Assessing Economic, Social and Environmental Impacts on Housing Prices in Hong Kong: A Time Series Study of 2006, 2011 and 2016

1. Jing Li 2. Weixuan Fang 3. Yuan Shi* 4. Chao Ren

1. Assistant Professor, Department of Geography and Resource Management & Institute of Future Cities, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong SAR.
   victorli@cuhk.edu.hk
2. PhD Candidate, Centre for Urban and Public Policy Research, University of Bristol, Beacon House, Queens Road, Bristol, UK.
   rn19865@bristol.ac.uk
3. Research Assistant Professor, Institute of Future Cities, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong SAR.
   shiyuan@cuhk.edu.hk
4. Associate Professor, Faculty of Architecture, University of Hong Kong, Shatin, New Territories, Hong Kong SAR.
   renchao@hku.hk

*Corresponding author: SHI Yuan

Email address: shiyuan@cuhk.edu.hk

ORCID: 0000-0003-4011-8735

Postal address: Room 905, YIA Building, The Chinese University of Hong Kong, Shatin, NT, Hong Kong SAR, China

Phone: +852 3943 9428

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Abstract

Given Hong Kong's unique high-density urban environment and limited land resources, more and more general public has been concerned about the living quality. Based on three waves of census data (2006, 2011 and 2016), combined with our spatial-temporal urban environmental database (consists of three local datasets of urban climate and air quality, this paper assesses the impacts of social, economic, and environmental factors on the logarithm of housing prices in Hong Kong through linear regression analysis. Specifically, both supply and demand-side economic factors have significant impacts on housing prices. Demographic factors are not as significant as expected in affecting housing prices. Transportation factors have more significant effects in the short run than in the long run. Environmental factors, including the number of hot night hours, Annual Air Quality Index (AAQI) of Nitrogen dioxide (NO_2) and particulates with particle sizes less than 10 microns (PM_{10}), significantly affect housing prices over time. The results have important implications: Current policy instruments to prevent housing price escalation are focused on increasing property tax or land supply (economic factors), while

little attention is paid to social or environmental factors which are geographically heterogeneous. Our findings suggest that housing provision in the New Territories may be a feasible solution to alleviate the housing crisis as its demographic pattern, transportation connectivity and air quality are significantly different from Hong Kong Island or Kowloon Peninsula. In regards to urban environmental problems brought by the high-density development in Hong Kong despite land use saving, intensified urban infrastructure, and promotion of public transportation, our study contributes to the understanding of its housing price dynamics from a more holistic perspective by comparing the impacts of economic, social and environmental factors.

Keywords: Housing Prices; Economic Factors; Social Factors; Environmental Factors

1. Introduction

Nowadays, people are increasingly concerned with the nexus between community, environment and healthy living. In the context of Hong Kong, a densely populated metropolis, the health impact of housing and community problems are experienced differently by people in income groups and health dimensions (Wang et al., 2018). For instance, Zhang and Huang (2018) found that the problem of abundant and unhealthy food is more severe than the problem of limited access to healthy food in Hong Kong in

proximity to people's homes. A global survey of urban professionals conducted by the Economist Intelligence Unit (2011) further revealed that urban livability and economic growth are inextricably intertwined. As for Hong Kong, a high-income economy by international standard, the situation can be even more complicated as its skyrocketing housing price limits the housing tenure choice of its low- and many middle-income households (Forrest and Xian, 2018). High housing price as a major challenge to people's living standard is determined by various social, economic, and environmental factors.

While previous studies have investigated the economic determinants of housing price, little is known about the combined effects of economic, social and environmental factors on housing price. The main challenge to this research gap is data incompatibility: there are typically two types of variables for explaining housing price, namely economic factors and hedonic factors. The former is at a large scale, such as across cities or regions, while the latter is at a building level, such as unit- or complex- specific. The former sample usually has good control for economic and social factors but is insufficient in controlling environmental factors, while the latter sample cannot control economic factors. To allow the impact study of different factors on housing price, a more comprehensive database is required.

Based on three waves of census data, combined with a spatio-temporal database (which is generated by integrating two datasets on the spatial estimation of air temperature and the counts of hot day/hot night hours developed in our previous urban climate studies and

one dataset of Annual Air Quality Index from local environmental protection authority. Details of the three datasets are shown in Table 2. As a part of a series of theme-based research on Hong Kong heat-health risk assessments, the database has been being used for local heat-health and environmental research). This paper makes an extensive comparison of the combined impacts of social, economic, and environmental factors on housing prices in Hong Kong at a macro level. We aim to evaluate to what extent the determinants of housing prices have changed during the period 2006 to 2016 when the average housing price in Hong Kong has increased by 3.6 times (Rating and Valuation Department, 2019). The remainder of this paper proceeds as follows. Section 2 reviews the literature on various related issues, i.e., high-density living; vertical city; Asian urbanism; housing price determinants (transport, amenity, demography, location, income) and hedonic price modeling. Section 3 describes the data structure and methods used for regression analysis. Section 4 presents the estimation results and discusses their research implications. Section 5 concludes the findings.

2. Literature Review

Hedonic price modelling is typically used to study the impacts of housing characteristics on real estate prices (i.e., Chau et al., 2001; Bao and Wan, 2004). In the context of Hong Kong, people are willing to pay for desirable housing attributes such as an apartment at higher floor and shorter distance from CBD (Mok et al., 1995). Choy et al. (2007) found

that attributes including the property of larger size, higher floor level, better view and proximity to a railway station all require a premium. Basically, there is a consensus that convenient transportation (So et al., 1997; Yiu and Wong, 2005; Yiu and Tam, 2007; Cervero and Murakami, 2009) and scenic view (Tse, 2002; Jim and Chen, 2009; Hui et al., 2012) tend to increase housing prices. However, buyers' tastes and preferences for other housing attributes may vary substantially (Chan et al., 2008; Mak et al., 2010; Tang and Yiu, 2010; Wong et al., 2011).

Data availability is a major constraint to input variables into the hedonic modelling (Chau and Chin, 2003). Tse and Love (2000) classified hedonic price attributes into four categories: structural, physical, neighborhood and environmental. Chau et al. (2004) found that green features such as balcony has a positive effect on housing prices, whereas air and noise pollution have a negative effect on housing prices. Wong (2008) revealed that the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003 lowered property price by 1.6 percent on average. Zhang et al. (2012) identified that the green roof is not an option for buildings in Hong Kong. Wadu and Wan (2013) discovered that people are willing to pay more for green features recognized by HK-BEAM and HK-GBC. Interestingly, Li and Li (2018) found that the smell from landfill does not have a negative impact on housing prices in Southeast New Territories of Hong Kong. Beyond Hong Kong, there are a few studies focusing on the relationship between environmental

factors and housing prices. For instance, Zheng et al. (2010) recognised that home prices are lower in cities with higher ambient pollution.

As a world-class financial center, Hong Kong has scarce land resources for development. High land prices have prompted Hong Kong to adopt a high-density urban development strategy, making it one of the most densely populated cities in the world (Yeh 2011). There have been debates on the pros and cons of high-density urban development (Clark and Moir 2015), as it inevitably brings urban environmental problems despite land use saving land use, intensified urban infrastructure, and promotion of public transportation. In Hong Kong, high-density urban forms reduce urban air ventilation (Ng 2009), and the environmental challenges it brings include, but not limited to, urban heat island effects (Shi et al. 2018), prolonged extreme hot weather (Cai et al. 2017; Shi et al. 2019), and deteriorated outdoor air quality and microclimate condition (Shi et al. 2016). Building morphological forms have been found to be influential to housing price in Hong Kong (Li et al. 2018). It has been found that concerns about climatic risks also affect the urban real estate market (Bunten and Kahn 2014). Besides that, studies also show that air quality has direct or indirect impacts on housing prices (Kenneth Y. Chay and Michael Greenstone 2005). For example, in Seoul, another Asian high-density metropolitan area, the benefits of air quality improvement on housing price have been measured by using a spatial hedonic approach (Won Kim et al. 2003). Having that said, there is still a lack of holistic understanding on the impacts of environment-related factors

on housing price in Hong Kong. Abovementioned literature reveals a major research gap about Hong Kong housing price: despite the substantial work that has been done at the micro-level (unit- or complex- specific), little is known about the relationship between housing price and macro-level (social, economic and environmental) variables. Although there are a handful of studies about the nexus among social, economic and environmental factors on buildings in Hong Kong (i.e. Chiang et al., 2014; 2016), the spatial-temporal effect of environmental factors on housing price remains underexplored. In particular, the impact of air quality on housing price dynamics requires further exploration.

3. Materials and Methods

The yearly data in territorial planning unit (TPU) level was collected for 2006, 2011 and 2016 to evaluate the impact of major socioeconomic and environmental factors on housing price in Hong Kong. In specific, We studied 13 socioeconomic factors and 6 environmental factors for their relationships with housing price growth in Hong Kong.

The socioeconomic factors, including (1) distance from Mass Transit Railway (MTR), (2) population, (3) median age, (4) labor force, (5) labor force participation, (6) median monthly income, (7) the number of households, (8) median household income, (9) median household rent, (10) private permanent housing, (11) degree course attender, (12) place of study in the same district and (13) place of work in the same district, were collected from the official website of Census and Statistic Department of the Government of Hong

Kong SAR. While the distance between each representative residence in each TPU and the nearest MTR was calculated by the linear distance in ArcGIS.

Table 1 *List of socioeconomic factors with their definitions and data sources.*

Factors	**Definition and data source**
Distance from MTR	The linear distance between the objective residence and its nearest MTR via the calculation in ArcGIS
Population	The total number of residents in each TPU (from census data)
Median age	The median age of residents in each TPU (from census data)
Labor force (person)	The number of residents who have the ability to work including both employed and unemployed people in each TPU (from census data)
Labor force participation (%)	The percentage of labor force in each TPU via the formula: f/d*100
Median monthly income (HK$)	The median monthly income of residents in each TPU (from census data)
The number of households	The number of households in each TPU (from census data)
Median household income (HK$)	The median monthly income of households in each TPU (from census data)
Median household rent (HK$)	The median rent of households in each TPU (from census data)
Private permanent housing (person)	The number of residents who own their own private permeant housing in each TPU (from census data)
Degree course attender (person)	The number of residents who have ever attended the degree course in each TPU (from census data)
Place of study in the same district (person)	The number of students who live and study in the same TPU (from census data)
Place of work in the same district (person)	The number of employees who live and work in the same TPU excludes who work at home (from census data)

Environmental determinants include (1) annual averaged daytime air temperature (temp_d06); (2)annual averaged nighttime air temperature (temp_n15); (3) number of very hot day hours (VHD06); (4) number of hot night hours (HN15); (5) Annual Air Quality Index (AAQI) of Nitrogen dioxide (NO_2) and (6) particulates with particle sizes less than 10 microns, which are known as respirable suspended particulates (RSP) or PM_{10}.

