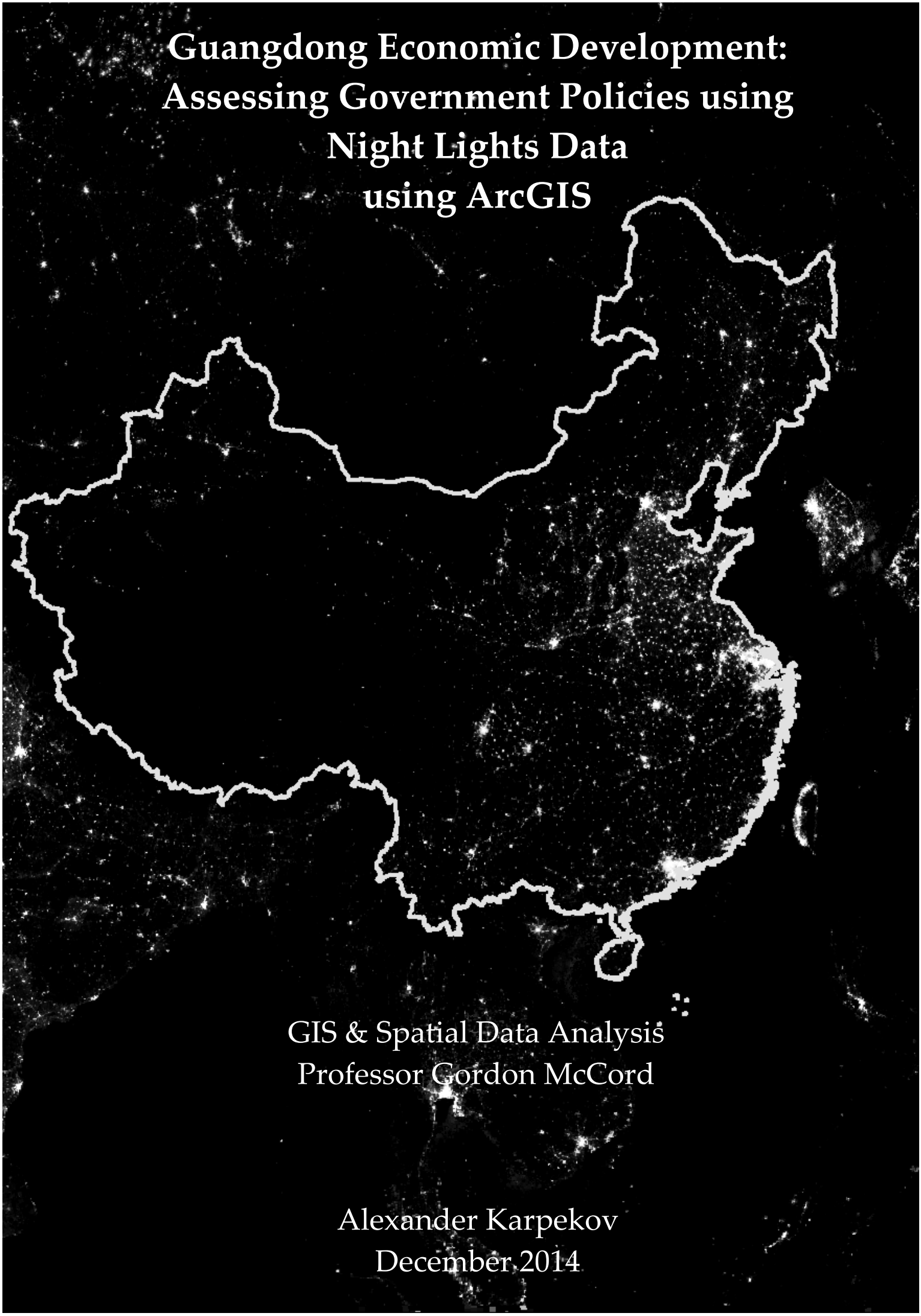
Guangdong Economic Development: Assessing Government Policies using Night Lights Data using ArcGIS



GIS & Spatial Data Analysis
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Introduction

China has witnessed an incredibly fast economic development in the past 20 years since the opening up of its market. The inflow of international capital and foreign direct investment have made a significant contribution to the Chinese economic miracle. However, the economic growth in China is not proportionally distributed, just as the Chinese population. 95% of population and all economic activity in China is concentrated to the West of the Aihui-Tengchong line that divides the country into two equal parts. The land to the East of that line is relatively flat and water abundant with a good land quality while the West is mountainous, lacks water supplies and cropland (Naughton, 2007).

