Housing mobility and adolescent mental health: The role of substance use, social networks, and family mental health in the moving to opportunity study

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ARTICLE INFO

ABSTRACT

The Moving to Opportunity (MTO) experiment was a housing mobility program begun in the mid-nineties that relocated volunteer low income families from public housing to rental units in higher opportunity neighborhoods in 5 US cities, using the Section 8 affordable housing voucher program. Compared to the control group who stayed behind in public housing, the MTO voucher group exhibited a harmful main effect for boys' mental health, and a beneficial main effect for girls' mental health. But no studies have examined how this social experiment caused these puzzling, opposite gender effects. The present study tests potential mediating mechanisms of the MTO voucher experiment on adolescent mental health (n=2829, aged 12–19 in 2001–2002). Using Inverse Odds Ratio Weighting causal mediation, we tested whether adolescent substance use comorbidity, social networks, or family mental health acted as potential mediators. Our results document that comorbid substance use (e.g. past 30 day alcohol use, cigarette use, and number of substances used) significantly partially mediated the effect of MTO on boys' behavior problems, resulting in -13% to -18% percent change in the total effect. The social connectedness domain was a marginally significant mediator for boys' psychological distress. Yet no tested variables mediated MTO's beneficial effects on girls' psychological distress. Confounding sensitivity analyses suggest that the indirect effect of substance use for mediating boys' behavior problems was robust, but social connectedness for mediating boys' psychological distress was not robust. Understanding how housing mobility policies achieve their effects may inform etiology of neighborhoods as upstream causes of health, and inform enhancement of future affordable housing programs.

1. Introduction

Mental health disorders are a major worldwide public health concern (Murray & Lopez, 2002), and the societal costs of such disorders are high (Ingoldsby & Shaw, 2002). Mental health and behavior problems often originate in childhood or adolescence (Kessler, Berglund, Demler, Jin, Merikangas & Walters, 2005), and may set youth on a negative trajectory of escalating mental health problems (Ingoldsby & Shaw, 2002). Exposure to disadvantaged neighborhoods is associated with poorer mental health (Leventhal & Brooks-Gunn, 2003), yet it remains unknown what specific mechanisms explain why certain neighborhood characteristics influence health (Macintyre, Ellaway, & Cummins, 2002).

We leverage the Moving to Opportunity (MTO) for Fair Housing demonstration, which tested whether receiving a rental voucher to move from disadvantaged neighborhoods improved families' outcomes, compared to public housing control group families. The MTO study provides strong causal inference and unbiased effects of being offered a housing voucher on outcomes because random assignment ensures that no confounder, measured or unmeasured, is associated with offered treatment, except by chance (Kleinbaum, Sullivan, & Barker, 2007). Moreover, MTO is a policy-relevant treatment, given that over 5 million low-income Americans in over 2 million households use Housing Choice Vouchers, the leading federal affordable housing policy, to subsidize housing costs (Center on Budget & Policy Priorities, 2015). Policy-relevant exposures identify concrete and realistic intervention points that can enhance impacts on health and health disparities (Glymour, Osypuk, & Rehkopf, 2013).

The MTO experiment aimed to improve household economic self-sufficiency among a low-income, predominantly minority, urban population, but the program changed very few socioeconomic outcomes (Kling, Liebman, & Katz, 2007; Orr et al., 2003). Recent work has highlighted some economic benefits for the younger cohort of children (Chetty, Hendren, & Katz, 2016), but the main domain affected by the program was, unexpectedly, health (Orr et al., 2003). Interim survey findings (4–7 years after random assignment) documented reductions in girls' psychological distress, lifetime marijuana use, lifetime smoking, and risky behavior index, compared to the in-place public housing control group (Kling et al., 2007; Orr et al., 2003; Osypuk, Schmidt, Bates, Tchetgen-Tchetgen, Earls & Glymour, 2012; Osypuk, Tchetgen Tchetgen, et al., 2012). In contrast, MTO treatment unexpectedly increased boys' psychological distress, behavior problems, smoking, and risky behaviors compared to controls (Kling et al., 2007; Orr et al., 2003; Osypuk, Schmidt, et al., 2012; Osypuk, Tchetgen Tchetgen, et al., 2012). Final survey (10–15 years after random assignment) findings were similar, with reductions (among a younger adolescent cohort) in girls' psychological distress, serious behavioral/emotional problems, and alcohol use, and increases in lifetime smoking for the total sample and for boys (Ludwig et al., 2011; Sanbonmatsu et al., 2011). These opposite gender findings have been quite puzzling, and this paper provides the first attempt to explicitly examine potential mediating mechanisms of MTO on adolescent mental health using causal mediation methods.

