Who reduces consumption in response to non-price watering restrictions? Evidence from micro-data linking household demographics and water consumption

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Road map

- Motivation
- Literature
- Data
- Empirical models
- Results
- Future work

Motivation

- Price vs. non-price policy
    - "…using price increases to reduce demand, allowing consumers to adjust their end uses of water, is more cost effective than implementing nonprice demand management programs" (Olmstead & Stavins, 2009 WRR).

- Significant political obstacles to municipal utility rate setting

- Little knowledge of which household characteristics drive water conservation during drought

Literature

- Residential water demand
  - Price specification
  - Price endogeneity

- Demand-side management
  - Renwick & Green (JEEM, 2000)
    - Aggregate data for eight municipalities in California.
    - Estimate effects of water conservation policies and technology adoption.
  - Renwick & Archibald (Land Econ,1998)
    - Micro-data for Santa Barbara & Goleta, CA.
    - High-income households are less sensitive to price changes; low-density households are more sensitive to irrigation restrictions.

Goals

- Estimate a reduced-form water demand model with household fixed effects using micro-level panel data

- Assess the relationship between household heterogeneity and responsiveness to non-price policies during drought

- Examine how parameter estimates change over relative volumes of consumption using quantile regression

Data

- ## Household water consumption data
  - Monthly quantity consumed
  - 30 months – July 2006 to December 2008
  - Chapel Hill, Hendersonville, Greenville, High Point, Fayetteville, Charlotte