Table 2 *Data Description of Collated Environmental Data based on 2011 version of TPU*

Column Name	**Data**	**Description**
TPU	TPU No. based on 2011 version.	GIS data from Planning Department.
temp_d06	Estimated annual averaged daytime air temperature in 2006.	Based on the methodology proposed in the following paper: Shi, Y., Katzschner, L., & Ng, E. (2018). Modelling the fine-scale spatiotemporal pattern of urban heat island effect using land use regression approach in a megacity. *Science of the Total Environment*, 618, 891-904. doi: https://doi.org/10.1016/j.scitotenv.2017.08.252
temp_n15	Estimated annual averaged nighttime air temperature in 2015.	
VHD06	The number of very hot day hours in 2006.	Based on the methodology proposed in the following paper: Cai, M., Ren, C., Lau, K. K. L., & Xu, Y. (2017). Spatial Analysis on Intra-Urban Temperature Variation under Extreme Hot Weather by Incorporating Urban Planning and Environmental Parameters: A pilot study from Hong Kong. In Passive Low Energy Architecture (PLEA) 2017, Edinburgh, Scotland.
HN15	The number of hot night hours in 2015.	
NO2_06	The AAQI of NO_2 in 2006.	The Annual Air Quality Index (AAQI) is the ratio of the past 12-month rolling average concentration to the annual air quality guidelines (AQG) of the World Health Organization (WHO). http://www.who.int/phe/health_topics/outdoorair/outdoorair_aqg/en/index.html AAQI data used here is from EPD official records. More information is available at: http://www.aqhi.gov.hk/en/annual-aqi/annual-aqi-trend.html
RSP_15	The AAQI of PM_{10} in 2015.	

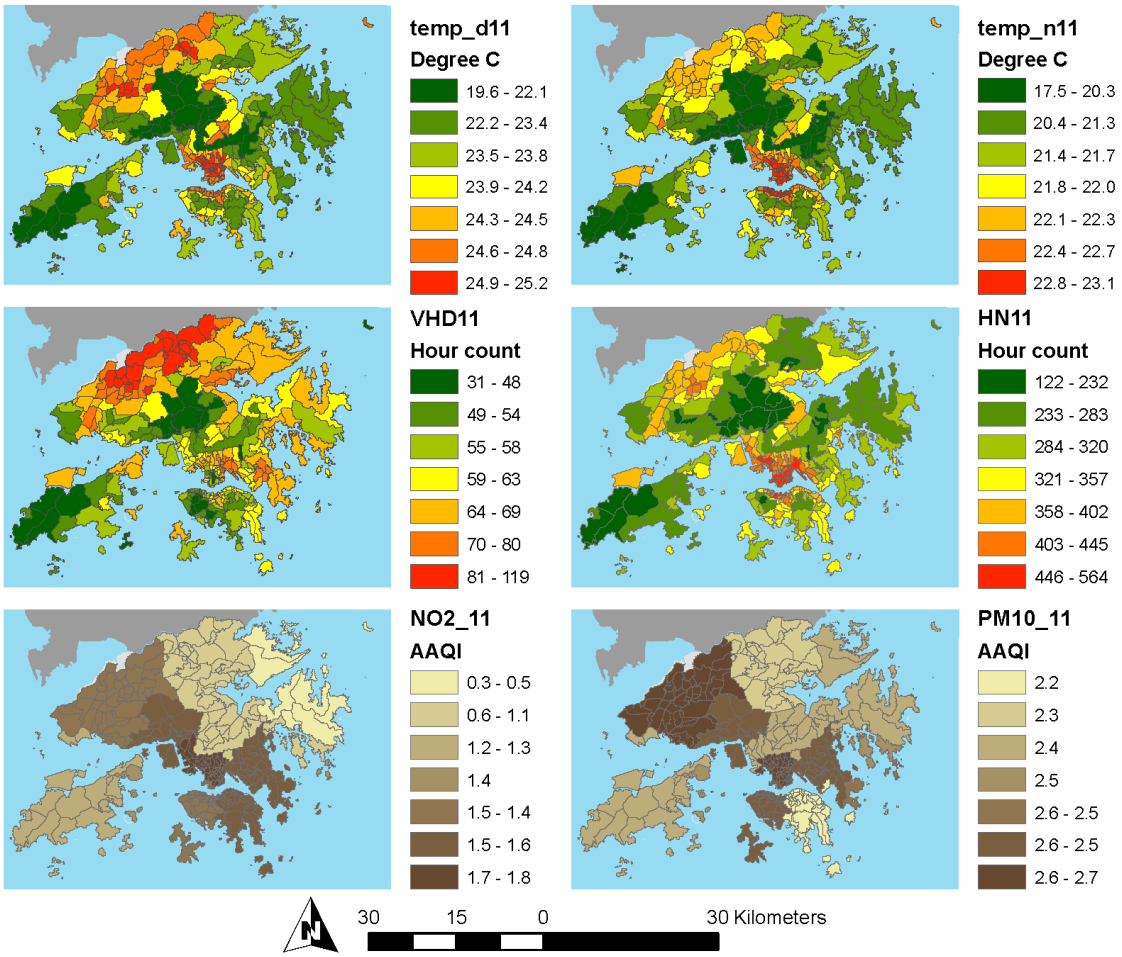


Figure 1 *Geographical distribution maps of the environmental data described in Table 2.*

The collected dataset for this study consists of 227 samples in total with 82 in 2006, 79 in 2011 and 66 in 2016. Since the housing price data was not normally distributed, we

processed the data into the log form based on 10. All the determinants listed in Table 1 and 2 were standardized as follows:

$$X_{std} = \frac{X - X_{min}}{X_{max} - X_{min}}. \quad (1)$$

We assumed that the effects of the determinants on housing price were linearly additive. That is the housing price can be described by

$$Housing\ price = \sum_{i=1}^{13} \alpha_i x_i + \sum_{j=1}^{6} \beta_j e_j\,, \quad (2)$$

Where α_i is the coefficient of the socioeconomic factor x_i, and β_j is the coefficient of the environmental factor e_j. Based on the processed data, we conceived 6 models covering different types of factor to examine the independent effects of socioeconomic variables and environmental determinants, respectively, as well as their interactive effects on housing price in an integrated fashion. To be specific, the first model focuses on environmental factors over three years:

$$Housing\ price = \sum_{j=1}^{6} \beta_j e_j \quad (3)$$

The second model focuses on socioeconomic factors over three years:

$$Housing\ price = \sum_{i=1}^{13} \alpha_i x_i\,. \quad (4)$$

The next three models focus on an integration of socioeconomic and environmental factors for the year of 2006, 2011 and 2016, respectively.

$$Housing\ price^{year} = \sum_{i=1}^{13} \alpha_i^{year} x_i^{year} + \sum_{j=1}^{6} \beta_j^{year} e_j^{year}, \quad year = 2006, 2011, 2016. \tag{5}$$

The final model integrates all socioeconomic and environmental factors over three years:

$$Housing\ price = \sum_{i=1}^{13} \alpha_i x_i + \sum_{j=1}^{6} \beta_j e_j, \tag{6}$$

In order to avoid the collinearity between determinants with similar attributes, each of the six models were further examined by several sub-models with different combinations of considered variables. The number of combinations depends on the number of variables which indicate the same influencing factor of housing price. For 6 environmental variables, temp_d and temp_n both indicate temperature. As a result, two preliminary sub-models and two optimized sub-models based on these two can be built. For 13 socioeconomic variables, there are four indicators of the number of residents: (1) population; (2) labor force, (3) labor force participation and (6) the number of households; and two indicators of the income of residents: (1) median monthly income and (2) median household income. In each sub-model, we selected only one indicator from the number of residents and one from the income of resident to conduct the analysis. Besides, the median household income is specially used to match the number of households.

Consequently, there are four initial sub-models in Model 2 - 6. Then, four optimized sub-models can be built respectively according to the significance analysis of those four initial sub-models. The full list of variables combination can be found in Table 3 - 8 for the Model 1 - 6, respectively. Then, all the sub-models were calibrated by the corresponding dataset through linear regression analysis.

4. Result and Discussion

4.1 Impact of environmental factors

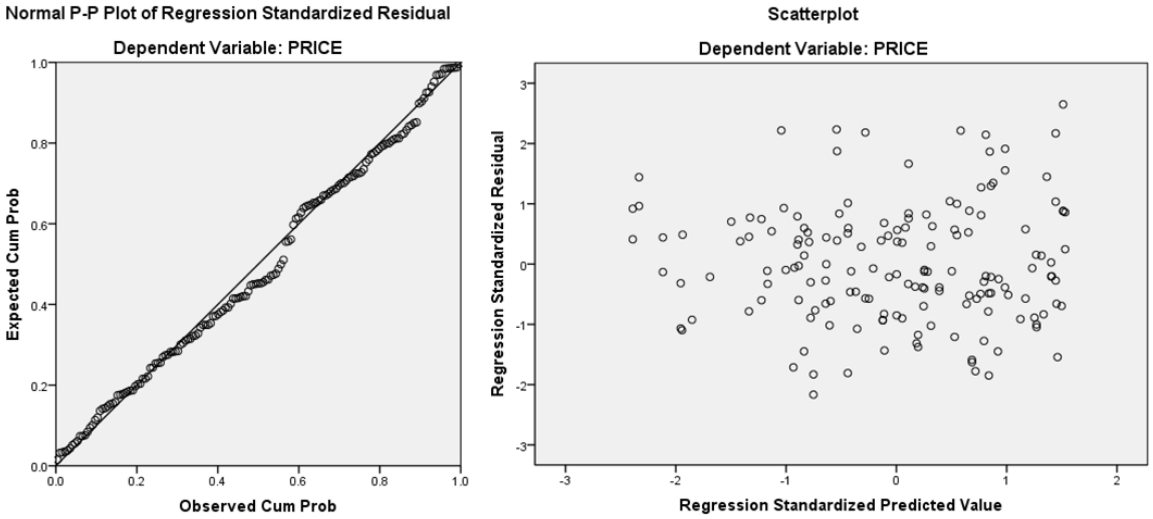
Table 3 provides the environmental determinants of housing prices, with the residual distribution for Model 1 & 2 displayed in Figure 2. Model 2 is the optimal model from baseline Model 1, while Model 4 is the optimal model from baseline Model 3. In both baseline models, the number of hot night hours also has a significant effect on housing price. As the signs of their impacts are opposite, the variable of HN is excluded in the optimal models. In Model 1 & 2, daytime air temperature has a significant but negative effect on housing price. The impacts of very hot days and AAQIs of PM_{10} on housing price are significant and negative; while the impact of AAQIs of NO_2 on housing price is significant and positive.

Table 3 *Environmental determinants of housing price (06&11&16)*

		Sub-model 1	Sub-model 2 （optimized model based on sub-model 1）	Sub-model 3	Sub-model 4 （optimized model based on model 3）
Parameters	Constant	3.905	3.907	3.961	3.962
	Temp_d	-0.450*++	-0.390+		
	Temp_n	0.661**++	0.592**+	0.229***	0.231***
	HN	-0.053		0.007	
	VHD	-0.067	-0.094	-0.180***	-0.178***
	NO_2	0.363***	0.353***	0.375***	0.377***
	RSP	-0.757***	-0.752***	-0.836***	-0.838***
Reliability	R Square	0.594	0.594	0.589	0.589
	Adjusted R Square	0.583	0.584	0.580	0.582
	Durbin-Watson	1.069	1.056	1.008	1.009

Note. *indicates significant at 10% level, **indicates significant at 5% level, ***indicates significant at 1% level. +indicates VIF>10, ++indicates VIF>20, +++indicates VIF>30.

