ADAPTATION OF PARKING BEHAVIOUR TO PRICE-POLICY ADJUSTMENTS IN TAIPEI CITY: PATTERNS AND SPATIAL ANALYSIS

M. C. Tsai [1*], S. van Gasselt [1], T.C. Lin [1]

[1] Dept. of Land Economics, National Chengchi University, Taipei, Taiwan (107257033, svg, tclin)@nccu.edu.tw

Commission IV, WG IV/3

ABSTRACT: Parking issues are an extraordinarily important topic in highly populated urban areas. To balance parking demand, the Taipei city government implemented a price adjustment during policy establishment. In the planning process, the Traffic Analysis Zone (TAZ) is a common analysis unit used for parking and transportation-infrastructure planning, which is also the unit referred to in this contribution. Due to the local variation of spatial and social characteristics in various urban areas, drivers seem to behave more differently on a local level, than it could be represented by a relatively generic policy that is aimed for a regional context. A unified city-wide parking policy could not respond to this individual behaviour in an efficient and effective way. In this study, a dataset published by city covering detailing numbers on the demand, supply, and the illegal parking situation in each traffic zone is applied. By the implementation of Geographically Weighted Regression, the sensitivity of the parking fee setup, and also the influence of other variables on parking occupancies, which makes up for the shortcomings of the global model by allowing relationship to vary over spaces, can be captured. The eventual result verified that although parking price is an influential factor to occupancy, other factors such as the total supply of on-road parking spaces and the substitute parking spaces can affect parking behaviour as well. In general, if parking facilities can be provided without restriction, an average increase of 7 to 10 roadside parking spaces in a traffic area will attract 10 additional drivers to park their cars inside. This approach is considered beneficial for a policy review in order to identify the impact of policy adjustments in spatially heterogeneous settings. Based on the result proposed in this research, a recommendations of policy adjustment could also be put forward.

1. INTRODUCTION

1.1 Background

Taipei City is geographically located in a basin surrounded by mountainous areas and has a rich historical background of urban development and transportation infrastructure design in order to accommodate the needs for 2.65 million people (Parking Supply and Demand Survey, 2015). What is more is that Taipei City is an administrative island enclosed in the administrative area of the New Taipei City county, and thus it is confined in its lateral development. Like other cities in Asia, it holds a crowded urban scene with an average population density of 9700 residents per square kilometre making the urban area of Taipei more than twice as densely populated as most capitals in Europe (Department of Budget, Accounting and Statistics, 2015). Also, high occupancy on on-road parking spaces, which can cause traffic congestion and also severe air pollution deteriorates the city environment and quality.

Along with high population densities comes the challenge of efficient traffic management and a policy development that accounts for dynamics in urban transportation. As the awareness of urban sustainability rises, researches have been debating and developing indicators to evaluate the sustainability, especially in megacities. Parking is one of the important considerations to support the transportation system in developing cities. In several cities in Asia, such as Bangkok and Beijing, political measures of restrictions were taken to control the parking situation (Pojani and Stead, 2015; Shen et al., 2018). Also, adjustment on pricing mechanisms were also implemented meanwhile. This was

considerably more efficient due to the flexible adaption to different conditions (Anas and Lindsey, 2011). To improve the transportation system in a city, examination of parking behaviour is indispensable to understand, in how far a driver's parking behaviour is affected by various factors, including price, implementing policy, local and regional social characteristics, time periods, or parking purposes. Among all, parking fee has been the most dominant factor affecting the individual parking behaviour (Ibeas et al., 2014; Ma et al., 2013). Therefore, the Taipei city government implemented a new parking policy to solve the saturated parking situation in order to adjust the parking behaviour. Before this implementation, driver used to have a long holdover occupying on-road parking spaces in primarily residential areas, which caused difficulties for new visitors to find vacant parking space. Previously, setting parking price in a uniform scheme was the most common approach which the government used to take. Nevertheless, policies which used uniform pricing scheme in all areas and across time periods usually neglect the existing spatio-temporal characteristics. Intuitively, if demands lack homogeneity, it would be erroneous to set prices uniformly through space and time (Fiez et al., 2018).

1.2 Research Purpose

To make the best use of the policy, it requires a detailed understanding of the effects of influencing factors on different actions (Axhausen and Polak, 1991). However, drivers' responses are important in designing of parking facilities and policies, while policy can control relevant factors to regulate parking behaviour (Zong et al., 2019). Due to the local variation of spatial and social characteristics in various urban areas,

drivers behave differently to what a regionally implemented policy is able to represent. The efficiency and effectiveness of a unified city-wide parking policy could not reflect and respond to this individual behaviour. It would escape common sense if all parking spaces were charged at the same price despite considerable social heterogeneity across an urban landscape. For the past two decades, analysis was conducted on a city-wide scale, as local variability was difficult to assess. The city government used to review the parking effectiveness through a traditional regression of ordinary least square model. For this research we have been collecting variables on the traffic analysis zone (TAZ) level, aggregating data into areas and evaluating parking behaviour. The Traffic Analysis Zone (TAZ) is a common analysis unit used for parking and transportation infrastructure planning, which is also the unit referred to in this contribution. In this research, examining and analysing the spatial patterns are a first step to explore and understand the situation. The second step is to create a rational for an adaptive pricing scheme.