Traditionally urban and economic development has been concentrated in the river deltas and on the sea coast line. China is not an exception. The three largest rivers in China, Yangtze, Yellow and Pearl, accommodated a great proportion of Chinese population and Yangtze and Pearl river deltas host two the most rapidly developing metropolitan areas – Shanghai and Guangzhou (Guangdong province).

In this paper we will focus on the Guangdong province development from the beginning of 1990s to the present time. Guangdong has shown the fastest growth over the past two decades since it became the "World Factory". However, recently Shanghai and surrounding areas' growth has surpassed that of Guangdong that prompted the policy makers to develop a brand new strategy aimed at expanding the development from Pearl River Delta to the periphery of the province. The first attempts to pursue this policy were made at the beginning of 2000 and then reinvigorated in 2008 with a new official policy. In this paper we are trying to see how over time the development in Guangdong become less clustered around the Pearl River Delta and make an attempt to estimate how efficient the policy to incorporate the rest of the province in the development process was. We do so by using the Nightlights data (available from 1992 to 2013) from the National Geophysical Data Center as a proxy for economic development.

The paper is organized in the following way. First, we introduce a brief overview of the development in Guangdong explaining why it was so much concentrated in the Pearl River Delta since 1980s. Then we summarize why Nightlights data is a legitimate proxy to measure development and how we will use it in our analysis. In the next part we will present our analysis starting with the hypothesis stating that over time the development in Guangdong province becomes less and less clustered around the Pearl River Delta area and extends to the outskirts of the province. Then we explain the steps done in Esri ArcGIS software to get the data necessary for the Ordinary Least Square (OLS) Regression and Geographically Weighted Regression (GWR). We summarize our analysis in two tables for OLS and GWR outputs and provide their interpretation. Finally, we conduct a test on whether the government policy initiated in 2008 had a statistically significant effect on growth in the province.

The Guangdong Development

The Guangdong development process can be subdivided into four main phases:

1. Pre-reform era (prior to initiated in 1978 Deng Xiaoping's reforms)
2. Stage reforms: 1980 – early 1990s: period when Guangdong was selected as an experimental zone for new export-oriented reforms

3. Pearl River Delta (PRD) led boom: 1990s-2000: period of rapid industrial expansion of PRD when it emerged as "The World's Factory"
4. Periphery-oriented model: incorporation of first the Outer Pearl River Delta (Outer PRD) region and then the rest of the province into the process of economic expansion (OECD, 2010).

Here we will mostly focus on the third and the forth periods. However, it is important to mention that as early as in 1980 three Special Economic Zones (SEZ) were established in Guangdong: in Zhuhai, in Shenzhen and in Shantou. The choice was strategic: the main purpose of these economic zones was to benefit from economic spillovers from the regions that China had strong economic and cultural relations with and to attract foreign investment from those territories (Naughton, 2007).

The SEZ in Shenzhen is located right on the border with the British Hong Kong (which wasn't Chinese up until 1997), the SEZ in Zhuhai is adjacent to at that time Portuguese Macao and the SEZ in Shantou is on the other side of the Taiwan strait from the Republic of China on Taiwan. Both Shenzhen and Zhuhai are located in the Pearl River Delta where Guangzhou at the time has already started its industrial growth. In 1984 after Deng Xiaoping's Southern Tour and announced that these "SEZs will be China's windows to the world" the whole Inner PRD area was opened up to the foreign investment (OECD, 2010). These were among the main factors (besides historically PRD concentrated development) that maid PRD the center of economic gravity of the region.

However, after 2000 the Guangdong as well as the national government of China realized that there was a potential for extensive economic growth in the Outer PRD and an urgent need for restructuring (the Guangdong's growth already began to slow down in the late 1990s). Population and economic activity were over concentrated in the Inner PRD.

In the 11th (2006-2010) and 12th (2011-2015) Guangdong provincial Five-Year plan the following goals were set:

- Develop lagging non-PRD regions through the "Double Relocation" policy (DRP).
- Release land in PRD and attract more low-skilled labor and manufacturing capacities outside of PRD.

For the first time the development of the PRD region itself was not mentioned as a government's priority. In 2008 the first in the modern Chinese history government sub-provincial regional development strategy was articulated: "Outline of the Plan for Reform and Development of the Pearl River Delta region in 2008-2010" (aimed at non-PRD development). As of year 2012 5.7 billion US dollars were allocated for these regional programs (OECD, 2012).