Baseline model (Model 1 in Table 3)



Alternative & optimal model (Model 2 in Table 3)

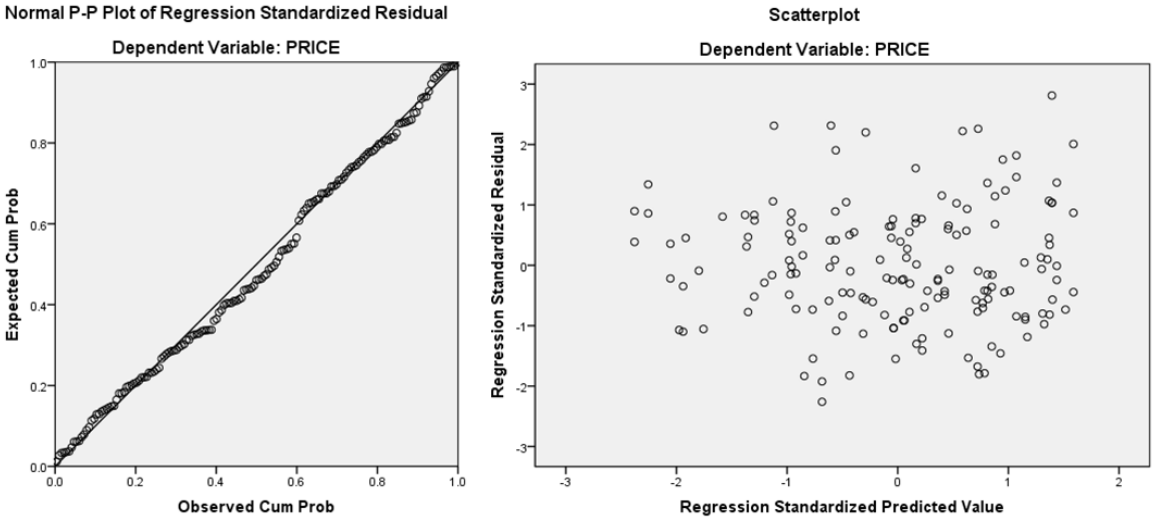


Figure 2 *Estimated Residuals of environmental determinants (charts of other models are available upon request).*

4.2 Impact of economic and social factors

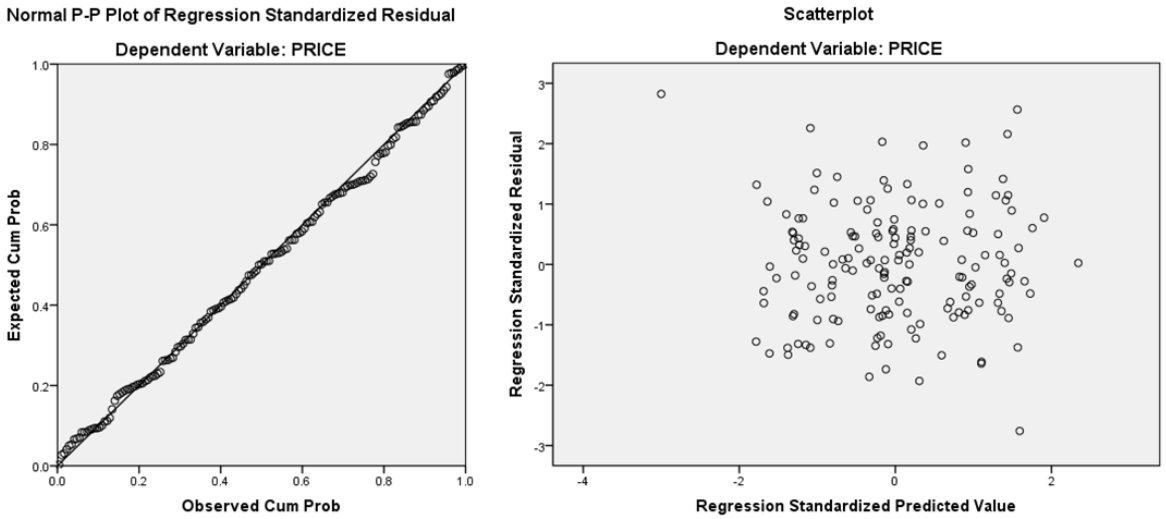
Table 4 provides the economic and social factors influencing housing prices, with the associated residual distribution for Model 1 & 5 displayed in Figure 3. Model 5 to 8 are the optimal models from baseline Models 1 to 4. Various factors are consistent in most models regarding their effects on housing price. For instance, the distance to the nearest MTR station has significant and negative impact on housing price in all models, echoing many studies about the synergy between real estate development and MTR, i.e. the so-called R(railway)+P(property) model (So et al., 1997; Yiu and Wong, 2005; Cervero and Murakami, 2009; Tang, 2017; He et al., 2018). Another influential factor is the housing demand, which is reflected in terms of medium household income (model 4 & 8) or medium household rent (model 1-3 & 5-7). It is significantly and positively associated with housing price, which is logically understandable and consistent with the literature (Leung, 2004; Li, 2013; 2016). Education level has a positive impact in model 1 & 2, consistent with previous work that high education attainment boosts housing price (Choy and Li, 2017; Wen et al., 2019). However, it is interesting that various demographic variables, i.e. population, labor force and the number of households has a significant and negative effect on housing price in various models, although they should be demand side factors that contribute to the housing price increase. One plausible explanation is that they may not be "real" demand, as high housing price has prevented many households from getting on the housing ladder in Hong Kong (Forrest and Xian, 2018; Li, 2018).

Table 4 *Economic and social determinants of housing price (06&11&16)*

		Sub-model 1	Sub-model 2	Sub-model 3	Sub-model 4	Sub-model 5 (optimized model based on 1)	Sub-model 6 (optimized model based on 2)	Sub-model 7 (optimized model based on 3)	Sub-model 8 (optimized model based on 4)
Parameters	Constant	3.816	3.823	3.743	3.620	3.792	3.797	3.784	3.639
	Distance from MTR	-0.188***	-0.179***	-0.213***	-0.1201***	-0.199***	-0.202***	-0.198***	-0.224***
	Population	-1.116***+				-0.532***			
	Median Age	-0.006	-0.013	0.017	0.145***				0.133**
	Labor Force (person)		-1.268***+				-0.525***		
	Labor Force Participation %			0.071					
	h. Median Monthly Income HK$	-0.107	-0.138	0.037					
	The number of Households				-0.870***				
	Median Household Income HK$				0.735***				0.748***
	Median Household Rent HK$	0.594***	0.581***	0.625***	-0.074	0.591***	0.589***	0.634***	
	Private permanent housing (person)	-0.111	-0.130	-0.010	0.083				
	Degree Course (person)	0.452***	0.655***	-0.208	0.177				
	Place of Study in Same district (person)	0.420**	0.461***	-0.094	0.491***				
	Place of Work in Same district (person)	0.261**	0.254**	0.246**	-0.168	0.356***	0.367***		
Reliability	R Square	0.383	0.404	0.313	0.526	0.355	0.362	0.289	0.455
	Adjusted R Square	0.587	0.380	0.284	0.507	0.344	0.350	0.283	0.448
	Durbin-Watson	1.461	0.972	1.080	1.340	1.065	1.062	1.038	1.479

Note. *indicates significant at 10% level, **indicates significant at 5% level, ***indicates significant at 1% level. +indicates VIF>10, ++indicates VIF>20, +++indicates VIF>30.

Baseline model (Model 1 in Table 4)



Alternative model (Model 5 in Table 4)

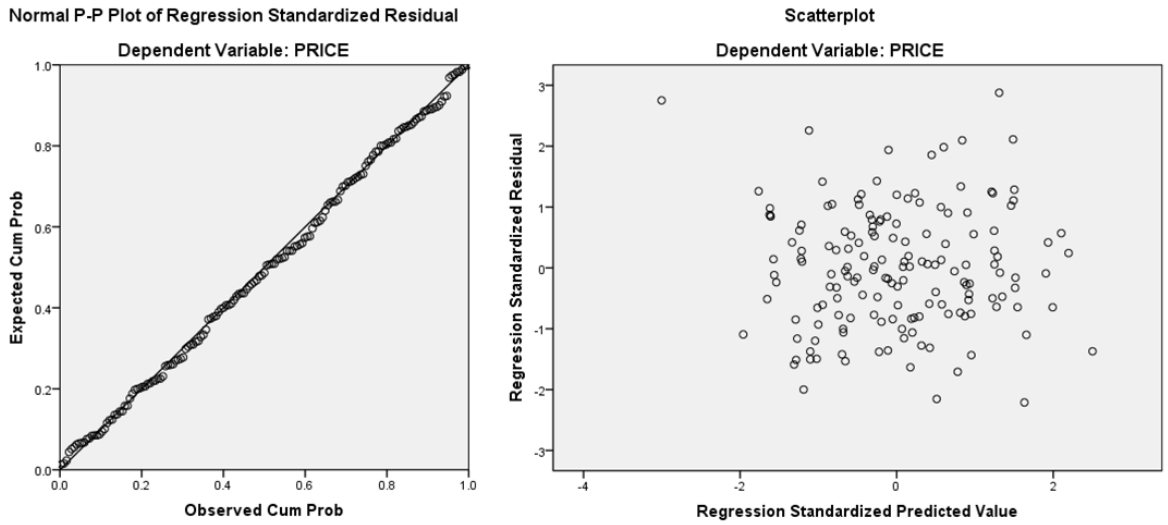


Figure 3 *Estimated Residuals of economic and social determinants (charts of other models are available upon request).*

4.3 Combined impacts over time

Table 5-7 combine the estimation results of economic, social and environmental determinants of housing prices in year 2006, 2011 and 2016 respectively, with their associated residuals in Figure 4-6. When cross sectional data without time effect is used for regression analysis, the impact of MTR distance becomes insignificant although still negative except for Model 6 & 7 in year 2011 (see Table 6).

The impacts of other economic, social and environmental factors vary over time. Specifically, medium age has significant and positive effect on housing price in Model 4 & 8 of Table 4, indicating that the purchasing power increases when people become more experienced and better paid. As for year 2006, the impact of medium age is insignificant (see Table 5). However, its impact is significant and positive in all models of Table 6 for year 2011, but becomes insignificant again for year 2016 (see Table 7). The coefficient of medium age effect for 2011 (ranged from 0.196 to 0.34) is higher than the coefficient of average medium age effect from 2006 to 2016 (ranged from 0.133 to 0.145). It is noteworthy that during 2004 and 2015, the Hong Kong government implemented the Capital Investment Entrant Scheme (CIES) which attracted substantial capital inflows of non-local buyers into the local housing market. CIES may hence mediate the effect of local buyers on housing price dynamics in Hong Kong (Li et al., 2019), thus making the impact of medium age population insignificant from time to time.

As for other housing demand indicators, total population (model 1 & 5) and labor force participation (model 2 & 6) still have significant but negative effect on housing price in year 2006, but insignificant in years 2011 & 2016. Medium household income or rent still has significant and positive effect on housing price in year 2006. However, only medium household rent has significant and positive effect on housing price in year 2011 and 2016. The implication is that income growth cannot catch up with housing price or rent growth (Li, 2018), in particular for young people over the last decade (Xian and Forrest, 2019), such that income is insignificant in representing housing demand.

Regarding the housing supply variables, the impact of the number of private permanent housing on housing price is most significant and negative in year 2006 (Model 1-3), partly significant and negative in year 2011 (Model 2), and insignificant in year 2016. While the society is calling for more housing supply and land reclamation to solve the problems of housing affordability and limited land resources in Hong Kong, our results suggest that it may not be feasible as housing price is increasingly inelastic to supply change in recent years. In fact, some scholars maintained that housing or land supply does not have a significant relationship with housing price (Tse, 1998). Some others argued the impact of supply side shock on housing price in Hong Kong may be asymmetric: a sudden scarcity of land sharply raises housing price (Peng and Wheaton, 1994), but the increase of land supply only modestly lowers housing price (Ho and Ganesan, 1998). This phenomenon is explained by the construction lags between supply-demand gap (Tse et al., 1999), partly

due to the lengthy procedure of approval from the urban planning department (Hui and Ho, 2003; Hui, 2004).