1.1. Neighborhoods and mental health

Social stress theory (Aneshensel, 1992; Pearlin, 1989) provides a framework for understanding how exposure to disadvantaged neighborhoods adversely affects adolescent mental health (Kling et al., 2007; Leventhal & Brooks-Gunn, 2003). Neighborhood context may shape exposure to stressors, coping mechanisms available to deal with stressors, and the expression of stress-related outcomes (Pearlin, 1989). The socially patterned distribution of exposure to stressors may be especially relevant for understanding why disadvantaged neighborhoods are associated with worse mental health. People living in poor-quality neighborhoods are more likely to encounter adversity and traumatic events, elevating their stress levels and thereby increasing the likelihood of mental disorders (Aneshensel, 1992). Since minority families, such as those targeted by MTO, disproportionately reside in disadvantaged neighborhoods (Osypuk, Galea, McArdle, & Acevedo-Garcia, 2009), they may be especially vulnerable to mental health problems.

An unequal distribution of resources and opportunities across neighborhoods means residents of disadvantaged neighborhoods cannot necessarily draw on beneficial resources to buffer the effects of stressors (Aneshensel, 1992; Pearlin, 1989). Although structural factors increase the probability of experiencing stress in certain environments, some groups may be more or less affected than others, or affected only under certain circumstances (Aneshensel, 1992). Gender may be one such characteristic that differentiates how individuals are exposed to, cope with, and react to neighborhood/contextual stress.

1.2. Gender-specific pathways and mediating mechanisms

First, gender may influence the types of stressors that individuals experience (Pearlin & Schooler, 1978). Women consistently report feeling less safe in their neighborhoods than men (Mulvey, 2002; Perkins & Taylor, 1996), and qualitative work with MTO families revealed that teenaged girls who moved to lower poverty neighborhoods experienced reduced sexual harassment, compared to the high poverty control group (Popkin, Leventhal, & Weismann, 2008). Although we cannot measure girls' sexual harassment or threat of assault directly in our data, it is possible to shed light on this pathway.

For example, if girls relied on destructive coping mechanisms like substance use to deal with sexual trauma (Miranda, Meyerson, Long, Marx, & Simpson, 2002), then perhaps removing this source of trauma would reduce substance use, and partially account for the mental health benefits of MTO among girls.

Second, boys and girls may experience the same structural context, but the effects of stressors may differ because of the different conditions that boys and girls experience in other domains (Pearlin, 1975). Both boys and girls in the MTO treatment group experienced the same structural context in new neighborhoods, yet they are conditioned to navigate them in very different ways. For example, boys in MTO were more likely to hang out in local parks, alleys, and street corners; since this is not the norm in low-poverty neighborhoods, treatment group boys who moved into these neighborhoods may have experienced more formal (e.g., police harassment) and informal (e.g., neighbors calling police) surveillance, and thus fallen in with riskier peer groups (Clampet-Lundquist, Edin, Kling, & Duncan, 2011). Moreover, treatment group boys often moved away from father figures (Clampet-Lundquist et al., 2011), and perhaps the loss of these social connections may explain their harmful outcomes. Therefore, social networks may be a potential mediating pathway to explain boys' harmful MTO effects.

Third, coping mechanisms differ by gender (Pearlin & Schooler, 1978). Boys rely more on problem-focused coping (Kort-Butler, 2009). Although problem-focused coping may buffer the effects of stress on depression, it also may exacerbate the effects of stress on externalizing behaviors (Kort-Butler, 2009), like substance use. Boys are more likely than girls to experience pro-drinking norms that are associated with increased substance use (Lo, 1995), and substance use, in turn, may affect mental health (Merikangas, Nakamura, & Kessler, 2009). Therefore substance use may be a potentially important mechanism for boys' mental health, particularly externalizing behaviors. Girls, however, rely more on emotion-focused coping (Kort-Butler, 2009), and inadequate emotional support from parents, in particular, is associated with depression (Stice, Ragan, & Randall, 2004). Parents with mental health problems are more unpredictable and less supportive (Cummings, Keller, & Davies, 2005); therefore, improving parental mental health may also increase parental ability to provide emotional support. Since the mental health of MTO mothers improved (Orr et al., 2003), this may be one potential mechanism to explain why girls' mental health also improved.

