Technical Appendix

China Innovation Capacity Growth Index 2015 and 2020

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1. Introduction

The Technical Appendix provides more in-depth information related to the CICGI for interested readers.

2. On the eight indicators

The following section defines each of the eight indicators and provides additional information on the reasoning behind them. It further shows the data included for both of the editions of the CICGI.

Indicator #1 – Share of new-to-world innovations

China's share of new-to-world innovations aims to be indicator of Chinese companies' capacity to produce innovative products and business models capable of competing in the global market. A large number of innovations furthermore indicates a move away from the imitation of products developed by high-income economies and toward indigenous invention (Lewin, Kenney & Murmann, 2016). The CICGI suggests a metric of global patenting output, namely triadic patents, to measure China's share of new-to-world innovation (Murmann, 2016), a recognized indicator to assess a nation's innovation capacity (Lee, 2016; Feng & Chen, 2010; Sternitzke, 2009). A triadic patent is defined as a multinational set of patents, protecting the same invention and filed at three major patent offices—the United States Patent and Trademark Office, the European Patent Office, and the Japanese Patent Office (OECD, 2020; Sternitzke, 2009). The OECD (Organisation for Economic Co-operation and Development) collects and annually publishes data on triadic patent filing activity (OECD, 2020).

In 2012, out of the total 54,008 newly filed triadic patents, 1,951.6 patents are attributed to Chinese residents (OECD, 2020). That yields a calculated share of 3.6% of triadic patents filed by inventors residing in China, which results in a score of 4 for indicator #1 in 2015. For the 2020 score, the most recent data stems from 2018 (OECD, 2020). With Chinese-filed patents contributing 5,323 of the total 57,230 triadic patents worldwide, China in 2018 filed 9.3% (OECD, 2020). Consequently, a score of 9 is included in the second edition of the CICGI.

Indicator #2 – Chinese articles in leading international journals

Indicator #2 aims to measure China's progress in building science and engineering (S&E) know-how. The indicator included in the CICGI is a composite of China's *share of scientific articles in leading international journals* as well as of the citation of these articles to reflect Chinese researchers' capability to qualitatively contribute to the global scientific dialogue (Lewin, Kenney, & Murmann, 2016). Furthermore, a high share of scientific articles published in international magazines undergoing a strict review process is a positive indicator for the quality and relevance of research done (Lewin, Kenney, & Murmann, 2016). Freeman (1969) supports the approach to

measure research output in scientific contribution, as it is a method that "lends itself readily to large-scale statistical application."

SCImago annually publishes the h-index, which takes into account not only a country's publication output, but also the number of citations. The h-index therefore also accounts for research quality, with citations being an indicator of the impact of the respective publications. Similarly, the h-index is also included in global indices[1] to assess innovation capability. To provide for better interpretability, the Chinese h-index is set in relation to the top-performing country reported by SCImago. Mester (2016) reports the 2014 data of China as 495 and of the United States as 1648, which made the USA the 2014 top performing country. This means China has 30% of the top performing country. SCImago Lab shows the Chinese h-index in 2019 at 884 and the United States at 2386. This gives China 37% of the top performing country. Compared to the 2014 values, China's h-index in 2019 thus gained 7 percentage points relative to the best performing economy.

Indicator #3 – Intellectual property (IP) system effectiveness

Indicator #3, *intellectual property (IP) system effectiveness,* aims to measure whether China has adopted an intellectual property regime that encourages and rewards innovation, by using global best practices. Legal protection for intellectual property is mentioned by Furman, Porter, and Stern (2002) as one of the drivers for cross-country differences in national innovation capacity.

