)	(18.24)	(16.71)	(12.55)	(4.810)	(25.83)	(25.12)	(21.26)	(1.056)	(3.669)	(3.670)	(3.688)
City fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,385	3,309	3,278	3,268	1,897	1,860	1,837	1,828	1,488	1,449	1,441	1,440
R^2	0.742	0.765	0.765	0.757	0.743	0.771	0.770	0.762	0.643	0.673	0.673	0.678

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The first four specifications included in Table 1 imply that processes of innovation in the 283 Chinese cities in the sample are mainly shaped by four of the factors captured by the model. R&D expenditure is found to be positively and statistically significantly associated with patent generation in all four of the specifications (Table 1, Specifications 1-4). The innovative capacity of these cities appears to be mediated by the depth of their skilled labour forces as well. The coefficients of the tertiary educational attainment variable are positive and strongly significant across Specifications 1-4. Positive relationships also emerge between patent intensity and both the agglomeration of economic activity —captured by the inclusion of the employment density variable— (Table 1, Specifications 2-4) and employment in manufacturing (Table 1, Specifications 3 & 4). There is, on the other hand, no evidence to suggest that the innovative performance of these cities is linked to the youthfulness or size of their respective populations (Table 1, Specifications 2-4) or the state of their infrastructure endowments (Table 1, Specification 4).

However, the full sample specifications do not tell the whole story. Theory suggests, as alluded to in Section 2 and the end of Section 3, that the socioeconomic heterogeneity of China's more and less developed cities, respectively, influences how the two types of cities generate innovative output. The testing of this hypothesis is facilitated by the disaggregation of the sample into more and less developed cities, respectively. A more nuanced story does, in fact, emerge when China's more economically developed cities are separated from their less developed counterparts.

Processes of innovation in China's more developed cities are shaped by five factors. First, more developed cities succeed in transforming R&D into innovation. The positive and significant relationship between R&D expenditure and patent generation unearthed by the analysis implies that China's more developed cities are realising considerable benefit, in the form of tangible innovative outputs and technological progress, from the sizable financial commitments they make to the cultivation of knowledge (Table 1, Specifications 5-8). A similar inference is formed about the link between exposure to extra-locally generated knowledge flows and innovative performance. The direction and statistical significance of the coefficient for spatially-lagged R&D variable across all specifications of the model indicates that China's more developed cities have a robust facility for the translation of R&D knowledge flows emanating from neighbouring cities into innovative output (Table 3, Specifications 1-5). These cities' facilities for the mobilisation and exploitation of both local and extra-local R&D are attributable, at least in part, to their relatively highly-skilled workforces that function not only as facilitators of the absorption, internalisation and exploitation of knowledge (e.g. Vinding, 20006; Vogel, 2015), but also are themselves evidently catalysts for innovation. That is, a positive, statistically significant relationship between tertiary education attainment and patenting suggest that the innovative capacities of more developed cities are directly enhanced by the ready availability of skilled labour (Table 1, Specifications 5-8). The positive and significant relationship between employment density and patent intensity that emerges from the analysis provides evidence to support the assertion that externalities associated with the agglomeration of economic activity are a boon to the innovative capacity of China's more economically developed cities as well (Table 1, Specifications 6-8) (Rodríguez-Pose and Zhang, 2019; Zhang et al., 2020). Finally, the innovative capacities of China's more developed cities are also a function of the prevalence of more generally innovation-prone, manufacturing activities in them; employment in manufacturing is positively and significantly linked to patent generation (Table 1, Specifications 7 & 8).

Stated simply, the innovativeness of China's more developed cities is explicable by a marked facility for the application of basic knowledge and a supportive structural and socioeconomic context. That is, locally and extra-locally generated knowledge in China's more developed cities is made readily available by the well-funded R&D efforts they undertake. They are amply exposed to the latter in large part because of the extent of the clustering of China's more economically developed cities on the country's east coast (e.g. Figure 1). This ready availability of knowledge is matched by a comparable availability of skills. Skilled human capital, much of which is employed in more innovation-prone manufacturing activities, works in close physical proximity to translate knowledge into applied innovation. All of this gives rise to innovative capacities that exceed those of China's less developed cities.