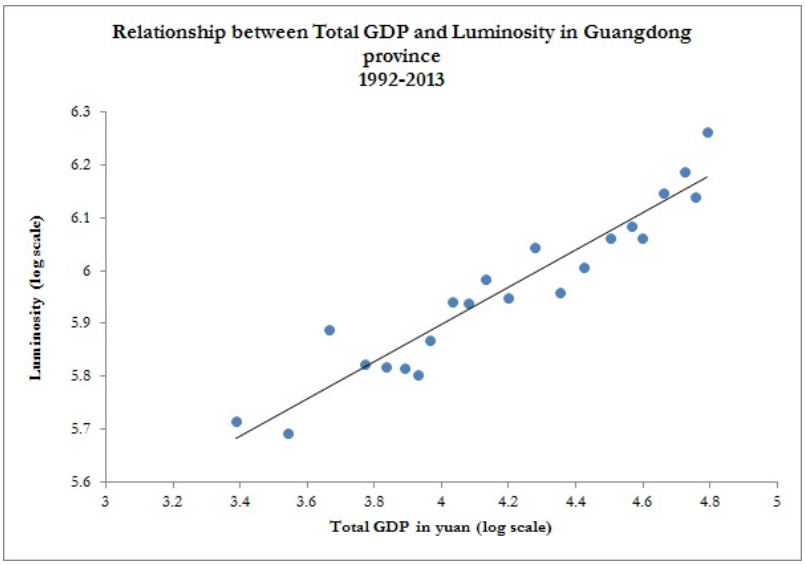
Night Lights Data

The night lights data we use are Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) Nighttime Lights Time Series from National Oceanic and Atmospheric Administrations (NOAA) National Geophysical Data Center (NGDC). The data is available from 1992 to 2013.

A number of studies have shown that night lights data (luminosity) can be used as a remarkably unbiased proxy for national and regional economic development in general and GDP in particular. See, for example, Ebener, Murry, Tandon and Elvidge (2005), Suttin, Elvidge, Ghosh (2007), Henderson, Storeygard, Weil (2012) (You, 2013).

Using zonal statistics tool in ArcGIS we calculated the sum of luminosity for Guangdong province for every year from 1992 to 2013. The following regression is aimed at looking at the correlation between Guangdong luminosity level (log scale) and GDP (log scale):

$$\boldsymbol{Luminosity} = \widehat{\boldsymbol{\beta_0}} + \widehat{\boldsymbol{\beta_1}} * \boldsymbol{GDP}$$



The coefficient of correlation between luminosity and GDP for Guangdong province is 0.95. The coefficient of determination R squared for the above mentioned regression is 0.91 and the slope coefficient is 0.3517 (significant at 99% level). This is a sufficient evidence to believe that luminosity can serve as a good proxy for GDP. We use night lights data instead of GDP for two main reasons. First, it helps us track and visualize spatial development at a much more granular level then aggregate GDP for provinces,

prefectures or even counties. Second, due to unavailability of free data on China at sub-county level and biasedness of the data in some cases (especially for policy effectiveness estimation) we use luminosity as a proxy for economic development.

Analysis

Hypotheses

We predict that over time (beginning from the early 1990s to 2013) the economic development in Guangdong province will be less and less concentrated within the Inner Pearl River Delta (PRD) and after 2008 will extensively start to spread into the peripheral regions (Eastern, Western and Northern). We also predict that the regions within the Double Relocation Policy launched in 2008 will experience faster growth than the rest of the non-PRD regions which will be the sign of policy effectiveness.

