Estimating Heterogeneous and Hierarchical Peer Effects on Body Weight Using Roommate Assignments as a Natural Experiment

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ABSTRACT

We investigate peer effects in weight gain by exploiting a natural experiment, roommate assignments of 751 male and 845 female first-year college students. Results indicate that females are subject to peer influence in weight gain, with little evidence of peer effects for males. Peer influences appear to be heterogeneous as heavier and thinner females are affected by roommates more than average-weight females, and hierarchical with females influenced only by roommates who are thinner, of a higher socioeconomic status, and more sexually experienced relative to themselves. Similarity of academic performance, religiosity, and political views appears to facilitate transmission of peer influences.

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I. Introduction

Nearly one-third of all adolescents and young adults age 12–19 are classified as overweight or obese (Ogden et al. 2012), and obesity in early life is associated with a higher risk of adult obesity (Power, Lake, and Cole 1997; Must and Strauss 1999; Freedman et al. 2007). Obesity is one of the leading contributing factors to many chronic illnesses, including heart disease, Type 2 diabetes, stroke, and hypertension (NLHBI), and is estimated to account for $147 billion per year in medical costs in the United States alone (Finkelstein et al. 2009).

While the economic burden and health consequences of obesity have been well documented, reducing the prevalence of obesity has proven to be difficult. At a biological level, obesity results from an energy imbalance caused by consuming more calories than are expended through physical activity (Cutler, Glaeser, and Shapiro 2003). Several other biological and nonbiological factors influence this relationship between caloric intake and expenditure, including genes, metabolism, environment, behavior, and culture. The confluence of all of these factors makes understanding and addressing obesity a challenge.

Recently, researchers have begun investigating the role of the social environment in explaining obesity. Understanding how peers and other social contacts influence an individual's weight is important: If weight and weight-related behaviors are subject to social contagion, harnessing the power of social networks could help policymakers propagate an intervention through a group of individuals tied to each other within some social context, thus multiplying its overall impact. This leverage could be further strengthened by identifying and initially targeting highly influential individuals who subsequently may be more likely to impact others within their social group (Fowler and Christakis 2008). The social network approach to public policy could be of a particular interest in groups where traditional policy methods have proven to be ineffective in promoting the desired change.

II. Empirical Challenges and Approaches in Estimating Peer Influences

Measuring social contagion effects presents a number of empirical challenges first laid out by Manski (1993). First, selection muddles the true peer influence, because individuals tend to choose peers who are like themselves (McPherson, Smith-Lovin, and Cook 2001; Mare 1991; Pencavel 1998). In the context of body weight, individuals may choose friends or spouses who have similar preferences or constraints related to weight or related behaviors, such as physical activity. Because selection parameters are unknown and unobservable, they are difficult to control for and are believed to cause an upward bias in estimates of peer influences.

A second issue is simultaneity, referred to as "reflection" in Manski (1993), or the reciprocal nature of one's social interactions with her peers. Because in social studies, an individual's behaviors are typically observed by the researcher contemporaneously with her peers' behaviors, it is difficult to discern the extent to which the observed correlation is due to the individual influencing the peers or vice versa. This simultaneity may result in an upward bias on the estimated peer influence.

Third, social interactions occur within some larger shared environmental context. Characteristics of the shared environment may influence both the individual and her peers, and may produce a positive correlation in outcomes within social groups in the absence of a causal peer influence mechanism. For example, even individuals not directly influencing one another may display similar behaviors and weight outcomes if they live in the same neighborhood and, therefore, are exposed to the same restaurants, grocery stores, and fitness centers. Exposure to the same environmental factors will tend to bias the estimate of the true peer influence upward.

Finally, even after addressing the aforementioned biases, interpreting the empirically observed peer effect as being caused by the particular peer trait of interest can be difficult. For example, if, after controlling for shared environmental effects and dealing with selection and simultaneity, we find that one's weight is correlated with her spouse's weight, it may be the case that the correlation is indeed driven by one spouse's weight causally impacting the other spouse's weight (for example, reducing the stigma of being overweight). However, it is also possible that the correlation may instead be the result of some other characteristics of the spouse such as socioeconomic status or educational level. Peer effects of the former kind (that is, adopting a particular trait of the peer) are referred to as "endogenous" peer effects by Manski (1993), in that they are capable of producing social policy multipliers; the latter, on the other hand, is an example of an "exogenous" peer effect and is incapable of producing social policy multipliers.

III. Previous Studies of Peer Effects in Weight Gain

One of the first studies of social contagion of obesity analyzes 32 years of longitudinal data from the Framingham Heart study and finds that having an obese sibling, spouse, or friend significantly increases one's probability of becoming obese (Christakis and Fowler 2007). Having an obese friend is associated with a 57 percent higher probability of being obese, and having an obese spouse increases the probability of being obese by 37 percent. The authors attempt to address the selection bias by controlling for lagged values of both the individual's and her peer's weight, and also provide some indirect evidence that the findings are not driven by unobserved shared environmental influences. More precisely, the authors show that individuals in their study are only minimally, if at all, influenced by peers whom they did not consider to be their friends, even when they are presumably exposed to the same environment.

A subsequent series of studies use the National Longitudinal Study of Adolescents (AddHealth) to extend Christakis and Fowler's (2007) original work by examining peer effects among adolescents, and by addressing the shared environment issue more explicitly using school fixed effects (Cohen-Cole and Fletcher 2008a; Fowler and Christakis 2008; Trogdon, Nonnemaker, and Pais 2008; Halliday and Kwak 2009). Despite some methodological differences, all except one of these papers (Cohen-Cole and Fletcher 2008) find evidence consistent with the notion that an adolescent's weight is influenced by her peer's weight.

Cohen-Cole and Fletcher (2008a) use a longitudinal empirical approach similar to the original Christakis and Fowler (2007) paper and find that controlling for shared environmental influences with school fixed effects eliminates the peer influence. In a subsequent paper, Cohen-Cole and Fletcher (2008b) also investigate "implausible social networks" in acne, headaches, and height, showing that not fully accounting for selection and shared environmental confounding could lead to incorrect conclusions about the social contagion effect. However, they use a "static" friendship network relying only on friendships that existed in the first wave of the survey, which may have attenuated their findings, and their confidence intervals are actually wide enough to allow for the effect sizes originally found by Christakis and Fowler (2007). Fowler and Christakis (2008) attempt to reproduce Cohen-Cole and Fletcher's (2008a) analysis with school fixed effects using fluid friendship networks, and find a significant positive peer influence coefficient consistent with their earlier work.