Given difficulties in quantitatively assessing the quality of a patent system, qualitative data is included. To evaluate the quality of China's patent system, three indicators assessing IP protection and an economy's legal frameworks from the Executive Opinion Survey (EOS) of the GCR (Global Competitiveness Report) are aggregated with equal weighting: *intellectual property protection, efficiency of legal framework in challenging regulations* and *efficiency of legal framework in settling disputes*. For China, more than 700 Chinese executives answered the three questions (Schwab, 2019). The CICGI scores stem from the 2014-2015 GCR and the 2019 GCR. Following defined rounding rules, the CICGI score included in the first edition is thus 66, while the second edition CICGI is reported as 67 (based on Schwab & Sala-i-Martin, 2014; Schwab, 2019).

Indicator #4 – Share of resources flowing to non-state-owned enterprises

This indicator aims to track how many resources are flowing to private enterprise rather than to SOEs (state-owned enterprises). Research has shown that Chinese SOEs are more likely to accumulate debt, and underperforming SOE firms are more likely to survive than private firms (Molnar & Lu, 2019). As a result, China's non-financial corporate debt relative to GDP is higher than that of other major economies (Molnar & Lu, 2019). In China, the larger part is accounted for

[1] E.g. Global Innovation Index, Global Competitiveness Report, or European Innovation Scoreboard (Cornell University, INSEAD, & WIPO, 2020; Schwab, 2019; Hollanders, 2020).

by SOEs. Furthermore, despite being given access to a major part of R&D resources, SOEs are less likely to produce high-quality, innovative products than are private companies (Child, 2016). To improve China's innovation capacity, innovative non-SOEs need to gain access to R&D resources and financing (Lewin, Kenney, & Murmann, 2016). To assess the access to financing of China's non-SOEs, the 2017 International Monetary Fund (IMF) report on selected issues on the PRC is used, given its inclusion of more detailed data regarding China's debt structure. Providing an overview of the contribution of both SOE and non-SOE to total corporate debt, data up to 2016 is available (IMF, 2017). In subsequent reports, this topic is not covered in detail. The score included for the 2015 CICGI is thus the 2014 value of 46%. The most recent value for the second edition CICGI is 42% in 2016 (IMF, 2017).

Indicator #5 – Ease of starting a business

The fifth indicator measures the reduction of administrative and extra-administrative obstacles, focusing on the ease of starting a business in China. The capability of starting a business with little administrative cost and within a short timeframe reduces entry barriers for new and innovative firms (World Bank, 2020b). Reducing administrative obstacles and barriers in business is relevant to China's innovation capacity, as reduced barriers allow Chinese managers to allocate less time to fostering and tending to relationships with different levels of government (Lewin, Kenney, & Murmann, 2016); they can thus focus on contributing to China's innovation capacity.

Doing Business, an annual report published by the World Bank, compares how effectively business is done in 190 economies (World Bank, 2020b). Among ten topics covered in the report, one measures the ease of starting a business using four indicators: procedures measured in number, time measured in days, cost in percentage of income per capita, and, lastly, minimum capital in percentage of income per capita (World Bank, 2020b). The data is collected from the two largest business cities in China and weighted by population. Hence, Shanghai and Beijing, weighted 0.55 and 0.45 respectively, represent the two cities included influencing China's performance in the indicator (World Bank, 2020b). As the CICGI measures China's efforts to implement the best regulatory environment to foster innovation and should not focus on China's performance relative to other economies, the score for starting a business presents a fitting and representative metric for the CICGI. In 2014, China's score is 77.43 (World Bank, 2014). The 2020 report sets the ease of starting a business at 94.1. (World Bank, 2020a). As per the rounding approaches defined, the CICGI scores included are 77 in 2014 and 94 in 2020. China has thus between 2015 and 2020 rapidly approached the regulatory frontier, leaping forward in score by 17 points.

Addition September 2021: When we wrote this article, we were not aware that questions had been raised about the accuracy of the data for China in the 2020 „Doing Business" report by the World

Bank. No such questions were raised for the 2015 report. As of the 22. September 2021, we have no direct evidence that the 2020 „Ease of starting business“ measure was manipulated but the 94 score for 2020 should be viewed critically. We will look for alternative sources of data for the measure in future editions of our index.

