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Income and Productivity Trends of Guangdong: A Data-Driven Case Study of the Greater Bay Area*

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June 2022

Abstract

In 2017, the Chinese government announced plans for the development of the Greater Bay Area, a world-class city cluster in southern China. Our study statistically compares the income and productivity of Guangdong, home to nine bay area cities, to other mainland provinces since the announcement. We observed a decline in both measures in Guangdong due to the influx of people since the announcement. We attribute this increase in population to 1) higher employment in the construction, wholesale and retail sectors, and 2) key policies aimed at attracting talents from other mainland provinces.

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1 Introduction

The Guangdong-Hong Kong-Macao Greater Bay Area (GBA), consisting of nine Guangdong cities (also known as the Pearl River Delta region) and two Special Administrative Regions, is the new bay area and a megalopolis in the making in China. The proposal of the GBA, signed into agreement in 2017, comprises a multitude of policies which aims to provide the region with conditions suitable for high-quality economic growth.

Aim of study Our study aims to examine the impact of the 2017 announcement and signing of the 2017 GBA development framework on Guangdong's economy. Excluding the Hong Kong and Macau Special Administrative Regions, all the nine remaining cities in the GBA reside in the Guangdong mainland province and constitute most of Guangdong's economy.[1] Hence, to evaluate the impact of the 2017 GBA announcement, we focus on the Guangdong province's economic performance.

The Greater Bay Area The GBA consists of the Hong Kong Special Administrative Region, the Macao Special Administrative Region, and nine Guangdong cities in the Pearl River Delta (PRD) region (Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, and Zhaoqing), covering a total urban area of 56,000 square kilometres with a combined population of approximately 70 million.

The region's development was first introduced in 2015 in The Vision and Actions for Jointly Building the Silk Road Economic Belt and the 21st Century Maritime Silk Road jointly issued by the National Development and Reform Commission, the Ministry of Foreign Affairs, and the Ministry of Commerce. In 2017, a proposal to "draw up a plan for developing a city cluster in the Guangdong-Hong Kong-Macao Greater Bay Area" was written into the government report. Since then, the development of the GBA has obtained national focus. In 2019, China released the "Outline Development

[1] According to Guangdong Statistical Yearbook, in 2020, PRD contributed 80.5% of GDP in Guangdong province and includes 62.0% of the provincial population.

Plan for the Guangdong-Hong Kong-Macao Greater Bay Area." The outline stipulates a short-term plan to 2022 and a long-term project to 2035, establishing goals for the two phases.

This study uses the year 2017 as the year of intervention, as it marks the official launch of the GBA after the signing of the Framework Agreement on Deepening Guangdong-Hong Kong-Macao Co-operation in the Development of the Bay Area on 1^{st} July 2017. Figure 1 shows a map with China, Guangdong as our main province of interest, and the nine PRD cities within Guangdong.[2]

Empirical approach To examine the impact of the 2017 GBA announcement, our case study focuses on the Guangdong province as the epicentre of the GBA. We use the synthetic control method (Abadie and Gardeazabal 2003; Abadie et al. 2010) as a quantitative approach to a case study where only one unit experienced an intervention. Implementing the synthetic control method allows us to impute the counterfactual trend of Guangdong's Per Capita GDP and Population density using the weighted combination of the other mainland provinces. To the extent that the counterfactual analysis is valid, the difference between Guangdong's trend and the counterfactual trend reveals the impact of the 2017 announcement.

Our findings Our first set of findings is for Per Capita GDP. We find robust and statistically significant quantitative evidence that after the 2017 GBA announcement, Guangdong's Per Capita GDP falls relative to the counterfactual trend. A placebo exercise reveals that this drop in Guangdong's Per Capita GDP is absent in the other mainland provinces, suggesting that we are not simply capturing an economic shock common to the other China regions. We further perform a set of tests to show that the fall in Guangdong's Per Capita GDP, relative to the other counterfactual trend, is not sensitive to the subset of mainland provinces used to construct the counterfactual,

[2]The Framework was signed by the Chief Executive of the Hong Kong Special Administrative Region, Chief Executive of the Macau Special Administrative Region, Chairman of the National Development and Reform Commission, and Governor of Guangdong Province, witnessed by President Xi Jinping. The Supplementary Materials provides supplementary notes on Guangdong and the GBA.

not sensitive to restriction the synthetic control estimation to a shorter period, and not sensitive to the set of macroeconomic indicators used to predict the counterfactual trend.

Our second set of findings reveals a rise in population as the reason for the observed fall in Guangdong's Per Capita GDP. Our synthetic control estimation suggests that Guangdong experienced a sharp increase in population density following the 2017 GBA announcement. This increase in Guangdong's population is similarly robust and not present in the other mainland provinces. Since the standard productivity measure of Per Capita GDP is GDP divided by population size, our results suggest the fall in Guangdong's productivity is attributable to an increase in population.

In the discussion and further analyses, we focus on labour productivity instead, where we find a similar decline in Guangdong's productivity and suggest that the observed decline in economic performance is not unique to the Per Capita GDP measure. We also link our findings on the influx of population to GBA policies involving talent recruitment at the provincial level, including benefits such as housing subsidies. Overall, our results suggest a broad-stroke evaluation of an uprising bay area is not always straightforward because the inception of the bay area itself leads to compositional changes in the economy.

Related studies Since the Eleventh Five Year Plan (2006-2010), urban clusters have become the main driver of China's economic growth. The most successful examples include the Yangtze River Delta and the Pearl River Delta. Researchers have then dived into this area to examine various economic factors in the clusters, such as industrial development (Lee and Lin 2020; Tang 2021; Yixin and Miao 2021) innovation (Sheng et al. 2019; Hu and Kim 2022; Chow et al. 2020), infrastructure (Weng et al. 2020; Hui et al. 2020; Ding et al. 2019) and FDI (Wen 2014; Zhang et al. 2022).

On the one hand, studies have revealed that urban agglomeration is an important factor for innovation (Sheng et al. 2019) and the development of financial industries

(Yixin and Miao 2021). Ding et al. (2019), Hui et al. (2020) and Wen (2014) have discussed the importance of infrastructure and FDI to boost economic growth in the clusters. On the other hand, Xu and Jiao (2021) argued that the expansion of the urban population weakens the positive effect of urbanization. This finding is similar to ours, as we have shown that the rising population in Guangdong province has lowered the region's productivity.

Of the aforementioned studies, only a subset focuses on the GBA (Hu and Kim 2022; Yixin and Miao 2021; You et al. 2022). From other research field, Ni et al. (2020), Loo and Bo (2018), Bin and Lu (2020) have focused on regional integration in GBA. They have examined the degree of integration from spatial patterns, rail transit networks, and the establishment of free trade pilot zones. Zhang et al. (2022) contributes to this area from the angle of FDI. Since there is a differential development plan for Core and Node cities in GBA, the study examines whether manufacturing-related FDI is drawn to the Node cities and services-related FDI is drawn to the Core cities.

Our study fills the literature gap by studying the impact of the 2017 announcement on economic growth and its relations with a growing population, which may provide better insights into the area's talent attraction policies and innovation efficiency.

Section 2 describes empirical methodology we use. Section 3 describes our data. Section 4 and Section 5 presents the results for Per Capita GDP and Population density. Section 6 extends our analyses to productivity and discusses talent attraction policies. Section 7 concludes.

2 Methodology

The common methodological approach when studying the implementation or announcement of a policy is to use the difference-in-differences design. In such an approach, the counterfactual to the provinces with a policy intervention is the unweighted outcome

a China, Guangdong, and the PRD cities **b** Guangdong

Figure 1. Left panel shows the nine Pearl River Delta cities in the Greater Bay Area (shaded) as part of China. The broader outline indicates the Guangdong province. Right panel shows Guangdong and the nine Pearl River Delta cities (Guangzhou, Zhuhai, Shenzhen, Foshan, Huizhou, Dongguan, Jiangmen, Zhongshan and Zhaoqin) plus the Hong Kong and Macau Special Administrative Regions as part of the Greater Bay Area.

of the other provinces who would otherwise share the same trend had the policy intervention not been implemented.

Our Greater Bay Area study exists in a context that differs from the standard difference-in-differences setup in at least two ways. First, we only have one province, Guangdong, under the Greater Bay Area instead of many such provinces from which we can average over. Second, and more importantly, the standard parallel trends assumption needed to recover the average effect of the Greater Bay Area is unlikely to be satisfied given that Guangdong is already one of the larger economies in China and was on a different trajectory than the average mainland provinces even before the 2017 announcement (e.g., Lee and Lin 2020; Sheng et al. 2019; Weng et al. 2020 and Supplementary Materials). Hence, the empirical approach in our study is the synthetic control method which relaxes the parallel trend assumption and is designed for case studies with only a single "treated" unit, as in our case.

Below, we describe in more details our implementation of the synthetic control method (Abadie and Gardeazabal 2003; Abadie et al. 2010; Abadie 2020), where our aim is to impute the counterfactual trend of Guangdong using a weighted combination of the other mainland provinces.

The objective of our synthetic control method implementation is to create a synthetic Guangdong Province using the weighted average of the other Mainland China provinces to resemble the characteristics of Guangdong Province. The characteristics of our interest are in two areas: macroeconomic performance and human capital. Table A2 in the Supplementary Materials section lists the macroeconomic variables we use in our synthetic control estimation. Let Y and X represent the outcome variable and predictors, respectively. The main outcome variable in our model is Per Capita GDP, and the rest of the variables are predictors.

Let P be the number of provinces in the control group (there are 30 Mainland China provinces other than Guangdong). With a slight abuse of notation, let P also be the set of provinces. Let w_p be the weight assigned to each province, $p \in P$, with $0 \leq w_p \leq 1$ and $\sum_{p \in P} w_p = 1$.[3]

Let X_G and X_P be the set of predictors for Guangdong Province and the control provinces, respectively. We want to minimize the sum of the differences between the pre-policy intervention characteristics of Guangdong (X_G) and synthetic Guangdong ($X_P W$) by choosing the set of weights W:

$$\underset{W}{Min}(X_G - X_P W)' V (X_G - X_P W), \tag{1}$$

where V are the weights for each of the predictor variables, and V^* is calculated to minimize the difference in the outcome variable between Guangdong and synthetic Guangdong in the pre-intervention period:

$$\underset{V}{Min} \sum_{t \in T_0} (Y_{Gt} - \hat{Y}_{Gt})^2, \tag{2}$$

[3]We drop Hong Kong and Macau from the pool of donors because they do not operate in a similar system from the mainland provinces, and more importantly, receive the same shock as Guangdong as part of the GBA. See the Supplementary Materials for more details.

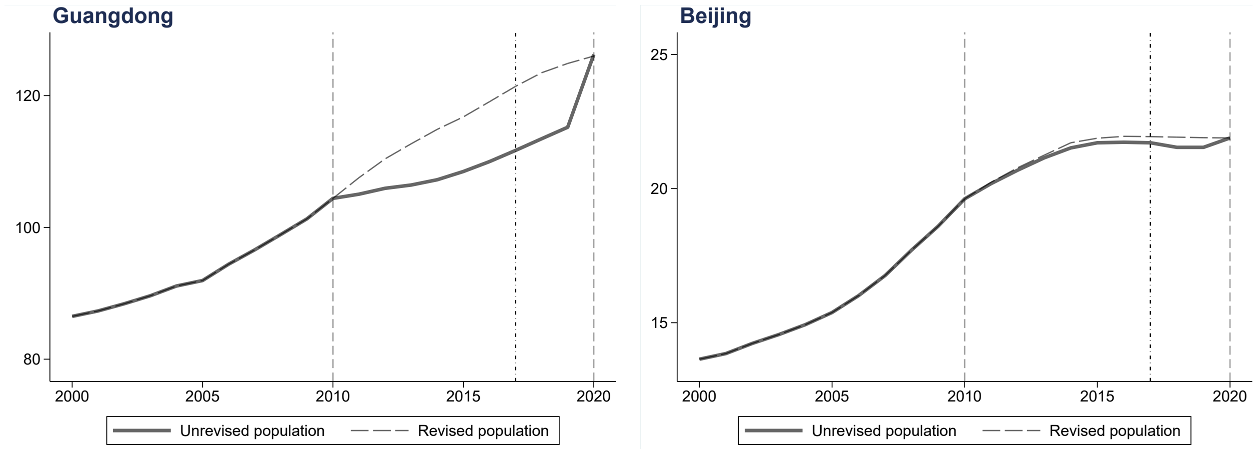


Figure 2. Population path plots for Guangdong and Beijing. Unrevised and revised population plotted are the raw data from the panel for the period 2000–2020. Dashed vertical lines are for the years 2010 and 2020, which are the endpoints for the (revised) census population smoothing. Dashed-dotted line is the 2017 GBA announcement.

where $\hat{Y}_{Gt} = \sum_{p=1}^{P} w_p^* Y_{pt}$ and T_0 is the time period before the policy shock.

The sets of weights W and V then together constitute the synthetic control of Guangdong, and the impact of the policy is calculated as the difference between Guangdong and synthetic Guangdong:

$$\tau_{Gt} = Y_{Gt} - \hat{Y}_{Gt}, \tag{3}$$

for each $t > T_0$.

3 Data

For this study, we collect data on macroeconomic indicators from various public sources, including the National Bureau of Statistics of China, China Statistical Yearbooks, provincial yearbooks, and China Labour Statistical Yearbooks. The sample period is over 21 years from 2000–2020.

In this section, we highlight the population data used in this study. As listed in Table A1 of the Supplementary Materials, the data for 2000, 2010, and 2020 are from the population census conducted every ten years. The sampling method for the data collection is the main difference between census year and non-census year. Census takers collected census data through a door-to-door method from all the households. To verify the accuracy of the census, for example, after the census in 2020, 32,000 households were randomly selected from 141 counties among the 31 Mainland China provinces. 0.05% of the households were not visited by the census takers, lower than the 3% international standard.[4]

For the non-census years, random sampling of households among the 31 provinces is conducted. The coverage is around 0.1% of the total population. At the mid-point between two census years, i.e., 2005 and 2015, the coverage is increased to 1% of the total population.

According to the National Bureau of Statistics, population data from 2011 to 2019 are revised based on the 2020 census results. We can see a clear data smoothing in Figure 2.[5] Population plots for the remaining provinces are in the Supplementary Materials (Figure A2–Figure A7). The unrevised population data is collected from the China Statistical Yearbooks or provincial statistical yearbooks, while the revised data is collected from the National Bureau of Statistics. We will be using the unrevised data in this study for 2011 to 2019.[6] Due to the unavailability of yearbooks for some provinces and to ensure consistency, for 2001 to 2009 data, we have collected the data from the National Bureau of Statistics in 2021. Thus, for this period, the data is revised.

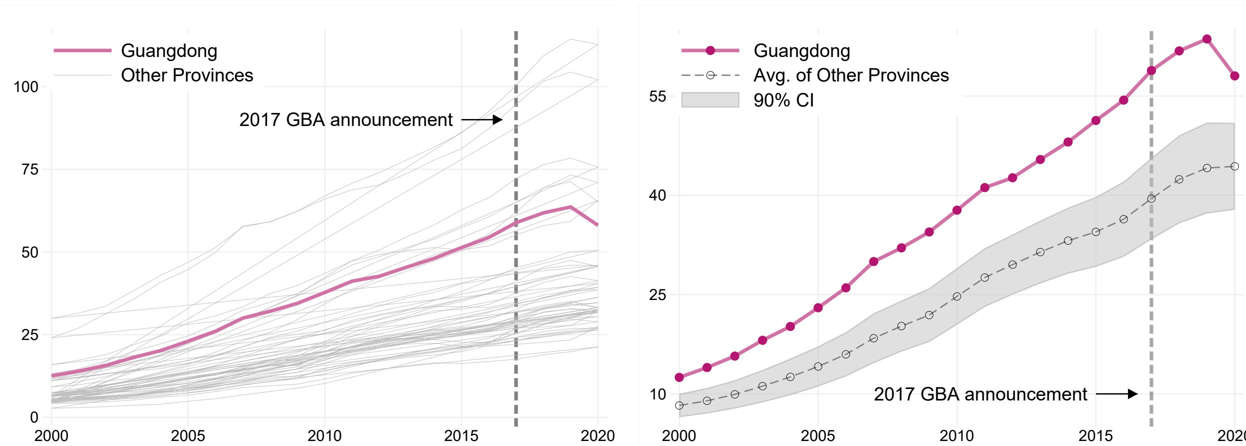
4 Potential Effect on Per Capita GDP

Figure 3 shows the general trend of Per Capita GDP using the raw data before and after the GBA announcement in 2017. To estimate whether the dip in Guangdong's

[4] http://www.stats.gov.cn/tjsj/zxfb/202105/t20210511_1817274.html accessed on 15 Dec 2021.

[5] http://www.stats.gov.cn/tjsj/zxfb/202105/t20210512_1817360.html accessed on 15 Dec 2021.

[6] For example, data for 2011 are collected from 2012 statistical yearbooks. Since the data could not be revised in the yearbooks, it will be considered the unrevised data which is collected by the random sampling method.



a Path plots of Per Capita GDP **b** Average of Per Capita GDP

Figure 3. Panel a shows the raw path plots of the province Per Capita GDP. Gray lines are mainland provinces other than Guangdong. Panel b shows the path plot of Guangdong and the average of the other provinces. Shaded gray area is the 90% confidence interval. Dashed vertical line indicates the 2017 announcement of the GBA.

Per Capita GDP can be attributed to the announcement, we use the synthetic control method described in Section 2. The synthetic control method imputes the counterfactual trend of Guangdong, using the weighted combination of the other mainland provinces before the GBA announcement, to construct synthetic Guangdong. To the extent that synthetic Guangdong is a good approximation, the difference between Guangdong and synthetic Guangdong reveals the impact of GBA on the Guangdong economy.