Girls are more likely to exhibit depression and anxiety, while boys are more likely to exhibit substance abuse and delinquency (Kessler & Zhao, 1999; Kort-Butler, 2009), so we focus on both internalizing and externalizing outcomes. We hypothesized that the harmful effect of MTO on boys' substance use and social networks may have partially accounted for some of the harmful effects of MTO on boys' mental health, while the beneficial effect of MTO on girls' substance use and maternal mental health may have partially accounted for the beneficial effect of MTO on girls' mental health.

2. Data and methods

2.1. Data

The US Department of Housing and Urban Development implemented the MTO trial in 5 large cities: Baltimore, Boston, Chicago, Los Angeles, and New York (US Department of Housing & Urban Development, 1996). Eligible volunteer families (N=4608) lived in public housing or housing projects, qualified for rental assistance, and had children under age 18 (Feins & McInnis, 2001). Public housing authorities drew applicants from waiting lists and evaluated families for eligibility, and applicants signed enrollment agreements, gave informed consent, and completed the Baseline Survey (Goering, Kraft, Feins, McInnis, Holin & Elhassan, 1999).

2.1.1. Treatment assignment

Families were randomly assigned by special software, to: 1) the "low-poverty" group, who received a Section 8 voucher redeemable only in a neighborhood with less than 10% of census tract residents in poverty, and relocation housing counseling; 2) the "Section 8" group, who received a traditional Section 8 voucher redeemable in any neighborhood; or 3) the control group, who could remain in public housing, but received no additional assistance (Goering et al., 1999). Families had 90 days to use the offered voucher or it expired. We combined the low-poverty and Section 8 experimental groups to improve statistical power and parsimony. Both groups experienced similar improvements in neighborhood poverty by 2002, and treatment effects on adolescent mental health were statistically similar (treatment effect heterogeneity p > .05).

2.1.2. Assessment

The baseline (1994 to 1998) and the interim (2001 to 2002) surveys were conducted using in-person interviews with household heads and sampled children (Goering et al., 1999; Orr et al., 2003). Final survey data have been collected, but we have not yet obtained the final data, so these are mediation analyses using interim data. Up to two children per household were sampled at interim. The interim data include youth randomized through 12/31/1997 who were aged 12–19 by 5/31/2001. Of 3537 eligible youth, 2829 were interviewed at interim (89.3%

Table 1
Youth Outcome and Mediator Descriptive Statistics by Gender, Moving to Opportunity Data (2001-02).

