Whom to Target under Peer Pressure?
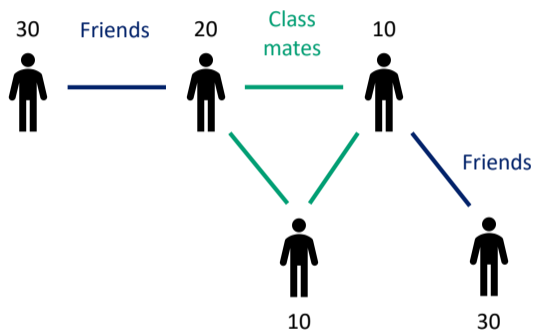# A Social Marginal Effects Approach

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This Paper

- Goal: reduce the total aggregate measure of a risky behavior

- Information: social connections, observed characteristics and outcomes

- Research Question: How do you choose the individuals to target?

Risky Behaviors

- Marijuana and e-cigarettes can be highly addictive and can harm adolescent brain development (CDC).

- The most common reason U.S. adolescents give for trying an e-cigarette is "a friend used them" (National Youth Tobacco Survey, 2021).

- Economic implications in education, wages, crime, and healthcare costs

Contribution

1. Identify influential individuals through the social marginal effects

2. Identification and estimation of peer effects using multilayer networks

3. Counterfactual policies to reduce aggregate risky behavior

▸ Previous Work

Social Marginal Effects

Peer Pressure in Preferences

- Individual chooses action $y_i \in \mathbb{R}$ to maximize $U_i(y_i, y_{-i})$

$$\underbrace{(\gamma^* x_i + z_i + \delta_1^* \bar{x}_{1i} + \delta_2^* \bar{x}_{2i}) y_i}_{\text{private utility}} - \underbrace{\frac{1}{2} y_i^2}_{\text{cost}} - \underbrace{\frac{\beta_1^*}{2} (y_i - \bar{y}_{1i})^2 - \frac{\beta_2^*}{2} (y_i - \bar{y}_{2i})^2}_{\text{peer pressure}}$$

- Best reply function:

$$y_i = \frac{1}{1 + \beta_1^* + \beta_2^*} \left[\beta_1^* \bar{y}_{1i} + \beta_2^* \bar{y}_{2i} + \delta_1^* \bar{x}_{1i} + \delta_2^* \bar{x}_{2i} + \gamma^* x_i + e_i \right]$$

- Estimate the regression:

$$\mathbf{y} = \beta_1 \bar{\mathbf{y}}_1 + \beta_2 \bar{\mathbf{y}}_2 + \delta_1 \bar{\mathbf{x}}_1 + \delta_2 \bar{\mathbf{x}}_1 + \gamma \mathbf{x} + \mathbf{e}$$

Social Marginal Effects

- Rewrite the best reply function as

$$\mathbf{y} = \underbrace{\mathbf{S}(\beta^*)}_{\text{social marginal effects}} \underbrace{[\delta_1^* \bar{\mathbf{x}}_1 + \delta_2^* \bar{\mathbf{x}}_1 + \gamma^* \mathbf{x} + \mathbf{e}]}_{\widetilde{\mathbf{x}}}$$

- $\mathbf{S}(\beta^*) = [(1 + \beta_1^* + \beta_2^*)\mathbf{I} - \beta_1^* \mathbf{W}_1 - \beta_2^* \mathbf{W}_2]^{-1}$

- $s_{ij} \equiv \frac{\partial y_i}{\partial \widetilde{x}_j}$ is the marginal effect that a change in j's characteristics has on i's outcome
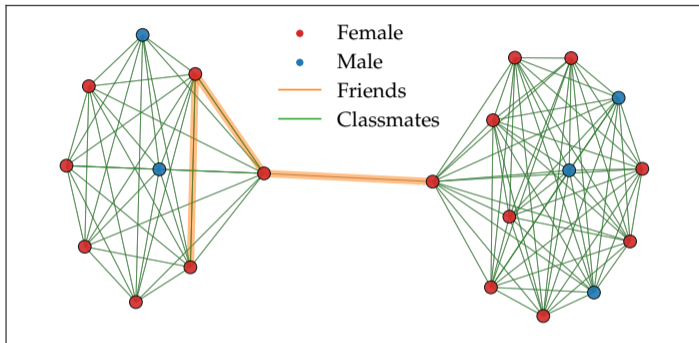
▸ Peer Pressure Centrality