As for environmental factors, the impact of the number of hot night hours is insignificant in most models except for model 4 of year 2011 and model 5 of year 2016 (the optimal model in Table 6). The impact is positive in both models. The impact of the number of very hot day hours remains significant and negative in all models of year 2006 and 2016, but turns insignificant in models of year 2011. The impact of AAQIs of NO_2 is insignificant of year 2006 and 2011, but becomes insignificant and positive of year 2016. The impact of AAQIs of PM_{10} is significant and negative in all models of year 2006, significant but positive in model 5 of year 2011, and insignificant of year 2016.

Table 5 *Determinants of housing price (Integrated) 2006*

		Sub-model 1	Sub-model 2	Sub-model 3	Sub-model 4	Sub-model 5 (optimized model based on 1)	Sub-model 6 (optimized model based on 2)	Sub-model 7 (optimized model based on 3)	Sub-model 8 (optimized model based on 4)
Parameters	Constant	3.684	3.84	3.483	3.573	3.882	3.882	3.567	
	Distance from MTR	0.009	0.012	0.052	-0.001				
	Population	-0.875**++				-0.793***			
	Median Age	0.033	0.020	0.041	0.060				
	Labor Force (person)		-0.822***++				-0.822***		
	Labor Force Participation %			0.187				0.220**	
	Median Monthly Income HK$	-0.143	-0.141	-0.062					
	Number of Households				-0.271+				
	Median Household Income HK$				0.250**				0.351***
	Median Household Rent HK$	0.193**	0.193**	0.207**	0.050			0.171**	
	Private permanent housing (person)	-0.312***	-0.319***	-0.298***	-0.194				
	Degree Course (person)	0.272+	0.310+	0.069+	0.107+				
	Place of Study in Same district (person)	0.049+	-0.067	-0.533**	-0.236			-0.258**	-0.238**
	Place of Work in Same district (person)	0.464+	0.526*+	0.334++	0.286+	0.422***	0.513***		
	temp_n	0.159	0.149	0.230***	0.145			0.199***	0.185***
	HN	0.179	0.177	0.094	0.102				
	VHD	-0.292***	-0.283***	-0.290***	-0.239***	-0.296***	-0.296***	-0.292***	-0.281***
	NO_2	0.051	0.057	0.061	0.068				
	RSP	-0.153**	-0.158**	-0.158**	-0.161**	-0.230***	-0.232***	-0.184***	-0.175***
Reliability	R Square	0.696	0.764	0.674	0.699	0.607	0.612	0.622	0.667
	Adjusted R Square	0.633	0.701	0.606	0.636	0.587	0.592	0.592	0.645
	Durbin-Watson	2.157	2.115	1.901	1.888	1.756	1.772	1.777	1.706

Note. *indicates significant at 10% level, **indicates significant at 5% level, ***indicates significant at 1% level. +indicates VIF>10, ++indicates VIF>20, +++indicates VIF>30.

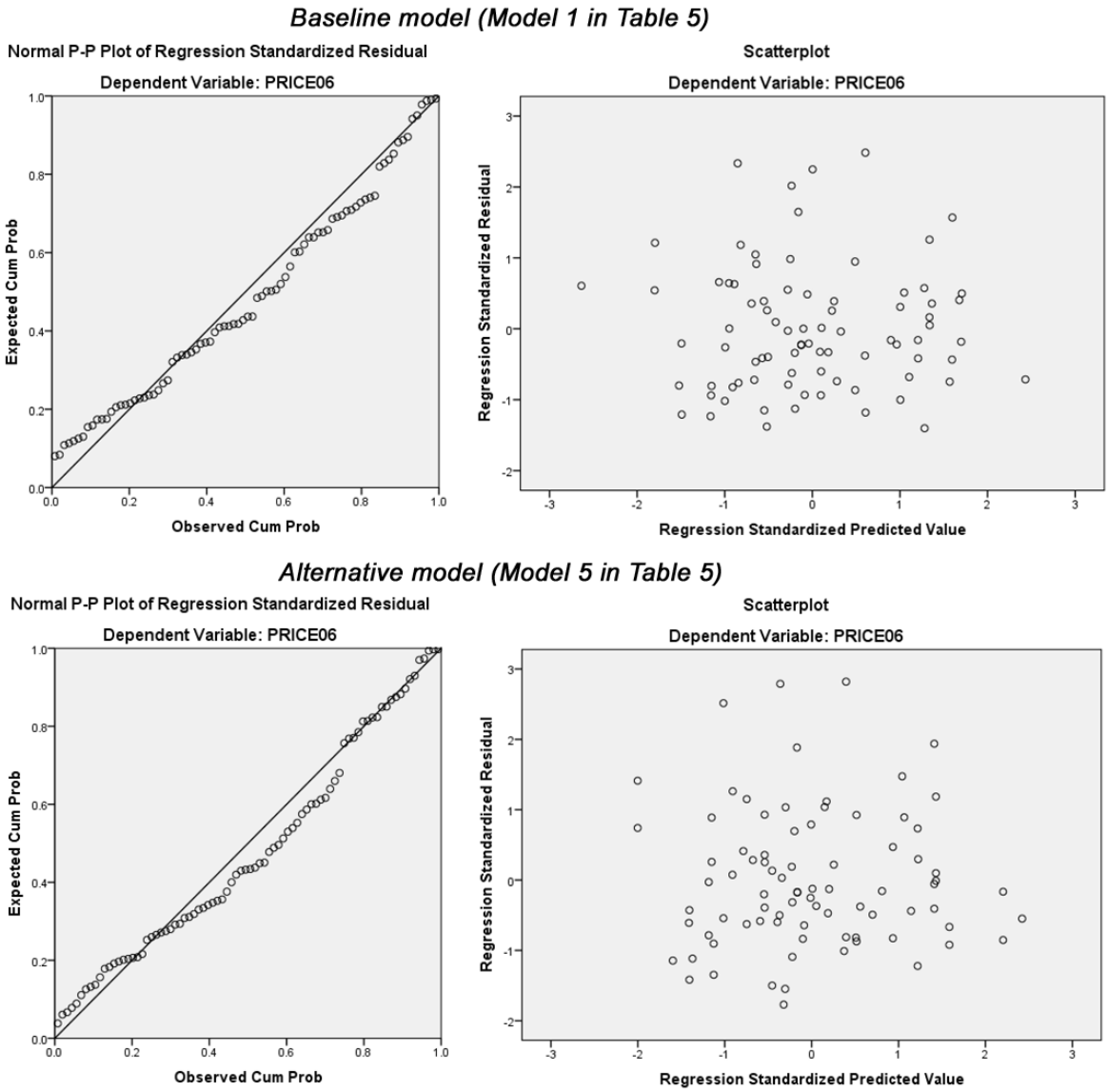


Figure 4 *Estimated Residuals of integrated determinants in 2006* (*charts of other models are available upon request).*

Table 6 *Determinants of housing price (Integrated) 2011*

		Sub-model 1	Sub-model 2	Sub-model 3	Sub-model 4	Sub-model 5	Sub-model 6 (optimized model based on 2 & 3)	Sub-model 7 (optimized model based on 1)
Parameters	Constant	3.494	3.525	3.505	3.459		3.648	3.648
	Distance from MTR	-0.097	-0.099	-0.129	-0.109		-0.273***	-0.281***
	Population	-0.860+++						
	Median Age	0.215**	0.196**	0.205**	0.237**	0.215***	0.340***	0.304***
	Labor Force (person)		-0.749+++					
	Labor Force Participation %			0.091				
	Median Monthly Income HK$	-0.017	-0.026	-0.007			0.157**	
	Number of Households				-0.714+++			
	Median Household Income HK$				0.428+++			
	Median Household Rent HK$	0.465	0.455***	0.472***	0.057+++		0.492***	0.582***
	Private permanent housing (person)	-0.226	-0.216**	-0.159	-0.149			
	Degree Course (person)	0.715**+	0.740***+	0.323**	0.577**+			
	Place of Study in Same district (person)	0.294+++	0.156+++	-0.346+	0.184+++		-0.220**	-0.300***
	Place of Work in Same district (person)	0.062	0.068	0.117	0.108			
	temp_n	0.069	0.068	0.143	0.056			
	HN	0.235	0.218	0.194	0.262**			
	VHD	-0.071	-0.066	-0.115	-0.072			
	NO_2	0.115	0.111	0.100	0.115			
	RSP	-0.110	-0.113	-0.117	-0.111	-0.124***		
Reliability	R Square	0.764	0.763	0.755	0.763	0.661	0.665	0.644
	Adjusted R Square	0.708	0.707	0.697	0.707	0.643	0.642	0.624
	Durbin-Watson	1.931	1.919	1.914	1.875	1.684	1.596	1.457

Note. *indicates significant at 10% level, **indicates significant at 5% level, ***indicates significant at 1% level. +indicates VIF>10, ++indicates VIF>20, +++indicates VIF>30.

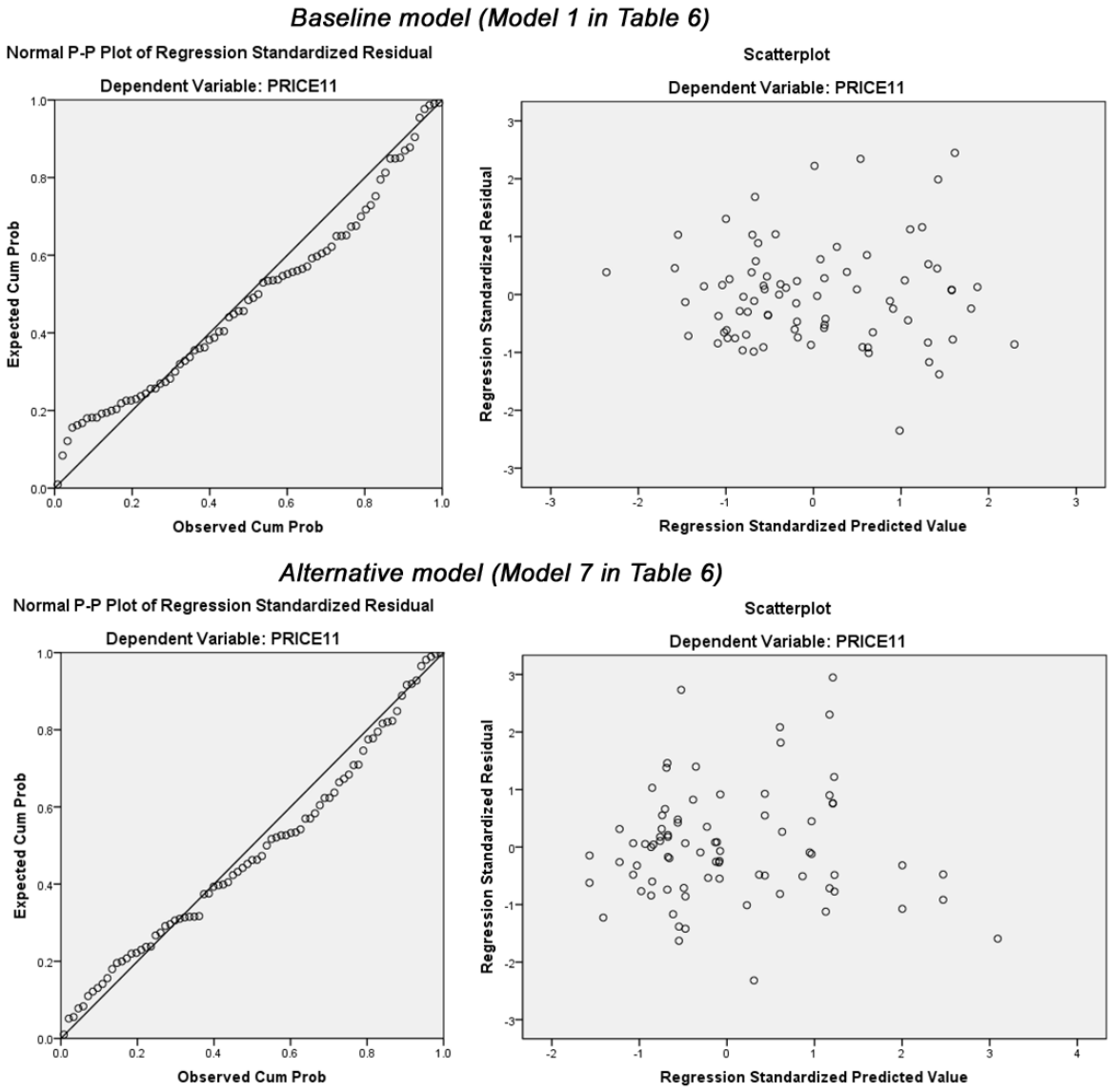


Figure 5 *Estimated Residuals of integrated determinants in 2011 (charts of other models are available upon request).*