Data

Mean volume per capita over time
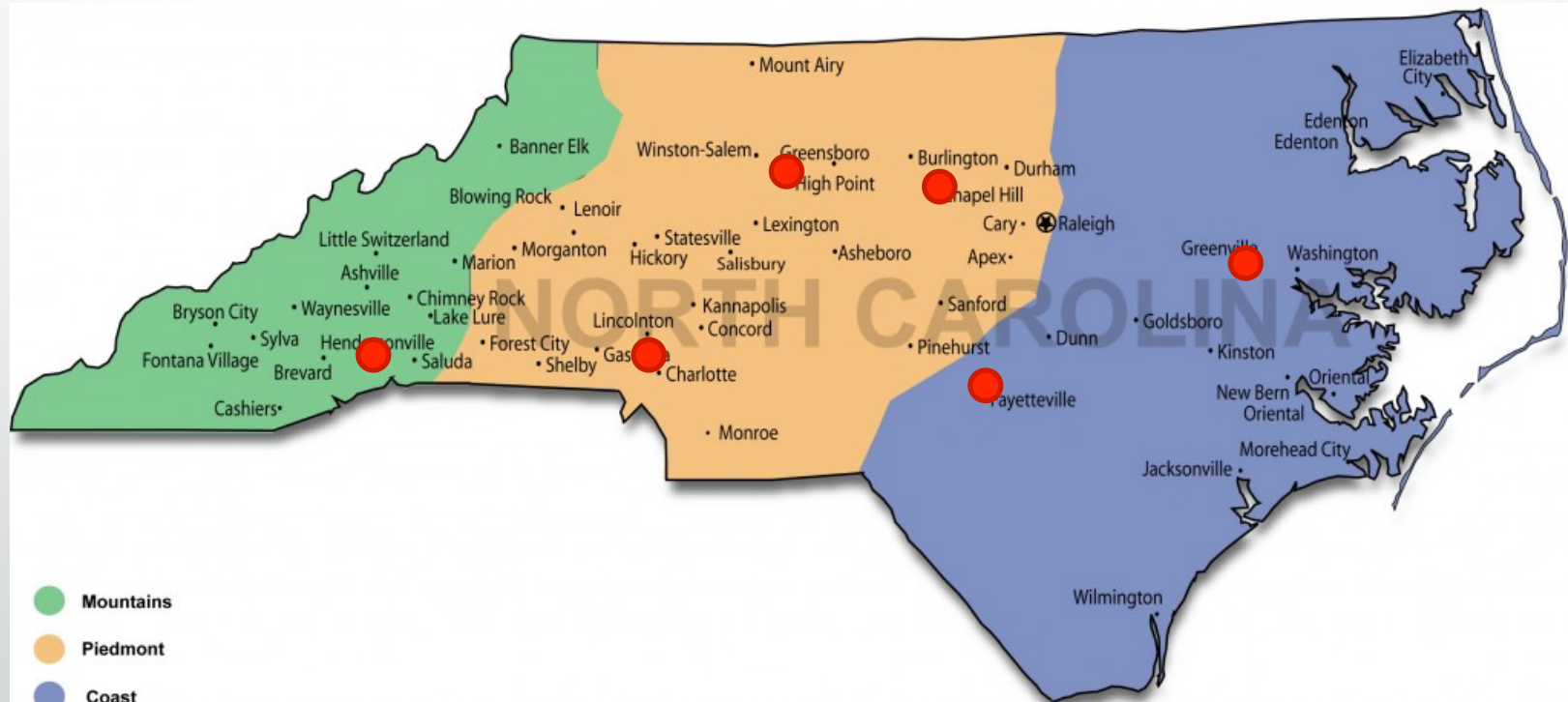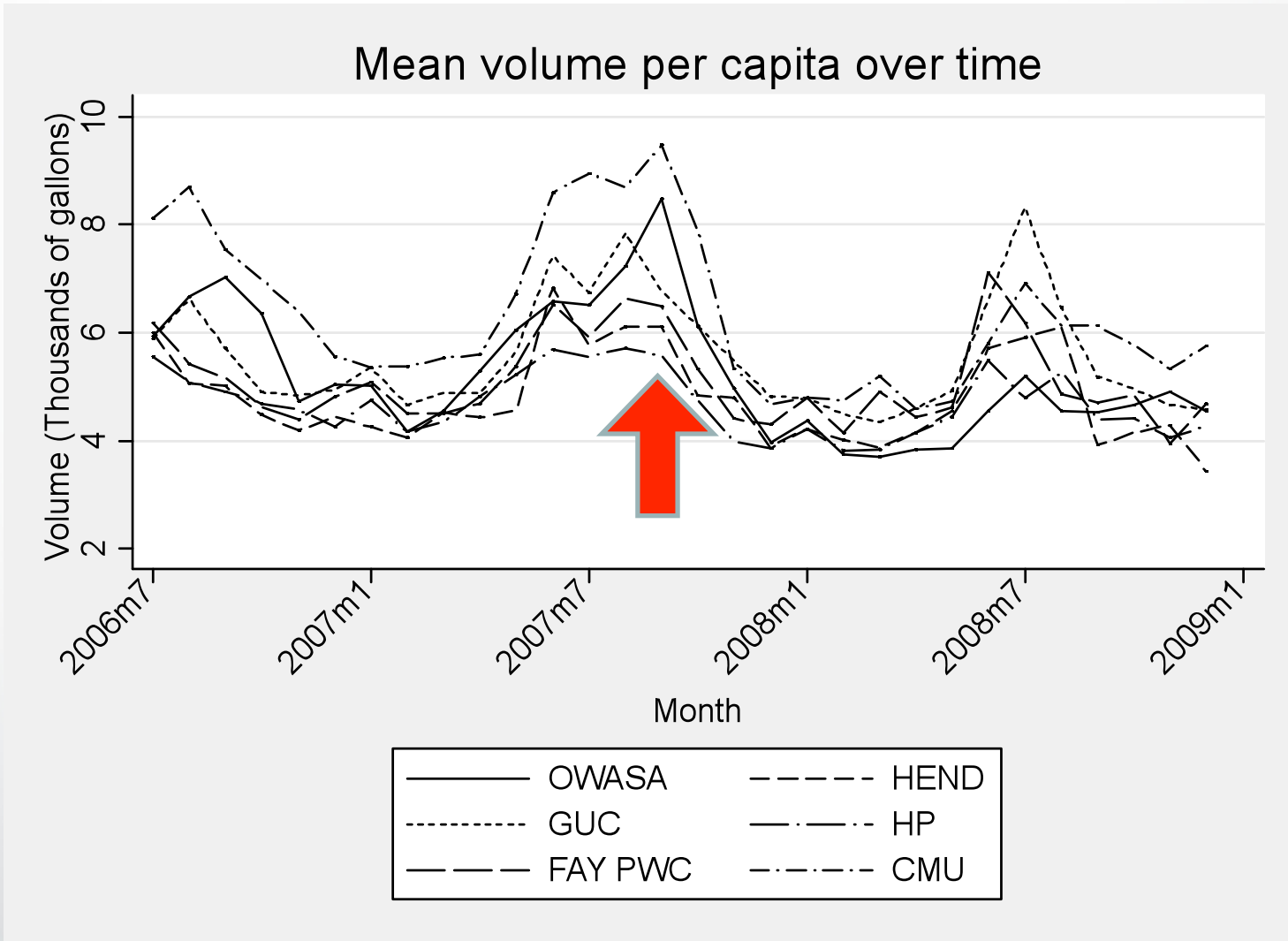
Data