In this section, we report quantitative evidence that the drop in Guangdong's Per Capita GDP coincides with the GBA announcement in a way that is not reflected in the other mainland provinces.

4.1 Results

Figure 4 show the lists of donor provinces and predictor variables we use in the synthetic control estimation. Each set of donor province weights corresponds to a potential synthetic control unit for Guangdong. The left panel of Figure 4 shows the set of weights we use, which minimizes the pre-GBA characteristics of Guangdong and the

a Synthetic control weights **b** Predictor weights

Figure 4. Weights to construct Per Capita GDP of synthetic Guangdong. Left panel are the synthetic control weights, where weights are W^* from Equation (1) chosen such that synthetic Guangdong best resembles Guangdong in the over the 17 years in the period 2000–2016 before the 2017 GBA announcement. Right panel are the predictor variable weights V^* from Equation (2).

Table 1. Balance of predictors of Per Capita GDP before the 2017 GBA announcement.

	Weight	Guangdong	Synthetic Guangdong	Average	Henan (nearest neighbour)	Beijing (next nearest neighbour)
Primary industry	0.028	0.059	0.096	0.132	0.155	0.011
Secondary industry	0.181	0.479	0.453	0.477	0.521	0.239
Tertiary industry	0.239	0.462	0.472	0.447	0.336	0.699
Household income per capita	0.003	19,214	16,935	14,217	11,714	26,354
Visitors	0.052	0.018	0.016	0.015	0.004	0.036
Unemployment rate (urban)	0.3	2.601	2.701	3.591	3.159	1.447
Annual wage	0.196	30,861	30,277	26,547	20,079	51,925

Each row is a predictor used to match the Per Capita GDP of the 30 mainland provinces to Guangdong. Column 1 is the variable weight. Column 2 is the mean values for Guangdong. Column 3 is the mean predictor values for synthetic Guangdong ($X_P W^*$ from Equation (1)). Columns 4, 5, and 6 are special cases of the synthetic control. Column 4 is where all 30 mainland provinces get equal weights (W is a vector with all elements $1/30$. Column 5 is when the nearest neighbour gets full weight (W all zeroes except with weight 1 for Henan, see Figure 4). Column 6 is when the second nearest neighbour gets full weight (W all zeroes except with weight 1 for Beijing).

pre-GBA characteristics of the counterfactual synthetic Guangdong (Equation (1)). As evident from the left panel of Figure 4, only four mainland provinces contribute to synthetic Guangdong.[7]

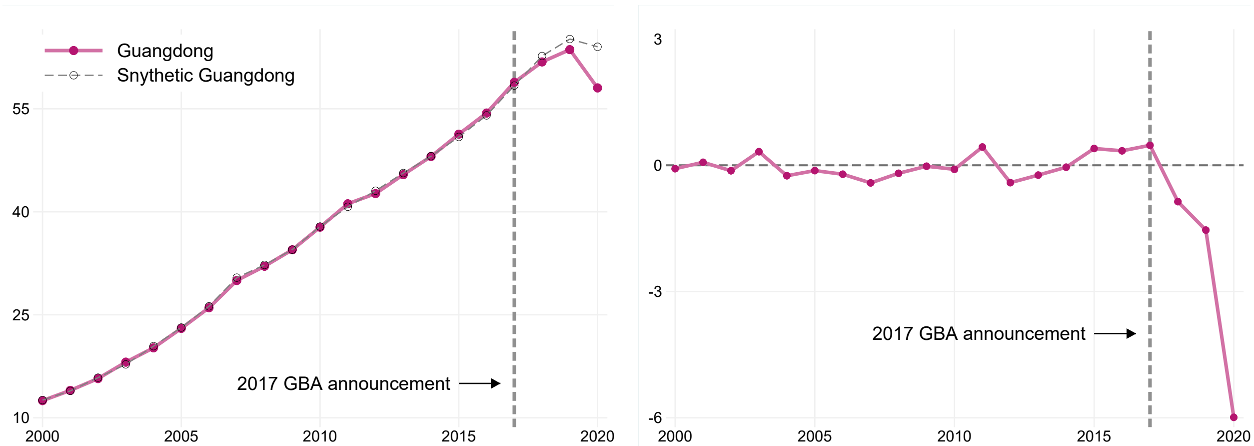
[7]The sparsity of synthetic weights is a feature of the synthetic control method (Abadie 2020). Guangdong, Beijing, Shandong, and Jiangsu are in the Eastern Coastal Region, which is the most developed area in China. In terms of GDP, Guangdong, Jiangsu, Shandong, Zhejiang, and Henan are the top five provinces in 2021. Thus, it is not surprising that these four provinces form synthetic Guangdong. One concern is that any single non-zero donor province (e.g., Henan, Beijing, Shandong, and Jiangsu) or other donor provinces in the initial donor pool artificially affects our results. For instance, Henan experienced heavy flooding in 2021. While this is not in our sample period, such events create an artificial depression of Per Capita GDP in the synthetic unit and lead to an artificially low decline in the estimated impact of the GBA. Other events that certain provinces encounter may lead to artificially high estimated increases. To deal with this, we perform leave-one-out sensitivity analyses that show

For the pre-GBA characteristics in the synthetic control estimation, the seven economic indicators we use are (i) the primary industry value (scaled by GDP), (ii) the secondary industry value (scaled by GDP), (iii) the tertiary industry value (scaled by GDP), (iv) annual (urban) household income per capita, (v) the number of international visitor arrivals (scaled by GDP), (vi) the (urban) unemployment rate, and (vii) the average annual wage of staff and workers (see Table A2 of the Supplementary Materials). The right panel of Figure 4 then shows the variable weights for the seven predictor variables where the value of the tertiary industry has the highest weight for predicting Per Capita GDP, followed by wage and the unemployment rate.

Table 1 shows how closely the pre-GBA characteristics of Guangdong matches the pre-GBA characteristics of pre-GBA synthetic Guangdong. We also report the pre-GBA match in characteristics between Guangdong and three special cases of synthetic Guangdong as a benchmark. The first special case is where each of the 30 mainland provinces receives equal weight in constructing synthetic Guangdong. The second special case is when the nearest neighbour, the province with the highest optimized weight, gets the full weight while all other provinces receive zero weight. The third special case is for the second nearest neighbour —the province with the second-highest optimized weight. Synthetic Guangdong constructed using the synthetic control method has the best overall match.

The synthetic control results in Figure 5 confirm that Guangdong's Per Capita GDP drops after the 2017 GBA announcement. The left panel shows the path plot of Per Capita GDP for Guangdong and for synthetic Guangdong. Both paths mostly coincide before the announcement and then diverge after, with Per Capita GDP lower for Guangdong than for synthetic Guangdong. The right panel shows the difference over time, with differences clustering around zero before diverging after the announcement.

that omitting any single donor province from the synthetic control estimation does not substantially affect our results (Section 4.2).



a Guangdong vs synthetic Guangdong **b** Difference

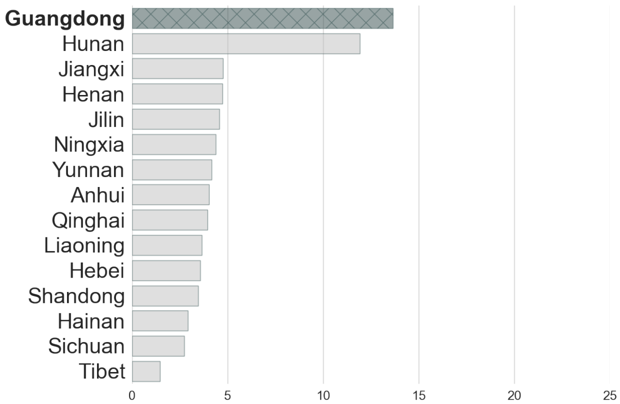
Figure 5. Per Capita GDP of Guangdong and synthetic Guangdong. Panel a shows the path plots for Guangdong vs. synthetic Guangdong (dashed gray line). Synthetic Guangdong is constructed using the synthetic control method where the synthetic counterfactual Guangdong is the weighted average of the other 30 mainland provinces, where weights are chosen such that synthetic Guangdong best resembles Guangdong in the over the 17 years in the period 2000–2016 before the 2017 GBA announcement. Panel b shows the difference over time between Guangdong and synthetic Guangdong (Equation (3)). Cumulative differences are show in Figure A9. Dashed vertical line indicates the 2017 announcement of the GBA.

4.2 Inference, robustness, and placebo tests

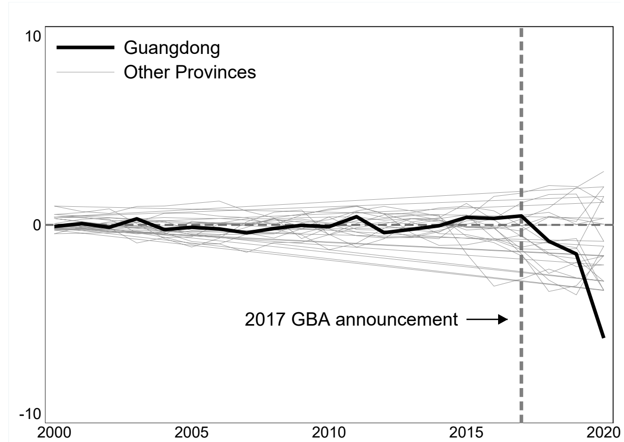
In this section, we validate our results using a series of sensitivity tests: (i) "placebo-in-place", (ii) "leave-one-out" analysis, and (iii) "placebo-in-time", as suggested by Abadie 2020. The first sensitivity analysis, placebo-in-place, also allows us to assess the extent to which the drop in Guangdong's Per Capita GDP is statistically significant.

Our main results for Per Capita GDP reported in Figure 5 are significant to the extent that the observed difference between Guangdong and synthetic Guangdong does not also manifest in the other mainland provinces. We operationalize this intuition as follows. First, we do the placebo-in-place analysis where we iterate over the other 30 mainland provinces (right panel of Figure 6). In each iteration, one of the donor provinces is the placebo-treated province, and we re-estimate the synthetic control unit for that placebo unit. The difference between the Per Capita GDP of the placebo unit and its synthetic control unit is the estimated placebo treatment effect ($\hat{\tau}_{pt}$).

The full set of placebo results, plus the original results for Guangdong, is reported



a Post-to-Pre RMSPE ratio



b Permutation-based differences

Figure 6. Permutation-based inference for Per Capita GDP. Left panel shows the distribution of the RMPSE (root mean square prediction error), with the full list in Table 2. Shaded bar is Guangdong. Right panel shows the synthetic control method results by using each of the other 30 mainland provinces in turn as the placebo in gray. The original synthetic control method result for Guangdong from Figure 5 in black. Dashed vertical line indicates the 2017 announcement of the GBA. Both panels retain only mainland provinces with good pre-period fit quality (RMPSE less than the median) for better resolution.

in Table 2. Column 4 reports the post-2017 GBA announcement's root mean square prediction error (RMSPE). The post-period RMSPE value is large if the difference between actual and synthetic is large, as defined in Equation (3).

We then derive the exact p-value using the distribution of estimated placebo effects, where the p-value for Guangdong is based on how extreme the estimated effect (the post-period RMSPE) for Guangdong is compared to the 30 other placebo units:

$$\text{p-value} = \Pr\left(\left|\bar{\hat{\tau}}_{pt}\right| \geq \left|\bar{\hat{\tau}}_{Gt}\right|\right),$$

where p is one of the 30 donor provinces, $\bar{\hat{\tau}}_{Gt}$ is the mean of the estimated post-period RMSPE for Guangdong, and $\bar{\hat{\tau}}_{pt}$ is the mean of the estimated post-period RMSPE for a donor province j that is not Guangdong.[8]

Given the distribution of post-period RMSPE for Guangdong and the 30 mainland

[8] Corresponding to Equation (3),

$$\bar{\hat{\tau}}_{Gt} = \frac{\sum_{t=2018}^{2020}\left(Y_{Gt} - \hat{Y}_{Gt}\right)}{3}.$$

Table 2. Permutation-based inference for Per Capita GDP

Province	Type (1)	Rank (2)	P-value (3)	Pre RMSPE (4)	Post RMSPE (5)	Adjustment for fit quality using RMSPE: Post-to-Pre RMSPE (6)	Adjusted Rank (7)	Adjusted P-value (8)	Adjusted Z-score (9)
Guangdong	Treated	13	0.42	0.26	3.62	13.65	1	0.03	2.14
Hunan	Donor	15	0.48	0.26	3.04	11.92	2	0.06	1.85
Zhejiang	Donor	5	0.16	1.14	9.83	8.61	3	0.10	1.66
Tianjin	Donor	7	0.23	1.37	7.77	5.67	4	0.13	1.52
Gansu	Donor	6	0.19	1.73	8.41	4.85	5	0.16	1.40
Jiangxi	Donor	27	0.87	0.32	1.55	4.77	6	0.19	1.30
Henan	Donor	26	0.84	0.33	1.57	4.73	7	0.23	1.21
Jilin	Donor	16	0.52	0.65	2.95	4.58	8	0.26	1.13
Fujian	Donor	2	0.06	4.51	19.87	4.40	9	0.29	1.06
Ningxia	Donor	19	0.61	0.51	2.23	4.39	10	0.32	0.99
Yunnan	Donor	22	0.71	0.50	2.07	4.17	11	0.35	0.93
Anhui	Donor	28	0.90	0.30	1.21	4.04	12	0.39	0.86
Qinghai	Donor	23	0.74	0.52	2.06	3.94	13	0.42	0.81
Liaoning	Donor	20	0.65	0.61	2.22	3.65	14	0.45	0.75
Hubei	Donor	3	0.10	3.80	13.76	3.62	15	0.48	0.70
Hebei	Donor	18	0.58	0.62	2.23	3.57	16	0.52	0.65
Shandong	Donor	24	0.77	0.57	1.99	3.47	17	0.55	0.60
Beijing	Donor	4	0.13	3.24	10.08	3.12	18	0.58	0.55
Inner Mongolia	Donor	11	0.35	1.36	4.11	3.02	19	0.61	0.51
Hainan	Donor	21	0.68	0.75	2.19	2.93	20	0.65	0.46
Xinjiang	Donor	14	0.45	1.12	3.18	2.84	21	0.68	0.42
Jiangsu	Donor	1	0.03	7.25	19.92	2.75	22	0.71	0.37
Sichuan	Donor	31	1.00	0.12	0.32	2.74	23	0.74	0.33
Shanghai	Donor	8	0.26	2.95	6.90	2.34	24	0.77	0.29
Heilongjiang	Donor	12	0.39	1.67	3.89	2.33	25	0.81	0.25
Guangxi	Donor	9	0.29	2.41	5.32	2.21	26	0.84	0.20
Guizhou	Donor	10	0.32	2.39	4.67	1.96	27	0.87	0.16
Chongqing	Donor	17	0.55	1.50	2.32	1.55	28	0.90	0.12
Tibet	Donor	30	0.97	0.36	0.52	1.45	29	0.94	0.08
Shanxi	Donor	25	0.81	1.65	1.57	0.95	30	0.97	0.04
Shaanxi	Donor	29	0.94	1.43	1.09	0.76	31	1.00	0.00

Table shows the synthetic control method by using each of the 31 mainland provinces as the treated unit. Column 1 indicates that Guangdong is the main treated unit of concern. Column 2 and column 3 are the ranking and p-value based on the highest post-period RMSPE (root mean square prediction error). Column 4 and column 5 are the pre and post-period RMPSE (Equation (3)). Column 6 is the ratio of the post-to-pre RMSPE which adjusts the post-period RMSPE by the pre-period RMSPEs (see Figure 6 and Figure A8). Columns 7–9 are the ranking, p-value and the associated Z-score after the post-period RMSPE is adjusted by fit quality in the pre-period.

provinces as placebo units (column 4 of Table 2), we operationalize the p-value for

Guangdong as:[9]

$$\text{p-value}_G = \frac{1 + \sum_p^{\mathcal{P}} \mathbb{1}\left(\left|\bar{\hat{\tau}}_{pt}\right| \geq \left|\bar{\hat{\tau}}_{Gt}\right|\right)}{1 + |\mathcal{P}|}. \tag{4}$$

As reported in column 3 of Table 2, the p-value for Guangdong is 0.42, which is statistically insignificant. This finding, however, may be an artefact of the placebo units having large post-period RMSPE, as well as large pre-period RMPSE, because of poor fit quality in the estimation stage (Equation (2) and Equation (1)). Hence, and as recommended by Abadie 2020, we scale the post-period RMSPE by the inverse of the pre-period RMSPE before computing the adjusted p-values:

$$\text{adjusted p-value}_G = \frac{1 + \sum_p^{\mathcal{P}} \mathbb{1}\left(\left|\bar{\hat{r}}_{pt}\right| \geq \left|\bar{\hat{r}}_{Gt}\right|\right)}{1 + |\mathcal{P}|}, \tag{5}$$

where the $\bar{\hat{r}}$'s are the ratio of the post-period RMSPE (column 6 in Table 2).[10]

Based on the adjusted p-value, which accounts for the fit quality, the drop in the Per Capita GDP of Guangdong is now statistically significant at the 5 per cent level, as reported in column 5 of Table 2.

This finding confirms that the dip in Guangdong's Per Capita GDP coinciding with the 2017 GBA announcement is unusual compared to China's other mainland provinces. We also report the ratio in the post-to-pre periods RMSPE in the left panel of Figure 6, which shows that the adjusted post-period deviation in actual and predicted Per Capita GDP is largest for Guangdong.

We further perform four additional sets of sensitivity tests. First, we perform a

[9] The p-value for the 30 mainland provinces as placebo units are computed in a similar way by swapping out the G subscript:

$$\text{p-value}_i = \frac{1 + \sum_{j \neq i}^{\mathcal{J}} \mathbb{1}\left(\left|\bar{\hat{\tau}}_{jt}\right| \geq \left|\bar{\hat{\tau}}_{it}\right|\right)}{1 + |\mathcal{J}|}.$$

where $\mathcal{J}$ is the set of all 31 mainland provinces including Guangdong.