The innovative capacities of China's less developed cities, on the other hand, are, similarly, a function of five of the factors contemplated by the analysis. First, China's less developed cities have an unexpected facility for the translation of knowledge generated both within and beyond their borders into innovative output. Lower levels of investment in R&D —that could conceivably, in many cases, fail to exceed the threshold below which returns to this expenditure are unlikely to materialise—, shallower pools of skilled human capital and weaker economic fabrics are chief among the factors that render them less receptive to and less able to absorb and apply the knowledge they generate or are exposed to. Yet, a positive and statistically significant relationship between R&D expenditure and patent intensity, however, implies that investments in

R&D do not represent a waste of scarce financial resources in China's less developed cities (Table 1, Specifications 10-12). Likewise, the positive coefficient of the spatially lagged R&D variable indicates that these cities can and do leverage the knowledge they are exposed to via intercity knowledge spillovers to generate innovation (Table 3, Specifications 6-10).

Skills support innovation in these environments as well; a significant relationship is observed between tertiary education attainment and patent generation (Table 1, Specifications 9-12). Unlike their more developed peers, neither employment density nor employment in manufacturing are robustly associated with the innovative capacity of China's less developed cities. Rather it is the availability of physical infrastructure that conditions their innovative capacities (Table 1, Specification 12). The implications of the positive and statistically significant relationship between infrastructure density and patent intensity are two-fold: first, the infrastructural deficiencies are a barrier to achieving innovation in these cities. Second, there is benefit to be realised from appropriate investments in the upgrading of the infrastructure endowments of China's less developed cities. Finally, the analysis provides an indication that population size cannot be overlooked in the context of China's less economically developed cities. That is, the negative and significant coefficient of the population size variable in the less developed specifications suggest that overcrowding in these generally populous cities has an adverse effect on their innovative potential (Table 1, Specifications 10-12).

Innovative processes in China's less developed cities do, in some respects, confound expectation. Notably, these cities can translate knowledge and knowledge resources into innovation. The issue, it would therefore seem, is not necessarily one of ability but rather one of availability.

China's less developed cities invest less in R&D activities than their more developed neighbours; locally generated knowledge is less ubiquitously available. These cities are more physically isolated as well, which limits their exposure to innovation-inducing knowledge spillovers. As a result, whatever capacity these cities have for the mobilisation and productive application of knowledge goes un- or underexploited. The same can be said of skills. The skilled labour with which these cities are endowed does support innovative processes and enhance the respective innovative capacities of these less developed areas. Skilled labourers are, however, few and far between in these cities.

The facility these cities have for the mobilisation of knowledge inputs and human capital provides a sense of why these underdeveloped environments are not wholly un-innovative. The scarcity of these inputs however also begins to explain why these cities lag so far behind their more developed counterparts in terms of innovation. Further limits to the innovative capacity of these cities are imposed by infrastructural deficiencies by which less developed environments are characteristically faced and by large populations that the analysis suggests are impediments to innovation.

At first glance, the factors shaping processes of innovation in China's more developed cities do not seem wholly dissimilar to those at play in its less developed ones. A closer look, however, suggests that China's more developed cities differ from their less developed counterparts in two critical, related respects.

First, while both types of cities have at least some facility for the mobilisation of different types of ‘knowledge inputs’ —knowledge resources generated by local and extra-local R&D activities and their skilled workforces—, China’s more developed cities do so considerably more efficiently (Table 1, Specifications 5-12; Table 3, Specifications 1-10), confirming hypothesis 1. China’s more economically developed cities are realising returns from (i) the R&D activities they host, (ii) the knowledge spillovers to which they are exposed, and (iii) the human capital they are home to that massively outstrip those available in their less developed neighbours. So, not only are these cities investing more in R&D activities; more exposed to intercity knowledge flows, and better endowed with skilled human capital than their less developed counterparts, they are putting the outputs of these investments, the spillovers and the skills to work with a comparatively advanced degree of efficiency and realising larger returns from them. This renders the innovation gap between China’s more and less developed cities that much more understandable.