Trogdon and colleagues (2008) also use AddHealth data and include school fixed effects to deal with shared environmental effects; however, they employ an instrumental variables technique to address selection. Specifically, they instrument for the peer's weight using the peer's birth weight and the peer's parents' obesity status and health status, which also eliminates the simultaneity issue because these variables precede the peers' exposure to each other. The study finds positive peer influences in BMI that appear to be stronger for females and among peers with the highest BMIs. In a similar approach, Halliday and Kwak (2009) find some evidence of peer effects among AddHealth adolescents when they estimate a first difference model of peer influence and instrument for the change in peer BMI with the peer's parental education level. However, the validity of the instruments in both papers could be questioned because, although adolescents probably do not choose their peers on the basis of the peers' birth weight or obesity, health, or education level of the peers' parents, those variables still could be correlated with unobserved peer variables that enter into the peer selection process and also affect own weight gain.

More recently, studies have used natural experiments to deal with peer selection. In one such study, Yakusheva, Kapinos, and Weiss (2011) find evidence of peer influences in weight among first-year college students in a setting with plausibly random variation in peer characteristics. The study examines weight gain and weight-related behaviors of college students who live with an assigned roommate during their freshman year of college. Because the students do not choose their roommates, selection is not an issue in the study, and they use pre-college peer variables to deal with simultaneity and shared environment biases. However, the study has limitations due to the small and unique sample (144 females from a small private Catholic university). Another quasi-experimental study (Carrell, Hoekstra, and West 2011) uses data from US Air Force Academy (USAFA) students from 2000 to 2004 to show that academy students randomly assigned to less physically fit squadrons have lower physical fitness scores. The study's findings are suggestive of a possible mechanism for a peer influence on body weight, but the study does not examine the effect on body weight.

Identification issues aside, conceptual approaches to examining peer influences in weight gain and obesity have been mostly limited to estimating the average effect size, therefore implicitly assuming homogeneity and symmetry of the peer influence. While empirically attractive, these assumptions are not necessarily theoretically grounded. Coleman's (1961) pioneering work on hierarchical structures of social networks sparked decades of research on the role of network structure and the individual's status within the network, including several studies on adolescent networks (Savin-Williams

1976, 1977, 1979; Ridgeway and Walke 1995; Faris 2012; Faris and Felmlee 2010; Staff and Kreager 2008; Papachristos 2009). Scholars have argued that susceptibility to peer influence is highly dependent on an adolescent's standing in the social hierarchy of her peers, with lower-status individuals more likely to adopt the behaviors of higher status individuals (Cohen and Prinstein 2006; Gerrard et al. 2008; Vargas 2011). Although rarely explored in empirical studies, these structural dimensions of peer influence are important for understanding who is most likely to respond to policy, as well as who should be targeted as conduits of social influence in order to induce the most effective flow through the social network.

The present study addresses both the abovementioned methodological challenges and conceptual gaps, and contributes to a deeper understanding of the directional causal patterns of peer influence in weight gain in adolescent networks. Similar to the Yakusheva, Kapinos, and Weiss (2011) study, the present study uses college roommate assignments to identify peer influences on weight gain, and contributes to the literature on social contagion in obesity in two key ways. First, the identification strategy accounts for biases due to selection, shared environmental influences, and endogeneity. Second, we draw on social network theories to examine two structural aspects of peer influence—heterogeneity and hierarchical asymmetry. Our results are consistent with a positive peer influence on weight for females. Furthermore, this influence appears to be both nonlinear (thin and heavy females are more susceptible to peer influence than average-weight females) and asymmetric (from thinner females to heavier females, from higher socioeconomic status females to lower socioeconomic status females, and from more sexually experienced females to less sexually experienced females, but not vice versa). We find little evidence of peer influence in weight among males.

IV. Data

This study uses data collected for a study of peer influences on a range of health issues among college students. The data collection is described in more detail in a paper reporting peer influences on mental health outcomes (Eisenberg et al. forthcoming). In brief, first-year students at two universities (large private and large public) were surveyed at two time points during the 2009–10 academic year—the baseline survey was administered just prior to the start of the fall semester (August 2009), and the followup survey was administered near the end of the academic year (March–early April 2010). With cash incentives, the study was able to achieve a 70 percent response rate at baseline. The survey data were linked to administrative data on roommate and housing preferences, dormitory and room assignments, and demographic characteristics.

We utilize a subsample of the data that includes only students who (1) are matched with at least one roommate in the sample, (2) did not request the roommate assignment, and (3) provided their height and weight data at both baseline and followup, and whose roommates also provided the baseline height and weight data. Our final sample includes 751 male and 845 female students, the majority of whom lived in double occupancy rooms, with triple- and quad- occupancy rooms accounting for only 16 percent and 3 percent of our sample, respectively.

Our main variables of interest are weight and height that are self-reported in pounds

Table 1
Descriptive Statistics

Variable		Mean	Standard Deviation	Minimum	Maximum	Change
Females, $n = 845$						
Weight	Fall	133.68	23.53	85	284	
	Spring	136.10	23.60	90	300	2.42***
Height	Fall	65.05	2.67	58	78	
	Spring	65.07	2.65	58	76	0.02
White		0.76	0.42	0	1	
Asian		0.16	0.37	0	1	
Age		18.33	0.36	17.48	19.94	
Males, $n = 751$						
Weight	Fall	161.75	28.84	105	343	
	Spring	163.40	27.67	105	300	1.65***
Height	Fall	70.52	2.79	62	80	
	Spring	70.67	2.77	60	80	0.15***
White		0.74	0.44	0	1	
Asian		0.20	0.40	0	1	
Age		18.46	0.44	17.43	22.06	

and inches, respectively. (See Table 1.) We focus our analysis on peer influences in weight conditional on height, rather than Body Mass Index (BMI), in order to avoid bias associated with the nonlinear structure of measurement and self-report errors in the derived BMI measure.