Empirical Strategy

Add Health Data

- National representative sample of over 20,000 adolescents

- 8,000 publications using Add Health data

- Questions about friends and classmates

- **Wave I:** 1994-95, saturated sample of 2K high school students

Descriptive Statistics

	Mean	SD
Cigarette Use	4.25	9.44
Friends Cigarette	1.95	6.15
Classmates Cigarette	4.25	3.42
Marijuana Use	1.61	7.22
Friends Marijuana	0.72	4.68
Classmates Marijuana	1.61	1.29
Friends Risk	0.17	0.34
Classmates Risk	0.41	0.1
Risk Aversion	0.41	0.49
Future Orientation	0.49	0.5
Physical Activity	0.54	0.5
IQ Test	0.01	0.97
College Parent	0.65	0.48
Two Parents	0.72	0.45
Smoker Parent	0.64	0.48

Econometric Challenge

$$\mathbf{y} = \beta_1 \bar{\mathbf{y}}_1 + \beta_2 \bar{\mathbf{y}}_2 + \delta_1 \bar{\mathbf{x}}_1 + \delta_2 \bar{\mathbf{x}}_1 + \gamma \mathbf{x} + \mathbf{e}$$

$$= \beta_1 \mathbf{W}_1 \mathbf{y} + \beta_2 \mathbf{W}_2 \mathbf{y} + \delta_1 \mathbf{W}_1 \mathbf{x} + \delta_2 \mathbf{W}_2 \mathbf{x} + \gamma \mathbf{x} + \mathbf{e}$$

- **Problems:**
  1. Reflection problem

  2. Homophily: $\mathbb{E}[e_j \, x_i] \neq 0$

- **Solutions:**
  1. Use the structure of the networks: intransitivity and group sizes.

  2. Find a $\mathcal{W}_m$ for $\mathbf{W}_m$ such that the dependence of individual i and j approaches zero when they are far enough across networks.

‣ Identification   ‣ Moments   ‣ Instruments   ‣ GMM Estimation   ‣ Inference

Results

Peer Effects on Cigarette Smoking

	OLS		2SLS		GMM	
Peer Effects						
Friends Use	0.396***	(0.021)	-0.009	(1.593)	0.469***	(0.021)
Classmates Use	0.178	(0.151)	0.191	(4.162)	0.351***	(0.003)
Contextual Effects						
Friends Risk	-1.888*	(0.992)	-2.680	(19.68)	-1.179***	(0.258)
Classmates Risk	2.717	(2.708)	11.29	(77.82)	2.177***	(0.818)
Additional Controls	Yes		Yes		Yes	
Instruments			Smoker Parent		Smoker Parent	

▸ Instruments   ▸ Fixed Effects   ▸ Full Results

Peer Effects on Marijuana Use

	OLS		2SLS		GMM	
Peer Effects						
Friends Use	0.152*	(0.080)	0.227	(2.495)	0.226***	(0.023)
Classmates Use	-0.067	(0.231)	0.005	(2.421)	0.281***	(0.012)
Contextual Effects						
Friends Risk	0.133	(0.144)	-2.041	(11.82)	0.157	(0.168)
Classmates Risk	-0.786	(0.795)	4.241	(12.98)	1.172	(0.976)
Additional Controls	Yes		Yes		Yes	
Instruments			Smoker Parent		Smoker Parent	

▸ Instruments   ▸ Fixed Effects   ▸ Full Results
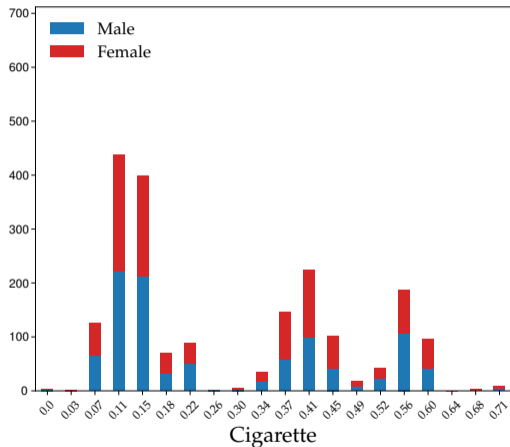
Peer Pressure Centrality

