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The Shape of Brazilian Cities

Recife
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Dissertação de Mestrado apresentada ao Programa de Pós-Graduação em Ciências Econômicas (área de concentração: Teoria Econômica), como parte dos requisitos necessários para a obtenção do Título de Mestre em Economia.

Orientador: Paulo Henrique Pereira de Meneses Vaz

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Resumo

Neste artigo analiso os efeitos do formato geográfico das cidades em varaveis econômicas. Cidades com formatos diferentes significam cidades com distâncias diferentes entre pontos internos e, consequentemente, diferenças na prestação de serviços, acessibilidade de trânsito e custos de transporte. Usando imagens de satélite, crio uma base de dados com várias estatísticas sobre o formato das cidades e, em seguida, uso barreiras geográficas naturais como instrumentos para o formato potencial das cidades como estratégia de identificação. Ao contrário do esperado pela literatura recente, não encontro evidências de efeito sobre aluguel, população e salário sob diferentes especificações e controles. Isso fornece evidências sugestivas contra a validade externa de descobertas anteriores em diferentes contextos institucionais e geográficos.

Palavras-chaves: Desenvolvimento Econômico. Economia Urbana. Economia do Transporte. Economia imobiliária. Padrões de Uso da Terra.

Abstract

In this article I analyze the effects of the geographic format of cities on economic outcomes. Cities with different formats mean cities with different distances between points and consequently differences in service delivery, transit accessibility, and transportation costs. Using satellite images, I create a dataset with several statistics about the format of cities, and then use geographic natural constraints as instruments for the potential shape of cities as the identification strategy. In opposition to recent literature, I find no evidence of an effect on rent, population, and wage under different specifications and controls. This provides suggestive evidence against the external validity of previous findings under different institutional and geographic contexts.

Keywords: Economic Development. Urban Economics. Transportation Economics. Real Estate. Land Use Patterns.

Sumário

1 Introduction

This article lies on the urban development debate by studying the economic implications of the geometric shapes of cities. The shape of a city or the geographic format of his urban area represents where most of the population lives, works, and interacts every day. The format of those areas may have an impact on how people interconnect inside a city, ones this may rise the distances between points inside them, as has been emphasized by urban planners, although mostly ignored by economists.

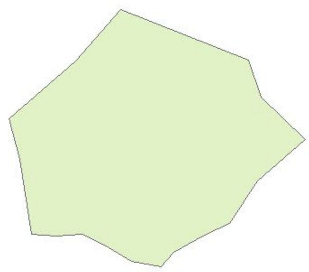
The geographic format of a city's urban area is a product of an equilibrium. As in Burchfield et al. (2006), the causes of sprawl can be associated with the way that employment is dispersed; work commuting patterns; population growth; the value of holding on to undeveloped plots of land; the ease of drilling a well; natural conditions; land use regulations; and impact of public service financing on local taxpayers.

The difference between the format of those footprints can be very significant, as exemplified in Figure 1, where the urban area of Uberlândia and greater Santos are compared. As well as the evolution of them in time as in Figure 2, where the shape of Recife in 1992 and 2013 are juxtaposed.

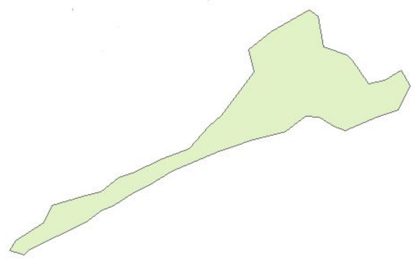
It's easy to notice that the compactness of those shapes impacts distances within cities, and that can affect other variables where mechanisms may pass through service delivery and transit accessibility. As in Henderson (1974), if a compact shape makes a city operate more efficiently, there is a tendency for population flow into that city, pressing up the rents and pressing down income. In contrast, if there are productivity advantages, firms flow to the city, pressing up income

In this scenario, an OLS estimation of shapes and population, rents, or wages can bring an endogeneity that possibly causes a bias of ambiguous signs in. Therefore to better understand if such an effect exists, is necessary an identification strategy that overlaps this issue constructing an instrument that isolates the variation in urban shape driven by topography and mechanically predicted urban growth by using the potential shape the city can have, given the geographic natural constraints, as in Harari (2020). Figure 3 exemplifies the

Figura 1 – Shape example



(a) Uberlândia



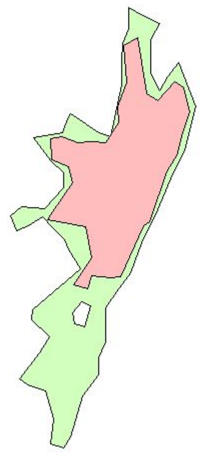
(b) Santos

impact of terrain slope on urbanization in Rio de Janeiro, where red means steeper inclinations.