[10] The RMPSE ratio (column 6 of Table 2) is computed as:

$$\bar{\hat{r}}_{jt} = \frac{\bar{\hat{\tau}}_{jt}}{\sum_{t=2020}^{2017} \left(Y_{jt} - \hat{Y}_{jt}\right)}.$$

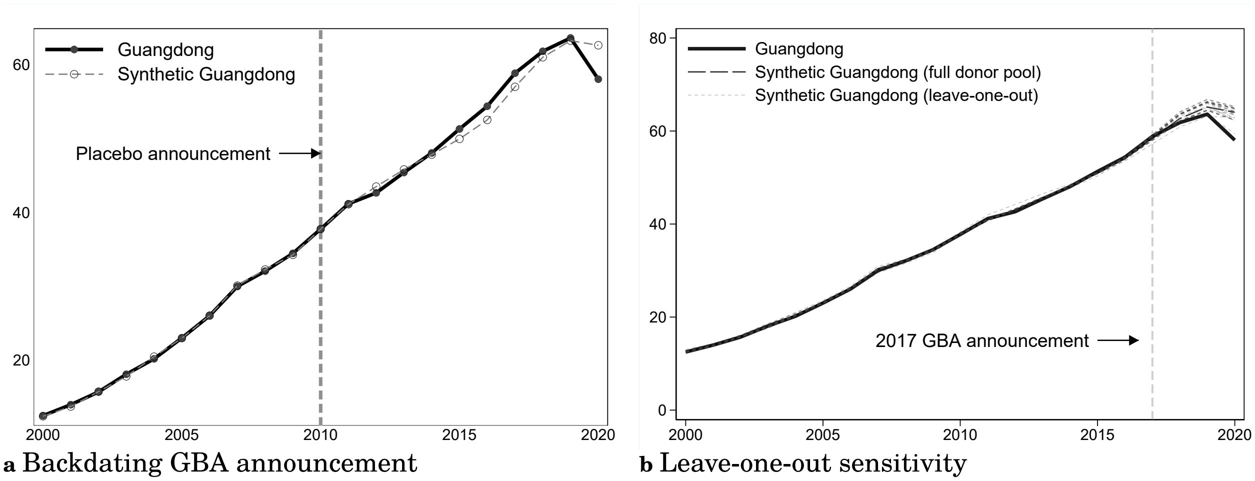


Figure 7. Sensitivity of results for Per Capita GDP. Left panel repeats the synthetic control method to estimate Per Capita GDP for synthetic Guangdong but with the GBA announcement backdated to 2010. Right panel shows the results from a leave-one-out synthetic control estimation where in each of 30 iterations one of the donor provinces is taken out of the donor pool before estimation. Dashed vertical line indicates the 2017 announcement of the GBA.

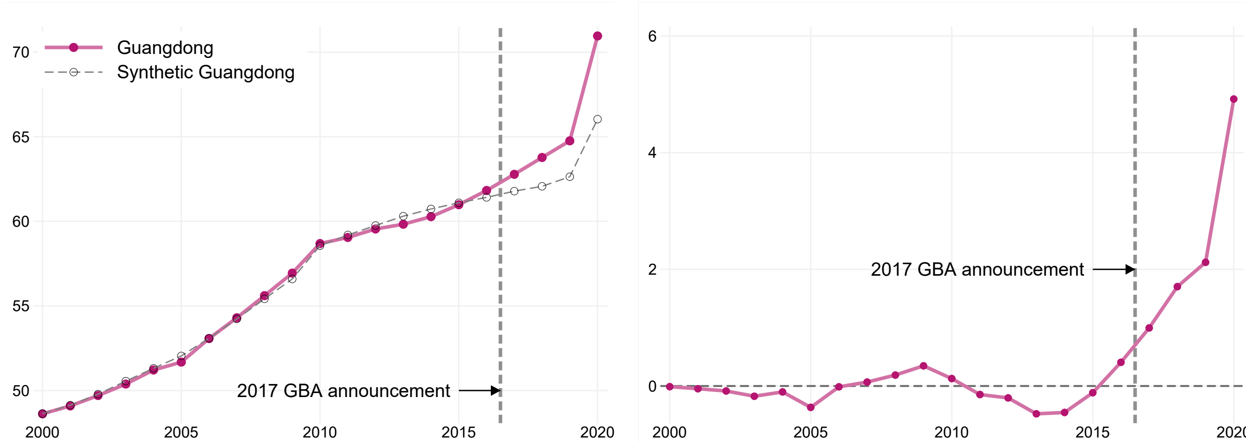
leave-one-out analysis where we repeat the synthetic control estimation for Guangdong over 30 iterations. Each iteration drops one of the 30 mainland provinces as a donor province before estimating the path of Per Capita GDP for synthetic Guangdong in the synthetic control estimation. The right panel of Figure 7 reports results from the leave-one-out analysis, with the dotted lines showing the Per Capita GDP of synthetic Guangdong where donor provinces are iteratively dropped from the donor pool. Suppose the exclusion of certain donor provinces has a large effect on the path of the estimated synthetic Guangdong. In that case, idiosyncratic macroeconomic shocks or other interventions related to the donor provinces may lead to an artificially large estimated effect in our synthetic control estimation. We find that this is not the case. The Per Capita GDP of the synthetic Guangdong's from the leave-one-out are still able to track Guangdong before 2017 and is higher than Guangdong after the 2017 announcement, especially in the final period in our sample, showing that the main estimated effect of the announcement is robust to the set of donor provinces.[11]

As the second test of sensitivity, we perform a placebo-in-time analysis where we

[11]Iterations that fail to converge are omitted from the right panel of Figure 7.

backdate the 2017 GBA announcement to 2010 before repeating the synthetic control estimation with the year 2010 as the placebo GBA announcement year. The left panel of Figure 7 reports the results from our placebo-in-time analysis and yields three observations. First, synthetic Guangdong estimated using only the period 2000–2010 still closely follows Per Capita GDP of Guangdong, both before and after 2010, where the sample ends for the estimation of the variable and synthetic control weights. Second, the gap in Per Capita GDP between Guangdong and synthetic Guangdong still appears after the 2017 announcement and is most distinct in the final year of our sample period, even when the synthetic control estimation procedure no longer has information on the 2017 announcement date. Finally, the absence of a gap in Per Capita GDP between Guangdong and synthetic Guangdong before 2017, even when the synthetic control estimation does not enforce a match, mitigates concerns of anticipatory effects.

Third, we extend the set of predictor variables with five additional variables: (i) illiteracy rate (percentage of population aged 15 and above), (ii) tertiary institutions (percentage of institutions), (iii) tourist arrivals (normalized by GDP), (iv) realized foreign direct investments (excluding regional investment and normalized by GDP), and (v) realized investments (normalized by GDP). We then re-estimate the synthetic control unit for both Guangdong and the 30 other mainland provinces to obtain the adjusted p-value for Guangdong, which turns out to be unchanged (Figure A10). Guangdong's Per Capita GDP after the announcement, as measured by the adjusted post-RMSPE, is still unusually low relative to the other provinces. Finally, we repeat the synthetic control estimation with a lower threshold margin for constraint violation in the constrained quadratic optimization, and the conclusions are similar (Figure A11).



a Guangdong vs synthetic Guangdong **b** Difference

Figure 8. Population density of Guangdong and synthetic Guangdong. Panel a shows the path plots for Guangdong vs. synthetic Guangdong (dashed gray line). Synthetic Guangdong is constructed using the synthetic control method where the synthetic counterfactual Guangdong is the weighted average of the other 30 mainland provinces, where weights are chosen such that synthetic Guangdong best resembles Guangdong in the over the 17 years in the period 2000–2016 before the 2017 GBA announcement. Panel b shows the difference over time between Guangdong and synthetic Guangdong (Equation (3)). Dashed vertical line indicates the 2017 announcement of the GBA.

5 Potential Effect on Population Density

5.1 Results

This section shows that the increase in population density can explain the decline in Per Capita GDP for Guangdong.

We repeat the synthetic control method described in Section 2 and Section 4, this time with Population density as the outcome variable. The set of predictor variables and the pre-intervention estimation period are otherwise the same. Figure 8 the main results and the Supplementary Materials reports the full set of estimation results. Panel a of Figure 8 shows that the Population density of synthetic Guangdong tracks the Population density of Guangdong well until 2017 before diverging. More specifically, panel b of Figure 8 suggests that, before the announcement, the difference between Guangdong and synthetic Guangdong is zero. After the announcement, the graph shows an upward trend.

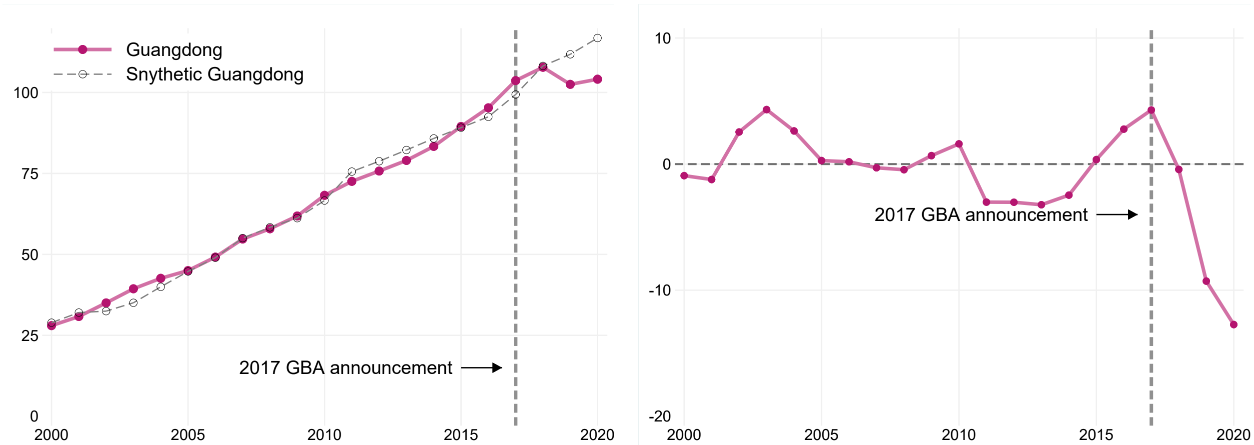
The synthetic control results confirm Guangdong's population density increased after the 2017 GBA announcement. Further, we find quantitative evidence that the increase in Guangdong's population density coincides with the GBA announcement in a way that is not reflected in the other mainland provinces.

5.2 Inference, robustness, and placebo tests

Similar to Section 4.2, we validate our results for the drastic increase in Guangdong's Population density. First, we do the placebo-in-place analysis (reported in Table A4 and Figures A16 to A17). Here, we find that Guangdong indeed had a population growth that is different from the rest of the mainland provinces. In particular, the sharp increase in Guangdong's population can be observed in 2019 (Figure 2 and Figure A16).

Second, we perform a leave-one-out analysis and get similar results (Figure A15). Third, we perform the placebo-in-time analysis which shows that even when we backdate the GBA announcement to 2010, and the estimation has no information on when the GBA announcement happened, a divergence still occurs after 2017. Fourth, we extend the set of predictors to the same five additional variables in Section 4.2 and get same results for Guangdong's Population density (Figure A18). Finally, we lower the threshold margin for constraint violation in the synthetic control estimation and get similar findings (Figure A19).

Overall, we find that the conclusion of a sharp increase in Guangdong's Population density leading to a recorded drop in Per Capita GDP using the synthetic control estimation is robust to a variety of sensitivity and placebo tests.



a Guangdong vs synthetic Guangdong **b** Difference

Figure 9. Labor Productivity of Guangdong and synthetic Guangdong. Panel a shows the path plots for Guangdong vs. synthetic Guangdong (dashed gray line). Synthetic Guangdong is constructed using the synthetic control method where the synthetic counterfactual Guangdong is the weighted average of the other 30 mainland provinces, where weights are chosen such that synthetic Guangdong best resembles Guangdong in the over the 17 years in the period 2000–2016 before the 2017 GBA announcement. Panel b shows the difference over time between Guangdong and synthetic Guangdong (Equation (3)). Dashed vertical line indicates the 2017 announcement of the GBA.

6 Discussion

6.1 Labor Productivity

Since we find a decline in Guangdong's Per Capita GDP and that the rise in population growth for Guangdong is a key contributing factor, a natural question is whether we would find similar changes in productivity. We use GDP in 1m yuan per 1,000 workers to track the productivity of the provinces. Repeating the same synthetic control estimation in Sections 4 to 5, we focus on Guangdong's productivity and examine how it changes after the 2017 GBA announcement.

Figure 9 shows a decline in Guangdong's productivity relative to trend in productivity for synthetic Guangdong after 2018. This decline, at least in our sample period ending 2020, is persistent, as shown in the right panel of Figure 9. From our permutation-based inference, we again confirm that this decline in productivity is unusual compared to the other provinces.[12]

[12] All other provinces with larger deviations from their counterfactual have an increase instead of a decrease in productivity (Table A6). Hence, for provinces with a decline in productivity, Guangdong is

The decline in productivity may be attributed to the significant rise in employment in relatively lower productivity sectors, such as construction, wholesale, and retail.[13] Based on the National Bureau of Statistics, the number of workers in these two sectors has increased from 15.4 million in 2015 to 23.1 million in 2019.[14] On the other hand, even though the employment in the ICT and finance sector has doubled (from 0.8 million to 1.7 million) during the same period, the lower employment level could not bring a significant increase in the overall productivity. We focus on the talent attraction policies in the next discussion section.

6.2 Population and Talent Attraction in the GBA

Our results above suggest that the decline, and the timing of the decline, in Guangdong's Per Capita GDP can be attributable to an unusually large increase in Guangdong's population (Figure 5 and Figure 8).

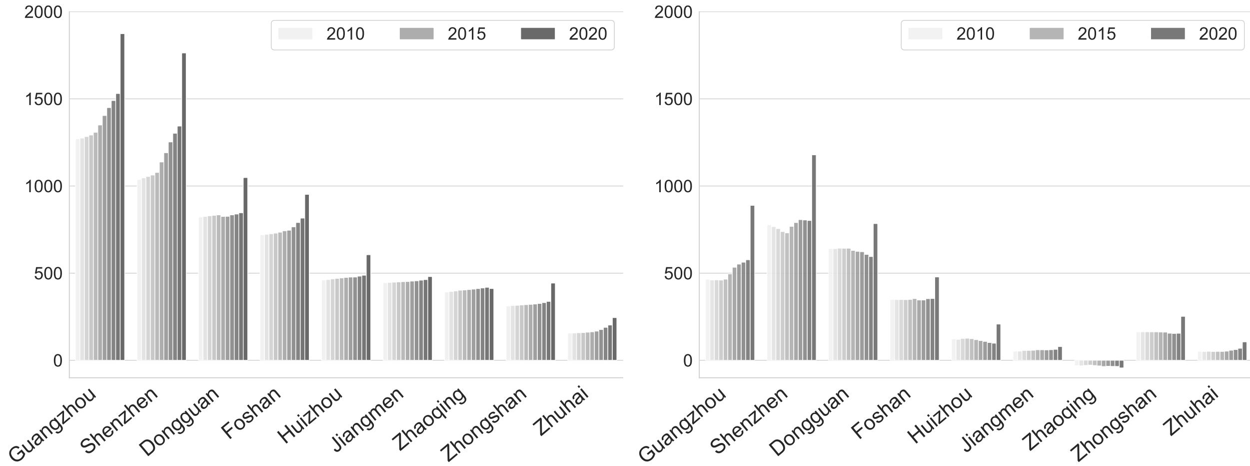
Figure 10 shows the city-level population data for the nine Pearl River Delta cities in Guangdong. Many of these cities experience a distinct jump in population corresponding to Guangdong's province-wide population jump 2019–2020.[15] In particular, Guangzhou, Shenzhen, Dongguan, Foshan, Huizhou, and Zhongshan all have a jump in population from 2010–2020, which suggests structural changes (e.g., Lee and Lin 2020). These jumps in the population likely relate, at least partially, to labour inflow since Guangdong and the nine Pearl River Delta cities all have policies related to tal-

the one with the largest decline relative to the counterfactual. This is best seen in Figure A24 of the Supplementary Materials which traces out the pre- and post-period difference for each province and its synthetic control unit.

[13]According to the Fourteenth Five Year Plan of Guangdong Province Construction Sector (2021), the productivity level of the construction sector in 2020 is around RMB 500,000 per capita, lower than that of Hubei Province, Shanghai and Beijing (see http://zfcxjst.gd.gov.cn/attachment/0/425/425095/3309876.pdf.)

[14]The employment number includes urban employed persons, employed persons in urban private enterprises, and self-employed individuals in urban areas.

[15]Total population includes all the people who live in the city for more than six months. The residential population includes people with Hukou registered in the city. Thus, the population without residence registration does not equal to the migrant population. But we can use it as a proxy for a city's population inflow.



a Total population   **b** Population without residence registration

Figure 10. Population ('0,000) in Pearl River Delta cities (2010–2020). City population without residence registration is the total number of population minus the population with residence registration by year-end. The last bar for each city is for the year 2020.

ent recruitment for the GBA. Below, we walk through some key talent recruitment policies of the GBA.

One key policy can be traced back to 2017 when the Guangdong government issued the Opinions on Deepening the Reform of the Institutional Mechanism for Talent Development which aims to establish a globally competitive talent system. It includes 16 entry policies for foreign talents, raising the R&D expenditure for firms, and promoting entrepreneurship for science and technology start-ups. The government provides housing subsidies up to RMB 3.5 million, RMB 2.5 million, and RMB 1.5 million, respectively, for top talents, leading national talents, and leading provincial talents.[16] On 1st January 2019, The Regulations of the Guangdong Talent Development took effect, which covered talent training and development, talent attraction, talent evaluation and incentivisation, and talent services and guarantees.[17]

There are three sources for talents: 1) other Mainland China provinces, 2) two SARs – Hong Kong and Macau, and 3) abroad. The relaxation of *hukou* or house-

[16] Guangdong issued the implementation of the reform of the talent development system mechanism. See http://www.gd.gov.cn/zwgk/zcjd/snzcsd/content/post_76542.html.