Table 7 *Determinants of housing price (Integrated) 2016*

		Sub-model 1	Sub-model 2	Sub-model 3	Sub-model 4	Model 5 (The optimal one)
Parameters	Constant	3.824	3.827	3.797	3.883	3.891
	Distance from MTR	-0.094	-0.093	-0.122	-0.112	
	Population	-0.244+				
	Median Age	0.070	0.067	0.069	0.075	
	Labor Force (person)		-0.229+			
	Labor Force Participation %			0.146		
	Median Monthly Income HK$	-0.320+	-0.319+	-0.432**+		
	Number of Households				-0.294+	
	Median Household Income HK$				-0.281	
	Median Household Rent HK$	0.673***+	0.669***+	0.752***+	0.610***	0.288***
	Private permanent housing (person)	-0.156	-0.154	-0.144	-0.127	
	Degree Course (person)	0.306+	0.305+	0.131	0.301+	
	Place of Study in Same district (person)	0.023	0.012	-0.073	0.055	
	Place of Work in Same district (person)	0.027	0.026+	0.016	0.045	
	temp_n	0.259**	0.257**	0.295***	0.240**	0.244***
	HN	0.066	0.070	0.012	0.058	0.211***
	VHD	-0.252***	-0.254***	-0.256***	-0.240***	-0.353***
	NO_2	0.189***	0.189***	0.189***	0.179**	
	RSP	-0.175++	-0.185++	-0.117++	-0.138++	
Reliability	R Square	0.699	0.699	0.703	0.702	0.608
	Adjusted R Square	0.609	0.608	0.614	0.613	0.582
	Durbin-Watson	1.593	1.585	1.704	1.646	1.500

Note. *indicates significant at 10% level, **indicates significant at 5% level, ***indicates significant at 1% level. +indicates VIF>10, ++indicates VIF>20, +++indicates VIF>30.

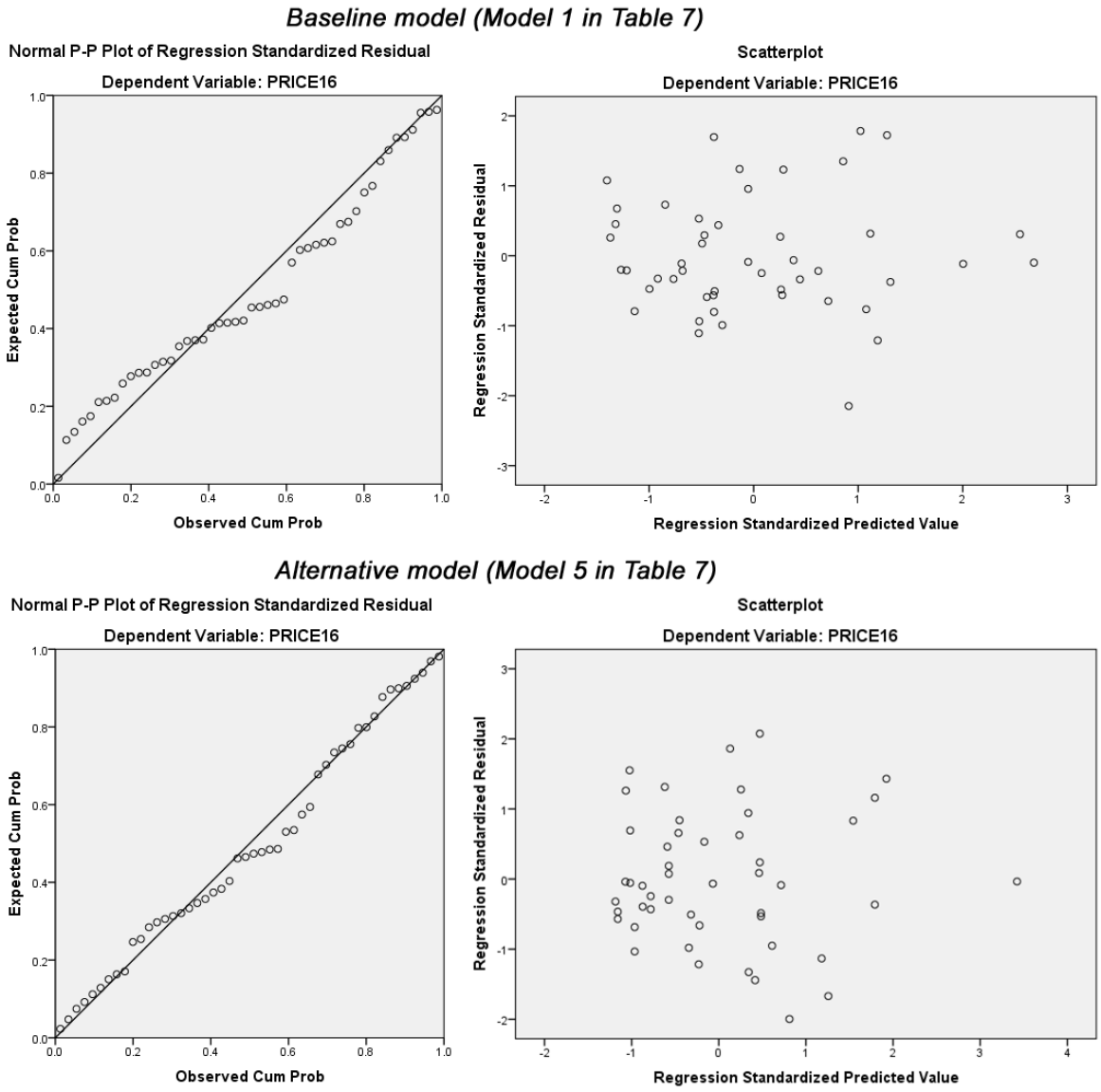


Figure 6 *Estimated Residuals of integrated determinants in 2016 (charts of other models are available upon request).*

Table 8 summaries the impact of different variables on housing prices over the period 2006 to 2016. After combining all variables with a time length of 10 years, it is interesting

to note that the impact of distance to MTR becomes insignificant in all models of Table 8. Yet the impact of place of work in the same district by a person is significant and positive. Demographic factors, i.e. total population, medium age, number of labor force and households are sometimes significant in different models of Table 8; however, the signs of their impact vary and may differ from the results of the individual year basis. Housing demand indicator by medium income or rent remains significant and positive in all models of Table 8, indicating that rigid demand still plays an important role in explaining housing price increase. Supply side factors such as private housing has significant and negative effect on housing price, while demand-side factors such as degree course have a significant and positive effect on housing price. It is noteworthy that the majority of environmental variables, including the number of hot night hours, AAQIs of NO_2 and PM_{10}, significantly affects housing price in the integrated model over the study period. Specifically, the impacts of hot nights and NO_2 are positive, while the impact of PM_{10} is negative.

Table 8 *Determinants of housing price (Integrated) 2006&2011&2016*

		Sub-model 1	Sub-model 2	Sub-model 3	Sub-model 4	Sub-model 5 (the optimal one)
Parameters	Constant	3.640	3.657	3.623	3.531	3.623
	Distance from MTR	0.021	0.020	0.031	-0.013	
	Population	-0.629***+				
	Median Age	-0.044	-0.047	-0.053	0.052**	
	Labor Force (person)		-0.722***+			
	Labor Force Participation %			-0.026		
	Median Monthly Income HK$	-0.091	-0.108	-0.010		
	The number of Households				-0.546***+	
	Median Household Income HK$				0.386***	
	Median Household Rent HK$	0.366***	0.364***	0.359***	0.030	0.371***
	Private permanent housing (person)	-0.222***	-0.231***	-0.169***	-0.103	
	Degree Course (person)	0.437***	0.549***+	0.086	0.284***	
	Place of Study in Same district (person)	0.094	0.118	-0.240**	0.176	
	Place of Work in Same district (person)	0.235***	0.233***	0.222***	0.201***	
	temp_n	0.022	0.009	0.059	0.012	
	HN	0.387***	0.387***	0.380***	0.330***	0.333***
	VHD	-0.052	-0.051	-0.070	-0.038	
	NO_2	0.171***	0.161***	0.183***	0.176***	0.192***
	RSP	-0.329***	-0.319***	-0.368***	-0.289***	-0.388***
Reliability	R Square	0.722	0.728	0.702	0.755	0.676
	Adjusted R Square	0.702	0.708	0.681	0.738	0.669
	Durbin-Watson	1.491	1.508	1.473	1.665	1.458

Note. *indicates significant at 10% level, **indicates significant at 5% level, ***indicates significant at 1% level. +indicates VIF>10, ++indicates VIF>20, +++indicates VIF>30.