- Household water consumption data
- Non-price policy data
  - Voluntary vs. mandatory watering restrictions
  - Voluntary policy (example)
    - Limit outdoor watering to every-other day. Households encouraged to reduce consumption.
  - Mandatory policy (example)
    - Turf irrigation restricted as well as washing vehicles, sidewalks, etc.
    - Enforced via fines.
    - Conservation goal: 10%

Data

Water Restrictions by Municipality

	2006						2007											2008											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
OWASA															V	M	M	M	M	M	V	V								
HEND															V	V	V	V	V	V	V	V	V	V		M	M	V	V	V
GUC																	V	V	V	V	V	V								
HP															V	M	V	V	V	V										
FAY PWC	M	M	M									M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
CMU													V	V	V	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Drought Conditions by region

	2006						2007											2008											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
OWASA	0	0	0	0	0	0	0	0	0.8	0.5	1.2	1	1.8	2.5	3.8	4.2	3.5	5	4	4.3	3	1.8	0.3	1.3	2	2	2	2	1.5	0.4
HEND	1.5	1.4	0.5	0	0	0	0	0	0.8	1	1.6	2	2	3.5	4	4.8	5	5	5	5	4.3	3.8	3.3	4	4	4	2.4	2	1.5	0.4
GUC	0	0.2	0	0	0	0	0	0	0.8	0.5	1.6	2	2	2.8	4	4.6	3.8	5	5	4.8	3.3	2	1	1.8	2.2	1	0.2	0	0	0
HP	0	0.8	0.5	0	0	0	0	0	0.8	0.5	1	1	1.8	2.8	4	4.6	4.3	5	5	5	4.3	3.2	2.3	2.8	2.4	2.8	1	0	1	0.4
FAY PWC	2	1.8	0.5	0	0	0	0	0.8	0.8	1.8	2.2	3	3	4.3	4	4.6	5	5	5	4.8	3.3	3	3.8	4.5	5	4.8	4	4	4.8	4.2
CMU	0	0.8	0.5	0	0	0	0	0	0.8	0.5	1	1	1.8	2.8	4	4.6	4.5	5	5	5	4.3	3	1.5	2.3	2.2	2.8	0.8	0	0	0

Data

- Billing data
- Non-price policy data
- Survey & household composition data
  - Household demographics and landscape characteristics
    - Lot size, square footage, irrigation system, income, household occupancy.

- Weather data
  - Monthly rainfall, maximum monthly temperature.