The major aims of this work are

(1) To identify the level of influence of parking fees on the occupancy before and after the policy implementation. By referring to maps of fee differences and occupancy difference, it can be seen whether the parking patterns remains the same.
(2) To review if the newly implemented policy could change the long holdover on on-road parking spaces effectively. A correlation can assist to find out whether the occupancy change after fee adjustment.
(3) To simultaneously test the impact of other variables, and to give out recommendations for future policy adjustment. A regional model of Geographically Weighted Regression is implemented to examine different factors and capture the sensitivity to each in local areas, in order to be able to give some advice.

2. METHODOLOGY

2.1 Data Description and Parking Patterns

Data used in this research were acquired from the Taipei City Parking Management and Development Office (TPMDO), which investigates parking supply and demand on an annual basis. Inspectors are sent to districts and investigate the actual occupancy situation on weekdays and weekends. All the administrative districts are investigated by turns. Six southern districts were surveyed during even years (2014 and 2016), and the other districts were surveyed during odd years (2015 and 2017). Twelve districts are investigated by detailing numbers on the demand, supply, and the illegal parking situation in each traffic zone. The overall dataset covers the actual number of cars parking inside the on-road parking spaces, cars that park off road in public parking lots or spaces attached to buildings, and those cars parking in illegal parking areas. The dataset has been published on an opendata drive by the Taipei city government.

Overall, there are 684 TAZs in 12 administrative districts, supplying over 18,000 curb parking places of which half are now charged since the parking policy has come into being in 2015. For the spatial distribution of TAZ refer to Figure 1. Data cover the time period between 2014 and 2017 and describe the situation describe the situation before and after the policy implementation. The locations of curb-parking and alternative parking spaces, such as public parking towers, are provided by the city government, which constructed an interpolated dataset

ready to use in geographical information systems. Data is provided on road-segment level but has been joined with the dataset on charged road segments to aggregate information more efficiency.

For the analysis of policy effectiveness, the decision about which factors to include plays an important role, and the process often refers to the past analysis experience and related literature to find the most suitable value to be included in the model estimation. On this account, locations, supply, demand and parking fee as factors are not sufficient in the overall policy review, since driver's preference may individually be affected by other attractiveness. Based on previous research, some potential factors influencing parking behavior will be selected to explore the relationship in areas (Van Der Waerden et al., 2011; Washbrook et al., 2006). Thus other demographic statistics describing the socio-economic and geographical features such as population density, the proportion of different land use, numbers of hospital, numbers of business and industries, are collected through data published by the Department of Statistics (DS). The investigated unit is based on the statistical area, and by considering both data accuracy and privacy exposure simultaneously, this level could be aggregated to other planning level and still maintain its detail. Since that the appropriate data unit to policy discussion in this research is on the TAZ level, parking fees are averaged to the same level to meet the same scale.

After initial data aggregation, derived higher-level data could be added using spatial data and pattern analysis. For this study, focus is put on a long-term parking behavior for on-road parking on weekend (curb parking spaces with grid lines), and traffic zones with no curb parking spaces are removed in this analysis. After that, through the observation on snapshots of parking fee difference and occupancy difference, the spatial distribution of whether different areas show heterogeneous sensitivity to various factors, which is displayed in Figure 1. It highlights the parking fee difference and the occupancy rate after adoption of the policy, which are both aggregated on TAZ level, and it can be seen that both are distributed in a heterogeneous pattern. Under this premise, policies set in a global aspect will be questioned, as more potential factors affecting parking behavior should also be taken into account for policy making.

The spatial distribution of traffic analysis zone is highlighted to show some characteristics describing the size of study area. Likewise, data collected are listed in Table 1, where the total number of occupied curb-parking spaces is set as the dependent variables and all others are treated as explanatory variables. All values follow the detailed verification to check if all explanatory variables are correlated to the dependent variable. Once the explanatory is not related to the dependency, they can hardly be explained in linear regression to be implemented in model estimation. And for an implementation of model estimation, these variables will then be carefully reviewed in the next step.

In the following process, this research will follow a systematic procedure to discuss the relationship between the actual occupancy and the tendency towards occupying parking space. Application of a multiple linear regression allows to explore the linear relationship between these variables. However, the spatial characteristic is used to be represented as dummy variable in traditional regression. This shortcoming is countered through a spatial-regression approach in this work. A geographically weighted regression is applied and the results are compared in order to search for the suitable spatial kernel to weight for all

observations, in order to better interpret the overall situation.