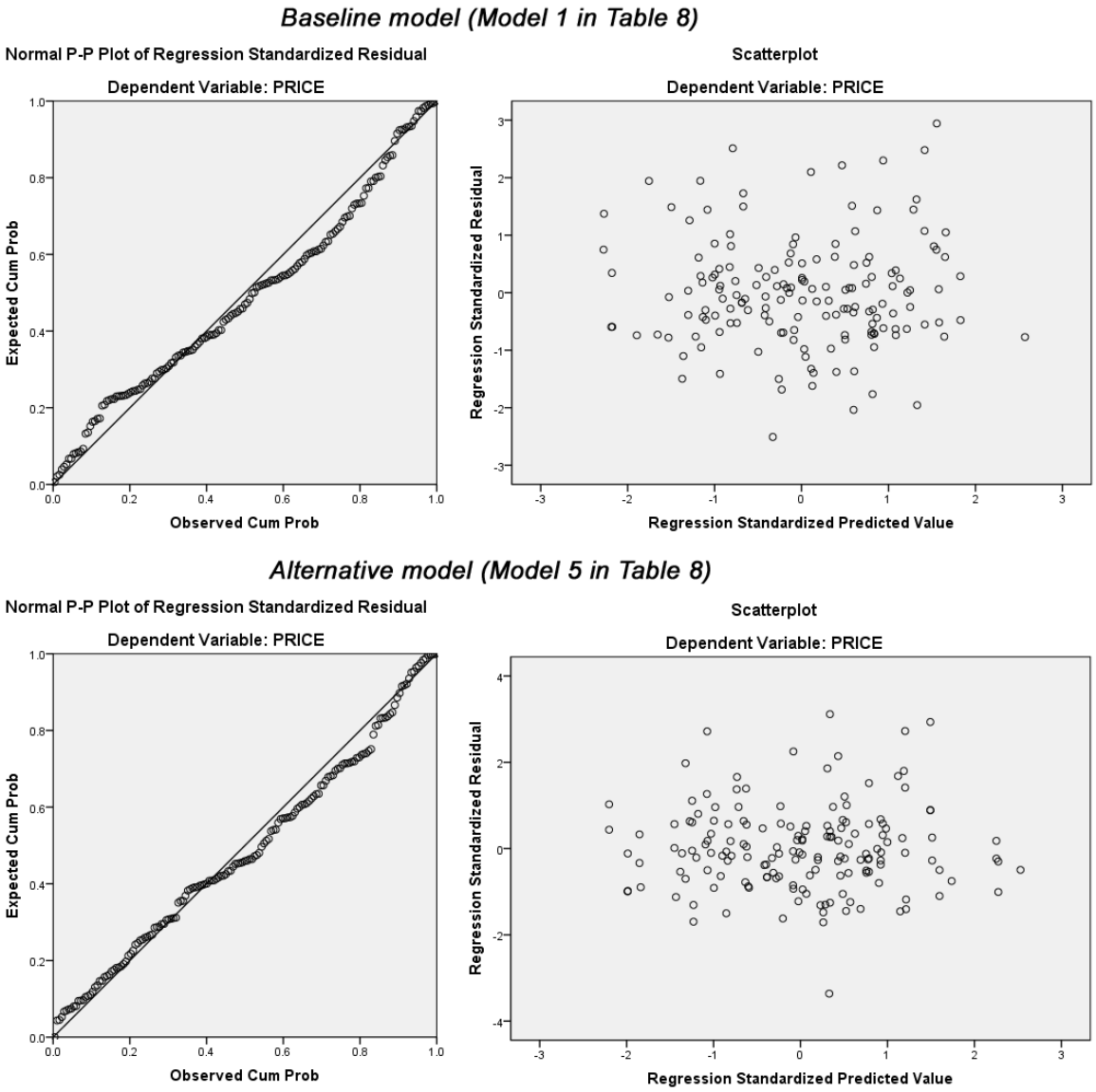


Figure 7 *Estimated Residuals of integrated determinants (2006-2016). Charts of other models are available upon request.*

5. Conclusion

This paper makes several research contributions: first, it is one of the first studies to compare the impacts of economic, social and environmental factors on housing price in Hong Kong, based on the analysis of a combination of census data and our spatial-temporal environmental database covering all districts with good data quality and representativeness. Second, the empirical results reveal various interesting effects. For instance, the impact of MTR is more significant in individual years rather than over the study period, indicating that announcement or completion of new MTR stations may be more influential to housing prices. The impacts of environmental factors are as expected. Specifically, the impact of PM10 is negative on housing price, indicating that people prefer housing locations with better air quality. Thus the areas of development nearby the Mainland (i.e. New Territory),which is affected more by the emissions of manufacturing sectors in Shenzhen, may have lower housing prices.

The results thus have important implications: Current policy instruments to prevent housing price escalation are focused on increasing property tax or land supply (economic factors), while little attention is paid to social or environmental factors which are geographically heterogeneous. Our findings suggest that housing provision in New Territories may be a feasible solution to alleviate the housing crisis as its demographic pattern, transportation connectivity and air quality are significantly different from Hong Kong Island or Kowloon: with lower residential density and more brownfield, New

Territories is suitable to accommodate the long-term housing needs of Hong Kong residents for public housing or subsidized housing at more affordable price, due to its relatively underdeveloped transportation system. Still, efforts should be made to improve the air quality through more collaboration in the Greater Bay Area, e.g. between Hong Kong and Shenzhen for more green development schemes. For example, Fang et al. (2019) adopted a multi-scale lag correlation analysis of air quality in the Greater Bay Area cities, and found that Foshan, Guangzhou and Dongguan have the worst air quality in the Greater Bay Area. While Hong Kong residents are allowed to buy one housing unit in the Pearl River Delta cities, the environmental determinants of housing price need to be considered from buyers. Evidence also shown that there is marginal health improvement of Hong Kong people due to the reduction in southern China's pollution (Xiao et al., 2006), when the Pearl River Delta was experiencing rapid economic growth (Zhong et al., 2013). The relationship between air quality and housing choice in Greater Bay Area cities remains to be further explored in future work.

Regarding research limitation, the three waves of census data cover a period when Hong Kong's housing market experienced boom-bust with immigration and tax policy changes. Specifically, Hong Kong's property market reached its first peak in 1997, followed by a 60% reduction in housing price from 1998 to 2003. Afterwards, the housing price went up and continued its uprising trend till present. As for immigration and tax policy changes, the government initiated the Capital Investment Entrant Scheme in 2004 but suspended

the policy in 2015. The government also charged or increased various taxes on housing buyers in 2010, such as buyer stamp duty, special stamp duty and double ad valorem stamp duty. Data sampling from the years 2001, 2006 and 2011 can therefore sufficiently capture the impacts of these market cycles and policy shocks. Due to the discrete data, we are unable to control the effects of policy shocks on housing price dynamics. Future research is needed to investigate the combined economic, social and environmental impacts under specific policies, i.e. new town development plan in the Northeast New Territories or developing the East Lantau Metropolis, on the housing market dynamics when more continuous data is available.

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Figure 1

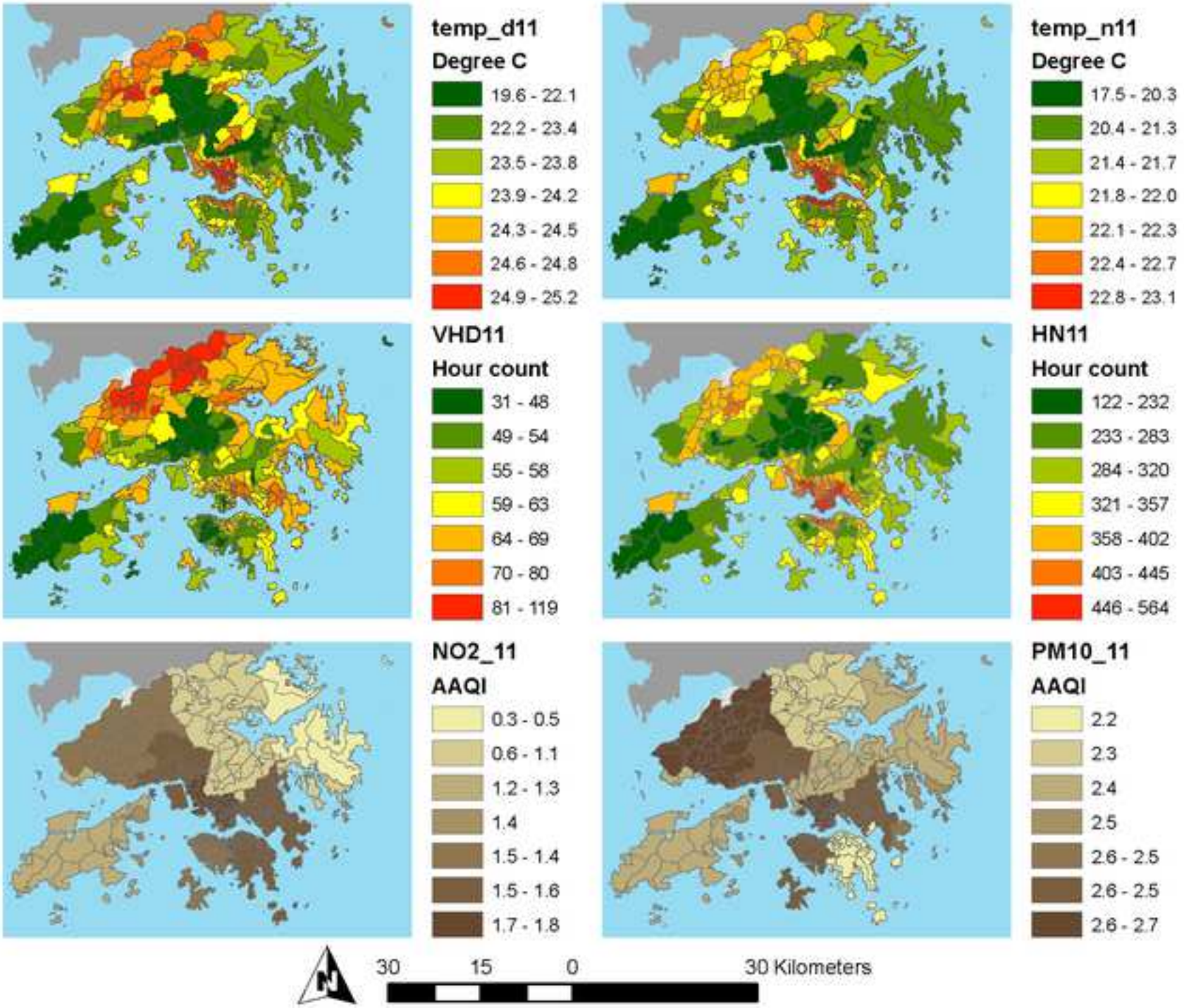
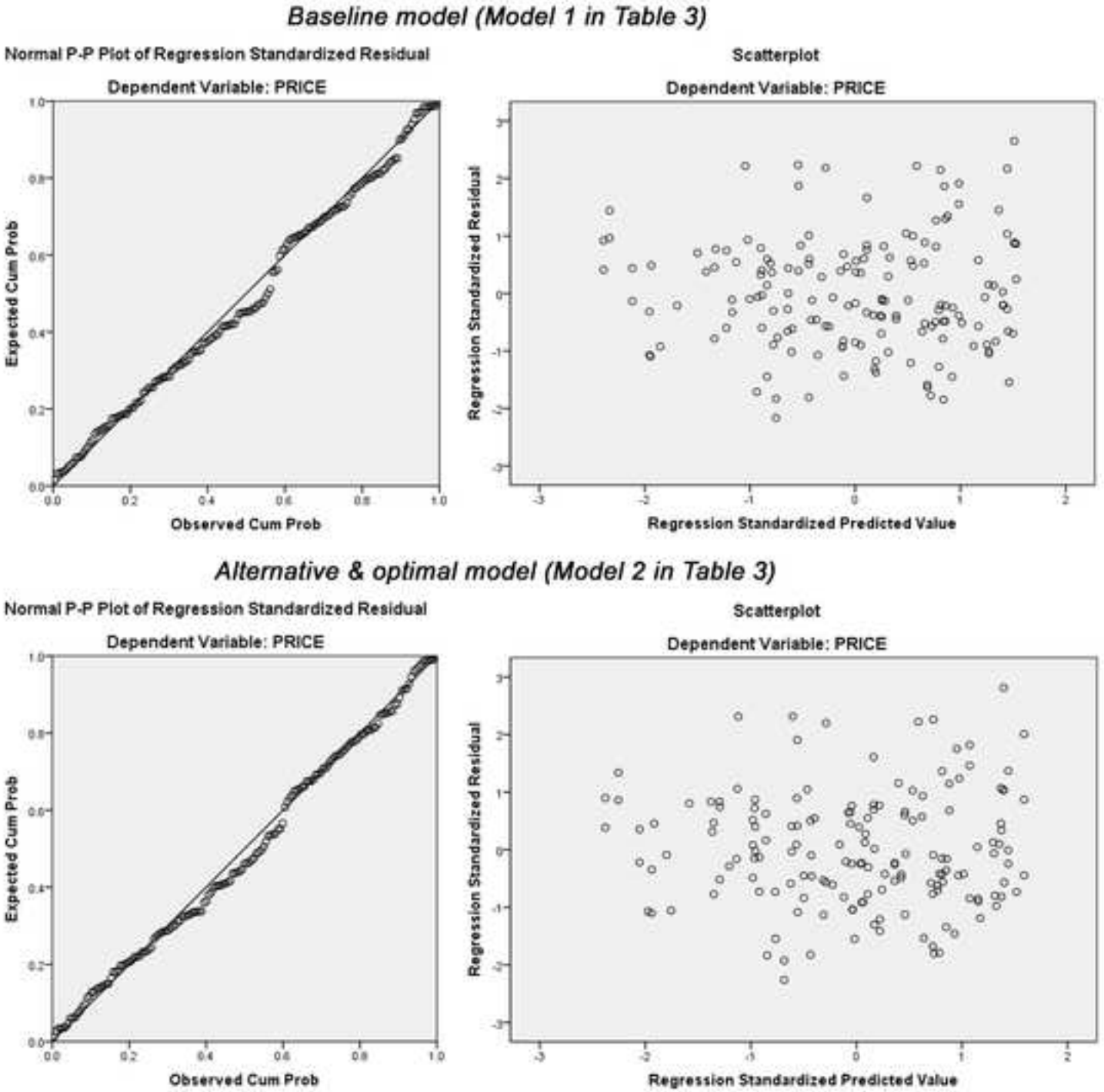