The second point of divergence between the two types of cities is discerned from the interaction terms that feature in Tables 2 and 3. The reason for including interaction terms in the analysis is that factors such as the level of education of the population, employment density, the size of industry, or infrastructure endowments may condition the returns of R&D investment, as indicated in hypothesis 2. These interaction terms facilitate the formulation of more nuanced inferences relating to the extent to which the socioeconomic and structural factors captured by the model directly affect and shape a city’s capacity to mobilise both the knowledge generated by the R&D activities they host and to which they are exposed to via inter-city knowledge flows and transform it into applied innovation. Simply stated, they reveal the indirect effects of these factors and the influences on the innovative capacity of China's more and less developed cities, respectively. The 'knowledge-related synergies' they expose provide an indicative sense, as we will address, of how integrated and evolved the innovation systems hosted by the two types of cities are.

Looking at the coefficients of the interaction terms, there seems to be considerably more scope for the emergence of 'knowledge-related' synergies in China's more developed cities. The various interactions of the model, and, more specifically, the positive and statistically significant coefficients of the R&D- and spatially-lagged R&D-interaction terms, respectively, provide evidence to suggest the skilled workforces and physical infrastructure with which China's more developed cities are endowed (Table 2, Specifications 1 & 4; Table 3, Specification 2); the industrially biased economic fabrics by which they are characterised (Table 2, Specification 3) and agglomeration externalities (Table 2, Specification 2; Table 3, Specification 3) they benefit from directly enhance their capacity to translate knowledge and/or knowledge spillovers into tangible innovative output. These synergies are fewer and farther between in China's less developed cities.[3] Moreover, the coefficients of the significant interaction terms indicate that when they materialise, these synergistic relationships are weaker in less developed cities than they are in their more developed counterparts, providing additional support for hypothesis 2.

[3] There is cursory evidence to suggest: (1) that, if they are endowed with them, adequately developed stocks of human capital and physical infrastructure may grant less developed cities a marginally greater facility for the exploitation of the R&D investment; and (2) that human capital, physical infrastructure and agglomeration externalities, again when they are available or arise in less developed environments, can aid, albeit minimally, in the absorption and mobilisation of inter-city knowledge flows (Table 3, Specifications 7, 8 & 10)

Table 2. More & less developed cities estimations, with interaction terms

Dependent variable: Patent intensity	More developed cities (1)	(2)	(3)	(4)	Less developed cities (5)	(6)	(7)	(8)
R&D expenditure (% of GDP)	8.404***	6.498***	8.521***	8.083***	1.981**	0.409*	0.345	1.356**
	(2.379)	(2.173)	(2.940)	(2.696)	(0.947)	(0.228)	(0.259)	(0.552)
Tertiary educational attainment	2.476***	2.601***	2.579***	2.656***	0.939**	0.888**	0.885**	0.913**
	(0.468)	(0.545)	(0.547)	(0.528)	(0.463)	(0.433)	(0.431)	(0.424)
Employment density	0.983**	0.945**	0.986**	1.073**	-0.0409	-0.0452	-0.0385	-0.0382
	(0.474)	(0.459)	(0.487)	(0.476)	(0.0416)	(0.0356)	(0.0384)	(0.0412)
Share of the population aged 15-24	-1.156	-1.070	-1.204	-1.337	-0.0796	-0.0712	-0.0723	-0.101
	(1.301)	(1.289)	(1.318)	(1.252)	(0.0796)	(0.0788)	(0.0784)	(0.0800)
Population	-0.0222	-0.0161	-0.0173	-0.0217	-0.0170**	-0.0160**	-0.0162**	-0.0157**
	(0.0235)	(0.0251)	(0.0247)	(0.0251)	(0.00652)	(0.00639)	(0.00640)	(0.00613)
Employment in industry/manufacturing	0.164**	0.176**	0.171**	0.174**	-0.00637	-0.00166	-0.00159	-0.00430
	(0.0806)	(0.0832)	(0.0816)	(0.0788)	(0.0135)	(0.0140)	(0.0143)	(0.0134)
Infrastructure density	-0.177	-0.149	-0.165	-0.309	0.0555**	0.0578**	0.0568**	0.0699**
	(0.160)	(0.161)	(0.158)	(0.198)	(0.0269)	(0.0282)	(0.0276)	(0.0285)
R&D expenditure x Tertiary education	1.110***				0.441**			
	(0.297)				(0.223)			
R&D expenditure x Employment density		0.574**				0.191		
		(0.262)				(0.0242)		
R&D expenditure x Employment in manufacturing			0.197**				0.001	
			(0.0830)				(0.006)	
R&D expenditure x infrastructure density				0.436**				0.128*
				(0.205)				(0.0550)
Constant	21.53	18.54	18.70	24.43	10.93**	10.49**	10.68**	10.65**
	(21.65)	(22.52)	(22.65)	(21.52)	(3.257)	(3.293)	(3.335)	(3.163)
City fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,828	1,828	1,828	1,828	1,440	1,440	1,440	1,440
R^2	0.771	0.765	0.766	0.767	0.686	0.678	0.678	0.688