Indicator #6 – Level of financing for start-ups and small- and medium-sized enterprises

Lewin, Kenney, and Murmann (2016) suggest the access to financing of micro-, small- and medium-sized enterprises (MSME) as a measure of effectiveness of the financial system (p. 423). In China, the importance of MSMEs' contribution has been recognized in recent years and thus SMEs have become a key component of Chinese government policy (Child, 2016). Yet, reports show that banks still prefer lending to SOEs due to the lower risk attached (Child, 2016). To fully unleash the potential of MSMEs, their ability to invest in R&D and thus gain access to financing is crucial to China's innovation capacity (Lewin, Kenney, & Murmann, 2016). To depict the level of access to financing in this index, data regarding the share of loans to micro- and small-sized enterprises (MSEs) from different types of banks are researched. The Mintai Institute of Finance and Banking annually publishes a China MSME Finance Report2, which shines light on developments in Chinese MSMEs' access to financing. The China MSME Finance Report includes data on the proportion of generalized MSE loans to total loans of major banking financial institutions.

The China SME Finance Report 2013 includes MSE loan data on three types of banks, namely large state-owned banks, joint-stock commercial banks and lastly urban commercial banks. On average, generalized MSE loans make up 21.95% of the total loan balance of banks covered (Ping, 2013). For the CICGI's first edition, 22 is the included indicator score as the rounded proportion of MSE loans (Murmann, 2016). The China MSME Finance Report 2018 expands the scope of banks included in the ratio. Included are rural and commercial banks, foreign and private banks, five major commercial banks, and joint-stock commercial banks. On average, generalized MSE loans form 24.67% of the total loan balance of banks covered (Ping, 2018). Therefore, following the same normalization and logic of the first edition CICGI, the second edition CICGI indicator value is 25. This means that there is a 3-point improvement from 2013 to 2018.

Indicator #7 – Institutionalized trust

An important catalyst for innovation is cooperation (Redding, 2016). To enable effective and efficient cooperation, Redding (2016) discusses the importance of the ability to trust strangers. This indicator aims to track the ability of the Chinese government to increase generalized trust by

[2] In 2013, the report is published under the name SME Finance Report.

focusing on transparency and procedural justice. Child (2016) mentions that, as a substitute for trust in strangers, an economy should provide effective and reliable institutions, such as transparent rules or rights, the availability of trustworthy information, and other items. In China, the absence of such institutions for interactions with strangers poses the challenge of a void of trust (Child, 2016).

Measuring a qualitative trait such as the level of trust within an economy presents many challenges, as it is highly subjective and is likely to vary strongly across segments. To substitute the measure of trust, perceived corruption is used in the first edition CICGI. The CPI (Corruption Perceptions Index) evaluates perceived public sector corruption, scoring countries on a scale from 0 to 100 as well as providing a rank to compare the included economies' performances (Transparency International, 2020b). A score of 100 indicates "very clean," while a score of 0 indicates "highly corrupt." A higher score thus indicates a better performance and thus a comparatively lower rank of corruption is reported.

The 2015 CPI was used as the metric for indicator #7, institutionalized trust, with China ranking 83rd of the 168 countries evaluated, with a score of 37 out of 100 (Transparency International, 2016a). Transparency International comments on the score saying that, despite China's strategy of strict prosecution of corruption, no substantial improvement of perceived corruption can be observed (Transparency International, 2016b). The 2019 CPI scores China with 41 out of 100 points, i. e. a slight decrease in perceived corruption. This means there is a 4-point improvement from for 2015 to 2020.

Indicator #8 – Autonomy of Chinese universities

The final indicator focuses on the question of whether China is increasing the autonomy of its universities. Increased autonomy enhances the ability of universities to react to opportunities and challenges. It also improves the impact in science and technology innovation and the increased quality of graduates (Lewin, Kenney, & Murmann, 2016). As the Chinese Ministry of Education (MoE) as well as provincial governments directly supervise most[3] Chinese universities, China's performance in this indicator is to be tracked closely and specifically for China (Lewin, Kenney, & Murmann, 2016).