Dependent Variable	
OCC	Curb parking occupancy in TAZ
Explanatory Variables	
FEE	The average parking fee in TAZ
HOU	The number of household in TAZ
PB_A	The ratio of public land use
RE_A	The ratio of residential land use
IN_A	The ratio of industrial land use
CO_A	The ratio of commercial land use
POP_DENS	The population density in TAZ
CURB_S	The quantity of supplied curb parking spaces
OFF_S	The quantity of supplied off-road parking spaces
ILL_P	The number of illegal parking events
HOSP	The number of hospitals in in TAZ
AVG_DIST	The average distance to the alternative parking
AVG_PB	The average price of alternative parking

Table 1 Selected variables
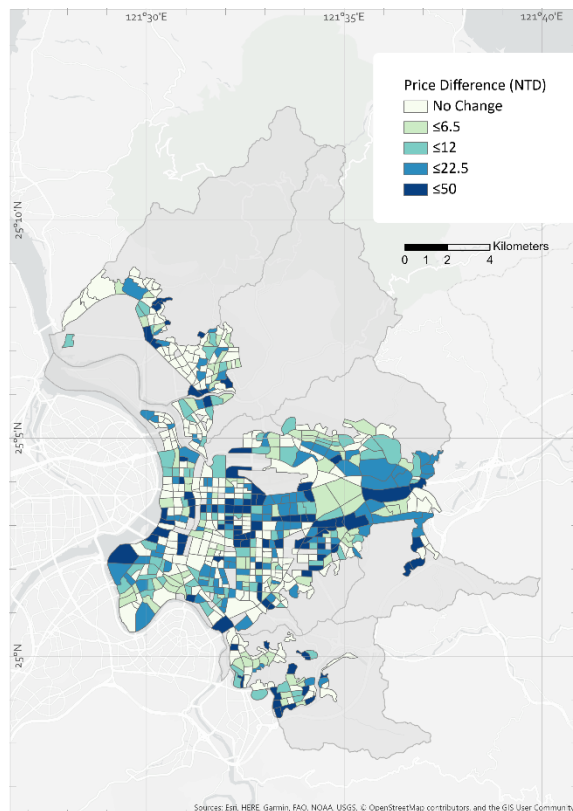
(a) Price Difference: showing the change of fee after the 2015policy change.
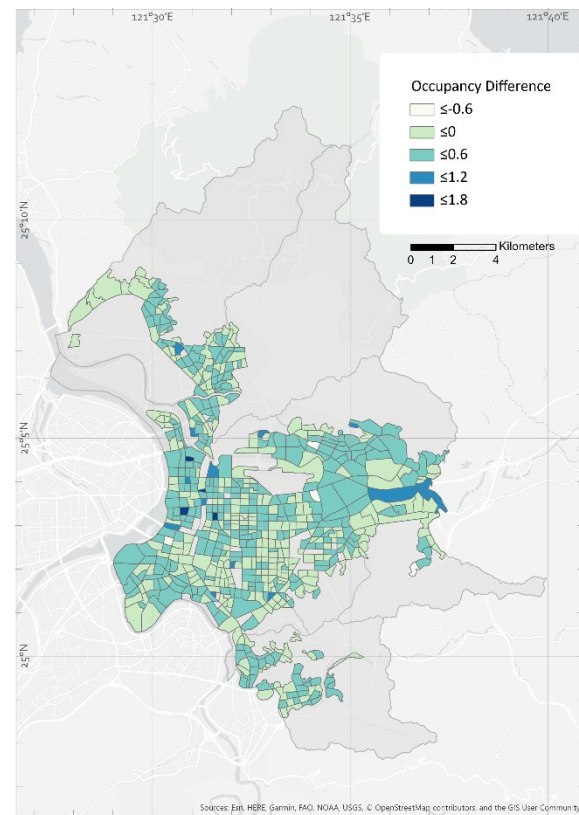
(b) Occupancy Rate Difference

Figure 1 Among all the traffic zones, 45 of them were removed because no parking spaces were provided. It can be identified that the change of occupancy rate does not correspond to the difference of parking fee, while in some specific traffic zones, raising the price does not seem to have significant influence on the suppression of parking demand.

2.2 Model Estimation of Multiple Linear Regression

In order to know how parking behavior adapted to the price policy adjustment, a multiple linear regression is applied, considering the actual number of occupied curb parking spaces in each TAZ, and discussing the relationship of selected explanatory variables in between. The calculation equation of Multiple Linear Regression is then shows as the following:

$$y_i = \beta_0 + \sum_k \beta_i x_i + \varepsilon_i \qquad (1)$$

Where β_0 is the intercept of this model
β_i then represents coefficients of explanatory variables
ε_i is the residual of this model

The model specified will be checked and compared, while selecting insignificant variables may lead to an inferior fit, hence some explanatory variables should be eliminated for estimating the better model. Additionally, a validation of checking multi collinearity by calculating the variance inflation factor (VIF) is required, in order to prevent the explanatory variables to be correlated to each other. This type of model considering multiple variables is exclusively used to estimate and predict drivers' discrete parking choices (Biswas et al., 2017; Washbrook et al., 2006), however, the heterogeneity in different areas cannot be presented. In a traditional regression model all variables are

treated as stationary, which would not correspond to reality at the end. Therefore, the standard error of estimated parameters may be underestimating the residuals, so an examination of spatial auto-correlation can be employed to check for non-homogeneous measurement errors by capturing the spatial heterogeneity in space (Anselin, 1995; Moran, 1950). In this case, a global regression is not efficient to interpret the overall situation, which is spatially limited and can hardly explore the differences, which prompts us to switch to regional regression analysis, targeting to solve the challenges with respect to spatial data aggregation and representation, and also turn to be another solution to the spatial non-stationarity.