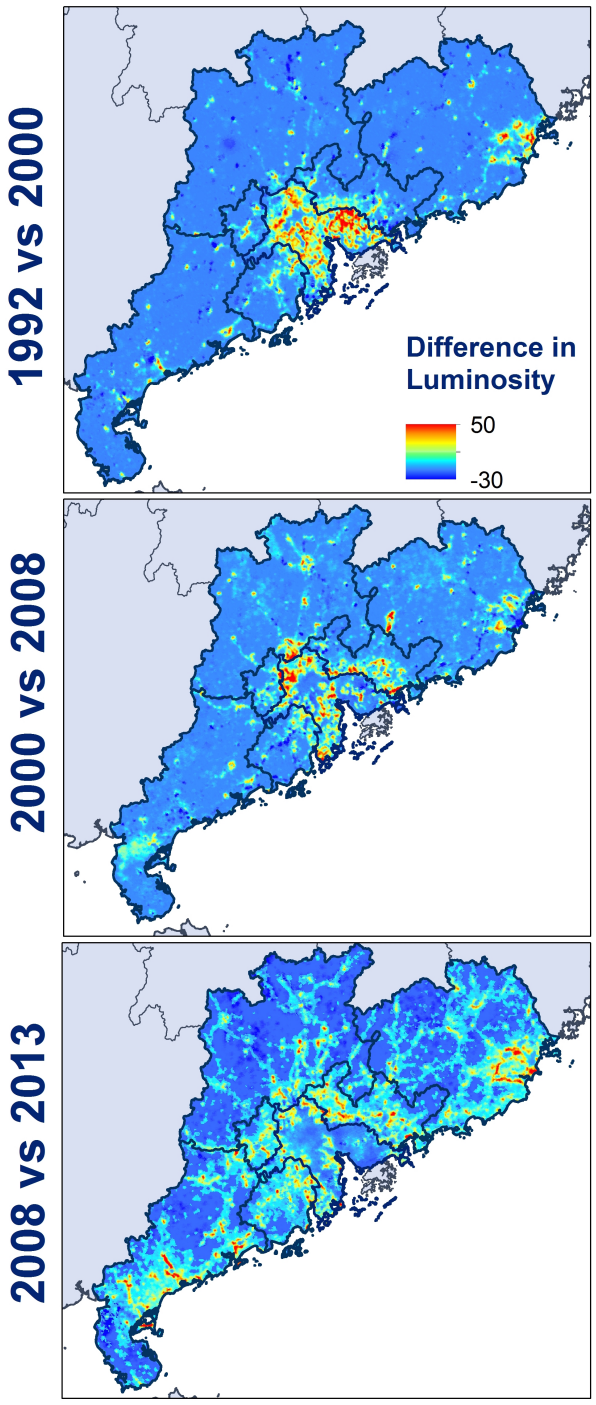
GIS Analysis

We selected three main time periods for our analysis:

- 1992-2000 (PRD-led boom)
- 2000-2008 (Expansion to the Outer PRD)
- 2008-2012 (Periphery development)

and created three rasters for the difference (in absolute values) from 2000 to 1992, 2008 to 2000 etc. using raster calculator. The luminosity data has a range from 0 to 63 with 63 being the brightest level. The negative value means drop in luminosity. In case of a small number for the difference (from 0 to approximately -5) this drop can be explained by certain level of noise in the data of the previous year. Therefore, on the following chart only very dark blue regions can be interpreted as a significant decrease in economic activity. All of the layers in the analysis were projected in Asia North Equidistant Conic Projected Geographic System (since our project will later include distance calculation).

On the chart below we can clearly see the spatial development pattern. For the first graph (1992 vs. 2000) the economic development measured by the difference in



luminosity is concentrated in the Inner PRD region with some small clusters in the Western region and a big clustering the Eastern region which is located right in the area of Shantou SEZ. The second graph clearly demonstrates that the economic activity starts to spread out into the Outer PRD region after 2000. From the third chart we can conclude that just in five years from 2008 to 2013 the growth has expanded outside of the PRD to include the rest of the Guangdong province. This data visualization gives us the first good proof of our hypothesis: gradually the development becomes less concentrated around the Pearl River Delta and starts to spread out.

Note: To calculate the sum of lights for the Guangdong province to compare the data with GDP we used the Zonal Statistics tool in the Spatial Analyst toolbox and then exported the data as Excel file.

In the next step we calculated the distance from the Inner Pearl River Delta and Shantou (as the only SEZ outside the PRD) raster using Euclidean distance tool with the cell size of 1,026 meters. To be able to run the OLS regression the rasterized data has to be converted into the tabular form. To do this, we created a point layer from the distance raster (with the mean values) within a fishnet of a cell size of 5 km for the whole area of the Guangdong province. Finally, using Multi Values to Points tool we imported the difference in lights data from the raster into the tabular form (prior to that operation we made sure all of the input rasters had the same cell size and fir within the net). In the final table we calculated two fields: one for distance in kilometers (dividing the initial distance in meters by 1,000) and one for the log of the distance to normalize the data distribution and because we believe that the distance matter less as it grows after a certain value.