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Estimations with spatially-lagged R&D variable and interaction terms

Dependent variable:	More developed cities					Less developed cities				
Patent intensity	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
R&D expenditure (% of GDP)	3.424**	4.981**	3.921**	4.269**	3.648**	0.136	0.192	0.170	0.137	0.199
	(1.710)	(1.940)	(1.790)	(2.118)	(1.735)	(0.129)	(0.145)	(0.140)	(0.165)	(0.136)
Spatially-lagged R&D expenditure	33.37***	29.55***	35.15***	32.50***	33.56***	3.390***	4.327***	3.591***	3.389***	4.450***
	(7.451)	(6.998)	(7.824)	(7.199)	(7.533)	(1.279)	(1.612)	(1.331)	(1.282)	(1.458)
Tertiary educational attainment	2.769***	2.990***	2.780***	2.738***	2.782***	0.833*	0.867*	0.836*	0.833*	0.856**
	(0.516)	(0.535)	(0.514)	(0.516)	(0.516)	(0.423)	(0.447)	(0.424)	(0.424)	(0.427)
Employment density	1.018**	1.004**	1.012**	1.012**	1.031**	-0.0323	-0.0322	-0.0460	-0.0323	-0.0330
	(0.474)	(0.467)	(0.474)	(0.477)	(0.481)	(0.0390)	(0.0410)	(0.0348)	(0.0391)	(0.0433)
Share of the population aged 15-24	-1.270	-1.278	-1.258	-1.264	-1.310	-0.0646	-0.0672	-0.0626	-0.0646	-0.0734
	(1.295)	(1.280)	(1.289)	(1.299)	(1.297)	(0.0771)	(0.0771)	(0.0772)	(0.0774)	(0.0766)
Population	-0.0133	-0.0146	-0.0125	-0.0141	-0.0141	-0.0174***	-0.0181***	-0.0172***	-0.0174***	-0.0178***
	(0.0259)	(0.0258)	(0.0262)	(0.0257)	(0.0258)	(0.00659)	(0.00673)	(0.00654)	(0.00659)	(0.00660)
Employment in industry/manufacturing	0.120	0.117	0.115	0.116	0.119	-0.00268	-0.00474	-0.00307	-0.00270	-0.00411
	(0.0797)	(0.0805)	(0.0809)	(0.0801)	(0.0795)	(0.0138)	(0.0137)	(0.0138)	(0.0141)	(0.0136)
Infrastructure density	-0.196	-0.231	-0.227	-0.195	-0.236	0.0517**	0.0508**	0.0528**	0.0517**	0.0547**
	(0.156)	(0.160)	(0.169)	(0.157)	(0.191	(0.0260)	(0.0256)	(0.0261)	(0.0258)	(0.0254)
Spatially-lagged R&D expenditure		0.570***					0.242*			
x Tertiary educational attainment		(0.170)					(0.141)			
Spatially-lagged R&D expenditure			0.338**					0.0263*		
x Employment density			(0.155)					(0.0154)		
Spatially-lagged R&D expenditure				0.0519					0.0001	
x Employment in manufacturing				(0.0389)					(0.0053)	
Spatially-lagged R&D expenditure					0.0582					0.087**
x Infrastructure density					(0.0399)					(0.0344)
Constant	-32.59	-27.09	-37.03	-32.49	-32.15	5.297**	5.355**	4.782*	5.298**	4.599*
	(28.51)	(28.08)	(29.50)	(28.49)	(28.57)	(2.629)	(2.613)	(2.637)	(2.629)	(2.543)
City fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,828	1,828	1,828	1,828	1,828	1,440	1,440	1,440	1,440	1,440
R^2	0.770	0.773	0.771	0.770	0.770	0.682	0.683	0.682	0.682	0.684