- Recover the structural parameters β^* from the peer effects estimates $\widehat{\beta}_{GMM}$

- Calculate the matrix of social effects

$$\mathbf{S}(\beta^*) = [(1 + \beta_1^* + \beta_1^*)\,\mathbf{I} - \beta_1^*\mathbf{W}_1 - \beta_2^*\mathbf{W}_2]^{-1}$$

- Individual's j social effects:

$$\bar{s}_j = \sum_{j \neq i} s_{ij}$$

Distribution of Peer Pressure Centrality
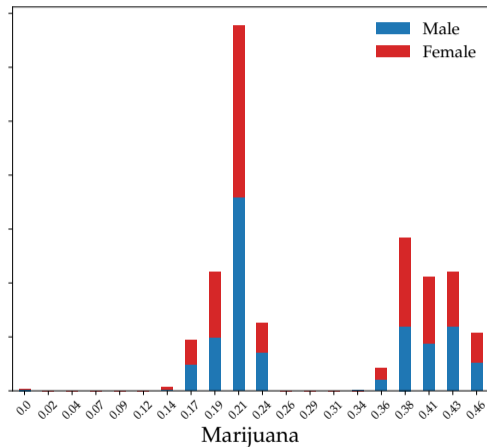
Difference between High and Low-Influence Adolescents

	Difference
Risk Aversion	-0.03
Future Orientation	-0.03
Physical Activity	-0.0
IQ Test	0.29***
Female	0.05**
Age	-0.08
Black	-0.1***
Asian	-0.0
Other Race	-0.04***
College Parent	0.02
Two Parents	0.06***
Smoker Parent	0.03

Conclusions

- Under the assumption of peer pressure, there are positive and significant peer effects on risky behaviors exerted from friends and classmates.

- Social influence is stronger in cigarette smoking than in marijuana use. The friends effect is larger than the classmates effect only for cigarette smoking.

- Identifying *influencers* present potential opportunities to decrease overall consumption of risky behaviors.

Appendix

Previous Work
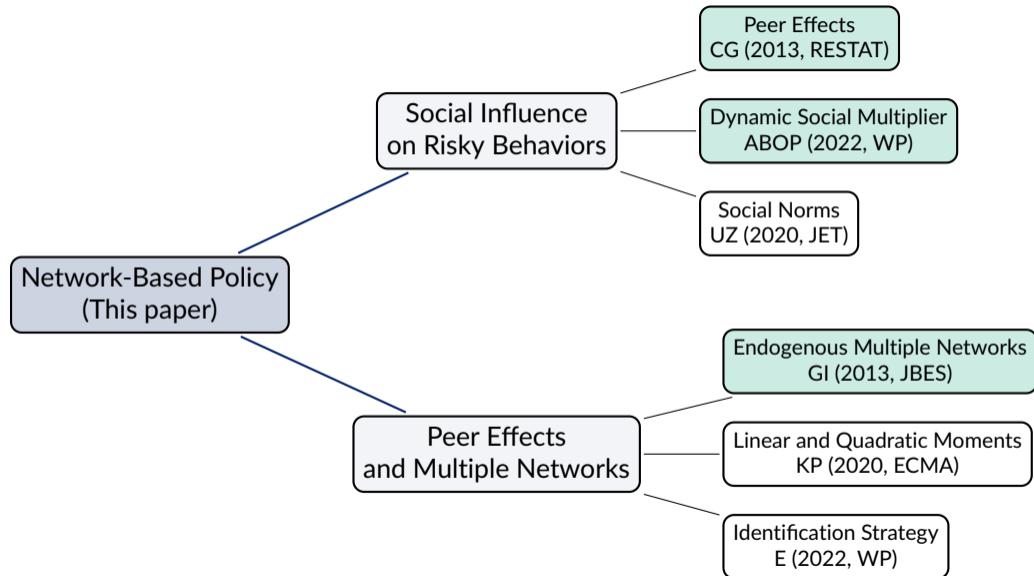
Peer Pressure Centrality

- Parameter-dependent network centrality measure

- Proportional to a multilayer Katz-Bonacich centrality

- How "central" individuals are in their social network with regard to pressuring their peers to adopt a behavior / consume a product?