OLS

Finally, we were able to run three OLS regression with the Change in Luminosity as the dependent variable and distance in kilometers (log scale) as an independent variable:

$$\Delta\, \boldsymbol{Luminosity} = \widehat{\boldsymbol{\beta_0}} + \widehat{\boldsymbol{\beta_1}} * \ln(\boldsymbol{Distance})$$

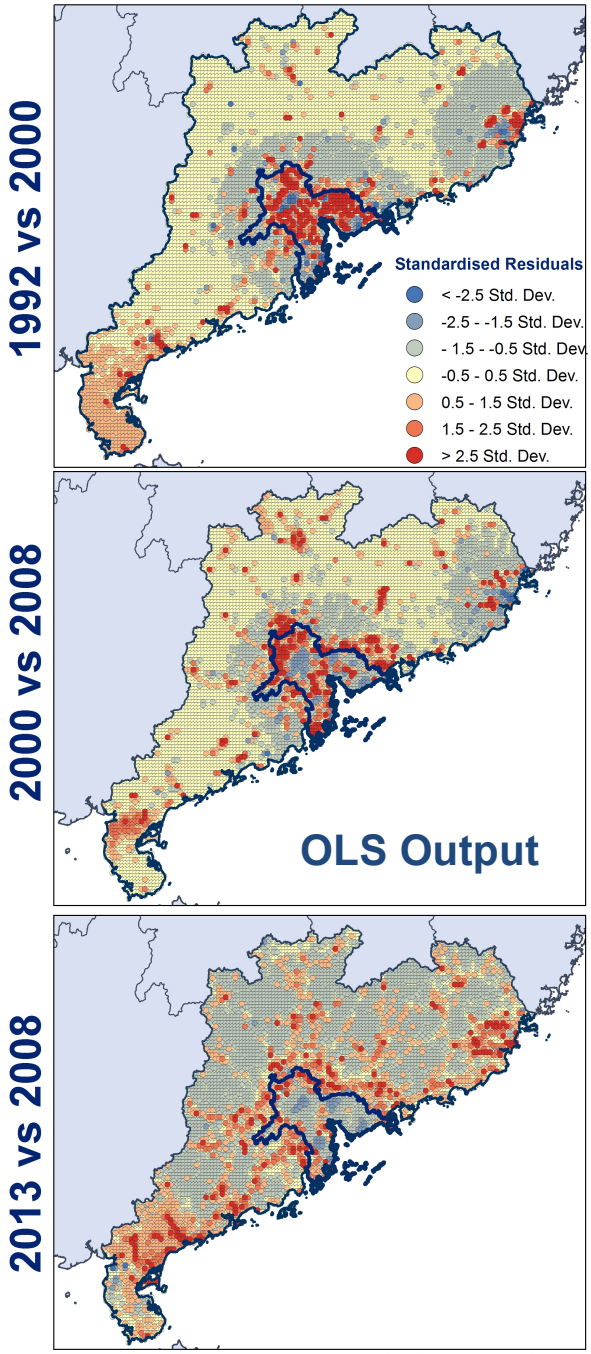
The summary of the three regressions is given in the following table:

Table: OLS Output
Dependent variable: Luminosity
Independent variable: Distance to PRD & Shantou (log scale)

Time:	1992 vs. 2000	2000 vs. 2008	2008 vs. 2013
Distance (log scale)	**-4.12*** **	**-2.05*** **	**-1.81*** **
	(0.14)	(0.11)	(0.09)
Adjusted R squared	0.28	0.1	0.07
Moran's I Index (for Std.Resid.)	0.38	0.25	0.24
n	6753	6753	6753

Notes:
Robust Standard Errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1*

First we see that all of the coefficients are negative and significant (for all of the three time periods). We interpret the negative coefficient in the following way: the farther you get from the PRD (or Shantou) the less bright (on average) the night lights get or the less economic activity growth is happening. For example, the "1992 vs. 2000" time period coefficient means that every extra percent (because of the log scale) in distance away from the PRD dims the luminosity by 4.12 units (on a scale from 0 to 63). We can also observe that over time the beta coefficient, although remains significant, gets smaller. We



can interpret it as the fact that over time the distance from the PRD has a lower impact on economic development, meaning that economic activity is less clustered around it. The same is happening to the R squared. While it is relatively high (for the univariate regression) for the difference in 2000, 28%, it drops by a lot in 2008 to 10% and even lower, 7%, I 2013. This brings us to two conclusions. First, the proximity to the PRD is less and less important for the economic development. Second, because the economic activity starts to spread out of the Inner PRD in a non-linear manner after 2000 and the very high and very low standardized residuals that can be seen on the following chart visualize this non-linearity. This can be also seen from the Global Moran's statistics in the table (highly clustered residuals in all three models).