Data

- Billing data
- Non-price policy data
- Survey & household composition data
- Weather data
- Price data
  - Marginal and average price
  - Includes base service fees & sewer charges
  - Difference variable: equal to the customer's bill minus what the customer's bill would have been if every unit of water was charged at the marginal price.

Baseline model

- Instrumental variables with fixed effects

$$VOLUME_{i,k,t} = \delta_1 \hat{PRICE}_{i,k,t-1} + \beta_1 VOL\_POLICY_{k,t} + \beta_2 MAND\_POLICY_{k,t}$$

$$+\beta_3 RAIN_{k,t} + \beta_4 TEMP_{k,t} + \sum_{s=2}^{12} \sigma_s MONTH^s + \alpha_{i,k} + u_{i,k,t}$$

$$\hat{PRICE}_{i,k,t-1} = \varphi_1 BASE_{k,t-1} + \sum_{b=1}^{B} \rho_b MP_{k,t-1}^b + \hat{\beta}_1 VOL\_POLICY_{k,t}$$

$$+\hat{\beta}_2 MAND\_POLICY_{k,t} + \hat{\beta}_3 RAIN_{k,t} + \hat{\beta}_4 TEMP_{k,t} + \sum_{s=2}^{12} \hat{\sigma}_s MONTH^s + \hat{\alpha}_{i,k} + v_{i,k,t}$$

All non-binary variables are in logarithmic form.

Results – Baseline models

VOLUME	(1) Baseline AP Model w/ HH Fixed Effects	(2) Baseline MP Model w/ HH Fixed Effects
AP	-0.450***	
	(0.036)	
MP		-0.323***
		(0.039)
DIFF		-0.001
		(0.001)
VOL_POLICY	-0.019***	-0.035***
	(0.005)	(0.006)
MAND_POLICY	-0.068***	-0.084***
	(0.006)	(0.007)
Observations	48,137	48,137
Fixed Effects:[T]	HH, Month	HH, Month
Controlling for:	RAIN, TEMP	RAIN, TEMP

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

[T] Month = Monthly; HH = Household

Price-policy equivalent for voluntary policy ranges from $0.41 to $1.06.

Price-policy equivalent for mandatory policy ranges from $1.48 to $2.56.

Interactive effects

$$VOLUME_{i,k,t} = \delta_1 P\hat{R}ICE_{i,k,t-1} + \beta_1 VOL\_POLICY_{k,t} + \beta_2(Z_{i,k,t} * VOL_{k,t})$$

$$+ \beta_3 MAND\_POLICY_{k,t} + \beta_4(Z_{i,k,t} * MAND_{k,t}) + \beta_5 RAIN_{k,t} + \beta_6 TEMP_{k,t}$$

$$+ \sum_{s=2}^{12} \sigma_s MONTH^s + \alpha_{i,k} + u_{i,k,t}$$

- Where $Z_{i,k,t}$ is a vector of household characteristics of interest

Results – Interactive effects

VARIABLES	VOLUME
VOL_POLICY	-0.005
	(0.785)
MAND_POLICY	-2.817***
	(0.700)
INCOME*VOL_POLICY	-0.096
	(0.142)
INCOME^2*VOL_POLICY	0.004
	(0.006)
INCOME*MAND_POLICY	0.465***
	(0.126)
INCOME^2*MAND_POLICY	-0.022***
	(0.006)
IRRSYS*VOL_POLICY	0.057*
	(0.032)
IRRSYS*MAND_POLICY	-0.054**
	(0.024)

Household & monthly fixed effects.

Robust standard errors in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Response to voluntary policies is decreasing at an increasing rate in income, but not significant.

Response to mandatory policies is increasing at a decreasing rate in income.

Households with an automatic irrigation system display increased consumption during voluntary policies, but decreased consumption during mandatory policies.