2.3 Geographically Weighted Regression

Geographically Weighted Regression (GWR) is a method applied in estimating land value and house price, which holds a benefits that not only the spatial auto-correlation problems are fixed, the sensitivity of different independent variable can also be marked out (Brunsdon et al., 1996; Du and Mulley, 2006). The estimated parameters in GWR models are allowed to vary over space, which can be more suitable to analyze among arbitrary areas. Additionally, it can have a better fit and better predict in a scenario showing significant spatial heterogeneity, since that spatial non-stationarity could hardly be explained in traditional model (Fotheringham et al., 2002). Nowadays, there are several software packages supporting the calculation of GWR. The GWmodel package also implements the methodology of GWR, which can help to explore the spatial heterogeneity (Lu et al., 2014a), it is applied to for further analysis in this paper.

A basic GWR model can be specified containing dependent variables, independent variables, and the coordinates describing the locations. Hence the following equation show the generic scheme of a GWR:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \qquad (2)$$

$$\hat{\beta}(u_i, v_i) = \left(X_i^T W(u_i, v_i) X_i\right)^{-1} X_i^T W(u_i, v_i) Y_i \quad (3)$$

where (u_i, v_i) denotes the coordinate of observation i,
ε_i is the error term of equation
$\hat{\beta}$ is the estimated value of β
β_i then represents coefficients of explanatory variables
$W(u_i, v_i)$ is the weight matrix

The weight matrix W in the formula is determined by the selected kernel. A kernel can be considered as a moving window weighting the observations through a distance-decay principal, and the size is then defined by the length of bandwidth (Mennis, 2006). In the regression, determination of kernel and bandwidth parameters is paramount, while the search radius for observations and weighting may affect the predictability and the fitness of the regression model. The kernel type can be either determined to be fixed or adaptive (Gollini et al., 2015; Lu et al., 2014b). While setting a fixed kernel, the bandwidth of regression points is set constant. Instead, while selecting an adaptive kernel then weights, the bandwidth distance changes according to the spatial density of features in the input feature class, thus for specific cluster appearing in the area, an adaptive kernel can better fit to the situation. (Fotheringham et al., 2002; Harris et al., 2010).

A notable point is that kernel is controlled by the bandwidth (Gollini et al., 2015). Therefore, two algorithms are employed

to select appropriate bandwidth, aiming to better fit the reality of locality. Selecting a cross-validation considers the model accuracy, which minimizes prediction error of dependent value (Brunsdon et al., 1996; Yang et al., 2013). A Corrected Akaike Information Criterion (AICc), which is the extension of original Akaike Information (AIC), minimizes the estimation error of the response variable during search of bandwidth (Akaike, 1974; Fotheringham et al., 2002; Wheeler and Páez, 2010). This considers both model complexity and accuracy, iterating the calculation several times to derive the best value of bandwidth. Equation 4 shows the principal of searching through a cross-validation:

$$CV = \sum_{i=1}^{n} (y_i - \hat{y}_{\neq i}(b))^2 \qquad (4)$$

where n is the number of total observations
$\hat{y}_{\neq i}(b)$ is the is the fitted value ignoring observation i calculated at the bandwidth size of b

And the equation of AICc is described as the following:

$$AIC_c = 2n \log_e(\hat{\sigma}) + n \log_e(2\pi) + n\left(\frac{n+tr(s)}{n-2-tr(s)}\right) \qquad (5)$$

where tr(s) represents the trace of the hat matrix, which is determined by the bandwidth.
n is the number of total observations
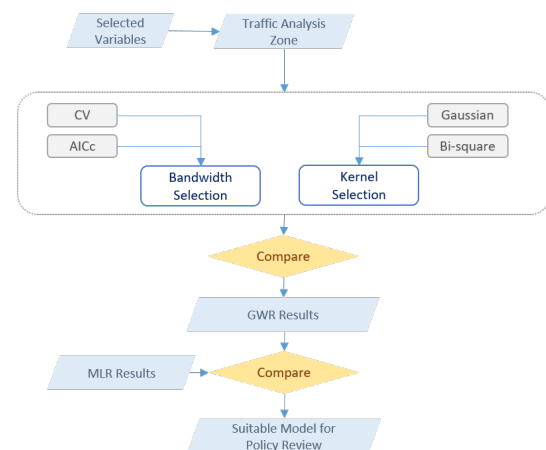$\hat{\sigma}$ is the estimated standard deviation of the error term