The measure used in the first edition of the CICGI is a framework set up by the OECD Education Policy Analysis to measure the extent of autonomy experienced by universities (OECD, 2003; Murmann, 2016). The framework consists of eight indicators to measure university autonomy, namely whether the institutions are free to (1) own their buildings and equipment, (2) borrow funds,

[3] Lewin, Kenney & Murmann (2016) mention specialized universities to be supervised by particular ministries.

(3) spend budgets and achieve their objectives, (4) set academic structure/course content, (5) employ and dismiss academic stuff, (6) set salaries, (7) decide size of student enrolment and, finally, (8) decide the level of tuition fees (OECD, 2003). This framework was submitted to expert Professor Futao Huang, Professor at the Research Institute for Higher Education, Hiroshima University in Japan for evaluation with respect to China.

Between 2015 and 2020, only factor number 4, the autonomy to set academic structure and course content, has decreased (Futao Huang, personal communication, 2020, April 01). The metric is normalized from 1 to 100, resulting in an indicator score of 72 for 2015 and 66 for 2020, marking a decrease in indicator performance of 6 points.

3. Calculation of the indicator scores

The following section provides a short overview of how each of the indicator scores was calculated. Rounding rules applied defined rounding to always be to the nearest integer.

Indicator #1 – Share of new-to-world innovations

Method:

China's number of patents filed divided by *total number of patents filed*.

Example: 2020 CICGI

Triadic Patent Families, OECD, 2019	
China's number of patents filed	5,323
Total number of patents filed	57,230
China's share	9.30%
CICGI score (rounded)	9

Indicator #2 – Chinese articles in leading international journals

Method:

SCImago Journal & Country Rank, Country Rank *(YEAR), in SCImago Lab,* most recently available edition.

Example: 2020 CICGI

SCImago Journal & Country Rank, Country Rank, SCImago Lab, 2020	
China's h-index	886
Top performing economy's h-index (United States)	2386
China divided by top-performing economy	37.133%
CICGI score (rounded)	37

Indicator #3 – Intellectual property system effectiveness

Method:

Normalization of GCR indicators: indicators *intellectual property protection*, *efficiency of legal framework in challenging regulations* and *efficiency of legal framework in settling disputes.*

Rank divided by number of countries participating. Subtraction of the quotient for higher values to indicate better performance and multiplication by 100 to obtain 0 to 100 scale.

Example: 2020 CICGI

Global Competitiveness Report, 2019	Rank	Division by No. of Countries (141)	Inversion & Multiplication by 100
Intellectual property protection	53	0.38	62.41
Efficiency of legal framework in challenging regulations	36	0.25	74.47
Efficiency of legal framework in settling disputes	52	0.37	63.12
Mean			66.67
CICGI Score			67

Indicator #4 – Share of resources flowing to non-state-owned enterprises

Method:

IMF Data: Corporate debt of non-SOEs as a percentage of GDP divided by total nonfinancial corporate debt as a percentage of GDP

Example: 2020 CICGI

2016 data, own representation based on IMF, 2017	
Total nonfinancial corporate debt, %GDP	128
Corporate debt of non-SOE, %GDP	54
Share of non-SOE nonfinancial corporate debt	42%
CICGI Score	42

Indicator #5 – Ease of starting a business

Method:

China's score in the indicator "Ease of Starting a Business" by the *Doing Business* report

Example: 2020 CICGI

Doing Business 2020	
Ease of Starting a Business – Score China	94.1
CICGI Score	94

Indicator #6 – Level of financing for start-ups and small- and medium-sized enterprises

Method:

Generalized MSE loans as percentage of total loan balance of banks covered in the China MSME Finance Report