▸ Social Marginal Effects

Main Identification Idea

- **Assumption:** correlation decreases with $\begin{cases} \textbf{(1) increase in shortest path length} \\ \textbf{(2) more edge-type changes} \end{cases}$

Study mates

Friends

Friends

Friends
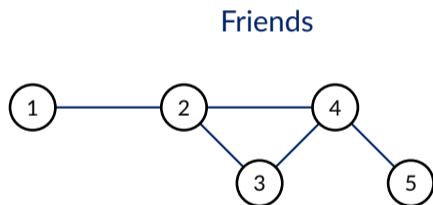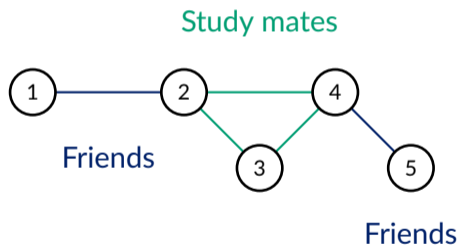
Moment Conditions

- Define $\theta = [\beta_1, \beta_2, \delta_1, \delta_2, \gamma]^\top$ and $\lambda = \beta, \delta$.

- The linear and quadratic instruments are

$$\mathbf{Z} = [\mathcal{W}_{1,\beta}\mathbf{X}, \ \mathcal{W}_{2,\beta}\mathbf{X}, \ \mathbf{W}_1^2\mathbf{X}, \ \mathbf{W}_2^2\mathbf{X}, \ \mathbf{X}]$$

$$\mathbf{A}_r = \mathcal{W}_{m,\lambda}\mathcal{W}_{m,\lambda}^\top - \mathrm{diag}\left(\mathcal{W}_{m,\lambda}\mathcal{W}_{m,\lambda}^\top\right), \ \ r = 1, \ldots, q$$

- And the moment conditions

$$\overline{\mathbf{m}}_l(\theta) = \mathbb{E}\left[\mathbf{Z}^\top \mathbf{e}(\theta)\right], \qquad \overline{\mathbf{m}}_q(\theta) = \mathbb{E}\left[\begin{array}{c} \mathbf{e}(\theta)^\top\mathbf{A}_1\mathbf{e}(\theta) \\ \vdots \\ \mathbf{e}(\theta)^\top\mathbf{A}_q\mathbf{e}(\theta) \end{array}\right]$$

Instruments

Choose two hyperparameters K_c and K_d and form the matrices $\mathcal{W}_{m,\beta}$ and $\mathcal{W}_{m,\delta}$

- $w_{m,\beta;i,j} = 1$ if $\mathbb{E}\left(\mathbf{x}_j e_i \mid c^* \geq K_c,\ d^c \geq K_d\right) = \mathbf{0}$

- $w_{m,\delta;i,j} = 1$ if $\mathbb{E}\left(\mathbf{x}_j e_i \mid c^* < K_c,\ d^* \geq K_d\right) = \mathbf{0}$

- $w_{m,\beta;i,j} = w_{m,\delta;i,j} = 0$ otherwise.

We can use $\mathcal{W}_{m,\beta}\mathbf{X}$ and $\mathcal{W}_{m,\delta}\mathbf{X}$ as instruments.

▸ Econometrics

GMM Estimator

- Stack linear and quadratic together $\overline{\mathbf{m}}_n(\theta) = \left[\overline{\mathbf{m}}_l(\theta)^\top, \ \overline{\mathbf{m}}_q(\theta)^\top\right]^\top$

- The GMM estimator for θ_0 is defined as

$$\hat{\theta} = \arg\min_{\theta \in \Theta} \ n^{-1}\overline{\mathbf{m}}_n(\theta)^\top \widetilde{\Omega} \ \overline{\mathbf{m}}_n(\theta) \tag{1}$$

where $\widetilde{\Omega}$ is a $p \times p$ moment weighting matrix.

▸ Econometrics

Inference

- *Network* HAC estimator that takes weighted averages of the network autocovariance terms with weights that go to zero after distances greater than some bandwidth D_n.

- Higher network density reduces the identification power in the population and increases the variance of the estimator in the sample.