Results – Interactive effects

VARIABLES	VOLUME
VOL_POLICY	-0.005
	(0.785)
MAND_POLICY	-2.817***
	(0.700)
MEDLOT*VOL_POLICY	0.002
	(0.012)
MEDLOT*MAND_POLICY	0.010
	(0.013)
BIGLOT*VOL_POLICY	-0.027*
	(0.015)
BIGLOT*MAND_POLICY	0.034**
	(0.014)
BIGHOUSE*VOL_POLICY	0.001
	(0.010)
BIGHOUSE*MAND_POLICY	0.010
	(0.010)

Household & monthly fixed effects.

Robust standard errors in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Medium lot size has no significant effect on response to voluntary or mandatory policies.

Response to voluntary policies is decreasing in big lots and the response for mandatory policies is increasing in big lots.

Square footage of the house has no significant effect on a household's response to voluntary or mandatory policies.

Results – Interactive effects

VARIABLES	VOLUME
VOL_POLICY	-0.005
	(0.785)
MAND_POLICY	-2.817***
	(0.700)
RAIN*VOL_POLICY	-0.008
	(0.008)
RAIN*MAND_POLICY	-0.010*
	(0.006)
TEMP*VOL_POLICY	0.127***
	(0.029)
TEMP*MAND_POLICY	0.067***
	(0.023)
KIDS*VOL_POLICY	0.028**
	(0.011)
KIDS*MAND_POLICY	0.033***
	(0.011)

Household & monthly fixed effects.

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Response to voluntary and mandatory policies is decreasing in rainfall.

Response to voluntary and mandatory policies is increasing in maximum temperature, but the magnitude of the effect is smaller for mandatory policies.

Response to voluntary and mandatory policies is increasing with the presence of children.

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Quantile regression

- Instrumental variables quantile regression with fixed effects (IV_FE_QR)
  - Following Harding & Lamarche (Econ Letters, 2009)

Quartile	Mean consumption (1,000 gallons/month)
25th	2.99
50th	4.48
75th	6.00

Results – IV_FE_QR

VOLUME	(1) Baseline Model	(2) 0.25 Quartile	(3) 0.5 Quartile	(4) 0.75 Quartile
AP	-0.364***	-0.327***	-0.382***	-0.371***
	(0.046)	(0.042)	(0.046)	(0.077)
VOL_POLICY	-0.021**	-0.027***	-0.026***	-0.021**
	(0.009)	(0.009)	(0.009)	(0.010)
MAND_POLICY	-0.084***	-0.087***	-0.084***	-0.084***
	(0.009)	(0.010)	(0.009)	(0.012)
INCOME	0.146***	0.126***	0.123***	0.132***
	(0.005)	(0.005)	(0.005)	(0.005)
Observations	36,224	36,224	36,224	36,224
Fixed Effects:T	Muni, Month	Muni, Month	Muni, Month	Muni, Month

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

T Muni = Municipality; Month = Monthly; HH = Household

Conclusions

- Voluntary and mandatory watering restrictions were effective in reducing quantity demanded by roughly 2-4% and 6-9% during the 2007 drought in NC.

- Response to mandatory watering restrictions is increasing at a decreasing rate in income.

- Households with an automatic irrigation system display increased consumption during voluntary policies, but decreased consumption during mandatory policies.

- Responsiveness to watering restrictions and price remain relatively flat across different quartiles of consumption.

Areas for future work

- Assessment of the distributional implications of price and non-price conservation policies in response to limited supply – who bears the welfare burden?

- Analyzing demand response to different non-price policy instruments – i.e. public information campaigns, outdoor irrigation restrictions, technology adoption, etc.