The first objective of this paper is to apply shape index methods to quantify the compactness of Brazilian cities. Secondly, analyze if those differences in shape have an impact on several outcomes of interest as population, rent, and income. And then, explore the natural constraints that surround cities as an instrument to identify those effects.

This paper's contribution lies in the first assembly of such statistics using Brazilian data, as an emergent country with the seventh largest population in the world and with 85% of the population living in urban areas, it seems

Figura 2 – Recife in 1992 (red) and 2013 (green)



a perfect laboratory to explore those effects. Also, explore different outcomes improving identification methods implemented in the recent literature, but leading to inconclusive results that may be evidence of the lack of such effect on this context.

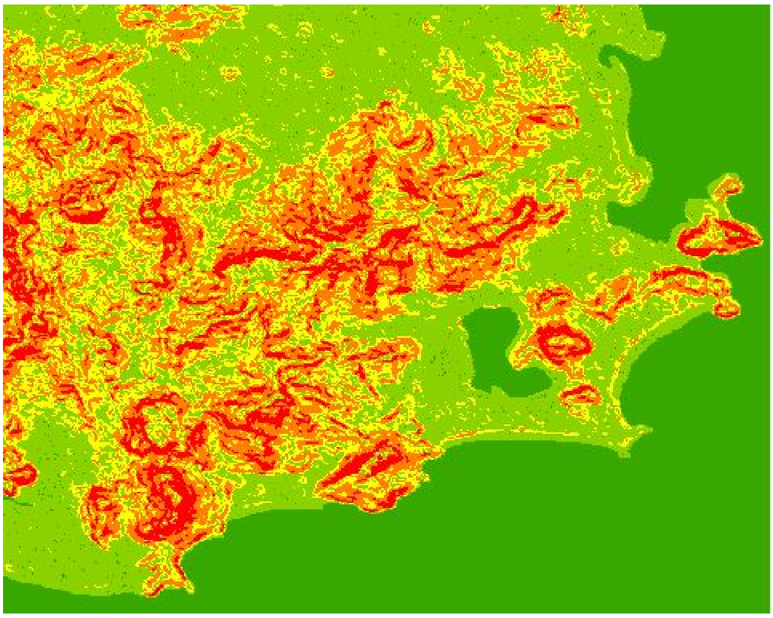
1.1 Literature

The economic literature on the geometric layout of cities doesn't abounds. Harari (2020) investigates the causal economic implications of city shape in India. Using geographic obstacles as an instrument, they found that compactness is associated with faster population growth and that households display a positive willingness to pay for more compact layouts.

Guedes (2020) examines the city shape compactness impact in the formation of slums in Brazil. Saiz (2010) examines geographic constraints, such as water bodies and steep-sloped terrain, to city expansion and relates it to the elasticity of housing supply in United States metropolitan areas. Bento et al. (2005) measure the effect of urban spatial structure on travel demand in the United States using a measure of city shape based on how much an urbanized area deviates from a circular format.

In the urban planning and geography literature, Duque et al. (2022) examine the linkages between urban form and city productivity using alter-

Figura 3 – Slope and urbanization in Rio de Janeiro



(a) Slope with ASTER GDEM data

(b) Google maps satellite image

native metrics for urban form in Latin-American cities. Baruah et al. (2020) show evidence that Francophone cities have more compact development than Anglophone due to colonial legacies of city planning and land allocation. Angel et al. (2020) review the literature on the Compact City Paradigm with a focus on the relationship between urban shapes and climate change and also focus on the physical attributes of cities that make them more or less compact. Bertaud

(2004) establishes linkages between city shape and transit use, motorization, air pollution due to transport, and poverty.