[17] See Guangdong Provincial Talent Development Regulations athttp://gdstc.gd.gov.cn/kjzx_n/gdkj_n/content/post_2696003.html.

hold registration status policy is the major initiative to recruit talents from the other provinces. The benefits of residence (i.e. with local hukou) include healthcare, education for children, and permit to purchase houses. Take Guangzhou, the capital city, as an example. In 2017, people with bachelor's degrees needed to continuously contribute to social insurance for at least one year, whereas the requirement was reduced to six months in 2019. This requirement is also removed for people with a master's degree and above in 2019.[18] Moreover, starting from 2020, talents with bachelor's degrees from "Double First-Class" universities can get their hukou once they start paying for social insurance.[19]

For foreign talents, Guangdong issued two Excellent Talent cards (Excellent Talent Card A and Excellent Talent Card B) to attract workers from overseas to work in Guangdong. Both types of cardholders will enjoy housing guarantees, education for children, social insurance, healthcare, long period of stay and multiple entries. They will have advantages in applying for China's permanent residence. To qualify for the Guangdong Excellent Talent Card A, one has to have received prestigious scientific awards and prizes in academia, be a senior executive of Fortune Global 500 companies, etc. To qualify for Talent Card B, one has to be selected for the National "Thousand Talents Plan" or be a post-doctoral from a top 200 university worldwide etc.[20] Moreover, starting from 2019, foreign talents working in the Greater Bay Area will receive a certain amount of income tax subsidy from the local government.[21]

For Hong Kong and Macao residents, in addition to all the preferential policies for the foreign talents, they also benefit from policies that give preferential treatment

[18] See http://www.gz.gov.cn/zwgk/zcjd/zcjd/content/post_2854375.html.

[19] See the Notice of Human Resources and Social Security Bureau of Guangzhou on relaxing the social insurance eligibility period for talents with bachelor's degrees from "Double First-class" universities at http://rsj.gz.gov.cn/ywzt/rcgz/rcyjrh/tzgg/content/post_6993948.html.

[20] See Notice of the People's Government of Guangdong Province on Implementation Measures of Guangdong Excellent Talent Card at http://hrss.zs.gov.cn/zcfg/pxjy/content/post_1382027.html.

[21] See Notice on The Implementation of The Individual Income Tax Preferential Policies in the Guangdong-Hong Kong-Macao Greater Bay Area at http://czt.gd.gov.cn/czfg/content/post_2519383.html?from=groupmessage&isappinstalled=0.

relating to law, healthcare and tourism in 2019.[22] Furthermore, the nine Pearl River Delta cities also have plans to set up specific youth innovation entrepreneurship bases to attract younger individuals from Hong Kong and Macao.[23] From 2021, the start-ups in these bases will be provided with rental subsidies of up to 6,000 RMB per year for up to 3 years and a one-time start-up subsidy of 10,000 RMB. Eligible young people from Hong Kong and Macao can apply for up to 5 million yuan loans and get discounted interest rates.[24]

While we scan a range of GBA policies in Guangdong that potentially explain the influx of population in Guangdong, we believe that most of these account for only a small proportion of Guangdong's growth in population. Our conjecture is that, while the GBA has plans and policies for foreign talent growth, most of the Guangdong's population growth still originates from the other mainland provinces. The fall in population in certain provinces in the same year where we observe Guangdong population spike (see the Provincial Population section in the Supplementary Materials)lends credence to our conjecture.

7 Conclusion

We conduct a quantitative case study of Guangdong as the epicentre of the newly developed GBA in China. Our results suggest that Guangdong's economic performance has declined since the 2017 GBA announcement in a way that is unusual compared to the other mainland provinces. In particular, we trace the decline of Guangdong's Per Capita GDP to an influx in population that is potentially related to population

[22]See http://hrss.gd.gov.cn/zwgk/gsgg/content/post_2711821.html.

[23]See Implementation Plan on Strengthening the Construction of Youth Innovation and Entrepreneurship Bases for Hong Kong and Macao Young Talents at http://www.gd.gov.cn/zwgk/wjk/qbwj/yfh/content/post_2469478.html.

[24]See Opinions on promoting high-quality development of Youth Innovation and Entrepreneurship Bases for Hong Kong and Macao Young Talents at https://www.cnbayarea.org.cn/policy/policy%20release/policies/content/post_319721.html.

and talent attraction policies in the GBA. The likely explanation is that most of the population in Guangdong comes from the other mainland provinces.

While the relation between Per Capita GDP and its dependence on population seems obvious, the value of the synthetic control method we use allows us to draw inference and conclude that the changes in Guangdong's Per Capita GDP and population are unusually large compared to its counterfactual and to the rest of the China economy. Overall, our results are only short-run and suggest that more obvious economic gains for the Guangdong-Hong Kong-Macao Greater Bay Area may come only later once the compositional change in population has reached equilibrium and the new population is assimilated into the economy.

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Supplementary Materials for “Income and Productivity Trends of Guangdong: A Data-Driven Case Study of the Greater Bay Area” (Jingwei Li, Lucas Shen, Xuyao Zhang, June 2022)

Table of Contents

A. Data Description and Population Data Source

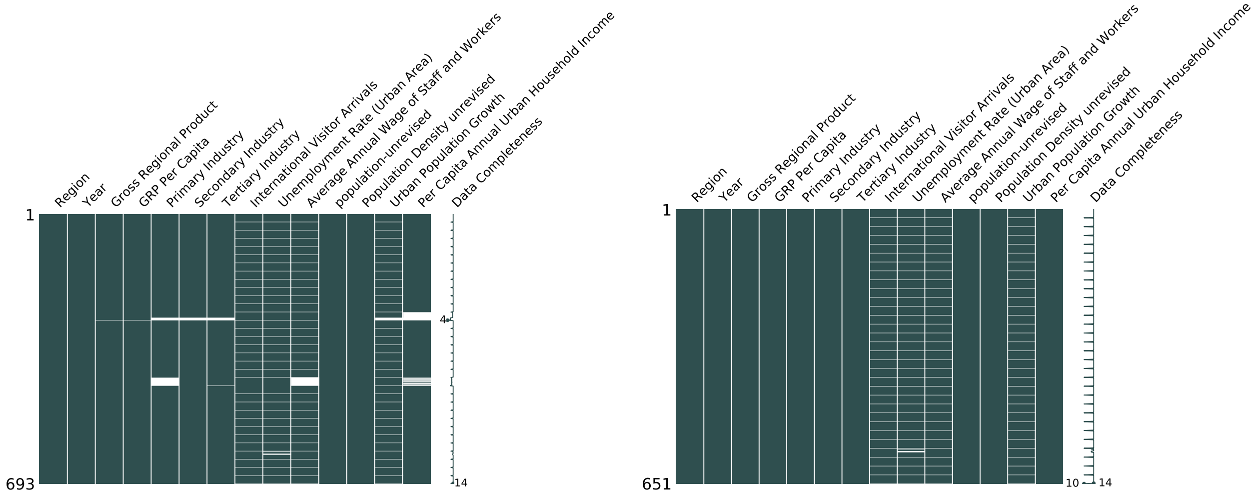
Table A1. Notes on annual province population data

Year	Type	Source	Additional/miscellaneous notes
2000	Decennial census	NBS accessed on 21 Dec 2021	—
2001	Revised	NBS accessed on 21 Dec 2021	—
2002	Revised	NBS accessed on 21 Dec 2021	—
2003	Revised	NBS accessed on 21 Dec 2021	—
2004	Revised	NBS accessed on 21 Dec 2021	—
2005	Revised	NBS accessed on 21 Dec 2021	—
2006	Revised	NBS accessed on 21 Dec 2021	—
2007	Revised	NBS accessed on 21 Dec 2021	—
2008	Revised	NBS accessed on 21 Dec 2021	—
2009	Revised	NBS accessed on 21 Dec 2021	—
2010	Decennial census	NBS accessed on 21 Dec 2021	—
2011	Unrevised	Yearbook 2012	Hunan’s data is from yearbook2021
2012	Unrevised	Yearbook 2013	Hunan’s data is from yearbook2021
2013	Unrevised	Yearbook 2014	Hunan’s data is from yearbook2021
2014	Unrevised	Yearbook 2015	Hunan’s data is from yearbook2021
2015	Unrevised	Yearbook 2016	Hunan’s data is from yearbook2021
2016	Unrevised	Yearbook 2017	Hunan’s data is from yearbook2021
2017	Unrevised	Yearbook 2018	Hunan’s data is from yearbook2021
2018	Unrevised	Yearbook 2019	Hunan’s data is from yearbook2021
2019	Unrevised	Yearbook 2020	Hunan’s data is from yearbook2021; Hebei Yearbook2020 hasn’t release, the data is from NBS accessed on 4 Oct 2021
2020	Decennial census	NBS accessed on 14 Dec 2021	

NBS refers to the National Bureau of Statistics of China.

Table A2. Data description and summary

Variable	Description	N	Mean	Std. Dev.	Min.	Max.
Primary industry	Primary industry value over GDP (both in Yuan, Constant Prices at 2000)	651	0.12	0.07	0.00	0.36
Secondary industry	Secondary industry value over GDP (both in Yuan, Constant Prices at 2000)	651	0.46	0.12	0.16	0.85
Tertiary industry	Tertiary industry value over GDP (both in Yuan, Constant Prices at 2000)	651	0.46	0.09	0.29	0.88
Household income per capita	Per Capita Annual Urban Household Income (Yuan, Constant Prices at 2000)	651	16,053.16	8,217.72	4,745.27	51,682.00
Visitors	International visitor arrivals (person-times) over GDP (Yuan, Constant Prices at 2000)	620	0.01	0.01	0.00	0.12
Unemployment rate	Unemployment rate in urban areas (Percentage)	616	3.50	0.72	0.80	6.50
Annual wage	Average Annual Wage of Staff and Workers (Yuan, Constant Prices at 2000)	620	29,552.82	17,224.01	6,918.00	115,966.00
Illiteracy rate	Population aged 15 and above who are illiterate (Percentage)	619	8.29	7.31	1.23	54.86
Tertiary institutions	Tertiary institutions out of total institutions (Percentage)	620	0.99	1.04	0.06	5.44
Tourist arrivals	Regional tourist arrivals (person-times) over GDP (Yuan, Constant Prices at 2000)	583	1.80	1.20	0.03	10.54
FDI	Realized foreign direct investment (excl. regional investment) over GDP (both in Yuan, Constant Prices at 2000)	523	0.04	0.04	0.00	0.26
Investments	Realized Regional Investment over GDP (both in Yuan, Constant Prices at 2000)	492	1.30	0.63	0.42	7.72
Per Capita GDP	GDP (Yuan, Constant Prices at 2000) over population at year-end	651	25.60	19.10	2.74	114.40
Population density	Persons per Square kilometer	651	42.47	62.38	0.21	394.92
Productivity (labour)	GDP (Yuan, Constant Prices at 2000) over employment at year-end	648	46.15	33.19	5.03	195.97



a 31 mainland provinces + Hong Kong + Macau **b** 31 mainland provinces

Figure A1. Province-year panel completeness. Each row is a province-year observation and each column is a variable. Holes indicate missing data.

B. Supplementary Notes on Guangdong and the GBA

In 2017, the Framework Agreement on Deepening Guangdong-Hong Kong-Macao Cooperation in the Development of the Bay Area (GBA) was signed, prioritizing the cooperation in infrastructure connectivity, market integration, technology and innovation within the region. In 2019, the Outline Development Plan for the Guangdong-Hong Kong-Macao Greater Bay Area was further officially announced, mapping out the whole development plan for the GBA. The Outline sets two stages of objectives for 2022 and 2035.

Overall, the GBA aims to build on the economic potential of the Pearl River Delta (PRD) region, which includes the nine Guangdong municipalities: Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Zhongshan, Jiangmen, Zhaoqin, and Huizhou. Since the 1990s, the PRD municipalities have been a leader in China's regional integration and economic development. The GBA, which includes the nine PRD municipalities in Guangdong together with Hong Kong and Macao, aims to become an international innovation hub. This region will leverage on the existing developments in Guangdong, which has attracted leading science and technology enterprises, such as Tencent and

Huawei, and abundant talents to boost its R&D capacity. Several platforms and innovation parks have also been established, including the Nansha Guangdong-Hong Kong Cooperation Park, Sino-Singapore Guangzhou Knowledge City, Artificial Intelligence and Digital Economy Pilot Zone in Guangzhou, Dongguan Binghaiwan Bay Area, Sanlong Bay High-end innovation Cluster Zone in Foshan, and Zhaoqing New Town (http://dfz.gd.gov.cn/sqyl/gmjj/content/post_3266899.html).

While Guangdong is geographically larger than these nine municipalities, in our main analyses (Sections 4 to 6.1), we focus on the Guangdong as the unit of intervention. This approach is because while Guangdong has 21 municipalities, the nine PRD municipalities collectively contribute 80.5% of GDP in the Guangdong province and include 62.0% of the provincial population (based on 2020 data from Guangdong Statistical Yearbook). Moreover, given that one key pillar of the GBA is innovation, six out of nine PRD municipalities cities—Guangzhou, Shenzhen, Dongguan, Huizhou, Zhuhai, and Zhongshan—took up 75.5% of the number of patents certified in Guangdong in 2020. Hence, whatever gain in economic benefits from the developement of the GBA should be reflected in the that of the Guangdong province.

We do not focus on the Hong Kong and Macao Special Administrative Regions in our analyses because (i) they have their own economic system, (ii) including the two Special Administrative Regions to Guangdong will likely inflate measures of economic performance for Guangdong and make it less likely that we have a convex combination in the synthetic control estimation, (iii) the two Special Administrative Regions are part of the intervened regions and should not be included in the donor pool when the unit of intervention for the GBA is Guangdong, and (iv) the two Special Administrative Regions have poorer data completeness (Figure A1). However, including the Hong Kong and Macao Special Administrative Regions in the donor do not affect the eventual optimal weights (untabulated).

C. Provincial Population

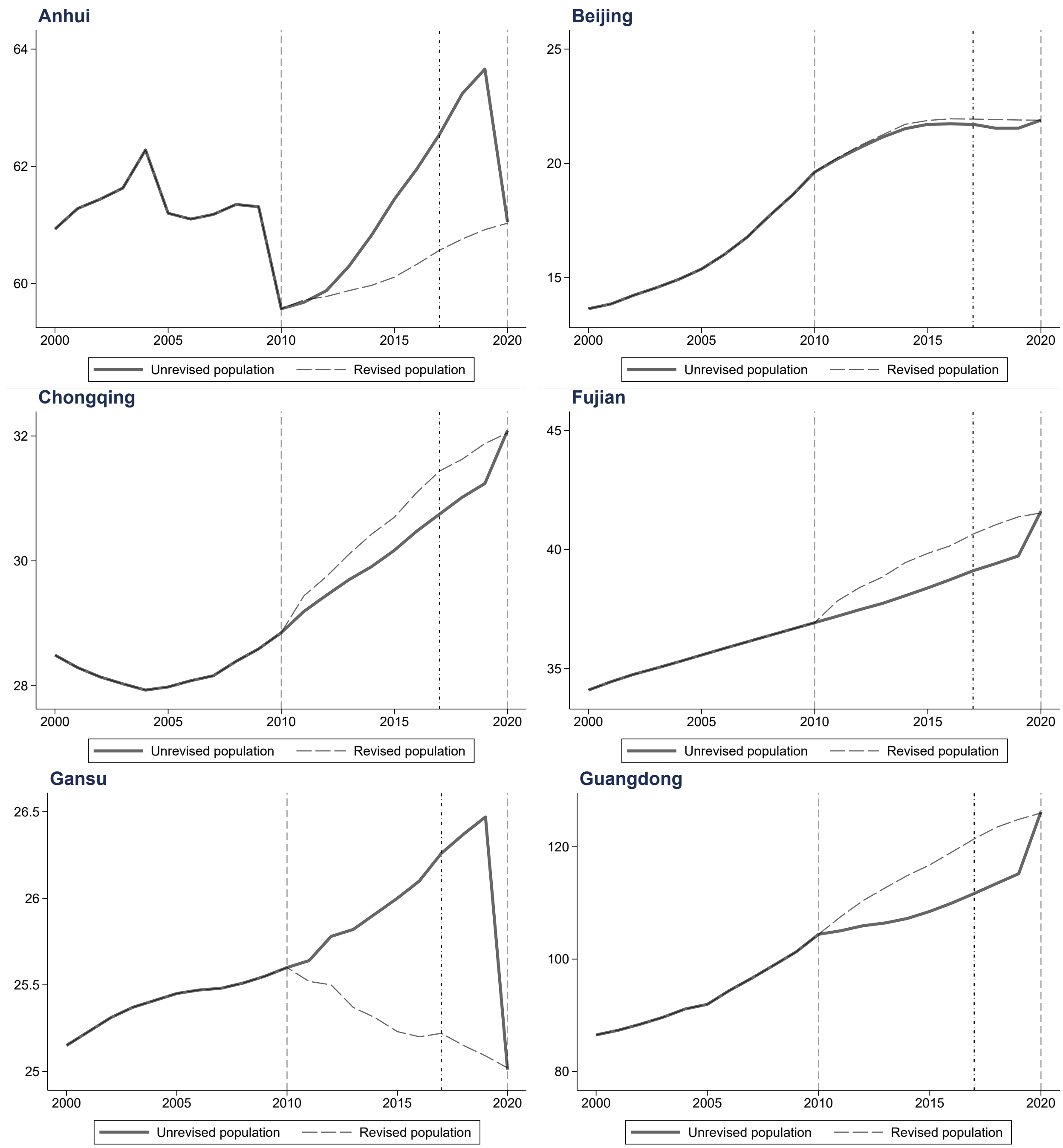


Figure A2. Population path plots for selected provinces [Part 1]. Unrevised and revised population plotted are the raw data from the panel for the period 2000–2020. Dashed vertical lines are for the years 2010 and 2020 which are the end points for the (revised) census population smoothing. Dashed-dotted line is the 2017 GBA announcement.