Example: 2020 CICGI

China MSME Finance Report 2018 (Ping, 2018, Charts 3-7)	
Ease of Starting a Business – Score China	24.67%
CICGI Score	25

Indicator #7 – Institutionalized trust

Method:

China's Score of the Corruption Perceptions Index by Transparency International

Example: 2020 CICGI

Corruption Perceptions Index 2019, Transparency International, 2020	
China's Corruption Perceptions Score	41
CICGI Score	41

Indicator #8 – Autonomy of Chinese universities

Method:

Cumulation of all eight grades (scale: 0-1) assigned by Professor F. Huang of the eight indicators in the OECD Framework to measure the extent of autonomy experienced by universities.

Normalization of 0-8 scale to 0 to 100.

Example: 2020 CICGI

Universities have autonomy to…	2020 Grade
… own their buildings and equipment	*1*
… borrow funds	*1*
… spend budget to achieve their objectives	*1*
… set academic structure / course content	*0.25*
… employ and dismiss academic staff	*0.5*
… set salaries	*0.5*
… decide size of student enrolment	*0.5*
… decide tuition fees	*0.5*
Total numeric grade (0-8)	5.25
CICGI Score	66

4. Limitations to the individual indicators

All measures of social phenomena simplify reality and have limitations. We want to discuss the limitations that we see in the eight measures.

Indicator #1 – Share of new-to-world innovations

The causes of the observed quantitative increase in the share of new-to-world innovations deserves further examination. In particular more study is needed whether the increase truly reflects an increase in Chinese innovation capacity. Cheng and Huang (2016) mention various incentives implemented by the Chinese Communist Party to foster patent applications, such as subsidies, remuneration, and preferential tax treatment. According to Zhang and Zhong (2016), however, the number of high-quality Chinese patents is lower compared to US patents. Cheng and Huang (2016) suggest 50 to 80% of Chinese patents in 2005 are junk patents. Therefore, an assessment of the quality of Chinese patents and thus the potential to commercialize them would prove useful to better assess China's current innovation capacity. As a qualitative measure, Cheng and Huang (2016) suggest using the average patent length in years, as high-quality patents would likely be maintained over a longer period of time.

Indicator #2 – Chinese articles in leading international journals

Given that Zhang and Zhong (2016) criticize the analysis of merely quantitative indicators in regard to publication output, measuring the impact of a research paper by, for example, referring to the citation count of an article (NSB & NSF, 2019a) is important to properly track the actual improvement in China's research output. As a matter of fact, Chinese publications account for 43% of total articles removed from Scopus due to low quality, amounting to about 250,000 articles or 6% of China's total article count (NSB & NSF, 2019b). With the CICGI as well as other innovation indices such as the GII (Global Innovation Index) and the GCR including the h-index, a measure accounting for both scientific impact as well as researcher productivity is represented in the CICGI (Cornell University, INSEAD, & WIPO, 2020; Schwab, 2019). The big advantage of these quantitative measures is that they are systematic and can be easily calculated. The downside is that even an h-index type indicator might not fully account for quality.

Indicator #3 – Intellectual property system effectiveness

Regarding providing incentive for patenting, Ma (2013) states that only a tenth of all annually patented technologies in China are actually commercialized, indicating an inefficiency of the Chinese patent system. Fostering qualitative patents, as already mentioned in indicator #1, will continue to remain crucial for the effectiveness of China's patent system.

Indicator #4 – Share of resources flowing to non-state-owned enterprises

Regarding the CICGI indicator score, the currently used normalization suggests 100% of resources flowing to non-SOEs as China's optimally achieved state. Given China's market characteristics, this approach to normalization might need to be reviewed in the future when SOE's role in the economy is even further reduced.