Therefore, this paper gets into a question that wasn't enough explored in the literature, and with space for new tests, improvements, and validation. The inevitable difficulty in constructing the shapes and constrain datasets is a possible reason to explain the lack of work exploring this question.

This paper is organized as: this introductory chapter, followed by a data explanation; empirical strategy; main results; discussion on identification threats and a conclusion.

2 Data

The dataset is assembled at the city-year level between the period of 1992 and 2013 covering 113 urban areas with a minimum population of 100,000 in Brazil. The data contains compactness metrics of footprints, topographic information, economic outcomes, and controls. In most specifications, I use long differences taken over 1992 and 2013 and in some exercises use year-to-year variation.

2.1 Shape Metrics

To assemble the footprint data, I employ the DMSP/OLS Night-time Lights dataset of satellite images to delimit urban areas based on the luminosity of pixels. Then turn into polygons and match cities with Global Rural-Urban Mapping Project (GRUMP) settlement points.

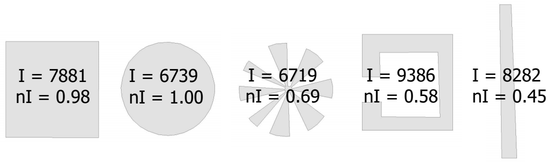
To calculate the footprint metrics I employ three indexes from Angel, Civco, and Parent (2010). Disconnection is the average Euclidean distance between all pairs of interior points; Remoteness is the average Euclidean distance from all interior points to the centroid; and Range is the maximum distance separating two points on the shape perimeter. I also use a normalized index that takes into account the radius of the geometric shape, equals 1 for perfectly rounded shapes, and get smaller for unrounded formats. Figure 4 shows examples of how Disconnection is calculated.

2.2 Instrument

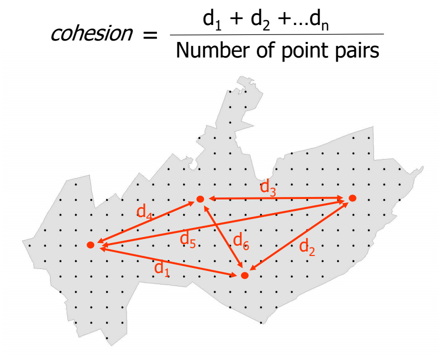
To construct the city shape instrument, as in Saiz(2010) I collect data on bodies of water and slope respectively from the MODIS Raster Water Mask and the ASTER dataset (Caroll et al. 2009, NASA and METI 2011).

As in Harari (2020), I build a projected radius obtained by a mechanical model for city expansion in space. And also I log-linearly projected the 1872 to 1980 population growth of a city to all subsequent years resulting in $\hat{p}_{c,t}$, as the

Figura 4 – Disconnection from Angel, Civco, and Parent (2009)



(a) Example of calculation of the disconnection index in meters



(b) Disconnection index for a sample of polygons

projected population. Then estimate the following regression:

$$log(area_{c,t}) = \alpha \cdot \hat{p}_{c,t} + \beta \cdot log\left(\frac{pop_{c,1991}}{area_{c,1992}}\right) + \gamma_t + \epsilon_{c,t} \tag{2.1}$$

Obtaining the predicted area $\hat{a}_{c,t}$ of city c in year t, and subsequently computing the radius of the circle with that predicted area as:

$$\hat{r}_{c,t} = \sqrt{\frac{\hat{a}_{c,t}}{\pi}} \tag{2.2}$$

Whit them in hand I consider the largest contiguous patch of developable land within the predicted radius around each city, denoting them as "potential footprint". Finally measure the shape indicators for predicted growth and use it as instrument of the actual shape.

2.3 Outcomes

Population, rent, and income data were collected from 1991 to 2010 Population Census. As well as other data on city characteristics that were complemented by RAIS/CAGED and PNAD. The population is the sum of the population of cities in polygons, and rent and income are the average of the domiciles in the main city of the polygon.