The proposed linear model seems to be reasonable only for the first time period 1992-2000 where this proximity-development dependence seems most appropriate.

GWR

To account for spatial non-stationarity and difference in relationship between the luminosity and distance across space we run the Geographically Weighted Regression (GWR) with the same variables specification (with one exception – distance is not in the log scale anymore[1]) for the same three time periods.

Using the Fotheringham Adjustment we found the new Critical Value to exclude non-significant beta-coefficients (for alpha = 0.05 the adjusted C.V. = 2.88). The significant beta-coefficients are mapped on the charts on the next page.

Table: GWR R squared

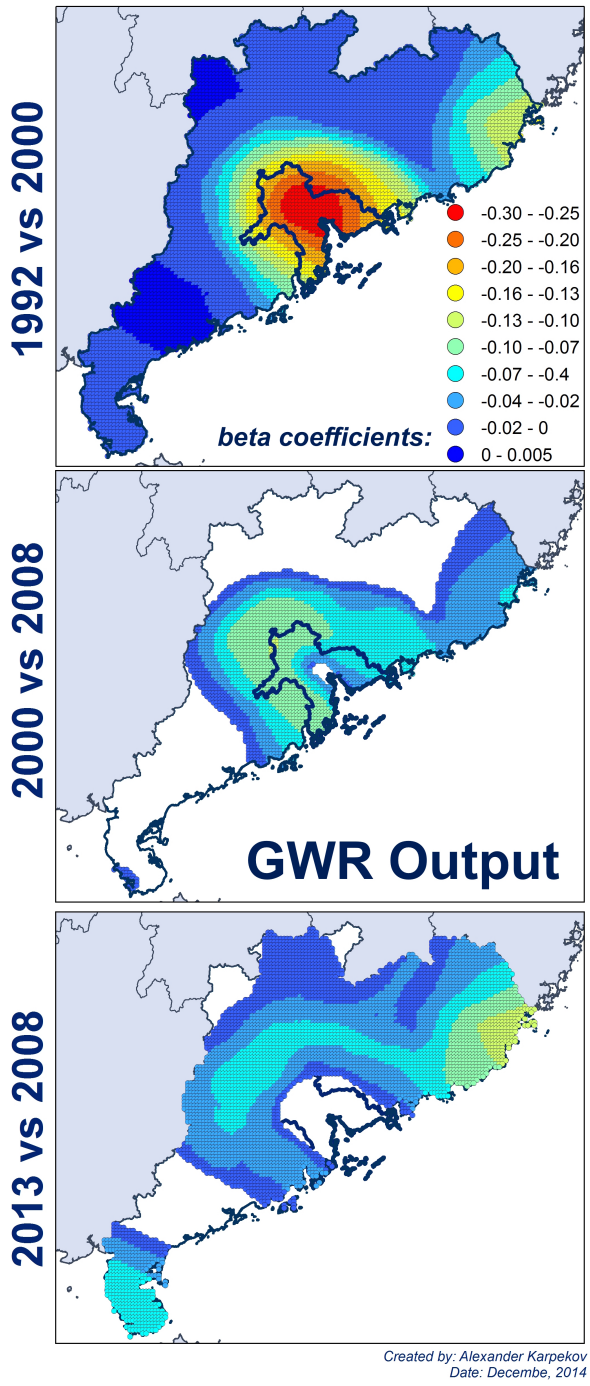
Dependent variable: Luminosity

Independent variable: Distance to PRD & Shantou

Time:	1992 vs. 2000	2000 vs. 2008	2008 vs. 2013
Adjusted R squared	0.4	0.2	0.22

From the R-squared table for GWR we see that accounting for spatial correlation we

[1] for some unknown reason ArcGIS refused to run the GWR with the logged distance even after I tried as professor McCord recommended to me to multiply the log distance by 1000