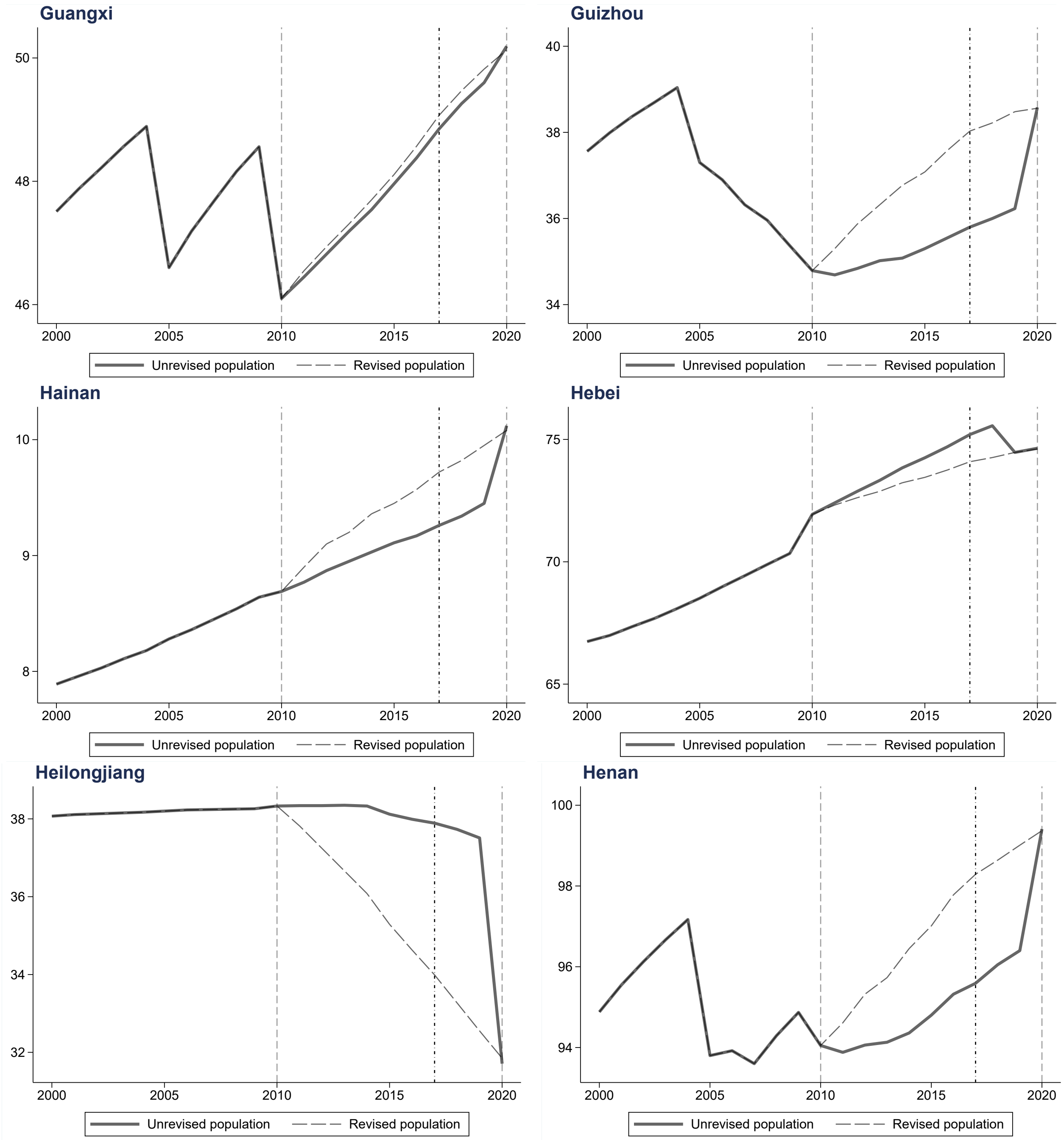


Figure A3. Population path plots for selected provinces [Part 2]. Unrevised and revised population plotted are the raw data from the panel for the period 2000–2020. Dashed vertical lines are for the years 2010 and 2020 which are the end points for the (revised) census population smoothing. Dashed-dotted line is the 2017 GBA announcement.

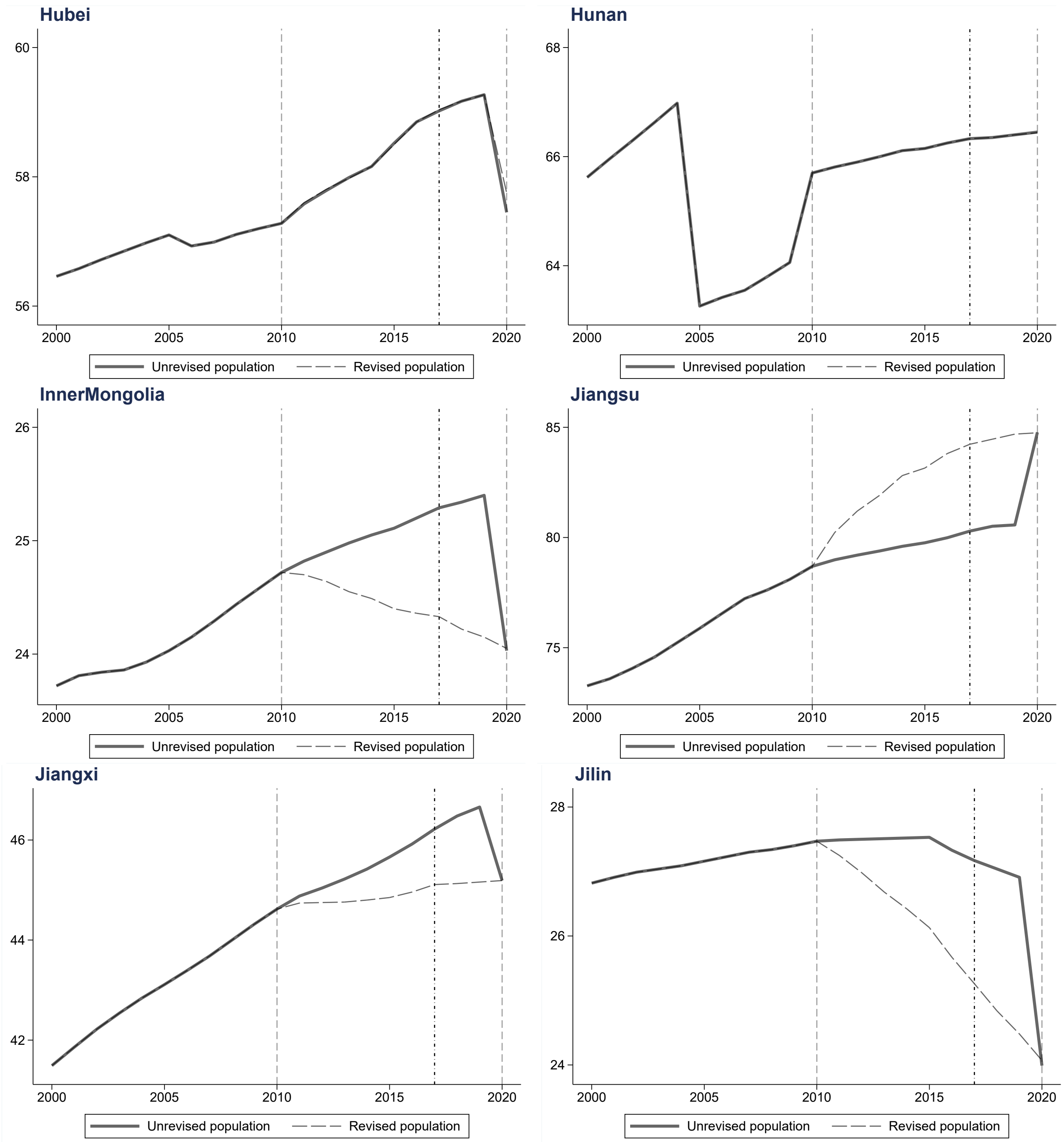


Figure A4. Population path plots for selected provinces [Part 3]. Unrevised and revised population plotted are the raw data from the panel for the period 2000–2020. Dashed vertical lines are for the years 2010 and 2020 which are the end points for the (revised) census population smoothing. Dashed-dotted line is the 2017 GBA announcement.

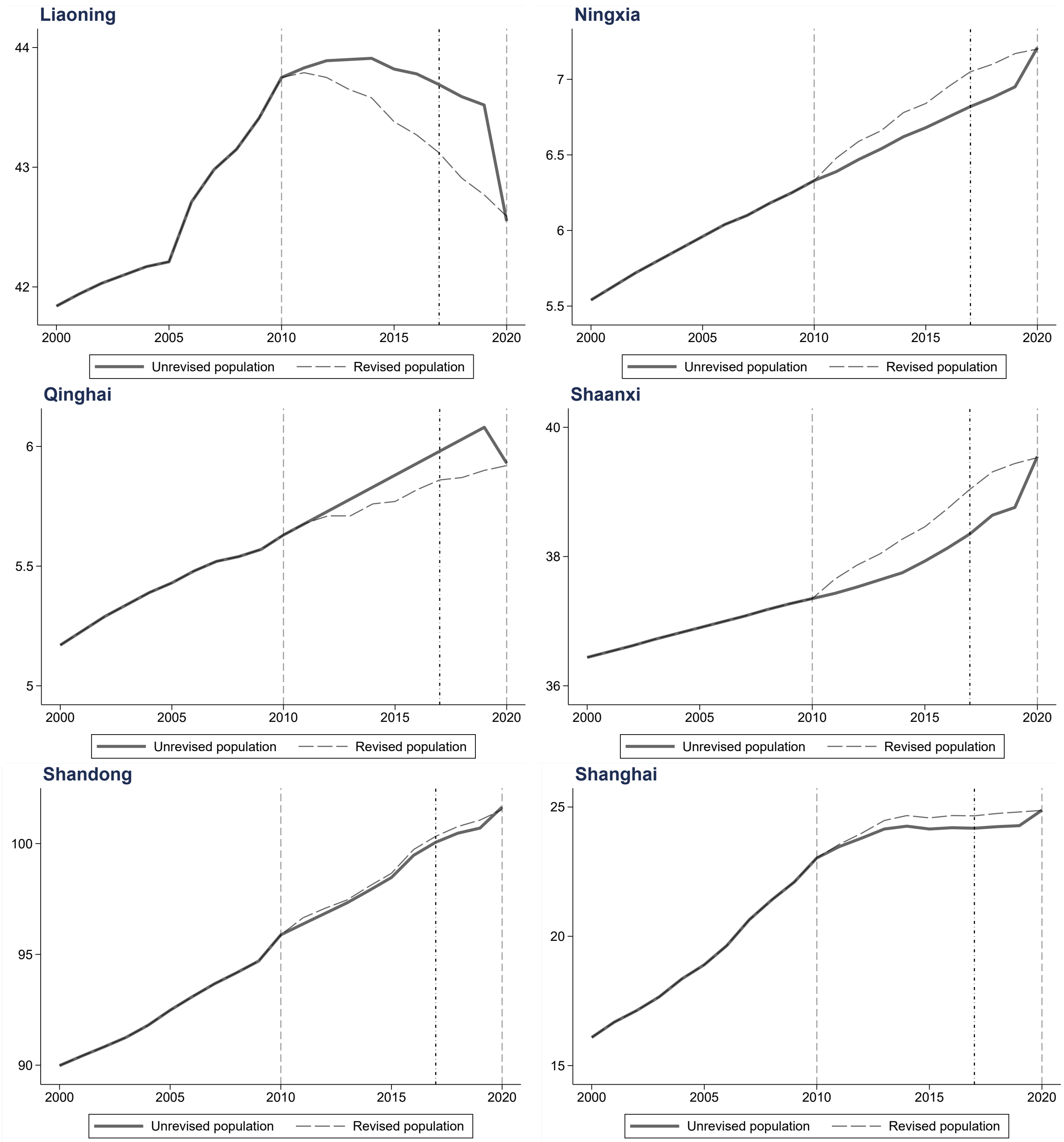


Figure A5. Population path plots for selected provinces [Part 4]. Unrevised and revised population plotted are the raw data from the panel for the period 2000–2020. Dashed vertical lines are for the years 2010 and 2020 which are the end points for the (revised) census population smoothing. Dashed-dotted line is the 2017 GBA announcement.

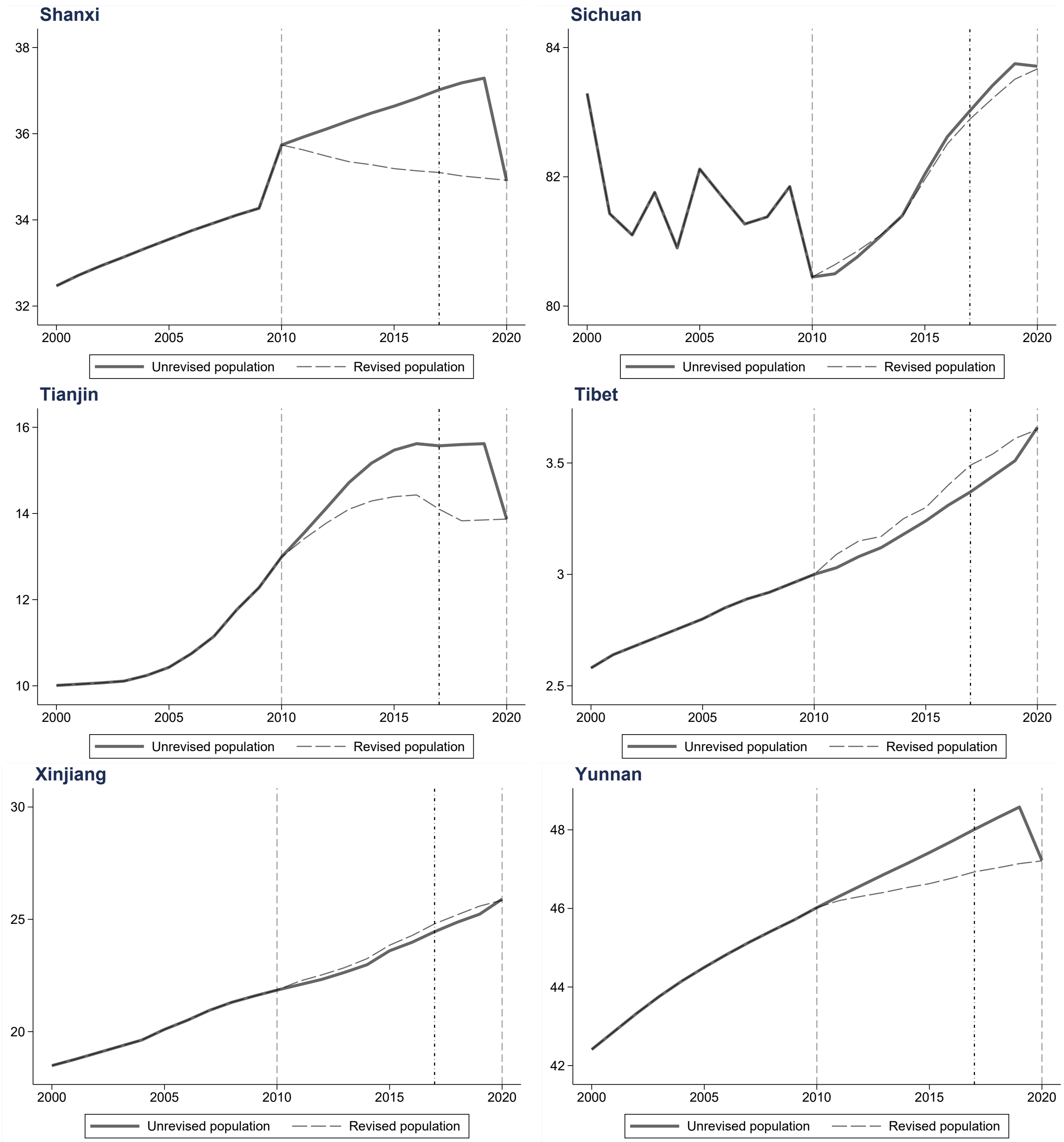


Figure A6. Population path plots for selected provinces [Part 5]. Unrevised and revised population plotted are the raw data from the panel for the period 2000–2020. Dashed vertical lines are for the years 2010 and 2020 which are the end points for the (revised) census population smoothing. Dashed-dotted line is the 2017 GBA announcement.

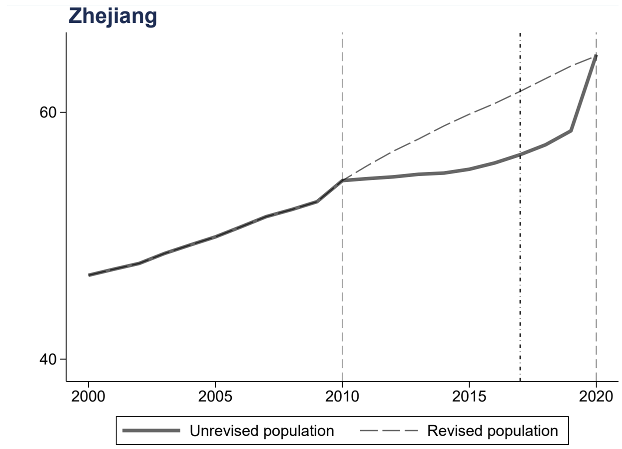


Figure A7. Population path plots for selected provinces [Part 6]. Unrevised and revised population plotted are the raw data from the panel for the period 2000–2020. Dashed vertical lines are for the years 2010 and 2020 which are the end points for the (revised) census population smoothing. Dashed-dotted line is the 2017 GBA announcement.