Indicator #5 – Ease of starting a business

One limitation to the insights of the *Doing Business* report regarding China is the two-city approach to measuring the entire economy's performance (World Bank, 2020b). Given the diversity of regulations in China's provinces and considering Beijing and Shanghai's status as Tier 1 cities (PwC & China Development Research Foundation, 2019), the insights from the *Doing Business* report are likely to overestimate the ease of starting a business in China. In order to examine this likely overestimation, further data on founding activities in China was analyzed in order to analyze regional differences. The compilation of data by Tianyancha on new firm registrations as well as population statistics published by the National Bureau of Statistics of China showed that the density of number of new companies founded per a province's total population is higher for both Shanghai and Beijing than most other provinces (exceptions: Hainan, Guangdong). This difference in density could be caused by a more restrictive regulatory environment for starting a business in the worse performing provinces. This would indicate that the 2015 and 2020 *ease of starting a business* score is most likely overestimating the ease of starting a business throughout China. It is however notable that, comparing the 2015-2020 growth rate in densities in Shanghai and Beijing (28.70%) to the remaining provinces (76.60%), the growth rate is more than double in the remaining provinces. Hence there is clearly a big improvement throughout China and we decided not alter the World Bank's scores for China.

Regional differences in founding activity in China

Provinces	Number of new companies founded (2020)[4]	Population (2020)	Density of new companies (2020)	Number of new companies founded (2015)	Population (2015)	Density of new companies (2015)	Growth rate 2015-2020
1) Beijing & Shanghai	600'459	46'763'990	**0.01284**	457'544	45'860'000	**0.00998**	**28.70%**
2) Remaining Provinces	7'647'983	1'363'014'734	**0.00561**	4'209'879	1'325'020'000	**0.00318**	**76.60%**
3) All provinces	8'248'442	1'409'778'724	**0.00585**	4'667'423	1'370'880'000	**0.00340**	**71.85%**

[4] For the total number of new companies founded, the authors accessed a dataset of new firm registrations in China in 2015 and 2020 by regions collected by www.tianyancha.com.s

Indicator #6 – Level of financing for start-ups and small- and medium-sized enterprises

Aside from financing, further factors influence MSMEs' innovation output. Child (2016), among others, mentions a shortage of trained and creative scientific staff, institutional barriers such as unfair competition from SOEs and foreign companies, and inhibiting management styles (p. 206). All in all, a better understanding of management techniques conducive to innovation as well as equally distributed risks for innovation is and remains crucial (Child, 2016). Child (2016) furthermore mentions the importance of clusters to foster innovation. Therefore, the limitations to indicator #6 lie in its mere quantitative evaluation of MSMEs' innovation capability, whereas qualitative factors such as awareness of management techniques and equal treatment are yet to be considered.

Indicator #7 – Institutionalized trust

Chiu, Liou, and Kwan (2016) mention findings showing that institutional trust is comparatively higher in economies ruled by non-authoritarian political institutions in the past. The CPI in its 2019 methodology chapter mentions its underlying data sources representing perceived levels of corruption by country experts and businesspeople. While this does contain very relevant information, it might lack meaning in representing a lower level and widespread level of trust. Measures such as the below-mentioned World Values Survey, as suggested by Redding (2016), would provide a measure of trust where a void between state and close relationships such as e. g. family exists. In the seventh wave of the survey, similarly low values for trust in strangers are found: 86.2% of respondents state they do not trust people they meet for the first time at all or do not trust very much (World Values Survey, 2020). This has not improved much since 2009. This implies that China has not been able to balance the existing void and guanxi, representing a system of exchanging favors within a network of influential relationships, might still be a driving force for cooperation in China's society. The trust in strangers might hold important implications for daily interactions in the context of innovation and might be equally valuable for the CICGI as a measure of corruption in future editions.

Indicator #8 – Autonomy of Chinese universities

For indicator #8, the reliability of the data included has to be mentioned as a limitation, given that it is the qualitative assessment of just one expert. For increased reliability, further data sources should be integrated. However, we need to emphasize that the OECD framework for evaluating autonomy of universities has been used by the expert to make his evaluation.

If you have further questions or suggestions, please contact Professor J.P. Murmann or A. Hochstrasser.

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