	BOYS						GIRLS					
	Experimental Group			Control Group			Experimental Group			Control Group		
Domain & Variable	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Outcomes												
K6 psychological distress scale; IRT model of 6-items, higher=more distress; YR	967	-0.09	0.92	436	-0.22	0.89	983	0.01	0.93	443	0.15	0.92
Behavior problems index (BPI); IRT model of 11-items, higher=more problems; YR	967	0.08	0.90	436	-0.08	0.90	983	-0.10	0.88	443	-0.04	0.89
Mediators												
Lifetime Substance Use, 3 Items, YR												
Youth ever drank alcohol; 0=no, 1=yes	959	0.33	0.47	431	0.28	0.45	979	0.27	0.45	441	0.32	0.47
Youth ever smoked cigarettes; 0=no, 1=yes	958	0.28	0.45	432	0.19	0.39	980	0.18	0.39	442	0.21	0.41
Youth ever smoked marijuana; 0=no, 1=yes	954	0.29	0.45	431	0.23	0.42	979	0.16	0.37	438	0.21	0.41
Past 30 Day Alcohol Use, 2 Items, YR												
Youth drank alcohol in the past 30 days; 0=no, 1=yes	956	0.15	0.36	430	0.09	0.29	977	0.11	0.31	439	0.16	0.37
Number of days youth drank alcohol in past 30 days; 0=0 days, 1=1−2 days, 3=3+	956	0.22	0.56	430	0.13	0.43	977	0.13	0.40	439	0.20	0.49
Past 30 Day Cigarette Use, 2 Items, YR												
Youth smoked cigarettes in the past 30 days; 0=no, 1=yes	953	0.18	0.38	431	0.09	0.28	974	0.10	0.30	440	0.13	0.34
Number of cigarettes youth smoked per day in the past 30 days; 0=none, 1=less than daily, 2=1−19, 3=a pack or more	953	0.29	0.67	431	0.12	0.45	974	0.16	0.52	440	0.20	0.56
Past 30 Day Marijuana Use, 2 Items, YR												
Youth smoked marijuana in the past 30 days; 0=no, 1=yes	949	0.13	0.34	430	0.10	0.30	978	0.06	0.23	437	0.10	0.29
Number of days youth smoked marijuana in the past 30 days; range 0 to 30	949	1.42	5.39	430	0.85	4.26	978	0.49	3.28	437	0.86	4.03
Past 30 Day Number of Substances Used, YR												
Number of substances used by youth in the past 30 days; 0=none, 1=1, 2=2, 3=3−4	932	0.45	0.83	424	0.28	0.64	961	0.27	0.63	433	0.38	0.75
Social Connectedness, 6 Items, YR												
Number of adults youth talks to about personal issues; 0=5+ adults, 4=0 adults	960	1.80	1.21	431	1.84	1.23	978	1.73	1.16	442	1.92	1.11
Number of adults youth can rely on for help; 0=7 or more adults, 5=0 adults	952	1.84	1.42	430	1.80	1.48	973	1.78	1.40	441	2.01	1.39
Youth has no friends; 0=no, 1=yes	951	0.04	0.21	431	0.06	0.24	980	0.04	0.21	443	0.04	0.20
Youth has less than 3 friends; 0=no, 1=yes	951	0.23	0.42	431	0.25	0.43	980	0.30	0.46	443	0.30	0.46
Youth has less than 5 friends; 0=no, 1=yes	951	0.43	0.49	431	0.44	0.50	980	0.53	0.50	443	0.57	0.50
Youth sees friends from baseline neighborhood; 0=no, 1=yes	928	0.59	0.49	426	0.67	0.47	941	0.56	0.50	428	0.68	0.47
Peer Deviance, 3 Items, YR												
Youth has friends who use drugs; 0=no, 1=yes	881	0.35	0.48	405	0.25	0.44	945	0.26	0.44	428	0.25	0.43
Youth has friends who are gang members; 0=no, 1=yes	912	0.13	0.34	413	0.18	0.39	937	0.14	0.35	434	0.14	0.35
Youth has friends who carry weapons; 0=no, 1=yes	902	0.14	0.35	418	0.12	0.33	956	0.10	0.30	435	0.09	0.29
Maternal Mental Health, 4 Items, AR												
K6 psychological distress scale; mean score of 6-items, range 1 to 5	946	2.02	0.97	422	1.93	0.87	951	1.93	0.91	426	2.09	1.02
Lifetime depressive symptoms; 0=no symptoms, 1=symptoms	945	0.16	0.37	422	0.17	0.38	949	0.16	0.37	426	0.20	0.40
Past year generalized anxiety disorder; 0=no, 1=yes	929	0.39	0.49	417	0.42	0.49	934	0.38	0.48	416	0.40	0.49
Past 30 days did not feel calm and peaceful all or most of the time; 0=felt calm/peaceful, 1=did not feel calm/peaceful	944	0.52	0.50	422	0.53	0.50	951	0.50	0.50	426	0.58	0.49

Table 2
First-Stage Mediation Results: MTO Treatment Regressed on Mediators by Domain.

	Number of Mediators in Domain	Boys			Girls		
		χ^2	p	Directionality	χ^2	p	Directionality
Lifetime Substance Use	3	3.96	0.27		4.22	0.24	
Past 30 Day Alcohol Use	2	4.75	0.09	−	6.01	0.05	+
Past 30 Day Cigarette Use	2	11.41	0.00	−	4.26	0.12	
Past 30 Day Marijuana Use	2	1.76	0.41		6.39	0.04	+
Past 30 Day Number of Substances Used	1	7.56	0.01	−	8.26	0.00	+
Social Connectedness	6	12.99	0.04	Mixed	24.06	0.00	+
Peer Deviance	3	10.07	0.02	Mixed	0.28	0.96	
Maternal Mental Health	4	3.47	0.48		6.57	0.16	

+ = Uniformly beneficial effects of treatment on all mediators in domain; − = Uniformly harmful effects of treatment on all mediators in domain; Mixed = Mix of both harmful and beneficial effects of treatment on mediators in domain
NOTES: Models adjusted for the following baseline covariates: youth age, black race; site; household head never married, teen parent, had a job, had a family member with a disability, was in school, education, moved more than 3 times in 5 years, lived in baseline neighborhood for 5+ years, chatted with neighbors; household size; youth had learning problems, needed special medicine/equipment, was in gifted/advanced class, was expelled, youth's school called to discuss school work/behavior problems. Includes all sites.

response rate) (Orr et al., 2003). Household heads provided written consent for themselves and their children (Feins & McInnis, 2001; Goering et al., 1999; Orr et al., 2003).