V. Method

This study joins a recent body of empirical studies that use college roommates to examine peer effects on academic performance, substance abuse, mental health, and other outcomes (Sacerdote 2001; Zimmerman 2003; Stinebrickner and Stinebrickner 2006; Kremer and Levy 2000; Foster 2002; Duncan et al. 2003a&b; Yakusheva, Kapinos, and Weiss 2011; Eisenberg et al. forthcoming). We follow a standard linear-in-means model of peer influence pioneered by Manski (1993) and further developed by Graham and Hahn (2005), and use the average of roommate characteristics in cases with more than one roommate.

Following terminology established in the social network analysis literature, we refer to the student who is receiving influence as the "ego" and to the roommate who is sending influence, as the "alter," hereafter. To deal with the selection, endogeneity, and shared environment biases discussed earlier, we estimate the effect of an assigned alter's baseline weight on the weight change of the ego during the freshman year:

$$(1) \quad \Delta Y_i = \alpha_1 + \beta_1 Y_{j0} + \gamma_1 H_{j0} + \psi_1 H_{i0} + \phi_1 H_{i1} + Z_{i0}`\theta_1 + \varepsilon_i$$

where ΔY_i represents the weight change of the ego from baseline to followup, $\Delta Y_i = Y_{i1} - Y_{i0}$, and Y_{j0} is the baseline value of the alter's weight (or the average of the alters' weights if there is more than one roommate). We control for the alter's baseline height, H_{j0}, (or its average if multiple alters) and the ego's height at both baseline, H_{i0}, and followup, H_{i1}, and also include a vector of baseline control variables, $Z_{i0,}$ consisting of the living environment preferences, age (exact to the day), and the university fixed effect. We adjust standard errors for clustering at the room level. Coefficient β_1 represents the effect of the alter's baseline weight on the ego's weight change during the course of the nine month-long study.[1] To examine heterogeneous effects in the relationship between the ego's weight gain and the alter's baseline weight, we stratify our sample into four groups based on the quartiles of the gender-specific distribution of baseline weight and then estimate Model 1 for each of the weight-quartiles separately.

The key identification assumption is that the error term in Model 1 is orthogonal to the alter's baseline characteristics. This is plausible, because the research design addresses the main identification problems in empirical studies of peer influences. Controlling for the variables used to make roommate assignments addresses potential issues related to correlated individual characteristics. Also, because the alter's weight was reported prior to exposure to the ego and to the same environmental influences, the analysis is free of the reflection and shared environmental effects biases.

Students are assigned to dormitories and rooms based on a set of living environment preferences that are recorded in the administrative data of each university and linked to the survey data. Not accounting for these preferences could have implications for the internal validity of the model. For example, certain living environments may attract similar students, introducing a selection bias. To control for any unobserved heterogeneity that could stem from living environment selection, Model 1 and all subsequent models control for a complete set of indicators for all possible combinations of the main factors used to make roommate assignments (area of campus, corridor type (same gender versus co-ed), smoker status, and room type), as well as separate controls for secondary factors (preferences about noise, socializing, waking hours, and music that were also used at one of the two universities). Further details of the assignment process can be found in Eisenberg et al. (forthcoming). A small number of students (less than 5 percent) changed their room after the initial assignments were made. Because we link ego's and alter's outcomes based on the initial (preswitch) roommate assignments, this situation is analogous to noncompliance in medical trial research, which results in "intent to treat" estimates that are typically smaller than the true effect sizes (Lachin 2000).

To examine asymmetries in peer influences in weight, we draw on theories of hierarchical network structures purporting that an individual's power within her network, and the amount of influence she receives from or sends to her peers, is determined by

1. We also estimated a lagged dependent variable model with the ego's followup weight as the dependent variable and the ego's baseline weight as one of the repressors. The lagged dependent variable model produces very similar estimates that are available upon request.

her relative position within the peer hierarchy. Theories predict that when the peer dyad is hierarchical, that is when the relationship is between two individuals of different network statuses, peer influence will be asymmetric. More specifically, the higher-level individual will direct or exert influence on the lower-level individual, but not vice versa (Cohen and Prinstein 2006; Gerrard et al. 2008).

We use several characteristics that may determine the hierarchical order between roommates. First, a significant body of literature reports a positive association between being overweight and having a low socioeconomic status, particularly among females and among adolescents (Lauderdale 2005; Wang and Zhang 2006; Borders, Rohrer, and Cardarelli 2006; Chang and Babey et al. 2010). Low body weight and low fatness are also primary determinants of male and female physical attractiveness (Singh 1993a, 1993b, 1994; Dixson et al. 2003; Grammer et al. 2003; Weeden and Sabini 2005). Therefore, we first test whether the peer influence is asymmetric with respect to the baseline weights of the roommates relative to each other. We then extend this analysis to define the hierarchical order between the roommates on the basis of socioeconomic status (SES, measured as the parents' education level), sexual experience (measured by the number of prior or current sexual partners at baseline), and academic performance (measured by the baseline standardized American College Testing, or ACT, score). Including these characteristics is consistent with earlier literature that suggests that physical attractiveness, socioeconomic status, and academic success are all determinants of one's status relative to the peers in adolescent social networks (Savin-Williams 1979; Frank et al. 2008; Faris and Ennett 2011; Faris and Felmlee 2011; Vargas 2011).

Lastly, following the literature on peer similarity as a facilitator of peer interaction and influence, we also explore the role of peer concordance on nonrank related characteristics (Cialdini 2001; Marmaros and Sacerdote 2004). Specifically, we examine the role of religiosity (measured as a categorical variable with categories "not at all," "somewhat," "fairly," "very"), and political views ("far right," "conservative," "middle of the road," "liberal," "far left"). We do not examine race because there is very little sample variation.