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

All this points in the direction of a singular, more general inference. The empirical analysis implies that China's more and less developed cities are not necessarily leveraging completely different sets of factors, resources or characteristics to cultivate innovation. Differences do exist, but more and less developed cities are both relying on similar 'knowledge inputs' to generate innovation. Where China's more and less developed cities differ most profoundly is in the complexity of the processes of innovation they host and the maturity of the innovation systems they are home to.

Processes of innovation in China's less developed cities conform closely to linear conceptualisations of innovation (e.g. Maclaurin, 1953; Grilliches, 1979). The analysis suggests that increases in R&D investment, exposure to knowledge flows or efforts to upgrade human capital will yield innovation. There is, however, comparatively little to suggest that the processes by which these knowledge inputs are translated into innovative outputs are profoundly affected or mediated by features, attributes or characteristics of the environments in which they transpire. Their innovative capacities are, for example, unconnected to their industrial compositions and extent to which actors and activities are co-located. Weaker contextual conditions are unsupportive of innovation and can compromise the innovative potential of less developed cities (Rodríguez-Pose, 1999). Moreover, the innovation systems these cities host have not matured or become integrated to a point where all elements of the innovation system work synergistically to maximise the efficiency with which knowledge inputs are mobilised. Knowledge-related synergies are considerably scarcer and weaker in less developed Chinese cities than they are in their more developed neighbours. Simply stated, the contextual influence on the processes by which knowledge inputs are translated into outputs is minimal. The result is that returns to knowledge and knowledge resources in China's less developed cities are modest and potentially limited, especially when compared to those being realised in more developed territories.

The exact opposite is true for China's more developed cities. There, knowledge inputs are transformed into innovation via processes that are considerably more multidimensional and, because of the array of influences to which it is evidently subject, complex. Their innovative potential is, for one, directly affected by much more than the availability of knowledge inputs (Edquist and Chaminade, 2006; Kline and Rosenberg, 2009). There is evidence to suggest, as literature has anticipated, that both externalities associated with the agglomeration of economic activity enhance their innovative capacities as do their industrially-biased economic fabrics (Storper and Venables, 2004; Glaeser, 2010). More revealing of the maturity and complexity of these innovation systems, however, is the abundance of knowledge-related synergies from which they benefit. The innovation systems of China's more developed cities have evolved to such an extent that territorial characteristics and attributes —that themselves impel innovation— interact and work in mutually-reinforcing ways to facilitate the maximisation of returns from inputs to innovative processes. The ultimate reflection of this, and of the maturity of these cities' innovation systems more generally, is the comparatively robust efficiency with which they mobilise and productively apply knowledge, and, relatedly, the returns they manage to realise from knowledge inputs that dwarf those available in China's less developed cities. In short, the innovative processes for China's more developed cities are more complex, and their innovation systems, more evolved, integrated and mature, than those hosted by their less developed counterparts.

7. Conclusion

The preceding research sought to unpack processes of innovation in China's more and less developed cities, respectively, with a view to identify and understand the differences between the sets of factors that drive and shape processes in these heterogeneous environments. A comparative econometric analysis of 283 cities was employed to form policy relevant insights and inferences that previous empirical research is yet to provide.

The analysis revealed that China's more advanced cities, on the one hand, mobilise and productively exploit R&D, knowledge spillovers and human capital with a comparatively high degree of efficiency. Processes of interaction, collaboration and a host of other proximity-related externalities borne out of the agglomeration of economic actors and activity in them are profoundly supportive of the innovative activities they host. These innovative processes unfold on more industrially-biased economic fabrics —functions of the types of economic actors, activities and sectors by which they are composed— that are themselves conducive to innovation. Innovation enhancing knowledge-related synergies were also found to be abundant; factors, features and territorial characteristics that support innovative activities, are working in mutually reinforcing ways to ensure that knowledge resources, locally generated or otherwise, are mobilised and productively exploited as efficiently as possible.