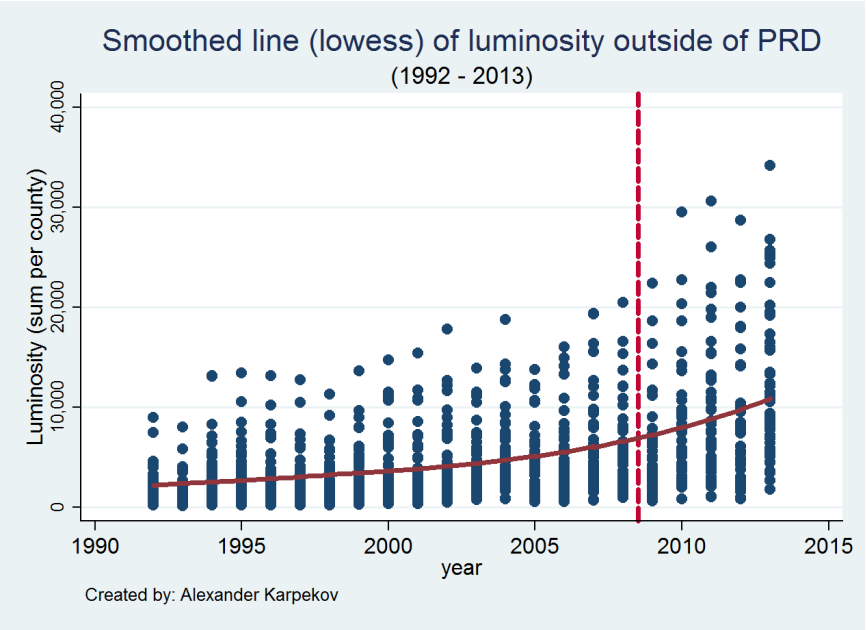
get a much better result for all three time periods (with R-squared of 40% for the first period versus 28% in OLS).

The chart shows the varying across space beta coefficients (only significant ones i.e., the ones with test-statistics (in absolute terms) greater than Fotheringham adjusted Critical Value). In the first time period almost 98% of the coefficients turned out to be significant. The coefficients, as predicted by our initial hypothesis, are greater (in an absolute value) in and around the Inner PRD and become smaller and smaller as the distance increases, which reflects the non-linearity of the relationship between distance and luminosity. In the second time period the coefficients are less strong (the strongest ones are barely equal to -0.10) and fewer of them are statistically significant. The coefficient of determination dropped to 20%. Virtually the same situation is depicted on the last map. This is another sign of the development acceleration in the Non-PRD regions post 2000.

Double Relocation Policy Efficiency

In this last part we will test if the Double Relocation Policy announced in 2008 was efficient. We will estimate it's efficiency by running fixed effect panel data estimation on night lights brightness time series for the counties outside of the Outer Pearl River Delta.

The Locally Weighted Smoothed (Lowess) scatterplot on the next page shows the trend line of how luminosity (sum of light brightness per each county) changed from 1992 to 2013 on the periphery of the Guangdong province. Before 2000 there was barely any growth. After 2000 the line gets slightly steeper showing that the economic development speeded up. The vertical red dashed line shows when the Double Relocation Policy was initiated (2008-9). In our statistical model we will estimate if the slope of the line i.e., the economic growth, was different after 2008. In other words, did the Double Relocation Policy have a statistically significant effect on the development in the Non-PRD regions.



To calculate the sum of the lights for each year in the Non-PRD regions we used Zonal Statistics as a table in the Spatial Analyst tool. Then we exported the data to Stata and run the Fixed Effects regression. The model specification looks the following way:

$$\boldsymbol{Luminosity}\ (\mathbf{log})_{i,t} = \widehat{\boldsymbol{\beta}}_{\mathbf{0}} + \hat{\boldsymbol{\lambda}} * \mathbf{log}(\boldsymbol{lumin})_{i,t-1} + \widehat{\boldsymbol{\delta}} * \boldsymbol{time\_trend}_{\boldsymbol{t}} + \widehat{\boldsymbol{\beta}} * \boldsymbol{DRP\_dummy}_{\boldsymbol{t}} + \boldsymbol{\varepsilon}_{i,t}$$

where:

- luminosity or night time lights brightness is normalized by log scale
- $\log(lumin)_{i,t-1}$ – one period lagged luminosity; included to account for serial autocorrelation
- time_trend – period counting variable; included to detrend the data
- DRP_dummy – "Double Relocation Policy" binary variable; simply = 1 for every year after 2008
- i – id for different counties (total of 24 counties in the non-PRD area).

The table with the regression coefficients is presented on the bottom of the page.