D. Additional Tables and Figures for Per Capita GDP

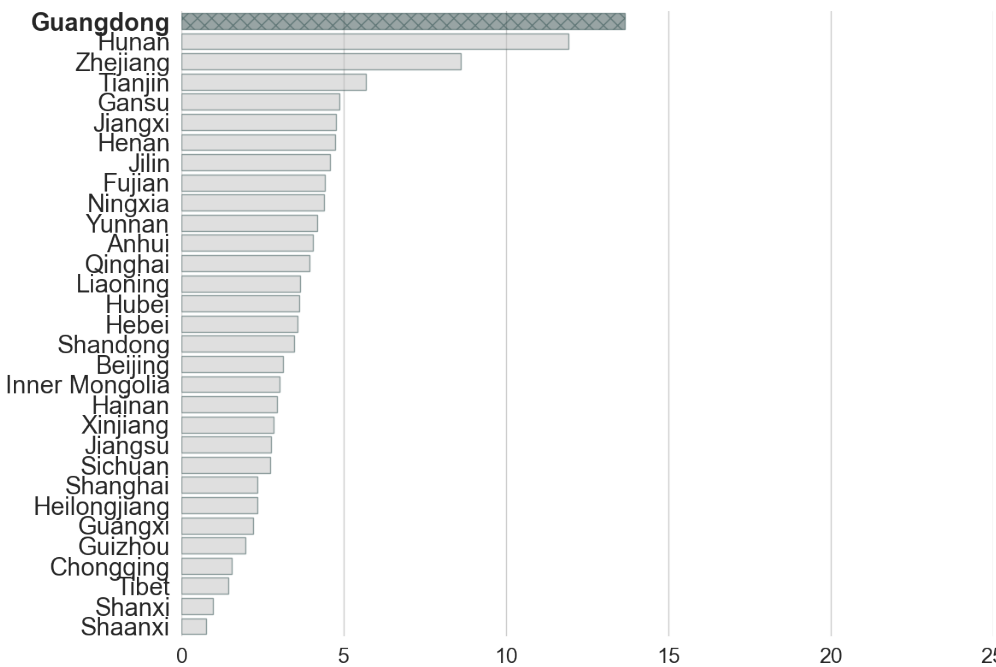
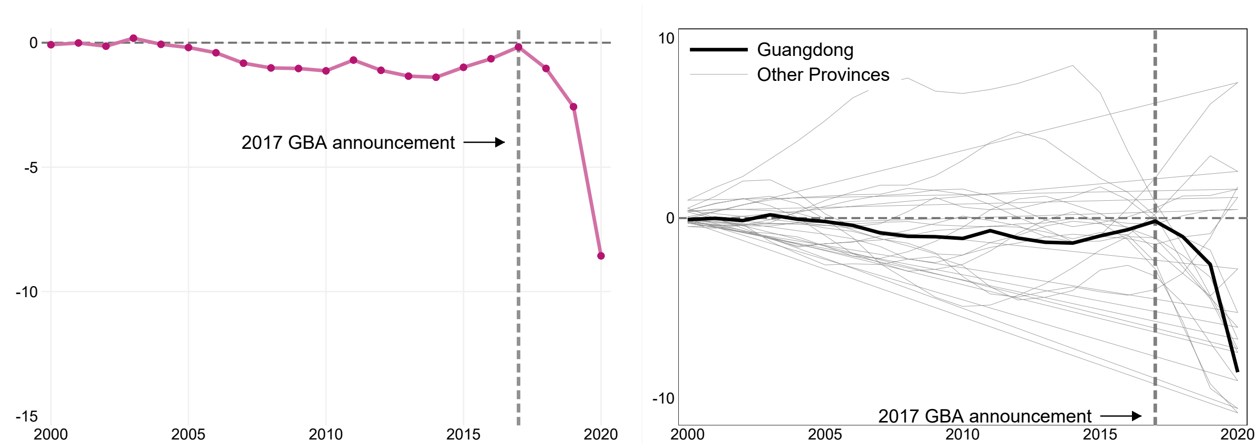
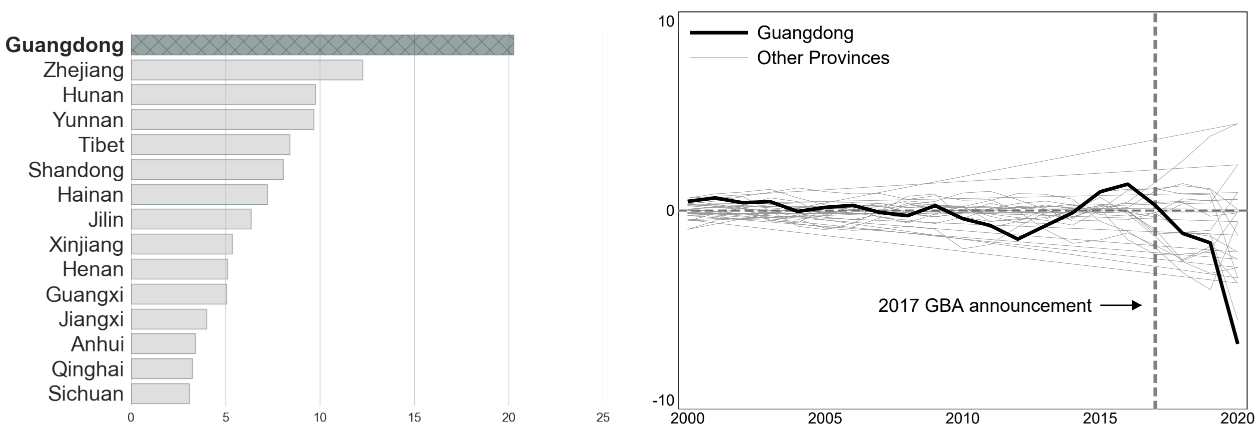


Figure A8. Post-to-pre RMSPE ratio for Per Capita GDP. Untruncated version of Figure 6 for all 31 mainland provinces.



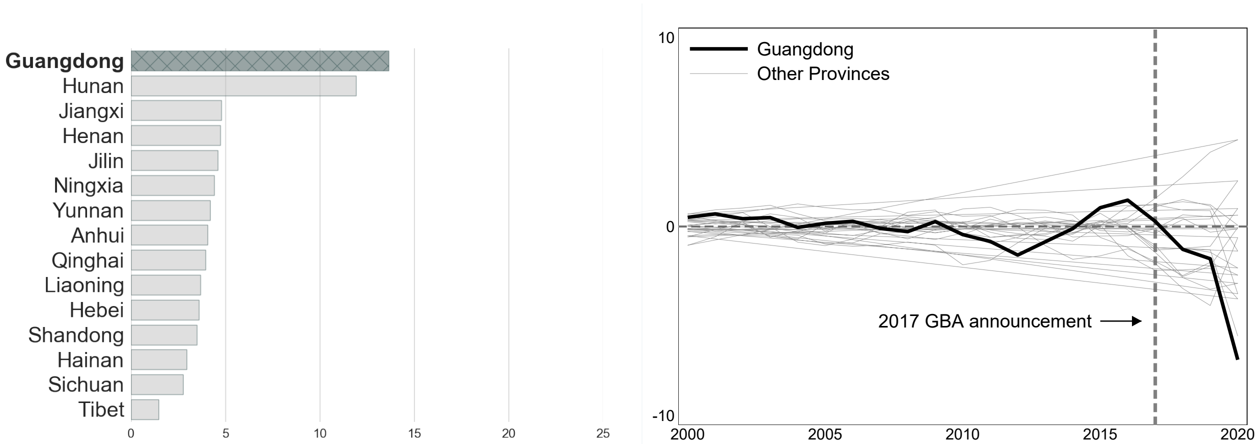
a Cumulative differences **b** Permutation-based cumulative differences

Figure A9. Cumulative differences for Per Capita GDP.



a Post-to-Pre RMPSE ratio **b** Permutation-based differences

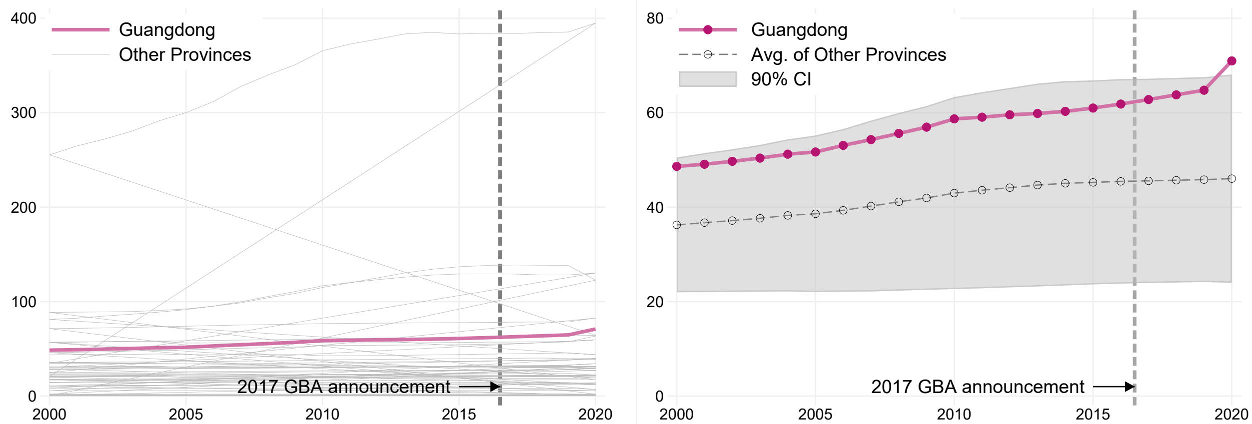
Figure A10. Robustness test for Per Capita GDP with additional predictors: (i) illiteracy rate (pecentage of population aged 15 and above), (ii) tertiary institutions (percentage of institutions), (iii) tourist arrivals (normalised by GDP), (iv) realised foreign direct investments (excluding regional investment and normalised by GDP), and (v) realised investments (normalised by GDP). Corresponds to Figure 6.



a Post-to-Pre RMPSE ratio **b** Permutation-based differences

Figure A11. Robustness test for Per Capita GDP with a lower constraint violation tolerance in the constrained quadratic optimization. The threshold is set to 0.1^{10} instead of 0.05. Corresponds to Figure 6.

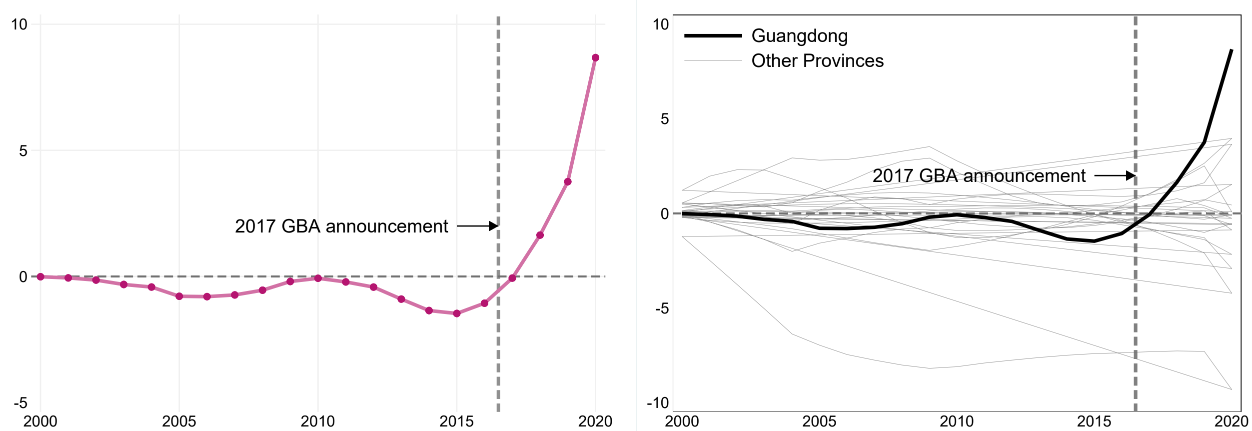
E. Additional Tables and Figures for Population Density



a Path plots of Population density

b Average of Population density

Figure A12. Panel a shows the raw path plots of the province Population density. Gray lines are provinces other than Guangdong. Panel b shows the path plot of Guangdong and the average of the other provinces. Shaded gray area is the 90% confidence interval. Dashed vertical line indicates the 2017 announcement of the GBA.



a Guangdong vs synthetic Guangdong

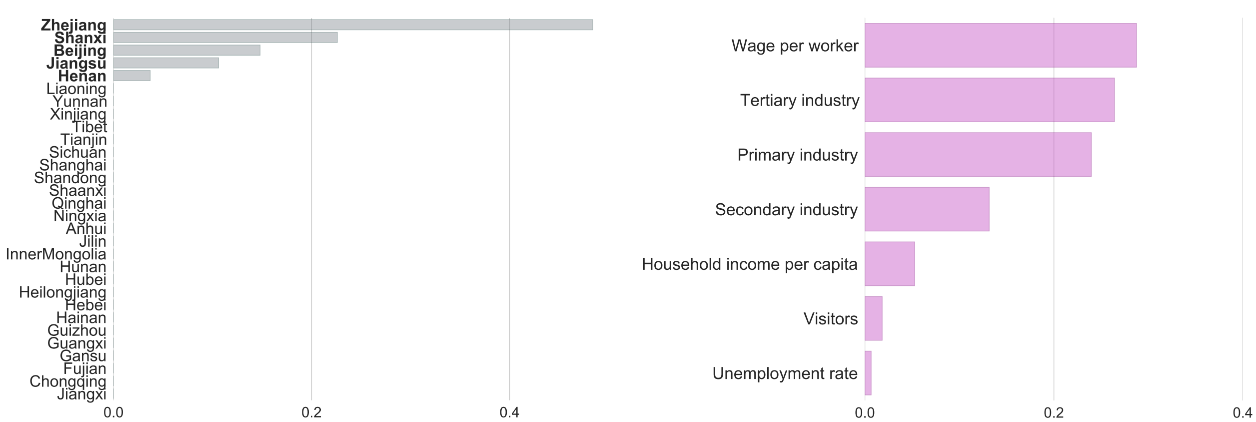
b Cumulative difference in Population density

Figure A13. Cumulative differences for Population density.

Table A3. Balance of predictors of Population density before the 2017 GBA announcement.

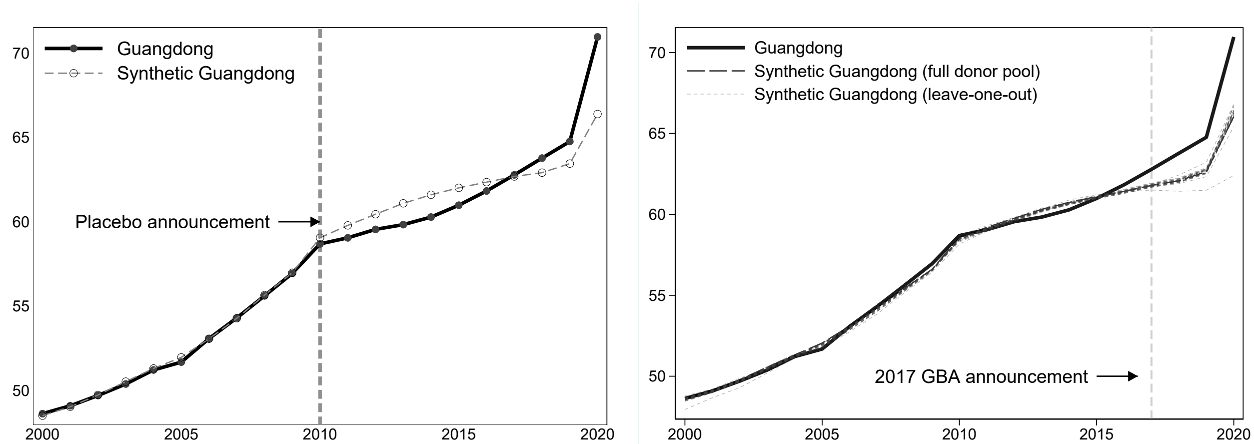
	Weight	Guangdong	Synthetic Guangdong	Average	Zhejiang (nearest neighbour)	Beijing (next nearest neighbour)
Primary industry	0.001	0.057	0.069	0.127	0.057	0.01
Secondary industry	0.065	0.473	0.472	0.467	0.501	0.231
Tertiary industry	0.006	0.469	0.473	0.456	0.447	0.712
Household income per capita	0.117	20,376	20,388	15,341	24,110	28,704
Visitors	0.006	0.018	0.017	0.015	0.015	0.034
Unemployment rate (urban)	0.001	2.585	3.033	3.537	3.293	1.437
Annual wage	0.803	33,876	33,916	29,353	35,670	57,715

Each row is a predictor used to match the Population density of the 30 mainland provinces to Guangdong. Column 1 is the variable weight. Column 2 is the mean values for Guangdong. Column 3 is the mean predictor values for synthetic Guangdong ($X_P W^*$ from Equation (1)). Columns 4, 5, and 6 are special cases of the synthetic control. Column 4 is where all 30 mainland provinces get equal weights (W is a vector with all elements $1/30$. Column 5 is when the nearest neighbour gets full weight (W all zeroes except with weight 1 for Zhejiang, see Figure A14). Column 6 is when the second nearest neighbour gets full weight (W all zeroes except with weight 1 for Beijing).