2.2. Measures

Table 1 provides the coding, data source, and descriptive statistics for our outcomes and potential mediators by gender and treatment group.

2.2.1. Outcomes

We examined two interim survey, youth self-reported dimensional outcomes. The K6 scale (Kessler et al., 2002) measured past-month psychological distress with 6 items: depressed, nervous, restless or fidgety, hopeless, everything was an effort, and worthless. Responses were 5-item Likert responses ranging from "none of the time" to "all of the time." The Behavior Problems Index (BPI) measured past 6-month behavior problems with 11 items such as have trouble concentrating, lie/cheat, tease others, etc. Responses were 3-item Likert responses ranging from "not true" to "often true." For both outcomes, we used 2-parameter binary item response theory (IRT) modeling to obtain a factor score that approximates a standard normal distribution (Kessler et al., 2002); the outcome mean(standard deviation) is approximately 0(1) with higher scores indicating worse outcomes. IRT scoring gives heavier weight to items with a stronger relationship to the underlying construct, increasing reliability and precision (Hambleton & Swaminathan, 1985; Kessler et al., 2002).

2.2.2. Mediators

Mediators were measured contemporaneously with outcomes at the interim survey (Table 1). Despite that temporal order is not maintained, our exploratory analysis provides an important first step in identifying potential mechanisms to investigate in the future, particularly since MTO is a rare and strong experimental design and represents a policy-relevant exposure. Mediators were coded such that higher values indicate worse responses. We grouped similar mediators into domains, and the variables within each domain were modeled simultaneously in our mediation analysis, testing each domain separately.

Youth self-reported lifetime substance use included lifetime alcohol use, cigarette use, and marijuana use. Past 30 day alcohol use included alcohol use and the number of days youth drank. Past 30 day cigarette use included cigarette use and the number of cigarettes smoked per day. Past 30 day marijuana use included marijuana use and the number of days youth smoked marijuana. Reliability is high for all substance use measures (Brener, Kann, McManus, Kinchen, Sundberg & Ross, 2002), and prevalences in the MTO sample are comparable for

cigarette and marijuana use, and slightly lower for alcohol use, to those obtained from national surveys (SAMHSA, 2012). Finally, we created a measure of past 30-day number of substances used by the youth, which included alcohol, cigarettes, and marijuana, and other non-prescription drugs.

Social connectedness included the number of adults youth can confide in, the number of adults who youth can rely on for help, the youth has no friends, has less than 3 friends, has less than 5 friends, and has friends from the baseline neighborhood. Peer deviance included binary measures indicating the youth has friends who use drugs, are gang members, or carry weapons.

Maternal mental health included past-month psychological distress, lifetime major depressive disorder (MDD), past-year generalized anxiety disorder, and past 30 days not feeling calm/peaceful. We refer to the mother/primary caregiver measures as "maternal" mental health, because nearly 90% of youth lived with their mothers.

2.2.3. Covariates

We adjusted all regression models for baseline covariates significantly related ($p < .10$) to mental health outcomes to adjust for potential confounding of the mediator-outcome relationship and to improve efficiency (see Table 2 notes). As expected in a RCT, baseline covariates were balanced across treatment groups, thus did not confound the treatment-mental health, or treatment-mediator associations.

2.3. Analytic plan

Total effect intention-to-treat (ITT) estimates of being offered a voucher were derived using linear regression of MTO treatment predicting the mental health outcome (excluding mediators). We then estimated first-leg ITT models to examine the effects of MTO treatment on each mediator domain using logistic regression, predicting treatment from all mediators within a domain. To assess directionality, we estimated models predicting each mediator individually from treatment. Mediation of the MTO treatment effects on mental health was then tested using an innovative, weight-based mediation method. Models were gender-stratified, because of the documented opposite gender effects of MTO on mental health, and adjusted for survey weights and family-level clustering using Stata 11.0.