Empirically, we interact the alter's baseline weight in Model 1 with two index variables, Δ_0^L and Δ_0^H, where Δ_0^L equals one in cases when the ego's baseline characteristic is suggestive of her lower status relative to her alter (heavier weight, lower SES, less sexual experience, lower ACT score), and Δ_0^H equals one in cases when the ego's baseline characteristic might indicate a higher status relative to her alter. Similarity of the roommates at baseline is, therefore, the omitted category, and is defined for continuous variables (weight, ACT) as the ego being within one standard deviation of her roommate. For nonrank related characteristics, that is for religiosity and political views, Δ_0^L and Δ_0^H are based on the values of the variables, so that Δ_0^L equals one when the ego is less religious and less politically liberal than her alter. Thus, our econometric specification is as follows:

$$(2)\quad \Delta Y_i = \alpha_2 + \beta_2 Y_{j0} + \delta_2 (Y_{j0}\Delta_0^L) + \lambda_2(Y_{j0}\Delta_0^H) + \eta_2 \Delta_0^L + \zeta_2\Delta_0^H + \gamma_2 H_{j0} + \psi_2 H_{i0} + \phi_2 H_{i1} + Z_{i0}`\theta_2 + u_i$$

We estimate Model 2 separately for each of the rank-related characteristics (weight, SES, sexual experience, ACT), and for each of the nonrank related characteristics (religiosity, political views). In all models, coefficient β_2 estimates the size of the peer effect in concordant peer dyads where the ego and the alter are similar at baseline, while the peer effect sizes in the two nonconcordant cases is estimated by ($\beta_2 + \delta_2$) for alter-dominant dyads and by ($\beta_2 + \lambda_2$) for ego-dominant dyads. If the peer influence is hierarchical, we expect that the effect size will be greater in dyads that are alter-dominant with respect the rank-related characteristics (weight, SES, sexual experience, ACT). Also, if similarity on nonrank related characteristics (religiosity, political views) is important for transmission of the peer influence, we would expect that the peer effect size in concordant peer dyads (ego and alter are similar) will be greater than in either of the two nonconcordant cases.

VI. Results

Table 1 shows the descriptive statistics of the sample stratified by gender, at baseline (prior to the fall semester) and at followup (at the end of the spring semester). The average age at baseline is 18.5 for males and 18.3 for females. Racial composition is predominantly Caucasian (74 percent of males and 76 percent of females), with Asian being the second largest ethnic group (20 percent of males and 16 percent of females), followed by Black (3 percent of males and 4 percent of females). The average baseline weight is 161.75 pounds for males (standard deviation, 28.84) and 133.68 pounds for females (standard deviation, 23.53). During the freshman year, both genders experience a small increase in body weight on average: 1.65 pounds ($p < 0.01$) for males and 2.42 pounds ($p < 0.01$) for females. Unlike males, however, the additional weight gain for females is not accompanied by an increase in height and leads to a reduction in the prevalence of underweight and an increase in the prevalence of overweight.[2]

Since our identification strategy relies on the ignorability of roommate assignments, we conduct tests on the baseline values of weight, height, and a host of other characteristics, as is done in previous studies based on roommate assignments (for example, Stinebrickner and Stinebrickner 2006). If the ignorability assumption fails and selection is an issue in our study, we expect many of the variables to be positively correlated at baseline due to the assignment process where similar peers are assigned to each other. Table 2 reports these baseline correlations, in which we control for housing preferences and implement the correction recommended by Guryan, Kroft, and Notowidigo (2009). We find no evidence that any of the roommate variables are positively correlated at baseline for either males or females.

In fact, weight appears to be negatively correlated for males (–0.175, $p < 0.01$). Resampling roommate pairs through a random number generating process with replacement from our full population of male students (1,000 repetitions) produces an empirical distribution of the baseline weight correlation coefficient with the mean equal to zero, standard deviation equal to 0.057, and observed range of values from

2. Based on the Center for Disease Control and Prevention age and gender adjusted ranges of the Body Mass Index, the prevalence of underweight among females decreases by two percentage points ($p < 0.01$) from 3 percent to 1 percent and prevalence of overweight among females increases by two percentage points ($p < 0.01$) from 10 percent to 12 percent. There is no significant change in the weigh-status distribution for males. These numbers are not shown in Table 1.

Table 2
Baseline Roommate Correlations

	Females *n* = 845	Males *n* = 751
Weight	–0.02	–0.18***
	(0.04)	(0.04)
Height	0.00	–0.08
	(0.05)	(0.05)
Exercise frequency	–0.04	0.02
	(0.03)	(0.04)
Exercise 5+	–0.03	–0.02
	(0.05)	(0.04)
Eating disorder	0.02	–0.01
	(0.04)	(0.03)
White	–0.01	–0.07
	(0.04)	(0.04)
Black	0.03	0.00
	(0.06)	(0.02)
Asian	–0.02	–0.06
	(0.04)	(0.04)
Hispanic	–0.02	0.04
	(0.05)	(0.06)
High school grade point average	0.00	0.05
	(0.04)	(0.05)
Parental education	0.02	0.05
	(0.04)	(0.05)
Religiosity	0.04	–0.04
	(0.04)	(0.04)
Liberal political views	0.05	–0.06
	(0.04)	(0.04)
Number of sex partners	–0.03	–0.01
	(0.04)	(0.04)
United States citizen	0.00	–0.02
	(0.04)	(0.04)

Notes: We report coefficients from a linear model of an individual's baseline value on the corresponding baseline roommate measure, controlling for housing preferences and university. Controls for housing preferences include area of campus, rate, corridor, room type, noise, cleanliness, and substance environment. All models are adjusted for the preference cell average per Guryan, Kroft, and Notowidigdo (2009). Standard errors in parentheses. ***<0.01, **<0.05, *<0.1

–0.204 to 0.205. Two-tailed probability of observing a correlation equal to or greater than 0.175 in absolute value is 0.002.

It is unclear how male students could have been negatively matched based on baseline weight, other than this happening by chance. A systematic effort on the part of university administrators to match students negatively based on weight would be contrary to the assignment process explained to us by the housing officials and would be unfeasible because housing officials do not collect incoming students' weight and height. In an attempt to further examine this issue we test all of the socioeconomic and demographic variables that were known to university administrators, including race, high school grade point average, and citizenship, as well as some variables unobservable to housing administrators such as religiosity and political views, parental education, and number of sexual partners. We find none of the variables to be significantly correlated between roommates for either gender. For a total of 30 tests that we present in the table, observing at least one significant correlation is consistent with what one would expect due to chance.

We present the peer influence estimation results of Model 1 in Table 3. We find a significant positive peer influence estimate for females; the ego's weight gain during the freshman year increases by 0.034 pounds for every one-pound increase in the baseline weight of the alter, which is equivalent to a 0.80 pound greater weight gain for the ego for every standard deviation increase in the alter's baseline weight. The magnitude of the coefficient is robust to different specifications of the model. For males, the peer influence coefficient is nonsignificant in all models.