Figure 2. Overall workflow of GWR processing

Through the methods described above, the appropriate bandwidth will be selected and employed in the GWR, and correspondingly help to describe the relationships between independent variables and the dependent variables in different districts. The selection of bandwidth and kernel parameters has a large impact because they smooth the data under different scales in an area. Consequently, if bandwidth weights data with an adaptive kernel, but the result is over-smoothed, all data will be weighted and considered as similar whose local variance cannot be captured eventually (Fotheringham et al., 2002). The complete workflow of GWR follows the one shown in Figure 2 to finish the model execution, and is eventually compared to the result of multiple linear regression. Since for the past decades, policy was usually set as a global perspective, it may divert from the actual aims during establishment. In this paper, a different regression model and the result will be compared to see which shows the better explanation for observed parking behaviour, and which can be put forward into policy review comments to

improve the recent shortages.

3. ANALYSIS RESULTS AND DISCUSSIONS

3.1 Empirical Results on Global Regression

The essential first step of model estimation is the selection of explanatory variables and the dependent variable. Aiming to explore if parking occupancy changes after implementation of the new policy, variables such as parking demand, supply of parking spaces, average price of alternative parking spaces, and the proportion of different land-use parameters were used in the discussion. These variables are selected during the estimation of a multiple linear regression, using two different models in order to search for the suitable variables to interpret the local variance in parking behaviour. Based on the first model, multicollinearity appears in several variables. To avoid this, they will be removed in the later process of analysis. Thereupon, in further steps of model estimation, some of the variables are removed according to the preliminary result obtained from the traditional model, and are implemented in the GWR afterwards. The estimated parameters of each variable in the global model are listed in Tables 2 and 3.

It is seen that parking supply and the actual fee shows the most significant influence on individual parking behaviour. In spite of that we often consider that drivers lower their parking expectations while suffering higher parking prices. However, the government's extensive implementation of parking charging policy has changed parkers' behavior.

Apparently, while the charged parking fee increases, the number of occupied curb-parking spaces increases as well. In both Model 1 and Model 2, drivers present surprising behavior to the parking fee. When the price increases, people will not decrease the choice for on-road parking. On the contrary, if price raise 0.15 NTD in the traffic zone, one more on-road parking space will be occupied. In addition, the ratio of public land use shows a positive effect on the occupancy, while the charged parking fee of off-road parking lots also holds some magnitude of influence, but at the insignificant levels of 0.6643. Although the result of the global model already holds a convincing explanatory power to interpret the policy impact, we are lacking information which shows the most apparent improvement after the policy implementation. In another words, a regional model examining data considering local perspective is indispensable.

	Model 1	
	coefficient	*p-value*
Intercept	0.6069	0.8129
FEE	0.189	0.0022
HOU	0.0023	0.3427
ILL_P	0.058	0.0492
OFF_S	-0.0039	0.000001
CURB_S	0.813	0
PB_A	2.13	0.052
IN_A	-25.24	2.88E-10
RE_A	-0.201	0.9664
CO_A	-0.088	0.9812
POP_DENS	3.1068	0.3737
HOSP	0.048	0.7764
AVG_DIST	0.0027	0.0013
AVG_PB	-0.01	0.6643
N	641	
Multicollinearity: HOU, RE_A (VIF>10)		
R^2	0.9365	
R^2_{adj}	0.9351	

Table 2 Estimated Coefficients of Model 1: Model 1 shows a convincing explanatory power overall, however, a few variables exist multicollinearity which may mislead the consequence where explanatory variables are not independent, which will be later removed in Model 2.

	Model 2	
	coefficient	*p-value*
Intercept	-0.088	0.9712
FEE	0.147	0.0148
HOU	0.0028	0.009
ILL_P	0.049	0.00001
OFF_S	-0.004	0.0626
CURB_S	0.808	0
PB_A	2.54	0.0189
IN_A	-24.26	0
N	641	
R^2	0.9353	
R^2_{adj}	0.9346	

Table 3 Several variables such as average distance to the alternative parking choice, the average fee of off-road parking, numbers of hospital are removed due to the insignificance result. And the number of household, population density and ratio of residential land use are eliminated due to the multicollinearity check based on the VIF.

3.2 Validations and Discussions of GWR Result

After comparing a series of given bandwidths selected via different methods, eventually a basic GWR determined through an adaptive kernel using the AICc search methods for the bandwidth was implemented, which can be seen in Table 4. The adjusted R-square value appears the highest. Accordingly, for GWR model estimation, weighting observations through a Bi-square kernel by AICc searching method will be chosen to explore the policy impact.