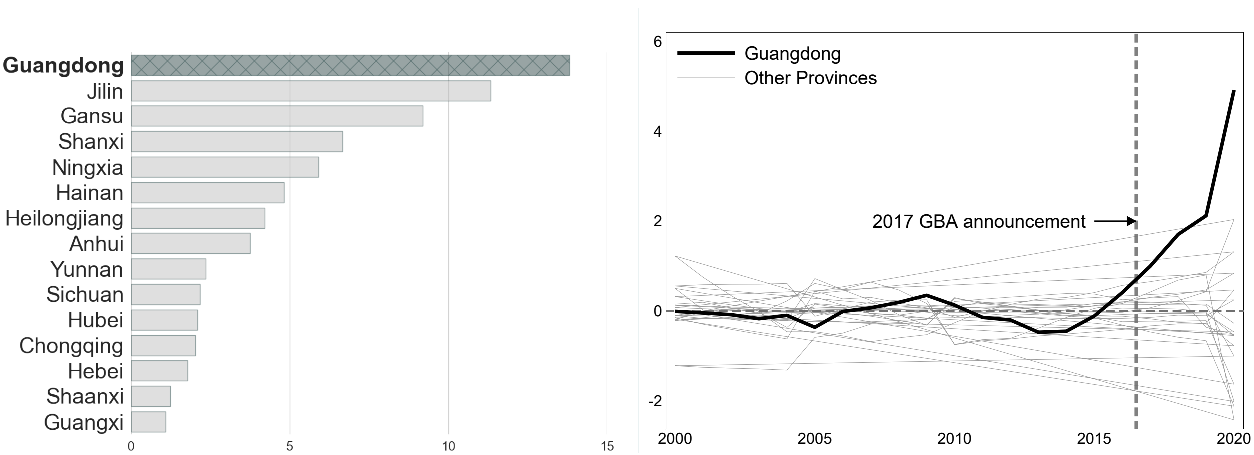
a Guangdong vs synthetic Guangdong **b** Difference

Figure A14. Weights to construct Population density of synthetic Guangdong. Left panel are the synthetic control weights, where weights are W^* from Equation (1) chosen such that synthetic Guangdong best resembles Guangdong in the over the 17 years in the period 2000–2016 before the 2017 GBA announcement. Right panel are the predictor variable weights V^* from Equation (2).



a Backdating GBA announcement   **b** Leave-one-out sensitivity

Figure A15. Robustness of synthetic control method for Population density. Left panel repeats the synthetic control method to estimate Population density for synthetic Guangdong but with the GBA announcement backdated to 2010. Right panel shows the results from a leave-one-out synthetic control estimation where in each of 30 iterations one of the donor provinces is taken out of the donor pool before estimation. Dashed vertical line indicates the 2017 announcement of the GBA.



a Post-to-pre RMSPE ratio   **b** Permutation-based bath plots

Figure A16. Permutation-based inference for Population density. Left panel shows the distribution of the RMPSE (root mean square prediction error), with the full list in Table A4. Shaded bar is Guangdong. Right panel shows the synthetic control method results by using each of the other 30 mainland provinces in turn as the placebo in gray. The original synthetic control method result for Guangdong from Figure 8 in black. Dashed vertical line indicates the 2017 announcement of the GBA. Both panels retain only mainland provinces with good pre-period fit quality (RMPSE less than the median) for better resolution.

Table A4. Permutation-based inference for population density

Province	Type (1)	Rank (2)	P-value (3)	Pre RMSPE (4)	Post RMSPE (5)	Adjustment for fit quality using RMSPE: Post-to-Pre RMSPE (6)	Adjusted Rank (7)	Adjusted P-value (8)	Adjusted Z-score (9)
Gansu	Donor	27	0.870968	0.00	0.06	16.43	1	0.03	2.14
Yunnan	Donor	28	0.903226	0.00	0.05	15.13	2	0.06	1.85
Shanxi	Donor	18	0.580645	0.01	0.18	12.53	3	0.10	1.66
Guangdong	Treated	12	0.387097	0.05	0.51	11.08	4	0.13	1.52
Ningxia	Donor	19	0.612903	0.02	0.16	9.75	5	0.16	1.40
Hainan	Donor	17	0.548387	0.02	0.20	8.22	6	0.19	1.30
Jilin	Donor	20	0.645161	0.03	0.14	5.00	7	0.23	1.21
Hebei	Donor	23	0.741935	0.02	0.10	4.61	8	0.26	1.13
Hubei	Donor	25	0.806452	0.03	0.09	2.88	9	0.29	1.06
Anhui	Donor	16	0.516129	0.10	0.27	2.80	10	0.32	0.99
Shaanxi	Donor	26	0.83871	0.03	0.08	2.58	11	0.35	0.93
Liaoning	Donor	15	0.483871	0.16	0.41	2.49	12	0.39	0.86
Tianjin	Donor	6	0.193548	0.57	1.29	2.26	13	0.42	0.81
Beijing	Donor	10	0.322581	0.33	0.72	2.16	14	0.45	0.75
Fujian	Donor	9	0.290323	0.41	0.83	2.05	15	0.48	0.70
Sichuan	Donor	29	0.935484	0.02	0.03	1.99	16	0.52	0.65
Hunan	Donor	24	0.774194	0.05	0.10	1.87	17	0.55	0.60
Jiangsu	Donor	11	0.354839	0.30	0.52	1.71	18	0.58	0.55
Shanghai	Donor	1	0.032258	22.78	36.77	1.61	19	0.61	0.51
Heilongjiang	Donor	14	0.451613	0.28	0.42	1.54	20	0.65	0.46
Henan	Donor	4	0.129032	1.30	1.99	1.53	21	0.68	0.42
Xinjiang	Donor	2	0.064516	1.81	2.72	1.50	22	0.71	0.37
Tibet	Donor	5	0.16129	1.14	1.69	1.48	23	0.74	0.33
Qinghai	Donor	13	0.419355	0.35	0.49	1.42	24	0.77	0.29
Jiangxi	Donor	8	0.258065	0.79	1.12	1.41	25	0.81	0.25
Inner Mongolia	Donor	3	0.096774	1.47	2.04	1.38	26	0.84	0.20
Zhejiang	Donor	7	0.225806	0.85	1.15	1.36	27	0.87	0.16
Guizhou	Donor	22	0.709677	0.08	0.11	1.33	28	0.90	0.12
Shandong	Donor	21	0.677419	0.19	0.13	0.68	29	0.94	0.08
Guangxi	Donor	30	0.967742	0.05	0.03	0.64	30	0.97	0.04
Chongqing	Donor	31	1	0.11	0.02	0.21	31	1.00	0.00

Table shows the synthetic control method by using each of the 31 mainland provinces as the treated unit. Column 1 indicates that Guangdong is the main treated unit of concern. Column 2 and column 3 are the ranking and p-value based on the highest post-period RMSPE (root mean square prediction error). Column 4 and column 5 are the pre and post-period RMPSE. Column 6 is the ratio of the post-to-pre RMSPE which adjusts the post-period RMSPE by the pre-period RMSPEs (see Figure A16 and Figure A17). Columns 7–9 are the ranking, p-value and the associated Z-score after the post-period RMSPE is adjusted by fit quality in the pre-period.

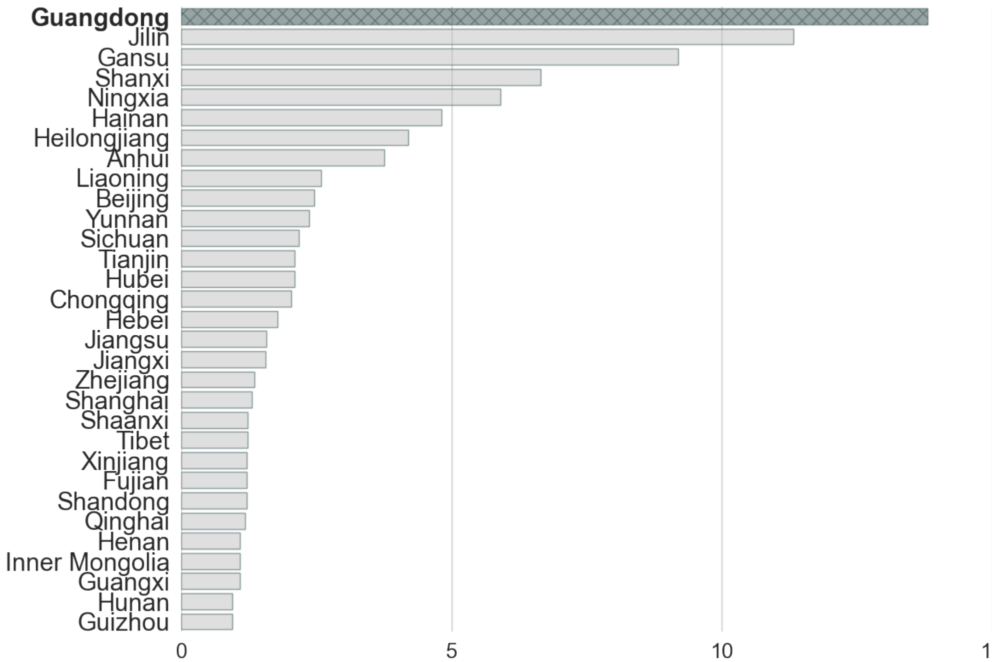
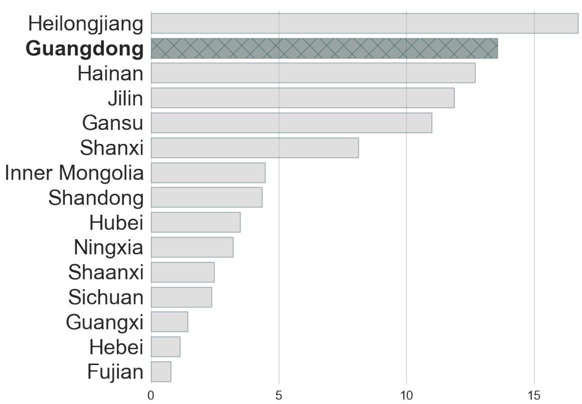
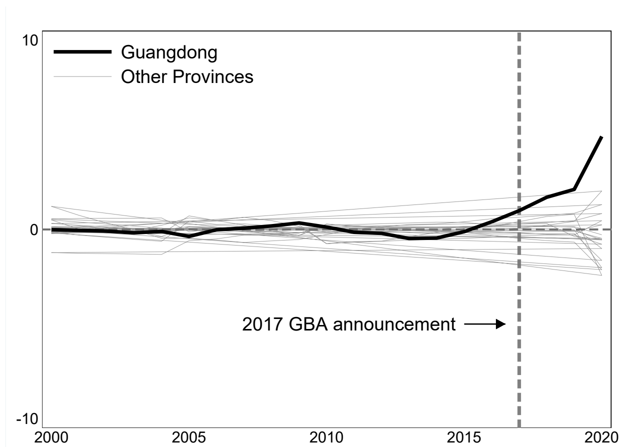


Figure A17. Post-to-pre RMSPE ratio for Population density. Untruncated version of Figure A16 for all 31 mainland provinces.

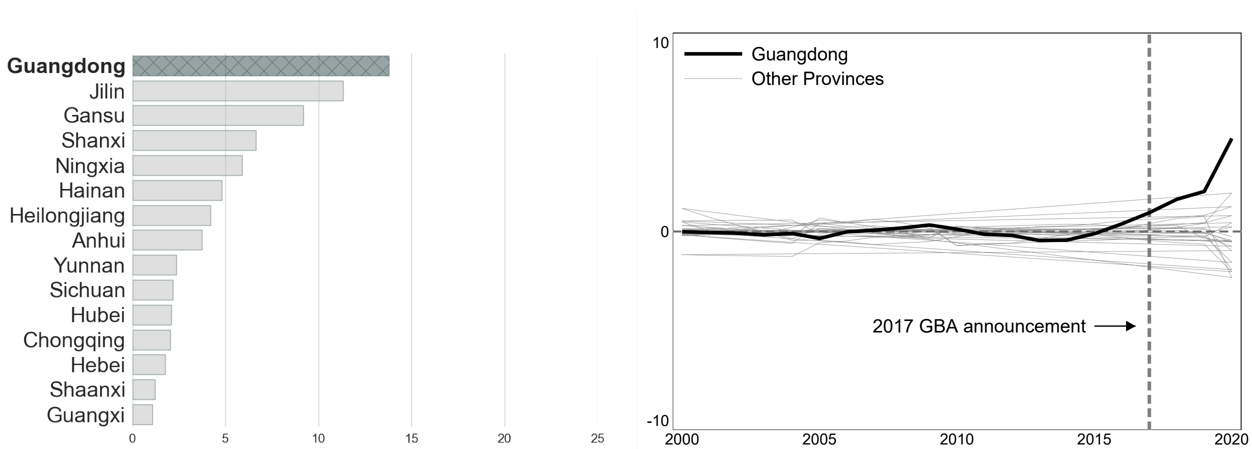


a Post-to-Pre RMPSE ratio



b Permutation-based differences

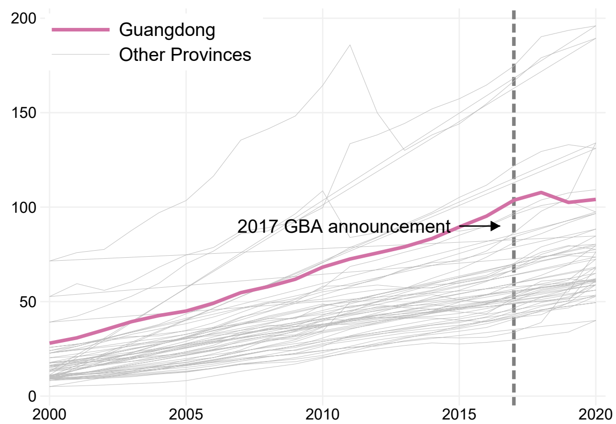
Figure A18. Robustness test for Population density with additional predictors: (i) illiteracy rate (pecentage of population aged 15 and above), (ii) tertiary institutions (percentage of institutions), (iii) tourist arrivals (normalised by GDP), (iv) realised foreign direct investments (excluding regional investment and normalised by GDP), and (v) realised investments (normalised by GDP). Corresponds to Figure A16.



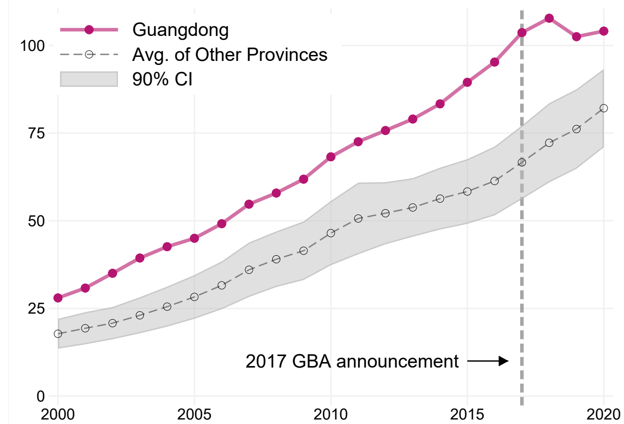
a Post-to-Pre RMPSE ratio **b** Permutation-based differences

Figure A19. Robustness test for Population density with a lower constraint violation tolerance in the constrained quadratic optimization. The threshold is set to 0.1^{10} instead of 0.05. Corresponds to Figure A16.

F. Additional Tables and Figures for Productivity

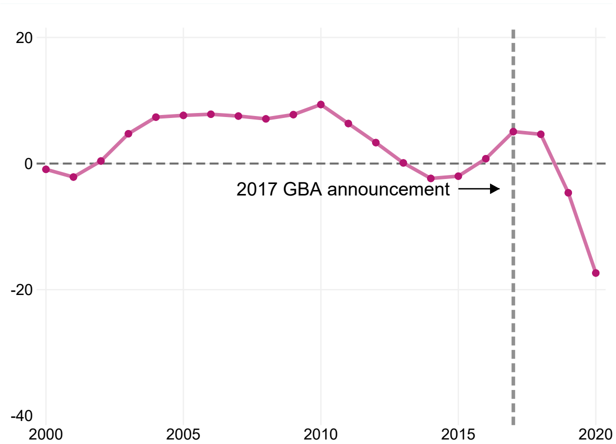


a Path plots of Population density

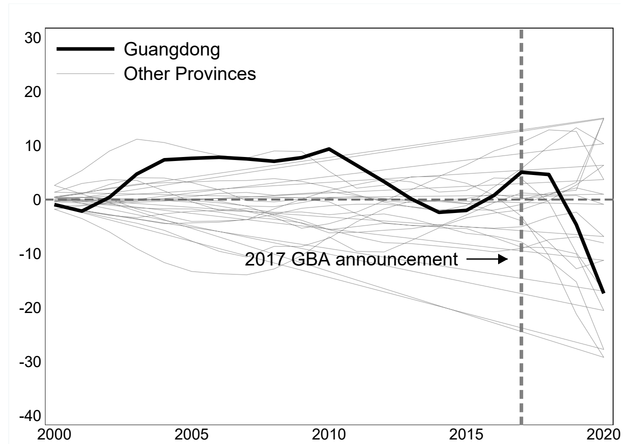


b Average of Population density

Figure A20. Panel a shows the raw path plots of the productivity. Gray lines are provinces other than Guangdong. Panel b shows the path plot of Guangdong and the average of the other provinces. Shaded gray area is the 90% confidence interval. Dashed vertical line indicates the 2017 announcement of the GBA.



a Guangdong vs synthetic Guangdong



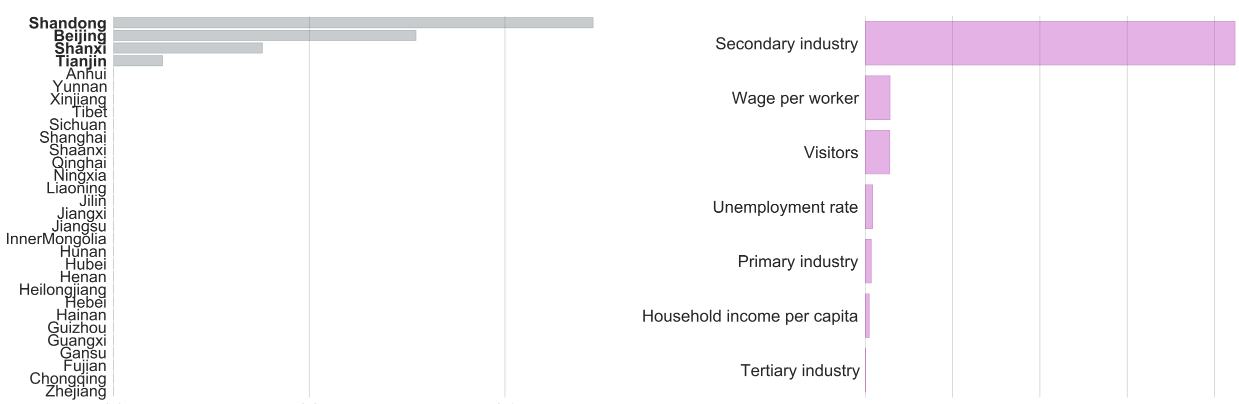
b Cumulative difference in productivity

Figure A21. Cumulative differences for productivity.