▸ Econometrics

Instruments - Cigarette Smoking

	OLS		2SLS		GMM	
Peer Effects						
Friends Effect	0.420***	(0.019)	0.171	(0.279)	0.480***	(0.021)
Classmates Effect	0.132	(0.161)	0.547***	(0.205)	0.316***	(0.008)
Contextual Effects						
Friends Risk	-0.777	(0.957)	-1.279	(4.686)	-0.510	(0.689)
Friends Future	-1.935**	(0.965)	-1.819	(4.632)	-0.511	(0.363)
Friends Physical	-0.991	(0.653)	-0.542	(2.829)	4.050***	(0.290)
Classmates Risk	2.162	(2.851)	1.642	(3.106)	-1.773***	(0.445)
Classmates Future	3.283*	(1.889)	0.598	(2.166)	1.639***	(0.391)
Classmates Physical	-2.385	(2.024)	-0.696	(1.787)	-1.801***	(0.385)

Fixed Effects - Cigarette Smoking

▸ Cigarette Smoking

	No FE		School FE		Cohort FE	
Peer Effects						
Friends Effect	0.472***	(0.014)	0.469***	(0.021)	0.474***	(0.020)
Classmates Effect	0.419***	(0.002)	0.331***	(0.004)	0.427***	(0.007)
Contextual Effects						
Friends Risk	-1.145***	(0.187)	-1.142***	(0.262)	-1.032***	(0.241)
Classmates Risk	2.418***	(0.311)	2.215**	(0.870)	2.521***	(0.478)
Additional Controls						
Risk Aversion	-1.616***	(0.046)	-1.711***	(0.047)	-1.599***	(0.046)
Future Orientation	0.068	(0.045)	-0.002	(0.045)	0.005	(0.045)
Physical Activity	-0.460***	(0.044)	-0.566***	(0.045)	-0.442***	(0.045)
IQ Test	-0.201***	(0.025)	-0.190***	(0.028)	-0.342***	(0.027)
Female	0.222***	(0.049)	0.380***	(0.049)	-0.138***	(0.050)
Age	0.144***	(0.007)	0.258***	(0.022)	-0.872***	(0.042)
Black	-0.580***	(0.077)	0.108	(0.089)	-0.766***	(0.077)
Asian	0.041	(0.078)	0.322***	(0.085)	0.027	(0.080)
Other Race	2.670***	(0.115)	3.107***	(0.119)	2.278***	(0.116)
College Parent	-1.541***	(0.051)	-1.406***	(0.051)	-1.541***	(0.051)
Two Parents	-1.904***	(0.058)	-1.700***	(0.058)	-1.979***	(0.057)
Smoker Parent	1.470***	(0.048)	1.309***	(0.049)	1.537***	(0.049)
Fixed Effects	School		School		School	
Instruments	Smoker Parent		Smoker Parent		Smoker Parent	

Full Results - Cigarette Smoking

▶ Cigarette Smoking

	OLS		2SLS		GMM	
Peer Effects						
Friends Effect	0.396***	(0.021)	-0.009	(1.593)	0.469***	(0.021)
Classmates Effect	0.178	(0.151)	0.191	(4.162)	0.351***	(0.003)
Contextual Effects						
Friends Risk	-1.888*	(0.992)	-2.680	(19.68)	-1.179***	(0.258)
Classmates Risk	2.717	(2.708)	11.29	(77.82)	2.177***	(0.818)
Additional Controls						
Risk Aversion	-1.514***	(0.488)	-1.523	(1.247)	-1.684***	(0.047)
Future Orientation	0.397*	(0.206)	0.284	(0.625)	0.029	(0.045)
Physical Activity	-0.472***	(0.154)	-0.439*	(0.245)	-0.525***	(0.045)
IQ Test	0.023	(0.294)	-0.063	(1.142)	-0.210***	(0.028)
Female	0.156	(1.086)	0.229	(1.830)	0.377***	(0.049)
Age	0.314	(0.231)	0.420	(1.955)	0.207***	(0.021)
Black	-1.828***	(0.326)	-2.077	(1.952)	0.136	(0.089)
Asian	0.284	(0.295)	0.179	(0.754)	0.406***	(0.085)
Other Race	1.000***	(0.348)	0.707	(1.134)	3.162***	(0.119)
College Parent	-0.315	(0.399)	-0.273	(0.430)	-1.477***	(0.051)
Two Parents	-1.062**	(0.418)	-1.342	(2.115)	-1.747***	(0.057)
Smoker Parent	1.827***	(0.380)	1.739	(1.194)	1.324***	(0.049)
Fixed Effects	School		School		School	
Instruments			Smoker Parent		Smoker Parent	