Bandwidth Searching Method	Kernel	R^2_{adj}
CV	Bi-square (Adaptive)	0.9441
	Gausssian (Adaptive)	0.9494
AICc	Bi-square (Adaptive)	0.9583
	Gausssian (Adaptive)	0.9522

Table 4. Comparison of different variable

The candidate variables to be put into the GWR model are then selected based on the result of global model. The descriptive statistics of individual variables are also shown in Table 5. This describes the distribution of all variables, showing their coefficients in a quantile distribution. Apart from this, as seen in the maps shown in Figures 4 to 6, relationships between different variables in individual districts are revealed. However, regarding some specific factors, particularly for parking fee, parkers in different district react diversely. Usually parkers show more desire to park at lower price, yet they show an opposite reaction in different traffic zones even located in the same administrative district. In the meanwhile, other variables are taken into discussion to see which of them can be the next targets to recommend the government to focus on.

Despite the pattern shown in the global model indicating that parkers' willingness of parking in curb-parking space does not decrease even though parking fee increases, the pattern of the local weighted regressions shows a divergent development. If other variables are controlled, the government can still implement a similar price adjustment policy to improve the situation, which is still valid for certain areas. As seen in Figure 5, it is identified that alternative parking supply in different districts does not show the attractiveness at the same level. Most parkers lower their expectations to park in curb parking spaces if the quantity supplied of off-road parking increases. However, in some districts, the amount of alternative parking spaces does not affect their preferences. And according to Figure 6, parkers are still attracted by the amount of curb-parking space, notwithstanding the increased price, and are still mainly attracted by on-street parking spaces. Each additional 0.7 to 1 curb parking space will attract an additional driver to park the car in.

To see if results improve after conducting a GWR model, it is discussed in parallel to the global model. Table 6 shows the regression result of GWR compared to the traditional regression. From the result, the average R-square value of the geographically weighted regression indicates a higher value of data variability, and an improved result when compared to the global regression on the fitness of model estimation. Nevertheless, to better consider variables holding global or local characteristics, an advanced model should be extended, which will be suggested to take in the future prospects. But at the current stage, GWR is apparently better than the traditional model used to analyse the parking patterns.

	Min	1st Q	2nd Q	3rd Q	Max
Intercept	-0.302	-3.094	-0.976	0.941	20.543
FEE	-0.348	-0.011	0.028	0.076	0.7274
HOU	-0.0027	0.0005	0.002	0.004	0.0158
CURB_S	0.609	0.845	0.942	0.968	1.0424
OFF_S	-0.016	-0.003	-0.001	-0.0002	0.0030
ILL_P	-0.142	0.0009	0.031	0.088	0.248
IN_A	-0.651	-0.109	-4.273	0.988	11.684
PB_A	-6.414	-0.849	0.044	2.024	11.139

Table 5. Summary of GWR coefficient estimates

Model	R^2_{adj}	RSS	IMPROVE
Global Model	0.9346	1965601	
GWR	0.9583	95400	1870201

Table 6. Comparison of Global Model and GWR

This result can be validated through in-situ observation, since land-use divergence in various districts in particular in southern Taipei show narrow alleys and roads leading to insufficient curb parking spaces, while setting up more spaces on- and off-road can possibly improve the current situation. For industrial land use and commercial areas, such as in eastern Taipei, charging higher prices cannot effectively change on-road occupancy, as their parking purpose is different from that in residential areas.
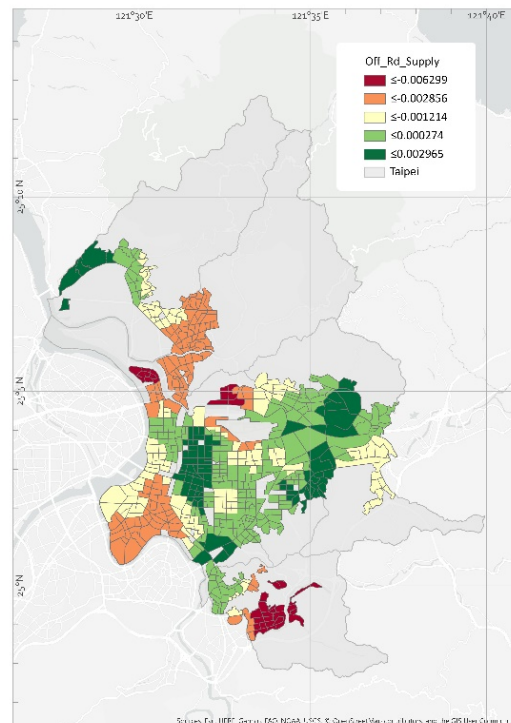

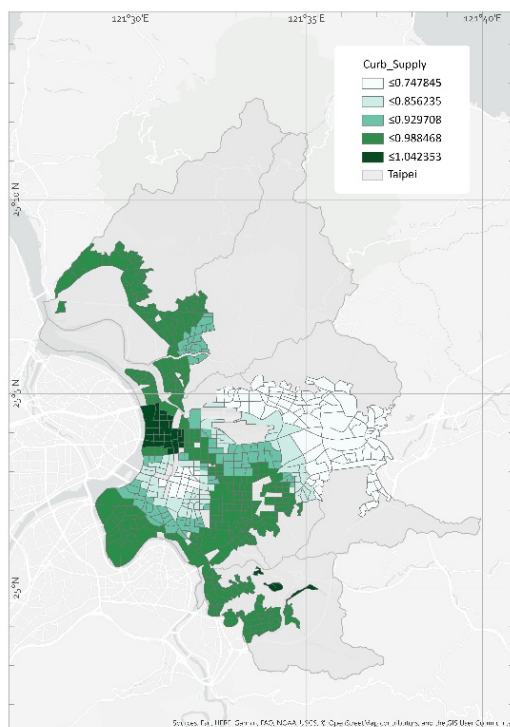Figure 3. Coefficient of Off-road Parking Space Supply