A different story emerged for China's less developed cities. While knowledge inputs do not go unexploited in these environments, they are translated into innovative outputs relatively inefficiently. Their innovative potential is detached from the broadly-defined types of economic activities they engage in and they are unable to reap the innovative benefits of and externalities associated with co-location and density. If anything, their generally large populations serve as barriers to innovative processes. Moreover, it is only the most basic of public investments — those in physical infrastructure— that are anticipated to yield returns in the form of innovative output. This suggests that these cities may be suffering from fundamental deficiencies the shoring up of which is likely prerequisite to the establishment of any measurable innovative capacity. Finally, the knowledge-oriented synergies that were abundant in China's more developed environments are relatively weak in these cities.

All of this indicates that the innovation systems hosted by China's more developed cities are more complex, integrated and mature than in the country's less developed cities where processes of innovation seem to unfold in a manner that is more consistent with basic, linear conceptualisations of innovation. This is something that is not exclusive to China. In studies conducted for developed nations, Rodríguez Pose and Wilkie (2019) find that innovation processes in North America's and Europe's lagging regions are far from identical and are governed by distinct combinations of factors. The complexity of innovation in more developed regions of these two continents is also greater. Our analysis corroborates that these differences are not exclusive to developed countries and that, in the case of China, the dynamics of innovation in advanced and lagging cities differ considerably.

Given the exploratory nature of the analysis, there are a number of issues that would require further consideration. First, patents, as an indicator of innovation, is not perfect. Some industries patent far more than others; some patent applications are complex, while others very simple. They are used for lack of a better alternative. There is a need to find better proxies for innovation to examine the robustness of the conclusion in this research. Second, further analysis will be needed in order to untangle the potential endogeneity problems related to the complex innovation mechanisms in Chinese cities,

Taking these caveats into account, the paper points to some overarching policy implications. It highlights how policy-makers responsible for the promotion of innovation in, and in turn, growth of China's less developed cities will need to walk a tightrope of sorts. That is, there is an obvious need to, on the one hand, capitalise on the facility these cities have for the mobilisation and application of knowledge and knowledge inputs. This will involve the pursuit of more traditional innovation policies based, for example, on the prioritisation of R&D and basic knowledge generation or, even more rudimentarily, infrastructure expansion. Such policies would, however, represent 'quicker-fixes' designed not with the longer-term performance or sustainability of the innovation systems in mind, but rather to cultivate innovative output, promote growth and stem the emergence of spatial inequalities in the immediate, shorter-term. Measures to impel the maturation of the innovation system as a whole will likely be necessary to achieve the former. These might include efforts to promote the integration of a system's constituent components and intra-system connectivity more generally, or interventions to upgrade the socioeconomic and structural environments within which these systems exist and address the institutional deficiencies by which they are burdened (Rodríguez-Pose and Zhang, 2020).

Policy-makers responsible for China's more developed cities, on the other hand, face a less daunting task. Further increasing the availability of knowledge inputs and/or expanding the innovation system via the attraction of economic actors and activities will undoubtedly be integral to the maintenance and expansion of their innovative capacities here as well. What is more important, however, is ensuring that these inputs and actors complement, and are integrated into, what are already relatively mature innovation systems. Simply stated, special attention should be paid to the maintenance of the synergistic dynamics —and the cultivation of new ones— that underpin these reasonably evolved innovation systems.