The hypothesized causal model is displayed in the directed acyclic graph (DAG) in Fig. 1. The effect of MTO on adolescent mental health is the total effect. Using the natural direct and indirect effect approach (Pearl, 2001), we decompose the total effect into the indirect effect: the MTO effect operating through variables that significantly mediate the total effect, and the direct effect: the MTO effect not operating through the modeled mediators. The magnitude of mediation was calculated
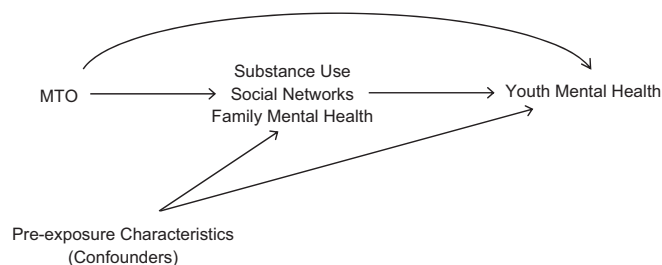
Fig. 1. Title: Directed acyclic graph (DAG) demonstrating the hypothesis that the effect of being randomly-assigned to the MTO treatment group (compared to the control group) on youth mental health is mediated by substance use, peer social networks, and family mental health, conditional on pre-exposure youth and family characteristics that may potentially confound the mediator-outcome relationship.

with a percent change ((direct effect-total effect)/total effect), such that a positive percent change indicates an increase in the effect of MTO on the outcome after accounting for the mediator, and a negative percent change indicates a decrease in the effect of MTO on the outcome after accounting for the mediator. We tested many potential mediators, so we grouped mediators into domains and modeled them simultaneously using a causal mediation method that can accommodate multiple mediators. These analyses may be considered exploratory, but we believe such an approach is merited, given that an expensive program such as MTO is not likely to be replicated soon, and policy-relevant exposures such as this are so rare.

Site heterogeneity exists for MTO effects on boys' behavior problems (Osypuk, Tchetgen Tchetgen, et al., 2012), with beneficial effects of MTO on behavior problems in Los Angeles (LA), and null or harmful effects in the four other sites (qualitative effect modification). In preliminary models, the opposite treatment effect in LA was so large that when analyzed with other sites, the pooled average total effect averaged out to be large and statistically significant. However, the qualitative differences in treatment effect estimates for LA versus other sites suggests a pooled indirect effect estimate is inappropriate. Substantively, we also would anticipate different mechanisms operating for beneficial versus harmful effects, therefore we stratified on LA versus the other sites in mediation models. Mediation models within LA alone were underpowered given the small sample size, with no significant mediation findings (not shown). No site heterogeneity was documented for psychological distress, therefore, we employ the full 5-site sample.

2.3.1. Inverse odds ratio weighting (IORW)

The Inverse Odds Ratio Weighting mediation method is a semi-parametric mediation method with several advantages (Nguyen, Osypuk, Schmidt, Glymour, & Tchetgen Tchetgen, 2015; Tchetgen Tchetgen, 2013). First, it can be used for mediators and outcomes of any functional form, allowing for effect decomposition even with nonlinear variables (Nguyen et al., 2015). Second, because the relationship between exposure and mediators is captured in the weight, it can model multiple mediators simultaneously (Nguyen et al., 2015). Finally, any complex interactions between the treatment and mediator(s) are captured in the weight, without having to specify them in the regression equation (Nguyen et al., 2015).

IORW causal mediation condenses information on the treatment-mediator relationship into a weight, adjusting for covariates (Tchetgen Tchetgen, 2013). The weight deactivates all indirect pathways through the mediator, isolating the direct effect of treatment. The indirect effect is then calculated by differencing the total effect and direct effect. Details on implementation (including statistical code) are presented in a recent paper (Nguyen et al., 2015). First, we obtained the predicted odds from a logistic regression model predicting treatment from the mediator and covariates. Ordinarily, IORW would create the weight from odds ratios, but, the predicted odds provides a more efficient,

stabilized weight (Nguyen et al., 2015). Second, we took the inverse of this predicted odds to create an inverse odds weight (IOW), with control group members set to 1. Third, we estimated the total effect of MTO treatment on our outcomes. Fourth, we re-estimated step 3, but applied the IOW to adjust for the mediator and recover the direct effect. Finally, we subtracted the direct effect coefficient from the total effect coefficient to obtain the indirect effect of MTO through the mediator. Direct and indirect effect standard errors were obtained using bootstrapping with 1000 replications.