Figure 2



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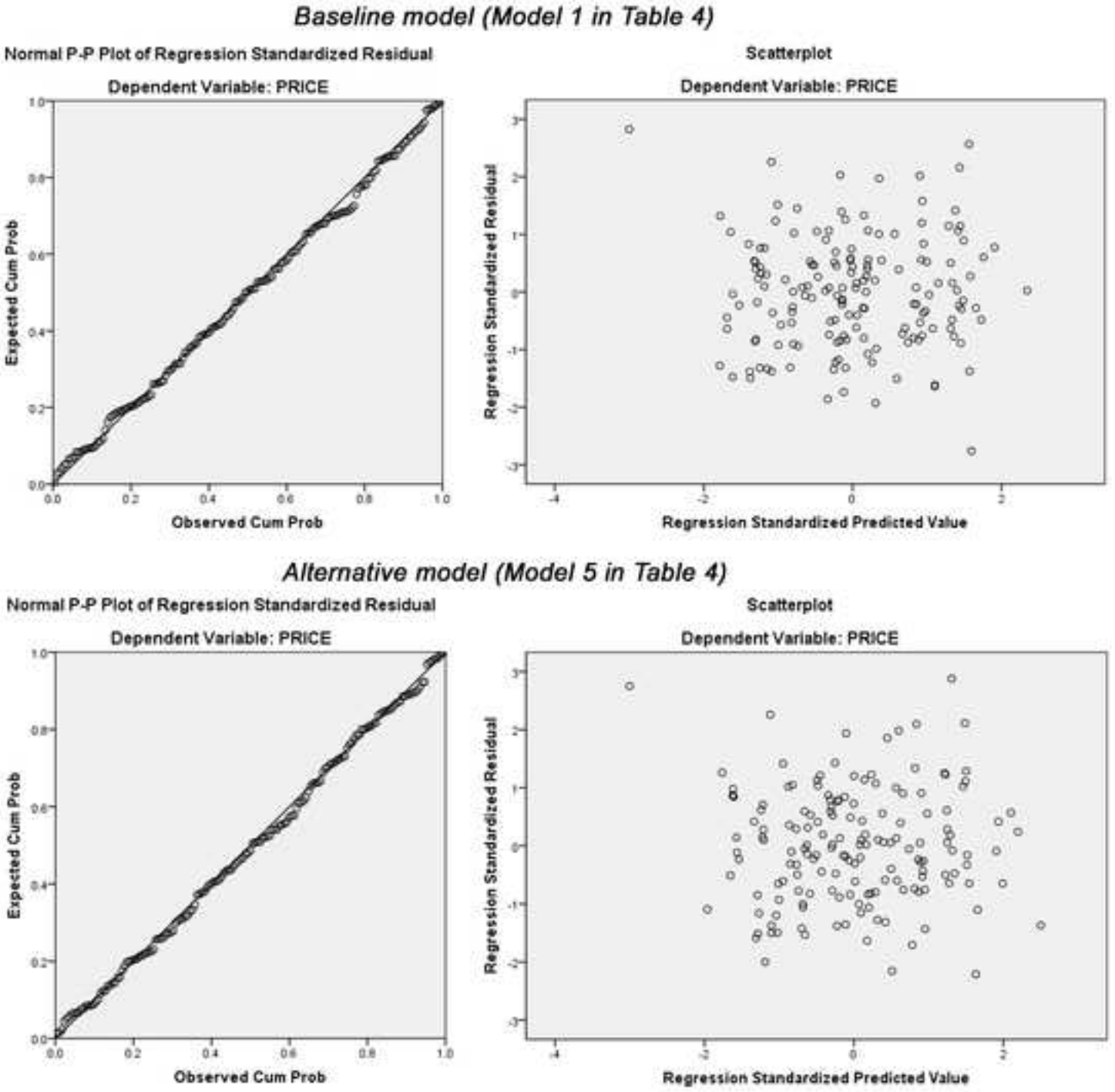