2.4 Other Data

Geography data was assembled from several sources. Distance from the coast from Global Self-consistent Hierarchical High-resolution Geography (GSHHG); distance of each city from nearest mineral deposit from Mineral Resources Data System of U.S. Geological Survey (2005); elevation from MODIS Raster Water Mask and the ASTER dataset (Caroll et al. 2009, NASA and METI 2011).

2.5 Descriptive Data

Table 1 provides an overall summary statistics for most of the variables and Table 2 shows descriptive data for the long-time distance variables used on most specifications.

Tabela 1 – Descriptive summary

	count	mean	sd	min	max
Area,km	2486	227.53	547.63	1.11	7583.09
Disconnection,km	2486	7.02	6.49	.62	60.61
Potential Disconnection,km	222	4.75	3.33	.57	27.57
Urban Area Population	565	720944.6	2191955	34661	23600000

The nature of those index variables, as well as the use of differences between long periods, makes the interpretation of the magnitudes of regression results a challenge.

Tabela 2 – Descriptive long-time distance

	First year	Last year	Difference
Area,km	154.85	343.96	184.1
	(416.48)	(751.75)	(340.5)
Disconnection,km	5.53	9.22	3.6
	(5.86)	(7.58)	(2.63)
Potential Disconnection,km	3.43	6.08	2.65
	(2.01)	(3.84)	(1.95)
Urban Area Population	578401.8	868432.3	278716
	(1842058)	(2580251)	(737287.2)

Note: reported results are mean and in parenthesis are standard deviation. First year is 1991 for population and 1992 for geographic statistics, and Last year is 2010 for population and 2013 for geographic statistics

3 Empirical Strategy

Following the strategy proposed by Harari(2020), the equation of interest in the city-year level without an instrument is:

$$log(Y_{c,t}) = a \cdot S_{c,t} + b \cdot log(area_{c,t}) + u_{c,t} \tag{3.1}$$

Here Y is the outcome of interest, S is the shape of the city where higher values denote less compact shapes, and *area* is the area of a city in square meters.

To surpass any possible endogeneity problem, the instrument version of the model lay on estimating the specification:

$$log(Y_{c,t}) = a \cdot S_{c,t} + b \cdot log(area_{c,t}) + \mu_c + \rho_t + u_{c,t} \tag{3.2}$$

With Y, S and *area* following the same definition as in equation 3, and with μ_c and ρ_t as city and year fixed effects. Using $\hat{S}_{c,t}$ as the shape of the potential footprint, and $\hat{p}_{c,t}$ for potential population, I assemble the fist-stage equation:

$$S_{c,t} = \sigma \cdot \hat{S}_{c,t} + \delta \cdot log(\hat{p}_{c,t}) + \omega_c + \varphi_t + \theta_{c,t} \tag{3.3}$$

and

$$log(area_{c,t}) = \alpha \cdot \hat{S}_{c,t} + \beta \cdot log(\hat{p}_{c,t}) + \lambda_c + \gamma_t + \epsilon_{c,t} \tag{3.4}$$

With ω_c and λ_c as city fixed effects and also φ_t and γ_t as year fixed effects.

However, not all variables are available for different years. Therefore I present most results as long differences, with the following estimating equation:

$$\Delta log(Y_c) = a \cdot \Delta S_c + b \cdot \Delta log(area_c) + u_c \tag{3.5}$$

I will use the long time distances (denoted by D or Δ) taken over 2013-1992 for shape statistics or 2010-1991 for census data.

With this, we are able to explore differences in the format of cities without being attached to the endogenous way that they expand.

4 Main Results

4.1 Population

Our most important outcome of interest is population, where here we will implement the strategies discussed earlier into the relationship between the log of the population and the geographic format of cities.

Table 3 presents the OLS Panel-data result for equation 3. It shows that faster-growing cities are cities that grow into more disconnected shapes. Collum 2 uses the distance from the coast, distance from the nearest mineral deposits, and elevation level as control variables, and also Year and City fixed effects getting similar results. Table A.1.1 in the appendix uses only the first and last years reaching similar results. The second line shows that, as expected, larger urban areas are the ones with bigger populations.