Table A5. Balance of predictors of productivity before the 2017 GBA announcement.

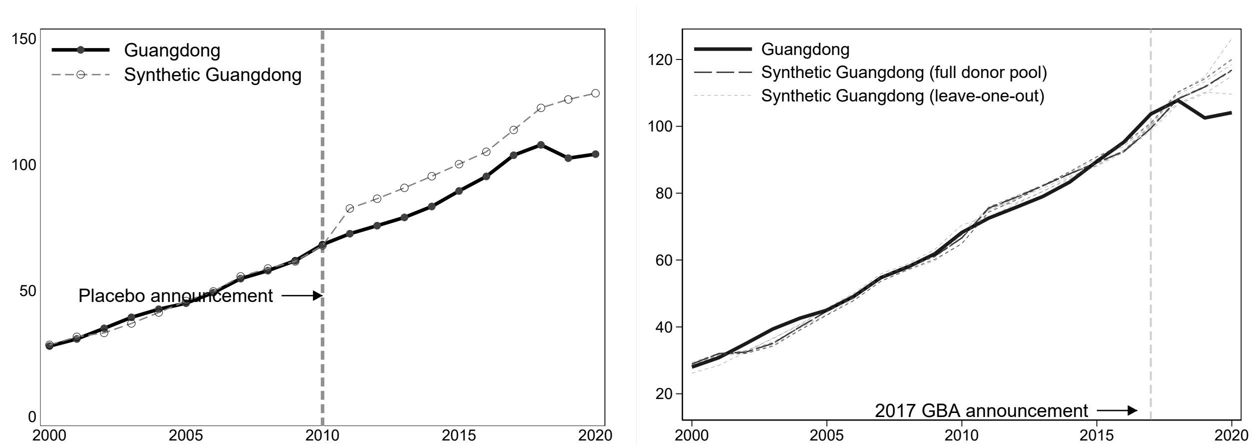
	Weight	Guangdong	Synthetic Guangdong	Average	Shandong (nearest neighbour)	Beijing (next nearest neighbour)
Primary industry	0.014	0.059	0.071	0.132	0.113	0.011
Secondary industry	0.847	0.479	0.479	0.477	0.588	0.239
Tertiary industry	0.001	0.462	0.516	0.447	0.426	0.699
Household income per capita	0.009	19,214	17,774	14,217	15,500	26,354
Visitors	0.056	0.018	0.017	0.015	0.008	0.036
Unemployment rate (urban)	0.017	2.601	2.775	3.591	3.382	1.447
Annual wage	0.057	30,861	31,900	26,547	24,927	51,925

Each row is a predictor used to match the productivity of the 30 mainland provinces to Guangdong. Column 1 is the variable weight. Column 2 is the mean values for Guangdong. Column 3 is the mean predictor values for synthetic Guangdong ($X_P W^*$ from Equation (1)). Columns 4, 5, and 6 are special cases of the synthetic control. Column 4 is where all 30 mainland provinces get equal weights (W is a vector with all elements $1/30$. Column 5 is when the nearest neighbour gets full weight (W all zeroes except with weight 1 for Zhejiang, see Figure A22). Column 6 is when the second nearest neighbour gets full weight (W all zeroes except with weight 1 for Beijing).



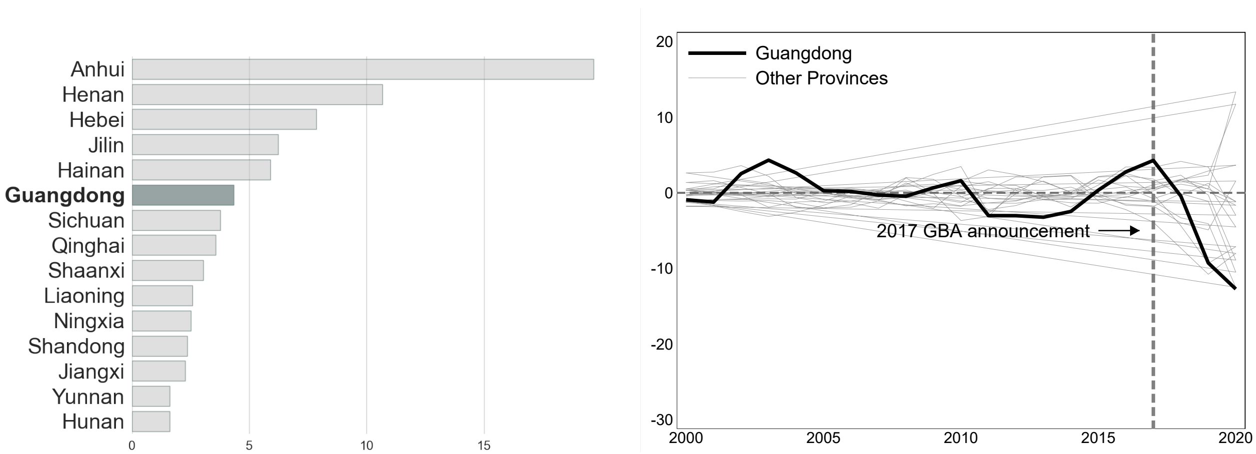
a Guangdong vs synthetic Guangdong **b** Difference

Figure A22. Weights to construct productivity of synthetic Guangdong. Left panel are the synthetic control weights, where weights are W^* from Equation (1) chosen such that synthetic Guangdong best resembles Guangdong in the over the 17 years in the period 2000–2016 before the 2017 GBA announcement. Right panel are the predictor variable weights V^* from Equation (2).



a Backdating GBA announcement **b** Leave-one-out sensitivity

Figure A23. Robustness of synthetic control method for productivity. Left panel repeats the synthetic control method to estimate productivity for synthetic Guangdong but with the GBA announcement backdated to 2010. Right panel shows the results from a leave-one-out synthetic control estimation where in each of 30 iterations one of the donor provinces is taken out of the donor pool before estimation. Dashed vertical line indicates the 2017 announcement of the GBA.



a Post-to-pre RMSPE ratio **b** Permutation-based bath plots

Figure A24. Permutation-based inference for productivity. Left panel shows the distribution of the RMPSE (root mean square prediction error), with the full list in Table A6. Shaded bar is Guangdong. Right panel shows the synthetic control method results by using each of the other 30 mainland provinces in turn as the placebo in gray. The original synthetic control method result for Guangdong from Figure 8 in black. Dashed vertical line indicates the 2017 announcement of the GBA. Both panels retain only mainland provinces with good pre-period fit quality (RMPSE less than the median) for better resolution.

Table A6. Permutation-based inference for productivty

Province	Type (1)	Rank (2)	P-value (3)	Pre RMSPE (4)	Post RMSPE (5)	Adjustment for fit quality using RMSPE: Post-to-Pre RMSPE (6)	Adjusted Rank (7)	Adjusted P-value (8)	Adjusted Z-score (9)
Anhui	Donor	14	0.45	0.39	7.75	19.67	1	0.03	2.14
Henan	Donor	19	0.61	0.66	7.01	10.66	2	0.06	1.85
Hebei	Donor	12	0.39	1.00	7.86	7.86	3	0.10	1.66
Jilin	Donor	10	0.32	1.46	9.11	6.23	4	0.13	1.52
Hainan	Donor	18	0.58	1.22	7.23	5.90	5	0.16	1.40
Inner Mongolia	Donor	7	0.23	2.63	13.84	5.27	6	0.19	1.30
Fujian	Donor	3	0.10	6.67	29.34	4.40	7	0.23	1.21
Guangdong	Treated	9	0.29	2.17	9.43	4.35	8	0.26	1.13
Gansu	Donor	5	0.16	4.29	18.15	4.23	9	0.29	1.06
Hubei	Donor	4	0.13	4.84	19.56	4.04	10	0.32	0.99
Sichuan	Donor	25	0.81	0.76	2.86	3.76	11	0.35	0.93
Qinghai	Donor	22	0.71	1.14	4.05	3.57	12	0.39	0.86
Tibet	Donor	11	0.35	2.72	8.54	3.13	13	0.42	0.81
Shaanxi	Donor	20	0.65	2.04	6.18	3.03	14	0.45	0.75
Guangxi	Donor	8	0.26	3.22	9.62	2.99	15	0.48	0.70
Jiangsu	Donor	1	0.03	17.05	45.00	2.64	16	0.52	0.65
Liaoning	Donor	21	0.68	2.09	5.39	2.58	17	0.55	0.60
Ningxia	Donor	23	0.74	1.55	3.89	2.50	18	0.58	0.55
Shandong	Donor	24	0.77	1.23	2.89	2.35	19	0.61	0.51
Jiangxi	Donor	28	0.90	0.47	1.08	2.26	20	0.65	0.46
Tianjin	Donor	6	0.19	7.99	18.07	2.26	21	0.68	0.42
Beijing	Donor	2	0.06	20.26	43.47	2.15	22	0.71	0.37
Guizhou	Donor	13	0.42	3.81	7.80	2.05	23	0.74	0.33
Heilongjiang	Donor	15	0.48	3.65	7.40	2.03	24	0.77	0.29
Yunnan	Donor	27	0.87	0.77	1.23	1.60	25	0.81	0.25
Hunan	Donor	26	0.84	0.92	1.47	1.60	26	0.84	0.20
Chongqing	Donor	17	0.55	6.14	7.24	1.18	27	0.87	0.16
Xinjiang	Donor	16	0.52	7.06	7.40	1.05	28	0.90	0.12
Shanxi	Donor	29	0.94	2.80	0.39	0.14	29	0.94	0.08
Zhejiang	Donor	30	0.97	6.29	0.35	0.06	30	0.97	0.04
Shanghai	Donor	.	.	.	.	.	.	.	.

Table shows the synthetic control method by using each of the 31 mainland provinces as the treated unit. Column 1 indicates that Guangdong is the main treated unit of concern. Column 2 and column 3 are the ranking and p-value based on the highest post-period RMSPE (root mean square prediction error). Column 4 and column 5 are the pre and post-period RMPSE. Column 6 is the ratio of the post-to-pre RMSPE which adjusts the post-period RMSPE by the pre-period RMSPEs. Columns 7–9 are the ranking, p-value and the associated Z-score after the post-period RMSPE is adjusted by fit quality in the pre-period.

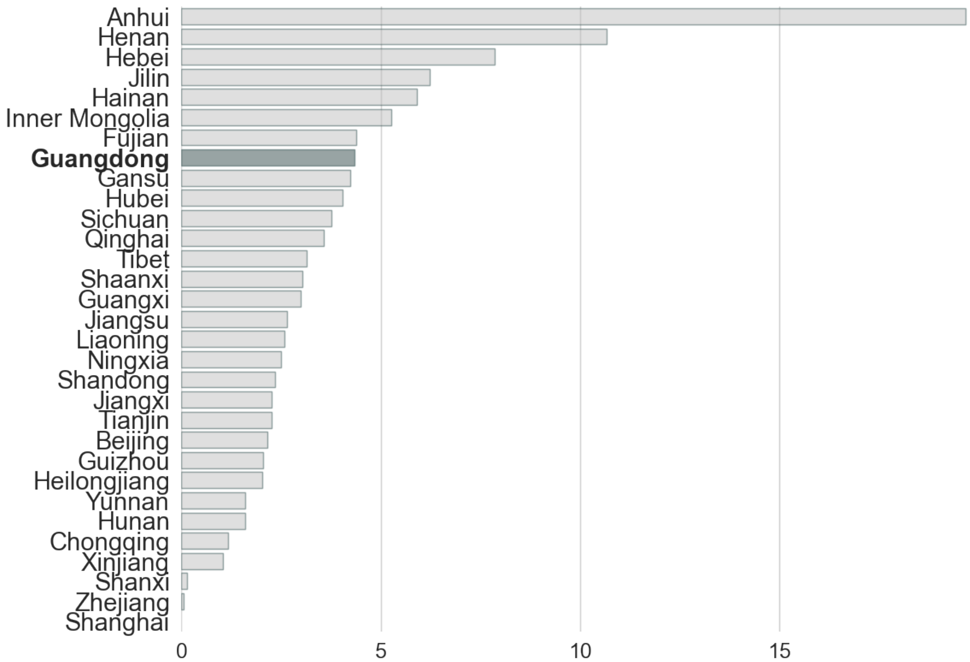
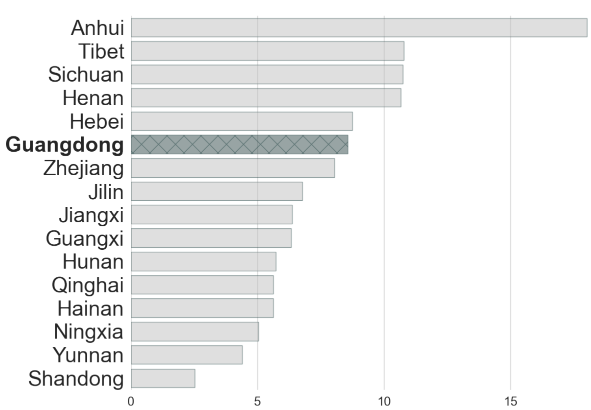
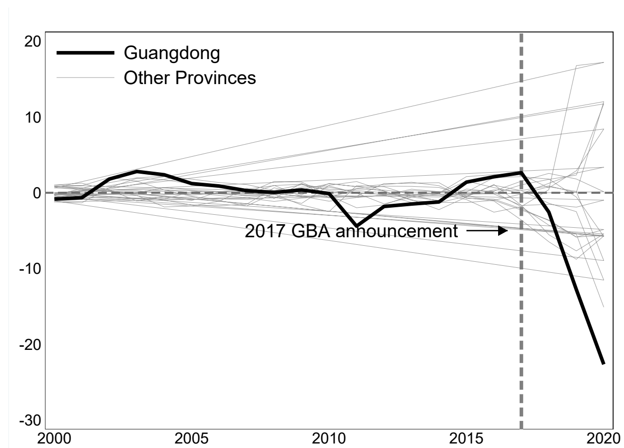


Figure A25. Post-to-pre RMSPE ratio for productivity. Untruncated version of Figure A24 for all 31 mainland provinces.

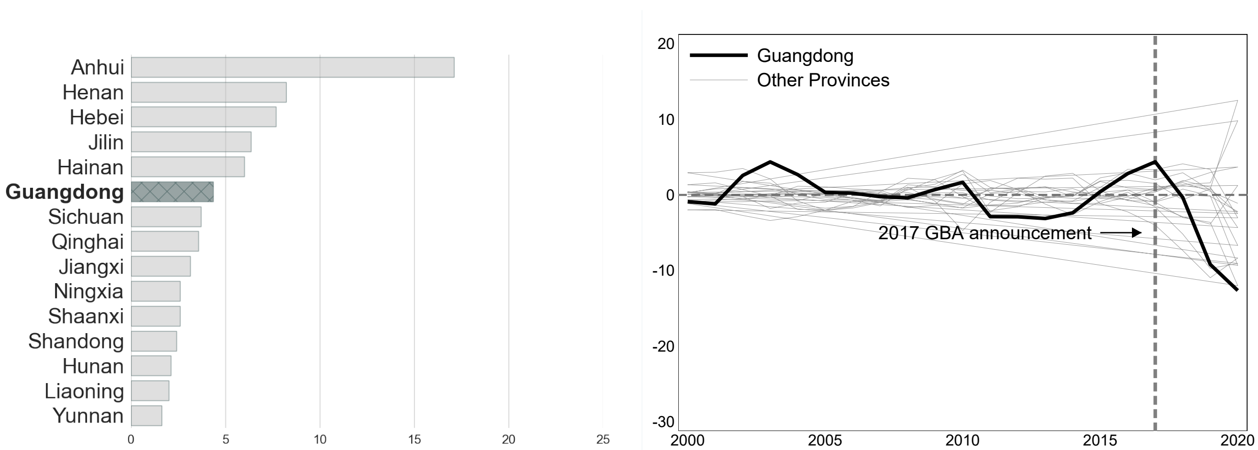


a Post-to-Pre RMPSE ratio



b Permutation-based differences

Figure A26. Robustness test for productivity with additional predictors: (i) illiteracy rate (pecentage of population aged 15 and above), (ii) tertiary institutions (percentage of institutions), (iii) tourist arrivals (normalised by GDP), (iv) realised foreign direct investments (excluding regional investment and normalised by GDP), and (v) realised investments (normalised by GDP). Corresponds to Figure A24.



a Post-to-Pre RMPSE ratio **b** Permutation-based differences

Figure A27. Robustness test for productivity with a lower constraint violation tolerance in the constrained quadratic optimization. The threshold is set to 0.1^{10} instead of 0.05. Corresponds to Figure A24.