The first model did not include the lagged variable, the second one did. We will focus on the second model coefficients. The time trend coefficient is positive and significant; it denotes the positive growth in luminosity on all of the Non-PRD counties over time. The lagged lights coefficient is also positive and significant and shows that there was serial autocorrelation that we now have accounted for. However, the DRP dummy is of the greatest interest for us: it is also positive and significant and equals to 0.065. We interpret it as a proof of the Double Relocation Policy efficiency: the growth in luminosity and consequently economic growth after 2008 was

Table: Fixed Effects Estimation of the "Double Relocation: Policy Effect
Dependent variable: Luminosity (log scale)

Model specification	Without lag	With lag
Variables:	Light (log)	Light
DRP dummy (=1 if year > 2008)	**0.115*** **	**0.065** **
	(0.032)	(0.027)
Time Trend	0.071***	0.048***
	(0.004)	(0.005)
Lights Lag		0.373***
		(0.052)
R squared (within = FE)	0.76	0.78
R squared (overall = within and between)	0.26	0.74
n	1056	1008

Notes:
Robust Standard Errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1*

faster than the one before 2008 even when the data is detrended and the autocorrelation.

We can also make an attempt of economic interpretation of the coefficient. After the year of 2008 (when DRP dummy = 1) the luminosity on average increased by 6.5%. Referring back to our regression of GDP and lights relationship, if we run the regression backwards (i.e., regress log GDP on log lights) we get the slope coefficient of 2.56 (significant at 99% level). Its interpretation is as follows: every 1% increase in light brightness leads on average to 2.56% increase in GDP. Since the DRP dummy coefficient says that luminosity increased by 6.5%, then we can predict that Double Relocation Policy impact was 6.5*2.56% = **16.64% of GDP increase** (for all of the years from 2009 to 2013 together).

To sum up, we found that Double Relocation Policy had a very significant impact on the Non-PRD regional development. We were able to estimate that on average thanks to this policy every county increased its GDP by 16.64% over the course of the past 5 years.

Model Limitations

We identified three main areas where the first OLS regression (with proximity to the PRD as an independent variable) and GWR could be improved in the future analysis:

1. Include other explanatory variables: we only presented bivariate regression which is not enough for robust results; therefore, our current model might run into the risk of the omitted variable bias. Such variables as population census, cropland quality and some other could be included in the future models.
2. In our model we look at the Guangdong province as an independent state or even an island without accounting for provincial cross-border economic spillovers. The proximity to some influential economic centers located in the neighboring provinces is not accounted for.
3. The model does not account for the inhabitable land in the province; in Guangdong province the land suitability is mostly determined by the slope of the terrain (inhabitable if slope is less than 8 degrees). However, we did not manage to file slope data at a granular level (with a cell size of at least 5km). (Note: Unfortunately, professor McCord's slope raster's resolution was not sufficient for the province level analysis).

There are two main dimensions in which the second Fixed Effects Model testing Double Relocation Policy Efficiency could be enhanced:

1. Include other explanatory variables.
2. The current model is lacking a counterfactual; in other words, the model doesn't account for the situation when the growth after 2008 has increased in other counties / regions not affected by the policy.

Conclusion

In this paper we made an attempt enrich spatial data analysis with a cross-temporal dimension by looking at the change of spatial relationship over time. First, we tested if the economic development in Guangdong province after the beginning of 1990s was initially related to the proximity to the Inner Pearl Delta and how this relationship changed and became less strong over time. Running first OLS regression and then GWR we found that before 2000 the

economic growth was densely concentrated in the Inner PRD and the spread of development within the Guangdong province could be explained by proximity to the biggest cities in the Delta. Over time this relationship became weaker becoming less and less important by 2013 when the mainland and provincial government managed to incorporate the periphery of Guangdong in economic advancement. We also tested the efficiency of the Double Relocation Policy initiated in 2008 and proved its success. We were able to give an estimate of this success: DRP in Guangdong province permitted the Non-PRD regions to grow their GDP by approximately 16 extra per cent.

What does it mean for the Guangdong province development? Our main conclusion is that the government policies implemented over the course of the past two decades have been extremely successful. Initially Pearl River Delta led economic boom was gradually channeled to incorporate first the Outer PRD and then the rest of the province into the rapid economic development process.

As of today Guangdong remains the most rich province in China with its economy being equivalent to that of Mexico by nominal GDP and that of Canada by PPP. The past 5-6 year development plans are proving to be successful in transferring the Guangdong economy from manufacturing and industry heavy into the economy of innovation by relocating its manufacturing capabilities from the PRD outside. Even if the growth will slow down and the economy will be surpassed by the Yangtze River delta region Guangdong has already proved two things: it was a cradle of Chinese double digits economic growth that the world has never witnessed before and it also demonstrated its ability to adjust to the new global and local economic challenges.

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