Thank you

VOLUME	(1) Baseline AP Model w/o HH Charac-teristics	(2) Baseline AP Model w/ HH Charac-teristics	(3) Baseline MP Model w/o HH Charac-terisctics	(4) Baseline MP Model w/ HH Charac-teristics	(5) Baseline AP Model w/ HH Fixed Effects	(6) Baseline MP Model w/ HH Fixed Effects
AP	-0.386*** (0.030)	-0.333*** (0.033)			-0.450*** (0.036)	
MP			-0.387*** (0.036)	-0.355*** (0.039)		-0.322*** (0.038)
DIFF			-0.005*** (0.002)	-0.006*** (0.002)		-0.001 (0.001)
VOL_POLICY	-0.022*** (0.008)	-0.022*** (0.008)	-0.053*** (0.011)	-0.054*** (0.012)	-0.019*** (0.006)	-0.035*** (0.006)
MAND_POLICY	-0.075*** (0.008)	-0.086*** (0.008)	-0.105*** (0.012)	-0.119*** (0.013)	-0.068*** (0.006)	-0.084*** (0.007)
INCOME	0.199*** (0.004)	0.148*** (0.004)	0.225*** (0.004)	0.163*** (0.004)		
RAIN	-0.028*** (0.004)	-0.031*** (0.004)	-0.031*** (0.004)	-0.033*** (0.005)	-0.028*** (0.003)	-0.029*** (0.003)
TEMP	0.549*** (0.072)	0.554*** (0.077)	0.694*** (0.082)	0.705*** (0.087)	0.522*** (0.050)	0.638*** (0.051)
ACRE		0.024*** (0.004)		0.027*** (0.004)		
SQFOOT		0.014** (0.007)		0.016** (0.008)		
HHSIZE		0.159*** (0.003)		0.178*** (0.003)		
Constant	-1.618*** (0.314)	-1.794*** (0.343)	-2.546*** (0.333)	-2.662*** (0.357)	0.417* (0.237)	-0.441** (0.222)
Observations	48,137	36,224	48,137	36,224	48,137	48,137
r2_between	0.929	0.789	0.494	0.479	0.360	0.000243
r2_within	0.217	0.289	0.0763	0.187	0.122	0.0747
r2_overall	0.249	0.304	0.0869	0.192	0.230	0.0252
Fixed Effects:[T]	Muni, Month	Muni, Month	Muni, Month	Muni, Month	HH, Month	HH, Month

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

[T] Muni = Municipality; Month = Monthly; HH = Household

Summary Statistics on Water Volume Consumed						
VOLUME	OWASA	HEND	GUC	HP	FAY PWC	CMU
5TH PERCENTILE	2.00	1.40	1.49	1.50	1.00	1.50
25TH PERCENTILE	3.00	2.70	2.99	2.99	3.00	3.74
MEAN	5.24	4.79	5.58	4.69	5.12	6.51
MEDIAN	4.00	3.80	4.48	3.74	4.00	5.24
75TH PERCENTILE	6.00	5.60	6.73	5.98	6.00	7.48
95TH PERCENTILE	12.00	11.20	13.46	9.72	11.00	15.71
MAXIMUM	49.00	47.60	48.62	42.64	48.00	49.37
OBSERVATIONS*	6,954	7,046	6,698	8,014	11,505	10,430

*Total number of observations for each municipality

	Chapel Hill	Hender- Sonville	Green- Ville	High Point	Fayette- Ville	Charlotte	*TOTAL*	*NC**	*US**
	Mean Household Characteristics by Municipality								
ANNUAL INCOME	183,227	124,061	107,555	114,613	88,196	134,903	122,649	43,754**	50,221 **
HOME VALUE ($)	354,861	288,469	188,551	188,192	141,463	245,131	226,506	143,700	185,400
LOT SIZE (ACRES)	0.51	1.05	0.50	0.50	0.58	0.49	0.59		
HOUSE SIZE (SQ FT)	2,720	2,800	2,644	2,627	2,801	2,718	2,725		
HOUSEHOLD SIZE	2.85	2.33	2.38	2.60	2.46	2.55	2.52	2.47	2.6
NUMBER OF CHILDREN	0.73	0.22	0.27	0.47	0.32	0.43	0.40		
N	234	245	226	271	388	362	1,726		

* Obtained from the US Census Bureau's State & County QuickFacts website

** Reported statistic is the median income

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