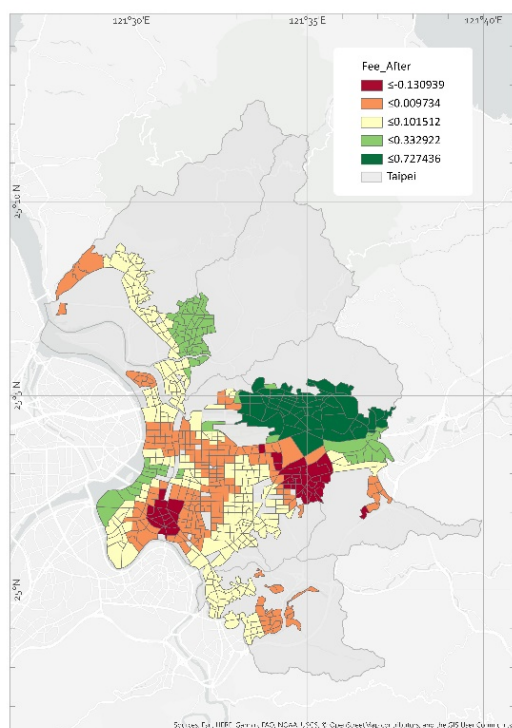Figure 3. Coefficient of Curb Parking Space Supply

Figure 4. Coefficient of Curb Parking Fee (After Policy Implementation)

4. CONCLUSIONS AND FUTURE PROSPECTS

4.1 Conclusions

The heterogeneity of parking patterns and the nonstationarity that are prone to occur in space lead to the government's

difficulties to propose policy improvement methods based on regional variation when conducting policy analysis. Thus a regional weighted regression as GWR possess the benefit to solve this challenge, since that this quantifying technique enables researchers to explore the exceptions and local variance of data. After a comparison of a traditional regression model and a geographically weighted regression, weighting observations under the implementation of an adaptive bi-square kernel searching the bandwidth through the AICc method shows the best result. While among all factors, parking fee before the policy implementation shows the most local variance, which has been partially improved through the new policy, yet showing divergent situation especially in the eastern area of Taipei. Apart from this, from the result it is shown that other variables show more attraction on parkers to park. If all the factors are controlled, only increase curb parking spaces may simultaneously attract one car to park inside.

This study applies GWR techniques for investigating an urban parking situation. Although this method has been widely applied in analyzing house price in real estates, analyzing parking occupancy and its potential attractiveness is a new contribution to assist policy makers to review the implementation in local regions. Overall, for the next stage of policy adjustment, here in this research it is advised that policies should consider the local variance during a modest revision, and concurrently target to other attractive variables for improving the current situation, which is shown as the following:

(1) As it can be seen from Figures 3 to 5, after this implemented policy, drivers in the eastern area of Taipei react differently from what we would expect. Only in some districts near the city central and the eastern area, drivers will decrease their willingness to park on road while the parking fee increases.

(2) Drivers still keep their preference on occupying curb-parking spaces, when the fee increases, it does not seem to change their choice on the on-road parking. Some drivers will tend to switch their choice on alternative parking type, however, drivers will make this decision when the district can provide at least one hundred off-road parking spaces to substitute the original parking choice.

Finally, recommendations given to the city government can be summarized as follows:

(1) Although the adjustment of parking fees is the dominant measure to take, recent analysis has shown that this measure has already changed the parking behavior, while for reviews on policy adjustment afterwards, targeting to parking fee may have limited benefits.

(2) Alternative parking choice provides less attractiveness to drivers, thus if the measure is being taken to the next level, focusing on establishing new off-road parking infrastructure should be put forward in the discussion. According to our analysis, it can be identified that the effectiveness of setting this goal can be limited

(3) Since drivers' behavior is mostly affected by the quantity of supplied curb parking spaces, decreasing on-road parking spaces to decrease the attractiveness can be another step to take, which can lead to less traffic congestion during cruising trips.

The result of this paper integrates data through a GIS approach

and by using open-source R-packages for the purpose of analyzing drivers' behavior which spatially varies over the city area of Taipei. It shows that the newly implemented policy by the government can improve the city's parking situation, but drivers' parking behavior is not only affected by the price. Hence increasing the quantity of alternative parking lots by considering the district responding to other preferences would be another action to take in a future step. Based on this structural approach, the magnitude of policy impact in different districts could be well identified, and also spatially varying effects of diverse social characteristic variables to the parking behavior. As a consequence, the methodology proposed in this paper could provide a guidance on policy adjustment and gives some recommendations for the city government, in order to set new goals henceforward. Such a workflow could easily be transferred as data model to other cities for which statistical data are available in order to assess the parking situation and to provide characteristics and recommendations for an improved policy development.