Tabela 3 – OLS: population

	(1)	(2)
	OLS	OLS
VARIABLES	Log Population	Log Population
Disconnection	0.0324***	0.0343***
	(0.00675)	(0.00726)
Log Area	0.223***	0.218***
	(0.0309)	(0.0317)
Observations	565	560
Controls	No	Yes
Year FE	No	Yes
City FE	No	Yes

Note: Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1

Besides some possible positive selection effects, the positive correlation between population and Disconnection can represent the encompass of cities by bigger conglomerates. When an urban center gets united with another city, the disconnection of the shape and population of this object suddenly increases. As discussed before the IV came as a necessary alternative approach.

Table 4 presents the first stage result using disconnection and area. As expected, the actual index of cities format is highly correlated with our potential index instrument. Here I use controls, and they have negative sign with statistical significance at p<0.01 for distance from the coast and at p<0.1 for distance from a mineral deposit and elevation. Also in this regression, the potential disconnection is negatively correlated with the area. This is intuitive since cities that are constrained by topographic barriers tend to optimize the utilization of space.

Tabela 4 – IV first stage

VARIABLES	(1) D Disconnection	(2) D Log Area
D Potential Disconection	0.464***	-0.0864**
	(0.0916)	(0.0346)
D Log Projected Population	0.485	0.216
	(1.021)	(0.247)
Observations	109	109
Controls	Yes	Yes

Note: Robust standard errors in parentheses.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5 presents the IV specification for Disconnection, Remoteness, Spin, and Range. This means that as cities become less compact, conditional on area, their population growth rise. This is not what we should expect following models in literature and Harari's findings for India. The use of the IV strategy makes our coefficient not statistically significant but it keeps the positive sign

4.2 Wages and Rent

Now, I examine the effect of geographic shape on wages and rent of the core city of the urban area. In the literature, they provide compensating differentials to families and firms as they allocate themselves between cities.

The model proposed by Harari(2020), sugests that compact city shape provides advantages in terms of quality of life or productivity, compact cities

Tabela 5 – IV population

VARIABLES	(1) IV D Log pop	(2) IV D Log pop	(3) IV D Log pop
D Log area	0.339	0.343	0.243
	(0.329)	(0.331)	(0.237)
D Disconnection	0.0583		
	(0.0430)		
D Remoteness		0.0825	
		(0.0609)	
D Range			0.0185
			(0.0129)
Observations	109	109	109
Controls	Yes	Yes	Yes

Note: Robust standard errors in parentheses.*** p$<$0.01, ** p$<$0.05, * p$<$0.1

will be characterized by higher rents and wages that may be higher or lower depending on whether households or firms value compact shape the most.

In Table 6, I use the log of wages in the main city of the urban footprint. Here disconnected format and wages are positively correlated but with no statistical significance. And Table 7 shows the effect on log rents of the main city in the urban area. Similarly to results on population, here we find small positive results for all 3 measuments.

Tabela 6 – IV Wage

	(1)	(2)	(3)
	IV	IV	IV
VARIABLES	D Log wage	D Log wage	D Log wage
D Log area	-0.0359	-0.0416	0.0298
	(1.058)	(1.049)	(0.757)
D Disconnection	0.0139		
	(0.150)		
D Remoteness		0.0189	
		(0.210)	
D Range			0.00703
			(0.0459)
Observations	109	109	109
Controls	Yes	Yes	Yes

Note: Robust standard errors in parentheses.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Tabela 7 – IV Rent

	(1)	(2)	(3)
	IV	IV	IV
VARIABLES	D Log rent	D Log rent	D Log rent
D Log area	0.586	0.569	0.755
	(0.713)	(0.700))	(0.556)
D Disconnection	0.00668		
	(0.0959)		
D Remoteness		0.00750	
		(0.133)	
D Range			0.00746
			(0.0334)
Observations	109	109	109
Controls	Yes	Yes	Yes

Note: Robust standard errors in parentheses.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

5 Discussion

5.1 Threats to Identification

The instrument may be correlated with geographic characteristics that have an impact on outcomes. To overcome this, I show that the result controlling for those characteristics in some previous results doesn't vary too much. But one possibility is that the settlement of cities in determinate areas is not exogenous, and may be a problem to exclusion restriction. I don't discard this possibility but it doesn't seem much plausible.