APPENDIX

Table A1. Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Patent intensity	1.000							
(2) R&D expenditure (% of GDP)	0.041	1.000						
(3) Tertiary education attainment	0.432	-0.042	1.000					
(4) Employment density	0.445	-0.016	0.423	1.000				
(5) Share of the population aged 15-24	0.290	-0.025	0.359	0.353	1.000			
(6) Population	0.052	-0.012	0.145	0.241	0.146	1.000		
(7) Employment in industry/ manufacturing	0.269	-0.104	0.218	0.289	0.067	-0.037	1.000	
(8) Infrastructure density	0.436	-0.144	0.352	0.378	0.228	0.027	0.330	1.000

Table A2. China's more and less developed cities

Less developed cities			More developed cities		
Ankang	Huanggang	Shantou	Beijing	Jincheng	Suqian
Anqing	Huangshan	Shanwei	Baishan	Jingmen	Suzhou
Anshun	Huludao	Shaoyang	Baoji	Jinhua	Taian
Anyang	Jiamusi	Shiyan	Baotou	Jinin	Taiyuan
Baicheng	Ji'an	Shuangyashan	Bayannur	Jinzhou	Taizhou
Baise	Jieyang	Siping	Beihai	Jiuquan	Taizhou
Baiyin	Jingzhou	Suihua	Binzhou	Kunming	Tangshan
Baoding	Jinzhong	Suining	Cangzhou	Laiwu	Tianjin
Baoshan	Jiujiang	Suizhou	Changchun	Langfang	Tongchuan
Bazhong	Jixi	Suzhou	Changzhi	Lanzhou	Tongliao
Bengbu	Kaifeng	Tianshui	Changzhou	Lianyungang	Weifang
Bozhou	Laibiri	Tiding	Chengde	Liaocheng	Weihai
Chaoyang	Leshan	Weinan	Chengdu	Liaoyang	Wenzhou
Chaozhou	Lijiang	Wuwei	Chenzhou	Lishui	Wuhai
Chizhou	Lincang	Wuzhong	Chifeng	Liuzhou	Wuhan
Chongziio	Linfen	Wuzhou	Chongqing	Longyan	Wuxi
Chuzhou	Linyi	Xiaogan	Dandong	Luoyang	Xi'an
Datong	Liupanshui	Xingtai	Daqing	Mudanjiang	Xiangyang
Dazhou	Loudi	Xinxiang	Deyang	Nanjing	Xianyang
Dingxi	Lu'an	Xinyang	Dezhou	Nanning	Xining
Fuxin	Luliang	Xinzhou	Dongguan	Nanping	Xuchang
Fuyang	Luohe	Xuancheng	Dongying	Nantong	Xuzhou
Fuzhou	Luzhou	Ya'an	Erdos	Ningbo	Yan'an
Ganzhou	Meishan	Yibin	Ezhou	Ningde	Yancheng
Guang'an	Meizhou	Yichun	Fangchenggang	Panjin	Yangquan
Guangyuan	Mianyang	Yichun	Foshan	Panzhihua	Yangzhou
Guigang	Nanchong	Yiyang	Guangzhou	Putian	Yantai
Guilin	Nanyang	Yongzhou	Guiyang	Qingdao	Yichang
Guyuan	Neijiang	Yulin	Haikou	Qinhuangdao	Yinchuan
Handan	Pingdingshan	Yuncheng	Hangzhou	Quanzhou	Yingkou
Hanzhong	Pingliang	Yunfu	Harbin	Quzhou	Yingtan
Hechi	Pu'er	Zhangjiajie	Hebi	Rizhao	Yulin
Hegang	Puyang	Zhangjiakou	Hohhot	Sanmenxia	Yuxi
Heihe	Qingyang	Zhangye	Huai'an	Sanming	Zaozhuang
Hengshui	Qingyuan	Zhanjiang	Huangshi	Sanya	Zhangzhou
Hengyang	Qinzhou	Zhaotong	Hulunbuir	Shanghai	Zhengzhou
Heyuan	Qiqihar	Zhoukou	Huzhou	Shaoguan	Zhenjiang
Heze	Qitaihe	Zhumadian	Jiaozuo	Shaoxing	Zhongshan
Hezhou	Qujing	Ziyang	Jiaxing	Shenzhen	Zhoushan
Huaibei	Shangluo	Zunyi	Jiayuguan	Shijiazhuang	Zhuhai
Huaihua	Shangqiu		Jinan	Shuozhou	Zibo
Huainan	Shangrao		Jinchang	Songyuan	Zigong

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