We conduct three specification checks, in addition to our main empirical Model 1. First, we test whether the peer influence in weight is related to some potentially relevant underlying behavior changes, such as exercise or eating behaviors. Second, we estimate a two-stage least squares model where we instrument for the alter's weight at the end of the freshman year with the alter's corresponding baseline measure. Lastly, we test whether the peer influence estimates are robust to including a set of alter characteristics that may be correlated with the unobservable alter variables ("exogenous" as opposed to "endogenous" peer effects). The details of these additional analyses are presented in Appendix 1 and 2. In brief, we find little evidence of peer effects on exercise and eating-related behaviors and our peer effect on weight estimates are unaffected by controlling for the potential behavioral mechanisms (Appendix 1). The instrumental variable estimates support the presence of a significant positive peer influence in weight for females, and the magnitude of the estimate is very similar to the reduced form model, 0.032 ($p < 0.01$) (Appendix 2). In results not presented in this paper, the estimate of the peer influence in weight for females in our basic specification of the model (Column 5 of Table 3) decreases from 0.034 ($p < 0.01$) to 0.032 ($p < 0.01$) when we add a set of additional controls for baseline sociodemographic characteristics and high school test scores of the roommate.

We explore the potential for a heterogeneous relationship between the ego's weight change during the freshman year and the alter's baseline weight in Table 4. Females most influenced by their peers are in the lowest and highest quartiles of the baseline weight distribution, while those with the baseline weight in the middle of the distribution appear not to be significantly influenced by their alters. The magnitudes of the peer influence estimated in the bottom and the top quartile of the weight distribution (below 118 pounds and above 145 pounds, respectively) are 0.054 ($p < 0.05$) and 0.071 ($p < 0.05$), compared to –0.025 ($p = 0.21$) and 0.031 ($p = 0.22$) in the second and third quartiles. This implies a 1.27 and 1.67 pound greater weight gain for female egos weighing less than 118 pounds and greater than 145 pounds, respectively, for every standard deviation increase in their alter's baseline weight. We observe mixed evidence of peer influence for males: The peer effect coefficient is positive in the lowest

Table 3
Peer Influences in Weight Gain

	Dependent Variable = Ego's Weight Gain				
	1	2	3	4	5
			Females, $n = 845$		
Alter's weight in the fall	0.028***	0.030***	0.033***	0.028***	0.034***
	(0.009)	(0.010)	(0.012)	(0.010)	(0.012)
Adjusted for dormitory preferences	No	Yes	No	No	Yes
Adjusted for height	No	No	Yes	No	Yes
Adjusted for clustering	No	No	No	Yes	Yes
R squared	0.006	0.059	0.007	0.006	0.062
			Males, $n = 751$		
Alter's weight in the fall	0.012	0.016	0.008	0.012	0.010
	(0.011)	(0.011)	(0.012)	(0.010)	(0.012)
Adjusted for dormitory preferences	No	Yes	No	No	Yes
Adjusted for height	No	No	Yes	No	Yes
Adjusted for clustering	No	No	No	Yes	Yes
R squared	0.006	0.059	0.007	0.006	0.062

Notes: We report coefficients from a linear model controlling for age and university. Controls for dormitory preferences include area of campus, rate, corridor, room type, noise, cleanliness, and substance environment. Adjustment for height includes the ego's height at baseline and follow-up, and the alter's height at baseline. Standard errors in parentheses are clustered at the room level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 4
Nonlinearities in Peer Influence in Weight

	Dependent variable = Ego's weight gain			
	1st Quartile 1	2nd Quartile 2	3rd Quartile 3	4th Quartile 4
	Females, $n = 845$			
Alter's weight in the fall	0.054** (0.024)	–0.025 (0.022)	0.031 (0.024)	0.071** (0.035)
Observations	191	205	218	231
R squared	0.150	0.154	0.197	0.180
	Males, $n = 751$			
Alter's weight in the fall	0.032** (0.015)	–0.024* (0.014)	0.005 (0.024)	–0.050 (0.056)
Observations	194	190	187	180
R squared	0.231	0.159	0.231	0.459

Notes: We report coefficients from a linear model. All models control for the ego's height at baseline and followup, the alter's height at baseline, dormitory preferences (area of campus, rate, corridor, room type, noise, cleanliness, and substance environment), age, and university. Standard errors in parentheses are clustered at the room level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

quartile, 0.032 ($p < 0.05$), negative in the second lowest quartile –0.024 ($p < 0.10$), and insignificant in the two upper quartiles.

Table 5 shows the results of testing for asymmetries in the direction of peer influence. We report estimated peer influence effect sizes based on regression coefficients from Model 2 with interaction terms between the alter's weight and two dummy variables representing the ego's measure relative to the alter.[3] The estimates in Columns 1–4 are consistent with the idea that peer influence in weight for females is hierarchical—that is, egos of a presumably lower network status relative to their adolescent peers (much heavier, lower SES, less sexually experienced, lower ACT, denoted as "Ego < Alter" in the table) are more likely to be subject to peer influences. In particular, Column 1 shows that peer influence from the alter to the ego exists only in peer dyads where the ego is, conditional on the height, more than one standard deviation heavier than the alter. In such dyads, the magnitude of the peer influence coefficient

3. Regression coefficients are presented in Table 8 in the appendix.

Table 5
Asymmetries in Peer Influence in Weight–Effect Sizes

	Weight 1	Socioeconomic Status 2	Sexual Experience 3	ACT Score 4	Religiosity 5	Political Views 6
			Females			
Ego = alter	0.017	0.015	0.036*	0.035**	0.057**	0.042**
	(0.493)	(0.352)	(0.074)	(0.017)	(0.049)	(0.025)
Ego < alter	0.173**	0.069***	0.052*	0.070	0.037*	0.023
	(0.041)	(0.001)	(0.062)	(0.211)	(0.079)	(0.319)
Ego > alter	0.012	0.035	0.021	0.023	0.0189	0.037*
	(0.607)	(0.212)	(0.261)	(0.353)	(0.308)	(0.064)
n	845	833	805	783	845	820

(*continued*)

Table 5 (*continued*)