2.3.2. Bias sensitivity analysis

Like all mediation methods, valid mediation estimates in IORW assume no unmeasured confounding, which we tested using a bias sensitivity analysis. Although randomization ensures unconfounded treatment-outcome and treatment-mediator associations, the mediator was not randomized, so the mediator-outcome association may be confounded, e.g. by pre-exposure youth or family characteristics (Fig. 1), such as genetic predisposition to substance abuse and mental disorder. Our mediation analyses and bias sensitivity analyses assume no mediator-outcome confounders affected by exposure.

Confounding sensitivity analyses strengthen our approach to evaluate a key assumption, providing increased confidence in our findings. This method documents how much confounding bias there may be in the direct and indirect effects across various potential levels of unmeasured confounding (Nguyen et al., 2015; Tchetgen Tchetgen & Shpitser, 2012). This is achieved by subtracting from the outcome a value we calculated from a selection bias function. We varied this selection bias function by adjusting a sensitivity parameter (lambda) across a range of values, each time subtracting it from the outcome, creating 30 new outcomes. We then reestimated the direct and indirect effects across this range, plotting the bias to see how quickly the curve changes across varying levels of the bias.

With no unmeasured confounding (i.e., when lambda is zero), the estimates will return the direct effect of treatment among treatment group members who exhibit the mediator, compared to treatment group members who do not. In the presence of confounding, lambda captures the extent to which confounding may change the average potential outcome among treatment group members who exhibit the mediator, compared to those who do not. For our purposes, positive values of lambda indicate that subjects with more behavior problems are more likely to exhibit the mediator, while negative values of lambda indicate that subjects with more behavior problems are less likely to exhibit the mediator (details in Appendix A).

3. Results

3.1. Total effects

The MTO treatment was harmful for boys' behavior problems (b(SE) = .271(.065), p < .001) and boys' psychological distress (b(SE) = .140(.060), p = .021), beneficial for girls' psychological distress (b(SE) = -.123(.060), p = .042), and nonsignificant for girls' behavior problems (mediation analyses for girls' behavior problems not shown).

3.1.1. First-leg analyses

Table 2 displays first-leg models of how MTO treatment changed the overall mediator domains, as well as the directionality of change. For boys, MTO changed past 30 day alcohol use, past 30 day cigarette use, past 30 day number of substances used, social connectedness, and peer deviance. Mostly MTO worsened mediators for boys, with the exception of improvements in a few social connectedness and peer deviance measures. MTO treatment also significantly improved many mediator domains for girls, including past 30 day alcohol use, past 30 day marijuana use, past 30 day number of substances used, and social connectedness. First-leg models of MTO treatment effects on

Table 3
IOW Mediation Predicting Adolescent Mental Health; Indirect Effects.

	Boys' BPI (Without LA)				Boys' Distress (With LA)				Girls' Distress (With LA)			
	Indirect			% Change	Indirect			% Change	Indirect			% Change
	b	SE	p		N	b	SE	p		N	b	SE	p		N
Lifetime Substance Use	0.034	0.028	0.226	-12.7%	1094	0.005	0.020	0.813	-3.8%	1371	-0.009	0.020	0.658	-7.0%	1409
Past 30 Day Alcohol Use	0.034	0.020	0.086	-12.5%	1106	0.003	0.017	0.879	-2.0%	1386	-0.003	0.017	0.857	-2.5%	1416
Past 30 Day Cigarette Use	0.037	0.020	0.070	-13.6%	1104	-0.002	0.016	0.920	1.2%	1384	0.009	0.014	0.534	6.9%	1414
Past 30 Day Marijuana Use	0.020	0.023	0.381	-7.5%	1102	-0.006	0.016	0.703	4.5%	1379	0.003	0.016	0.840	2.7%	1415
Past 30 Day # of Substances Used	0.049	0.024	0.040	-18.0%	1082	0.004	0.016	0.807	-3.2%	1356	-0.007	0.017	0.680	-5.5%	1394
Social Connectedness	0.024	0.024	0.331	-8.1%	1056	-0.034	0.021	0.094	26.9%	1318	-0.013	0.022	0.562	-10.5%	1354
Peer Deviance	0.026	0.035	0.459	-9.0%	955	-0.012	0.023	0.614	10.4%	1212	0.011	0.019	0.540	7.6%	1318
Maternal Mental Health	0.011	0.022	0.605	-3.9%	1072	-0.008	0.017	0.641	5.5%	1344	-0.014	0.023	0.539	-14.8%	1350

NOTE: Models estimated with 1000 bootstrap replications and adjusted for all covariates in first-stage models. Percent change was calculated by taking (direct effect-total effect)/total effect, total effect of treatment on BPI: Boys b(SE): .271(.065); total effect of treatment on Distress: Boys b(SE): .140(.060); Girls b(SE): -.123(.060).

individual mediators are shown in Supplemental Table 1.