Instruments - Marijuana Use

	OLS		2SLS		GMM	
Peer Effects						
Friends Effect	0.163*	(0.084)	0.639***	(0.147)	0.231***	(0.022)
Classmates Effect	-0.092	(0.255)	0.248	(0.273)	0.252***	(0.013)
Contextual Effects						
Friends Risk	0.543**	(0.251)	-0.500	(4.080)	0.390	(0.879)
Friends Future	-0.928**	(0.383)	-1.816	(1.925)	0.189	(0.564)
Friends Physical	-0.100	(0.385)	-0.136	(2.935)	3.275***	(0.278)
Classmates Risk	-0.999	(0.881)	0.501	(1.706)	-0.929**	(0.422)
Classmates Future	1.655	(1.134)	1.101	(0.818)	1.496***	(0.484)
Classmates Physical	-1.620	(0.987)	-2.403	(1.494)	-2.450***	(0.381)

Fixed Effects - Marijuana Use

▸ Marijuana Use

	No FE		School FE		Cohort FE	
Peer Effects						
Friends Effect	0.229***	(0.029)	0.227***	(0.023)	0.229***	(0.027)
Classmates Effect	0.335***	(0.012)	0.280***	(0.012)	0.321***	(0.022)
Contextual Effects						
Friends Risk	0.202	(0.174)	0.167	(0.168)	0.154	(0.182)
Classmates Risk	0.448	(0.291)	1.139	(0.983)	-0.754**	(0.341)
Additional Controls						
Risk Aversion	-1.090***	(0.046)	-1.132***	(0.048)	-1.169***	(0.046)
Future Orientation	0.766***	(0.045)	0.792***	(0.046)	0.805***	(0.046)
Physical Activity	0.441***	(0.044)	0.352***	(0.045)	0.420***	(0.045)
IQ Test	0.167***	(0.025)	0.260***	(0.026)	0.197***	(0.026)
Female	-0.942***	(0.048)	-0.973***	(0.048)	-0.967***	(0.050)
Age	0.075***	(0.007)	-0.059***	(0.022)	0.283***	(0.040)
Black	0.426***	(0.068)	0.251***	(0.086)	0.682***	(0.072)
Asian	-1.548***	(0.079)	-1.902***	(0.087)	-1.425***	(0.081)
Other Race	1.588***	(0.115)	0.997***	(0.122)	1.928***	(0.118)
College Parent	0.700***	(0.053)	0.763***	(0.052)	0.732***	(0.053)
Two Parents	-0.716***	(0.055)	-0.730***	(0.054)	-0.796***	(0.056)
Smoker Parent	0.427***	(0.049)	0.412***	(0.049)	0.362***	(0.049)
Fixed Effects	School		School		School	
Instruments	Smoker Parent		Smoker Parent		Smoker Parent	

Full Results - Marijuana Use

▸ Marijuana Use

	OLS		2SLS		GMM	
Peer Effects						
Friends Effect	0.152*	(0.080)	0.227	(2.495)	0.226***	(0.023)
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Classmates Risk	-0.786	(0.795)	4.241	(12.98)	1.172	(0.976)
Additional Controls						
Risk Aversion	-1.059***	(0.262)	-1.068***	(0.368)	-1.132***	(0.047)
Future Orientation	1.000***	(0.227)	0.974***	(0.469)	0.791***	(0.045)
Physical Activity	-0.025	(0.499)	-0.017	(0.467)	0.352***	(0.045)
IQ Test	-0.100	(0.102)	-0.061	(0.083)	0.259***	(0.026)
Female	-1.209***	(0.239)	-1.052	(1.376)	-0.973***	(0.048)
Age	0.012	(0.159)	-0.009	(0.187)	-0.059***	(0.022)
Black	-0.763***	(0.113)	-0.739*	(0.415)	0.253***	(0.086)
Asian	-1.913***	(0.213)	-1.801	(2.163)	-1.903***	(0.087)
Other Race	-0.301	(0.246)	-0.347	(1.387)	1.001***	(0.122)
College Parent	0.372	(0.268)	0.410	(0.816)	0.761***	(0.052)
Two Parents	-0.563**	(0.265)	-0.458	(1.113)	-0.730***	(0.054)
Smoker Parent	0.595***	(0.184)	0.473	(0.818)	0.409***	(0.049)
Fixed Effects	School		School		School	
Instruments			Smoker Parent		Smoker Parent	