	Weight 1	Socioeconomic Status 2	Sexual Experience 3	ACT Score 4	Religiosity 5	Political Views 6
			Males			
Ego = alter	–0.020	0.008	–0.002	0.010	0.001	–0.024
	(0.507)	(0.714)	(0.910)	(0.457)	(0.950)	(0.241)
Ego < alter	0.011	0.014	0.018	–0.001	0.021	0.025
	(0.156)	(0.322)	(0.484)	(0.979)	(0.415)	(0.284)
Ego > alter	0.021	0.006	0.021	0.023	0.006	0.010
	(0.302)	(0.824)	(0.334)	(0.523)	(0.722)	(0.621)
n	751	744	722	673	751	714

Notes: We report estimated peer effect sizes and *p*-values for each ego/alter category ("ego < alter", "ego > alter", and "ego = alter"), based on regression coefficients from Model 2. The estimates of the regression coefficients are shown in Table 8. For continuous measures (Columns 1 and 3), category "same" is assigned when the roommates' measures are within one standard deviation of one another. Political views and religiosity are categorical variables with greater values corresponding to having more liberal views and being more religious, respectively. All models control for the ego's height at baseline and followup, the alter's height at baseline, dormitory preferences (area of campus, rate, corridor, room type, noise, cleanliness, and substance environment), age and university. Standard errors in parentheses are clustered at the room level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

is 0.173 ($p < 0.05$), as compared to 0.012 ($p = 0.61$) in dyads where the ego is thinner than the alter and 0.017 ($p = 0.50$) in dyads where the ego's baseline weight was similar to that of the alter; the differences are significant at the $p < 0.10$ level. Similarly, egos of a lower socioeconomic status relative to their alters appear to be influenced by their alters much more than egos in female dyads with alters of a lower or equal socioeconomic status (Column 2, 0.069 ($p < 0.01$) versus 0.035 ($p = 0.21$) and 0.015 ($p = 0.35$), respectively; the differences are significant at the $p = 0.01$ level). Peer influence also appears to be asymmetric with respect to prior sexual experience for females, as only egos equally or less sexually experienced relative to their alters are influenced by their peers (Column 3). We do not observe asymmetries in peer influence between peers by relative ACT scores. In homogeneous female dyads, where the ego's and the alter's ACT scores are within one standard deviation of one another, the peer influence coefficient is close to the sample average and statistically significant (0.035, $p < 0.05$). Although the magnitude of the estimated peer effect is larger in female dyads where the ego's baseline ACT score one standard deviation below the alter's, or lower, and smaller when the ego's baseline score is higher, neither are statistically significant.

Lastly, Columns 5 and 6 present some evidence of the importance of concordance on nonrank-related characteristics for females. The estimates suggest that female peer dyads that are homogeneous with respect to political views and religiosity appear to be more conducive to generating peer influence in weight compared to dyads where these characteristics differ considerably between the roommates. Being concordant on religiosity increases the estimate to 0.057 ($p < 0.05$), and having similar political views increases the peer effect coefficient to 0.042 ($p < 0.05$). Evidence of peer influences in nonconcordant dyads is weaker, and it appears that egos who are more religious or more politically conservative than their alters are the least likely to be subject to peer influence. The results of asymmetries in peer influence among males are insignificant.

VII. Discussion

The results of this study show that the amount of weight gained by female students during the freshman year is positively related to the baseline weight of their roommates. On average, female students gained 0.80 pounds more during the freshman year for every standard deviation increase in the baseline weight of their roommate. Our estimates of peer influence in weight gain are consistent with the idea of social contagion in weight gain and support the notion that public policy aimed at reducing obesity may produce a multiplier effect through person-to-person interactions.

Our estimates suggest a nontrivial peer effect size, given the small average amount of weight gain among females in our study, 2.4 pounds, and the study's short time period (nine months). Additionally, because we identify this effect using only roommates and not the individual's full reference social group, this finding is suggestive of potentially large global social influences on weight gain among young adults. In fact, most roommate peer effect studies produce small effect sizes due to their narrow focus on only one type of peer (roommates) and because roommate exposure is only captured over a short period of time (Sacerdote 2011). One study of email traffic on a college campus implies that as much as 80 percent of all social interactions of freshman students may be outside of their freshman dormitory (Marmaros and Sacerdote 2006).

Our finding of a positive peer influence in weight does not support the earlier roommate study (Yakusheva, Kapinos, and Weiss 2011) where the authors find that living with a heavier roommate is associated with a smaller amount of weight gain for female students (negative peer influence), despite finding positive peer influences in eating and exercise behaviors. Yakusheva, Kapinos, and Weiss (2011) show that, in their small sample, heavier females are more likely to diet, exercise, and use weight-loss supplements than thinner females, and thus, suggest that the positive adoption of these peer behaviors is what causes a smaller weight gain for females students living with heavier than average roommates. Although we do not assess eating and use of weight-loss supplements in the present study, heavier women in our sample do not exercise more than thinner ones, in fact they are slightly less likely to exercise regularly (results are available on request). The difference in the reduced form findings could result from the unique underlying behavioral patterns displayed in the earlier study.

The behavioral mechanisms through which peer influence in weight is being transmitted in our sample are unclear. Our results suggest that the main mechanisms are not physical activity or aspects of eating disorders, but we could not evaluate what would arguably be the most likely mechanism: eating habits and caloric consumption. Future studies aimed at uncovering the behavioral mechanism behind peer influence in weight gain hold potential for identifying specific behaviors that could be leveraged in propagating anti-obesity interventions through social networks.

We do not find evidence of peer influences in weight gain for male students. It is possible that males are less susceptible to peer influences in weight gain, as earlier studies find that males and females are often differentially affected by exposure to peers (Eagly and Chrvala 1986; Mears, Ploeger, and Warr 1998). This could be particularly true for weight gain, as the notion of the "ideal body image" and physical attractiveness may be less important among adolescent males than females (Conner, Johnson, and Grogan 2004; Morrison, Morrison, and Sagerc 2004). However, it is also possible that we are not capturing peer influences for males to the same extent as we do for females, due to physiological and developmental differences between the genders. In particular, we do not distinguish between the sources of weight gain (that is, weight gain due to an increase in musculoskeletal tissue versus fatty tissue). Ideally, we would like to have other more reliable measures, such as waist circumference or skinfold measurements.