Figure 4

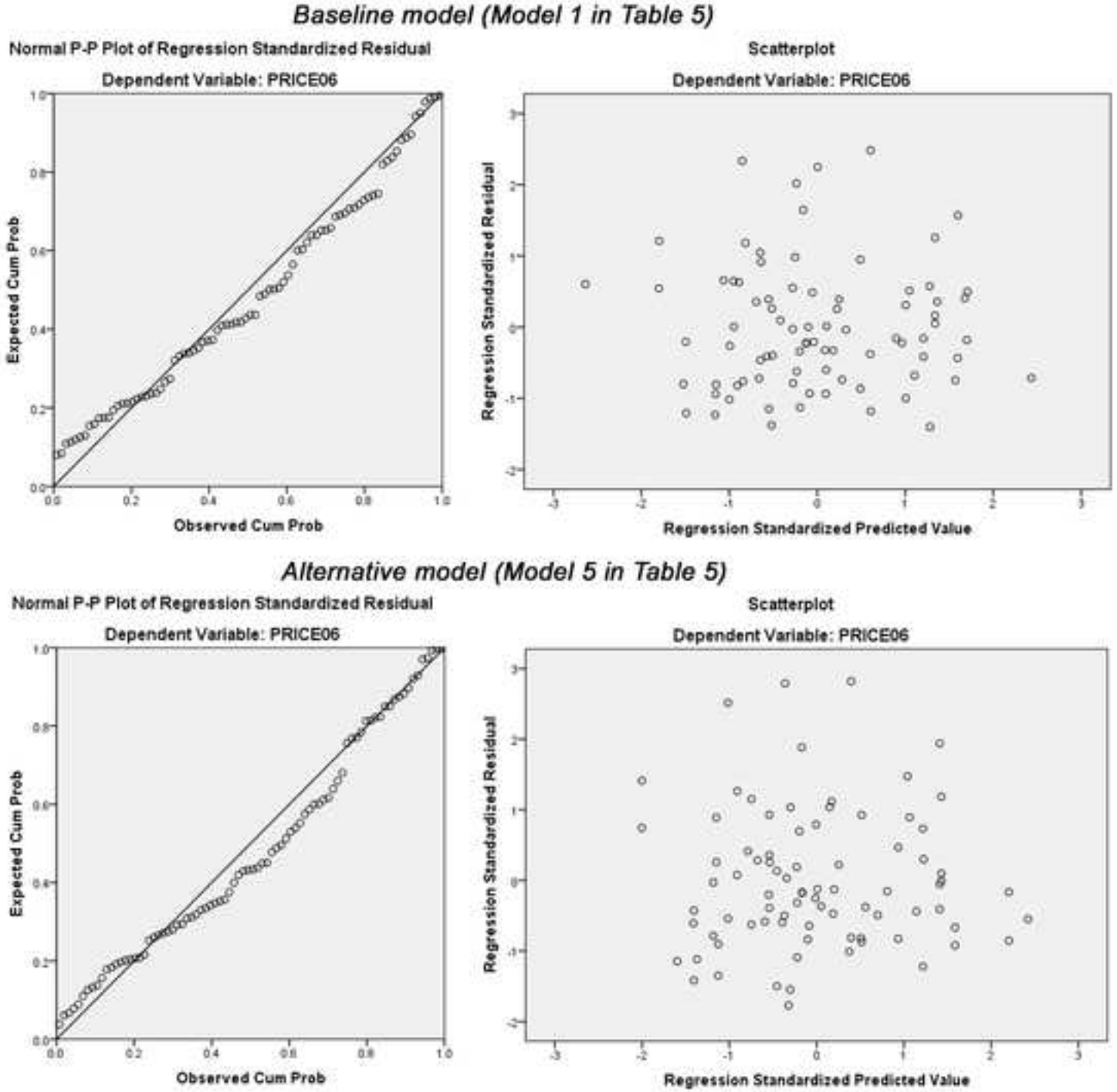


Figure 5

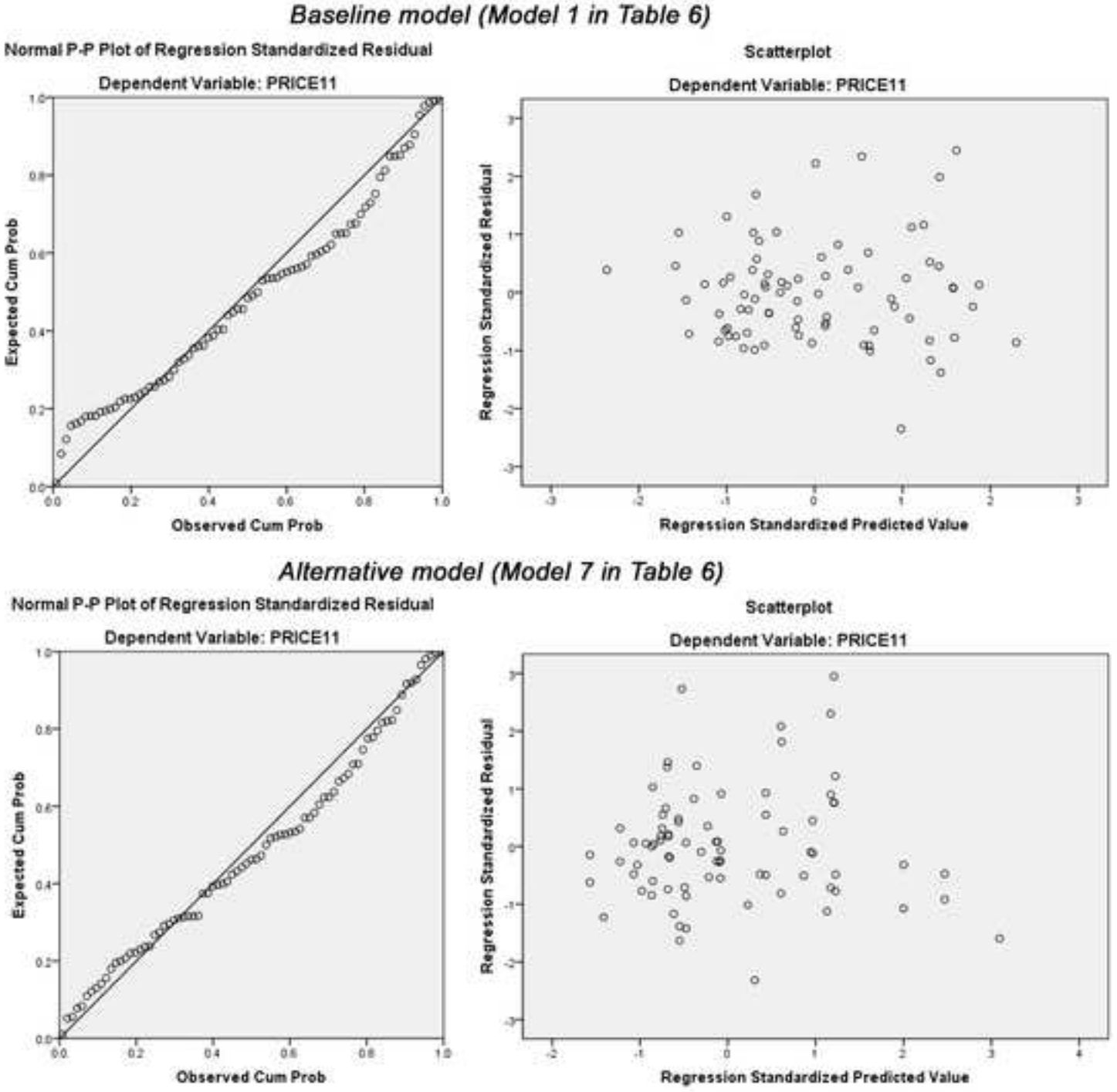
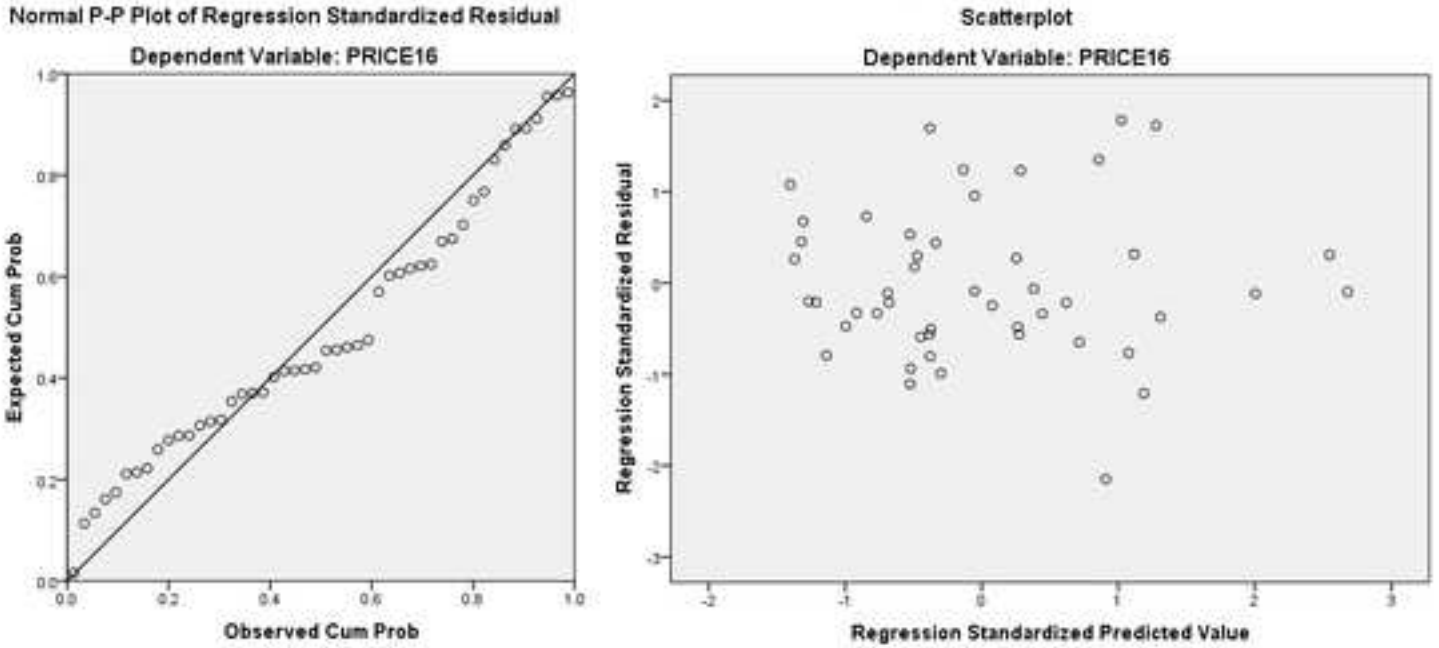


Figure 6

Baseline model (Model 1 in Table 7)



Alternative model (Model 5 in Table 7)

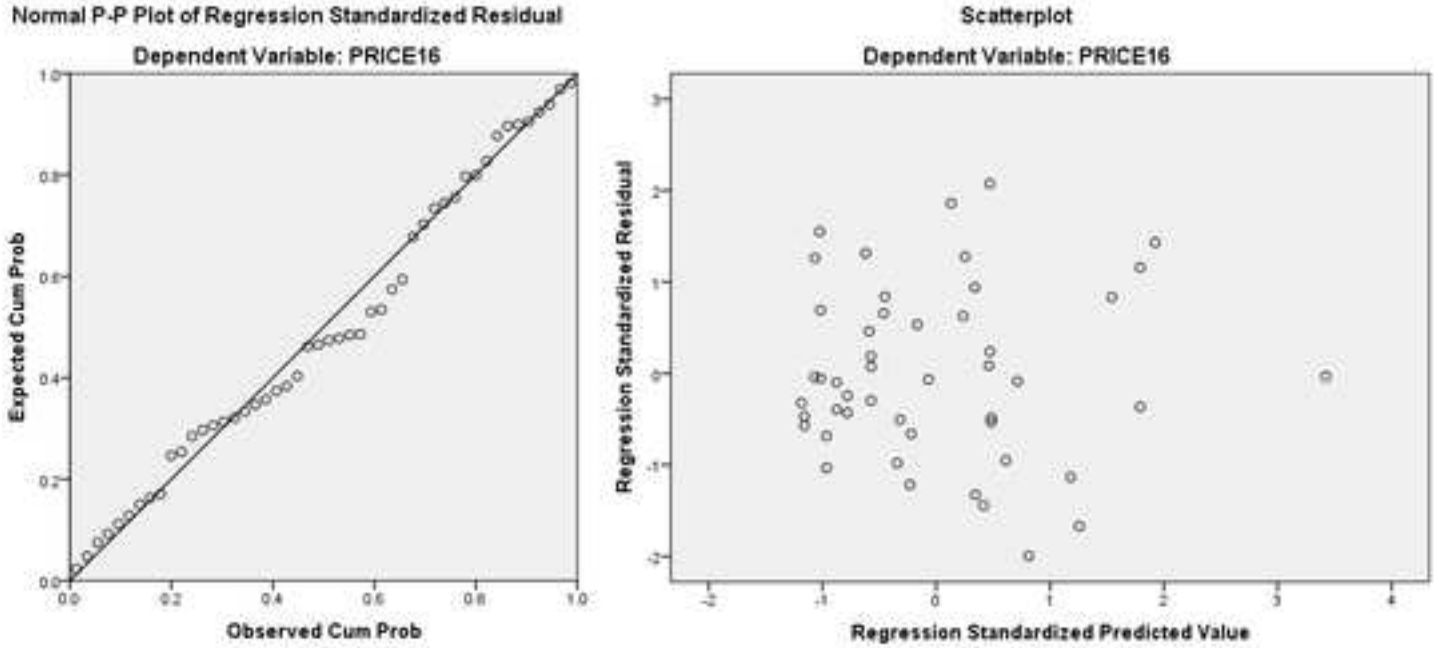
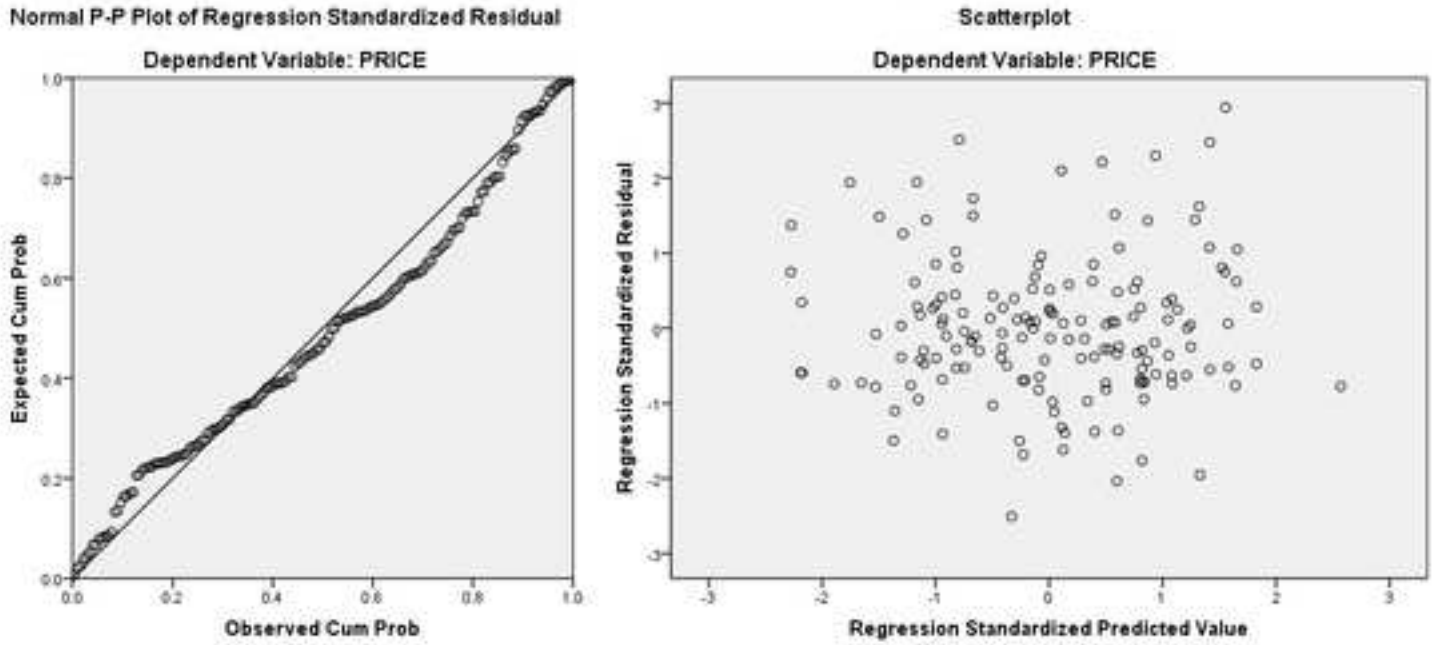


Figure 7

Baseline model (Model 1 in Table 8)



Alternative model (Model 5 in Table 8)