The population of a polygon is the result of the sum of the population of each city inside that polygon. Once the polygon expands in time, it incorporates new cities into its boundaries. To overpass any mechanical correlation between new cities added in population calculus and the change in the shape due to this incorporation, I use two population variables that don't change their composition in time. One uses the set of cities inside the polygon in 1992, and the other with the set in 2013. The results in Table 6 don't change much from the previous specification.

Tabela 8 – IV Population with fixed cities

VARIABLES	(1) IV D Log pop (cities in 1992)	(2) IV D Log pop (cities in 2013)
D Log area	0.434	0.417
	(0.339)	(0.336)
D Disconnection	0.0478	0.0546
	(0.0550)	(0.0528)
Observations	109	109
Controls	Yes	Yes

Note: Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1

To address any concerns on the correlation of the historical populational growth that is used to project city size in the instrument and outcomes today, as did in Harari (2020), I build a mechanical expansion path of the city that is not the result of the previous populational growth. Also, instead of controlling for the area in regressions, we could use normalized measurements of the shape index that take the radius of the polygon into account.

The results in Table 9 show a switch in wage signal but without statistically significant results, and the population stays unchanged, while

Tabela 9 – IV Mechanical variation and normalized measures

VARIABLES	(1) D Log population	(2) D Log Rent	(3) D Log Wage
D Norm. Mec. Disconnection	4.207	-2.939	1.901
	(7.606)	(6.410)	(6.561)
Observations	110	110	110
Controls	Yes	Yes	Yes

Note: Robust standard errors in parentheses.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

5.2 Results on Literature

The results show that cities with bad shape format have faster populational growth and higher rents and wages. The OLS results on population are in concordance with Harari(2020), but using the instrumental variable I didn't find evidence of a negative effect of bad shape. Even with different specifications, and similar outcomes the result it keeps the same. Is not clear exactly why we have this result when previous works have found opposite-direction effects on different contexts, but it is possible that the effect found in India doesn't exist in the Brazilian context.

Someone may argue that the geographical characteristics of India may lead to cities being constrained by mountains and high-stepped terrains, while in Brazil only endogenous circumstances are responsible for the shape format. Although, we find a strong correlation between the real city shape taken by satellite and the potential city shape instrument built using geographical barriers, both mechanical and regular versions. Therefore is evidence that the real format is influenced by geography.

Further investigation would require a bigger range of satellite data, but with this impossibility, it would be feasible to use military maps on the urban footprint of the'60s and '50s as bottom dates for the long-time distance evaluation. Also, the preparation of the instrument in panel data for the years between 1992 and 2013. The compilation and treatment of the dataset in this paper are beyond work intensive, therefore was not feasible to have the panel data in all specifications but is definitely not impossible to do so. Spotting any possibility of a small sample problem that made us not be able to see this effect, we could be more affirmative in saying that this effect does not exist in Brazil.

6 Conclusion

In this paper, I build for the first time a dataset on the format of urban centers for Brazilian cities using satellite images. Also, using geographic barriers I construct an instrument for the constraints on city development that forces a city to have a determinate format. Then I study the relationship between those shapes of cities and economic outcomes.

In opposition to Harari(2020), my point estimation is positive for population under the IV strategy with different specifications. This result goes in the opposite direction of their model and may be evidence of a different arrangement of populational settlement in Brazil.

For rent and wages, I find positive effects, that may be explained by a possible compensation effect under people and firms migration. Although the results are not statistically significant.

Those results may be a product of differences in the Brazilian and Indian contexts. But also further investigation is needed to a more assertive conclusion. Nevertheless, is one of the first articles investigating this effect, contributing to the discussion about to which extent this effect is present and the need of revisiting this topic.

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A Appendix

A.1 Supplementery Results

Tabela A.1.1 – OLS: population using long time distances

VARIABLES	(1) OLS Log Population	(2) OLS Log Population
Δ Disconection	0.0408***	0.0419***
	(0.00755)	(0.00906)
Δ Log Area	0.254***	0.243***
	(0.0330)	(0.0354)
Observations	113	112
Controls	No	Yes

Note: Robust standard errors in parentheses.*** $p<0.01$, ** $p<0.05$, * $p<0.1$