4.2 Future Prospects

As a future step, an extension of the GWR method is considered, which features a semi-parametric approach in order to calculate the regression model by considering both global and local effects. Under this assumption, it discuss factors more comprehensively from different perspectives.

REFERENCES

Akaike, H., 1974. A new look at the statistical model identification. Springer, pp. 215-222.

Anas, A., Lindsey, R., 2011. Reducing Urban Road Transportation Externalities: Road Pricing in Theory and in Practice. *Review of Environmental Economics and Policy* 5, 66-88.

Anselin, L., 1995. Local Indicators of Spatial Association—LISA. *Geographical Analysis* 27, 93-115.

Axhausen, K.W., Polak, J.W., 1991. Choice of parking: Stated preference approach. *Transportation* 18, 59-81.

Biswas, S., Chandra, S., Ghosh, I., 2017. Effects of On-Street Parking In Urban Context: A Critical Review. *Transportation in Developing Economies* 3, 1-14.

Brunsdon, C., Fotheringham, A.S., Charlton, M.E.J.G.a., 1996. Geographically weighted regression: a method for exploring spatial nonstationarity. 28, 281-298.

Du, H., Mulley, C., 2006. Relationship between transport accessibility and land value: Local model approach with geographically weighted regression. 1977, 197-205.

Fiez, T., Ratliff, L.J., Dowling, C., Zhang, B., 2018. Data Driven Spatio-Temporal Modeling of Parking Demand, 2018 Annual American Control Conference (ACC), pp. 2757-2762.

Fotheringham, A.S., Brunsdon, C., Charlton, M., 2002. Geographically Weighted Regression: The Analysis of Spatially Varying Relationships. Wiley.

Gollini, I., Lu, B., Charlton, M., Brunsdon, C., Harris, P., 2015. GWmodel: An R Package for Exploring Spatial Heterogeneity Using Geographically Weighted Models. *Journal of Statistical Software* 63, 1-50.

Harris, P., Fotheringham, A.S., Crespo, R., Charlton, M., 2010. The Use of Geographically Weighted Regression for Spatial Prediction: An Evaluation of Models Using Simulated Data Sets. *Mathematical Geosciences* 42, 657-680.

Ibeas, A., dell'Olio, L., Bordagaray, M., Ortúzar, J.d.D., 2014. Modelling parking choices considering user heterogeneity. *Transportation Research Part A: Policy and Practice* 70, 41-49.

Lu, B., Harris, P., Charlton, M., Brunsdon, C., 2014a. The GWmodel R package: further topics for exploring spatial heterogeneity using geographically weighted models. *Geo-spatial Information Science* 17, 85-101.

Lu, B., Harris, P., Charlton, M., Brunsdon, C., 2014b. The GWmodel R package: further topics for exploring spatial heterogeneity using geographically weighted models. *Geo-spatial Information Science* 17, 85-101.

Ma, X., Sun, X., He, Y., Chen, Y., 2013. Parking Choice Behavior Investigation: A Case Study at Beijing Lama Temple. *Procedia - Social and Behavioral Sciences* Volume 96, 2635-2642.

Mennis, J., 2006. Mapping the Results of Geographically Weighted Regression. *Cartographic Journal* 43(2), 171-179.

Moran, P.A.P., 1950. Notes on Continuous Stochastic Phenomena. *Biometrika* 37, 17-23.

Pojani, D., Stead, D., 2015. Sustainable urban transport in the developing world: beyond megacities. *Sustainability* 7, 7784-7805.

Shen, L., Du, L., Yang, X., Du, X., Wang, J., Hao, J., 2018. Sustainable strategies for transportation development in emerging cities in China: A simulation approach. *Sustainability* 10, 844.

Van Der Waerden, P., Timmermans, H., Barzeele, P., 2011. Car Drivers' Preferences regarding Location and Contents of Parking Guidance Systems: Stated Choice Approach. *Transportation Research Record* 2245, 63-69.

Washbrook, K., Haider, W., Jaccard, M., 2006. Estimating commuter mode choice: A discrete choice analysis of the impact of road pricing and parking charges. *Transportation* 33, 621-639.

Wheeler, D.C., Páez, A., 2010. Geographically weighted regression, Handbook of applied spatial analysis. Springer, pp. 461-486.

Yang, Y., Tong, X., Zhu, J., 2013. A geographically weighted model of the regression between grain production and typical factors for the Yellow River Delta. *Mathematical and Computer Modelling* 58, 582-587.

Zong, F., Yu, P., Tang, J., Sun, X., 2019. Understanding parking decisions with structural equation modeling. *Physica A: Statistical Mechanics and its Applications* 523, 408-417.