We find that the heaviest and thinnest females are more likely to be influenced by their peers than average-weight females. This is consistent with earlier studies of female adolescents where very heavy and very thin females are reported as being more self-conscious, having a poorer body image, and worrying about their weight. (See, for example, Favaro, Ferrara, and Santonastaso 2003; Field et al. 2003; Pesa, Syre, and Jones 2000; Lundgren et al. 2004; Luder and Alton 2005; Waaddegaard, Davidsen, and Kjøller 2009; Sonneville et al. 2012.) Lack of self-confidence has been linked to an increased disposition to conformity with peers (Eagly and Chrvala 1986). This implies that anti-obesity interventions and policies, particularly those leveraging peer effects, may have a disparate treatment effect on the female population, impacting the top and the bottom of the weight distribution more heavily. While reaching heavy females may be desirable because their health is most likely to be negatively affected by obesity, policymakers should be cautious about potentially unintended consequences among female adolescents who are already very thin. Anti-obesity initiatives that aim to leverage peer influences should focus on healthy weight management practices while being careful not to exacerbate poor body images or unhealthy behaviors.

Although we do not observe the global social network in our sample, the peer ties we do observe are consistent with a hierarchical social network structure: for females, the direction in which peer influence is transmitted appears to be asymmetric, or directional, from the thinner peer to the heavier peer, from the higher SES peer to the lower SES peer, and from the more sexually experienced peer to the less sexually experienced peer. This apparent asymmetry in peer influence with regard to the roommates' relative weight, SES, and sexual experience is consistent with the adolescent psychology literature and the idea that susceptibility to peer influence is determined in part by an individual's status relative to their peer networks, with lower-status individual more likely to adopt the behaviors of their higher-status peers (Cohen and Prinstein 2006; Gerrard et al. 2008; Vargas 2011). Therefore, if social networks are to be used to propagate anti-obesity interventions, individuals with a high network status may be the most efficient to target, because they will be most likely to spread the intervention through their networks. Interestingly, homogeneity with respect to precollege academic performance, political views, and religiosity appears to facilitate the transmission of social influences in weight gain in our study. The importance of concordance in peer characteristics as a moderator of peer influence mechanisms should be examined in future studies.

The design of the present study eliminates biases that many previous studies of peer influences on weight status have struggled with; however, we point out the following caveats. Firstly, our outcome measures are self-reported. This may be problematic if misreporting bias is time-variant, that is a student's tendency to misreport the weight systematically changes over the course of the freshman year, and particularly if it changes in a way that is related to the baseline misreporting tendency of their roommate. While the design of our study does not allow us to account for time-variant misreporting bias, our results are robust to any time-invariant reporting errors.[4] Secondly, despite our high response rates at baseline, our estimates could be confounded due to nonresponse and attrition. However, Eisenberg et al. (forthcoming) examine nonresponse and attrition issues in these data and find they are largely unrelated to a range of risky behavior measures and other sample characteristics.

Lastly, we caution against generalizing our findings to broader populations, particularly to noncollege populations. Growing independence from parents and transitioning into adulthood can make freshman college students more susceptible to peer influences than both younger and older aged individuals. Studies have shown that peers take on a most important role in determining one's views and behaviors during adolescence (Brown 1982; Dolgin and Rice 2011). On the other hand, peer effects among randomly assigned roommates may be lower than peer effects for more intimate and longer-lasting relationships. While our policy recommendations may not

4. Because our dependent variable is a change in weight, any time-invariant misreporting bias (for example, a tendency to underreport own weight described by Rowland 1990; Nawaz and Katz 2001; and Burkhauser and Cawley 2008) will be effectively differenced out. Indeed, the weight change observed in our data is consistent with earlier studies that are based on measured weight (Hoffman et al. 2006; Morrow et al. 2006).

apply to other age groups and social settings, adolescent groups, and college campuses in particular, have long been identified as an opportune venue for policy intervention, due to relative ease of implementation and lasting effects (Petersen 1988; Dryfoos 1990; Millstein et al. 1993; Lerner and Galambos 1998; Truesdale et al. 2006; Lloyd-Richardson et al. 2009).

VIII. Summary and Conclusion

This study adds to the literature aimed at understanding social influences in obesity by utilizing a natural experiment—based on roommate assignments of first-year college students—to isolate the causal peer influences on adolescent weight gain. The study finds evidence of significant peer influences for females but not for males. Heavy and thin females are more likely to be influenced by their peers, especially when the peer is thinner, of a higher socioeconomic status, or is more sexually experienced. Peer influence is stronger when peers are similar with respect to their academic performance, religiosity, and political views. Further research on barriers and facilitators to the transmission of peer influence holds promise for improving effectiveness of anti-obesity policy through utilization of social networks.

Appendix 1

Mechanism of peer influence through behaviors

We test several exercise and eating behaviors as potential mediators of the peer influence in weight, by estimating peer influences in each of the behaviors separately, and then reestimating the Model 1 for weight with the behavior variables included. If these behaviors mediate the relationship between the weights of the roommates, the coefficients on those behavior variables should be significant and the magnitude of the peer effect in weight should be reduced.

The exercise measures are based on a multiple choice survey question about weekly frequency of exercise in the past month, with options of "less than 1 time," "1–2 times," "3–4 times," and "5 or more times," and include a set of category indicators. The survey does not ask about eating habits, such as the frequency, type, or amount of food intake. The eating-related measures are derived from the (SCOFF) eating disorder screen (Morgan, Reid, and Lacey 1999) filled out by students as part of the survey. The screen assigns a high likelihood of an eating disorder (anorexia nervosa, bulimia, or eating disorder not otherwise specified) based on affirmative answers on two or more out of five items (self-induced vomiting, loss of control over eating, recent large weight loss, feeling fat even though others say one is not, and feeling that food dominates one's life). We create a set of indicators for each item, and an indicator of a positive screen for an eating disorder.

The results of peer effects in exercise and eating-related behaviors are mixed, mostly insignificant, and not robust. Results of including the behavior measures as mediators of the peer influence in weight in Model 1 show that the coefficient of the

Table 6
Mechanisms of Peer Influence in Weight Through Exercise and Eating Disorders

	Dependent Variable = Ego's Weight Gain	
	Females, $n = 842$	Males, $n = 751$
Alter, fall:		
Weight	0.033***	0.0002
	(0.010)	(0.015)
Exercise 5+	1.109**	–0.060
	(0.565)	(0.702)
Eating disorder indicator	–0.219	1.393
	(0.496)	(1.200)
Ego, fall:		
Exercise 1–2	–0.132	1.620
	(0.784)	(1.322)
Exercise 3–4	0.159	1.240
	(0.760)	(1.100)
Exercise 5+	–0.543	1.300
	(0.765)	(1.207)
Eating disorder indicator	1.433**	–0.174
	(0.523)	(1.985)

Notes: We report regression coefficients. Each model includes the alter's weight, exercise, and the presence of eating disorder, instrumented with fall measures. All other controls are same as in previous tables. Standard errors in parentheses are clustered at the room level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

peer weight variable remains virtually the same (0.033, $p < 0.01$) (Table 6). Given the overall weakness of the evidence of peer influences in exercise or eating disorders, and the robustness of the peer influence in weight coefficient to the inclusion of these variables, it is unlikely that the peer influence in weight observed in our female sample is driven by person-to-person transmission of exercise habits or eating disorder symptoms.

Appendix 2

Instrumental variable approach

We instrument the alter's measures at the end of the freshman year with the alter's baseline measures (Table 7). While the sample size in the two-stage least squares estimation is smaller (496 males and 608 females), the results are consistent with the earlier findings. The magnitude of the contemporaneous peer influence in weight for females is 0.028 ($p < 0.05$), and it is similar in magnitude to the impact

Table 7
Instrumental Variable Results for Weight, Exercise, and Eating Disorder Score

	Dependent Variable = Ego's Weight Change			
	Females, $n = 608$		Males, $n = 496$	
	1	2	3	4
Alter, spring:				
Weight	0.0317***	0.0318***	0.0150	0.00620
	(0.0118)	(0.0115)	(0.0152)	(0.0176)
Exercise 5+		2.926		–2.093
		(1.946)		(2.719)
Eating disorder indicator		–0.708		5.762
		(1.172)		(4.324)
Ego, fall:				
Exercise 5+		–0.525		0.234
		(0.625)		(0.781)
Eating disorder indicator		1.344**		–0.607
		(0.677)		(2.074)
1st stage				
Under-identification test	59.25***	44.35***	68.43***	41.74***
Weak identification test	1606.55	19.68	645.23	16.41

Notes: We report regression coefficients. Each model includes alter's weight, exercise, and presence of eating disorder, instrumented with fall measures. First stage is the same in all models. All other controls are same as in earlier tables. Standard errors in parentheses are clustered at the room level. Under-identification test—Kleibergen-Papp LM statistic; weak identification test—Kleibergen-Paap Wald F-statistic. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

of the alter's baseline weight (Table 7, Column 1) When exercise and eating disorders are included in the 2SLS peer influence in weight model (Table 7, Column 2), the peer influence in weight remains the same, while neither of the alter's behavior measures appear to exert influence on weight gain. Note that the finding of a positive association between alter's exercise and ego's weight gain does not appear to be robust.

Table 8
Regression Coefficients of Interaction Models of Asymmetric Influences

	Weight 1	Socioeconomic Status 2	Sexual Experience 3	ACT Score 4	Religiosity 5	Political Views 6
			Females			
Alter's weight, fall	0.0172	0.0152	0.0357*	0.0345**	0.0574**	0.0421**
	(0.0251)	(0.0163)	(0.0199)	(0.0145)	(0.0291)	(0.0188)
(Alter's weight, fall)*(ego < alter)	0.156*	0.0536**	0.0160	0.0356	–0.0205	–0.0191
	(0.0849)	(0.0267)	(0.0338)	(0.0577)	(0.0358)	(0.0296)
(Alter's weight, fall)*(ego > alter)	–0.00528	0.0199	–0.0146	–0.0112	–0.0395	–0.00481
	(0.0301)	(0.0322)	(0.0275)	(0.0287)	(0.0342)	(0.0276)
Ego < alter	28.88	9.529	30.98*	–0.834	–24.47	–26.70
	(19.13)	(14.86)	(16.61)	(24.92)	(15.20)	(17.41)
Ego > alter	–3.226	2.653	19.29	–15.91	–41.23**	–17.77
	(15.45)	(17.49)	(15.55)	(13.89)	(16.85)	(14.35)
n	845	833	805	783	845	820
R squared	0.092	0.070	0.071	0.070	0.070	0.071

(*continued*)

Table 8 (*continued*)

	Weight 1	Socioeconomic Status 2	Sexual Experience 3	ACT Score 4	Religiosity 5	Political Views 6
				Males		
Alter's weight, fall	–0.0203	0.00847	–0.00187	0.0103	0.00112	–0.0238
	(0.0307)	(0.0231)	(0.0166)	(0.0138)	(0.0180)	(0.0202)
(Alter's weight, fall)*(ego < alter)	0.0311	0.00570	0.0200	–0.0116	0.0199	0.0488
	(0.0591)	(0.0269)	(0.0300)	(0.0518)	(0.0311)	(0.0308)
(Alter's weight, fall)*(ego > alter)	0.0410	–0.00279	0.0230	0.0124	0.00525	0.0334
	(0.0323)	(0.0344)	(0.0272)	(0.0382)	(0.0252)	(0.0282)
Ego < alter	–14.78	21.29	31.69	–32.45	42.70*	–21.21
	(26.52)	(20.69)	(21.77)	(65.46)	(23.29)	(19.37)
Ego > alter	–10.38	31.81	13.14	5.368	15.44	–30.10
	(18.14)	(22.59)	(23.70)	(27.41)	(23.98)	(23.89)
n	751	744	722	673	751	714
R squared	0.165	0.089	0.067	0.071	0.067	0.075

Notes: We report regression coefficients from a peer influence in weight Model 1 with interaction terms between the alter's weight and two dummy variables representing the ego's measure relative to the alter ("ego < alter" and "ego > alter "; the omitted category is "ego = alter"). Standard errors in parentheses are clustered at the room level. For continuous measures (Columns 1 and 3), category "same" is assigned when the roommates' measures are within one standard deviation of one another. Political views and religiosity are categorical variables with greater values corresponding to having more liberal views and being more religious, respectively. All models control for the ego's height at baseline and followup, alter's height at baseline, dormitory preferences (area of campus, rate, corridor, room type, noise, cleanliness and substance environment, and the housing application submission date age), age, and campus, and are adjusted for clustering at the room level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

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