3.2. Mediation analyses

For boys' behavior problems, the IORW indirect effect estimates demonstrated significant or marginally significant mediation of MTO treatment in 3 of the 8 domains (Table 3). Past 30 day alcohol use, cigarette use, and number of substances used significantly mediated, resulting in a percent change in the total effect ranging from -13% to -18%. For example, boys in the treatment group (compared to controls) used a greater variety of substances, and accounting for this significantly reduced the harmful total effect of treatment by 18%, suggesting partial mediation. These results hold when we include the substance use domains changed by treatment, e.g., alcohol and cigarette use, in one combined model. We found no significant mediators in the social connectedness, peer deviance, or maternal mental health domains for boys' BPI.

For boys' psychological distress, the IORW indirect effects demonstrated marginally significant mediation of MTO treatment in 1 of 8 domains (Table 3). Social connectedness corresponded to a 27% increase in the total effect, signifying possible countervailing mediation (B=-.03, p=.09). MTO treatment changed social connectedness, for example by reducing youth having friends in their baseline neighborhood, which in turn increased the overall harmful effect of treatment. Substance use and maternal mental health did not mediate boys' psychological distress. For girls' psychological distress, none of the mediation models were significant (Table 3).

3.2.1. Confounding sensitivity analysis

We estimated confounding sensitivity analyses on mediator domains that were significant or marginally-significant (Appendix A), by selecting one individual mediator from each domain. Specifically, we tested binary alcohol use, binary cigarette use, friends from the baseline neighborhood, and past 30 day number of substance used. For boys' behavior problems, the substance use measures showed consistent patterns with direct and indirect effects robust to potential unmeasured confounding. Across all levels of the induced bias, the direct effect remained statistically significant (p < .05), with betas ranging from .20 to .26. Indirect effect coefficients ranged from .02 to .05 and were robust to confounding when lambda ranged from -.7 to 1.5, with p < .10, but were somewhat sensitive to confounding in the lower ranges of lambda (-1.5 to -.8), with p-values rising above .10. This suggests the indirect effect may be over-estimated due to confounding in situations where the potential behavior problems of individuals more likely to exhibit substance use was actually at least .8 units lower than that of individuals less likely to exhibit substance use. So confounding may bias effects when the potential behavior problems outcome among substance users is almost a full standard deviation

(since behavior problems is standardized) below non-substance users – a rather large difference. It is hard to imagine a scenario in which the potential behavior problems outcomes would be drastically lower among substance users compared to non-users. These results provide confidence in substance use as a robust mediator. Findings were not robust for having friends in the baseline neighborhood.

4. Discussion

In this study, we examined mediation of the heretofore puzzling opposite gender effects of the Moving to Opportunity housing mobility experiment on adolescent mental health. Applying the innovative IORW mediation method, we tested whether variables related to youth self-reported substance use comorbidity, non-family social networks, and maternal mental health mediated the harmful effects of MTO on boys' behavior problems and psychological distress, or the beneficial effects of MTO on girls' psychological distress. With a few exceptions, MTO treatment worsened many of the mediators for boys, while it improved many of the mediators for girls. These changes were most evident for substance use.

MTO treatment increased boys' engagement in substance use, which also emerged as the main mediator domain of the harmful effect of MTO on behavior problems. This finding is not surprising given that males are more likely than females to exhibit substance use (Kessler & Zhao, 1999) and behavior problems (Merikangas et al., 2009). Notably, since substance use was measured contemporaneously with mental health at the interim evaluation, our results formally suggest covariation rather than mediation. This means the same boys in the MTO experiment who exhibited increases in mental health problems also exhibited increases in substance use problems, indicating treatment group boys experienced a constellation of harmful effects. Covariation between substance use and mental health problems is well-documented (Couwenbergh et al., 2006; SAMHSA, 2003), although it is unclear whether 1) poor mental health leads to substance use (i.e., through self-medication), 2) substance use leads to poor mental health, or 3) some earlier factor leads to both (i.e., prior common causes) (NIDA, 2010). Although we cannot differentiate between the first two, we have identified neighborhood mobility during childhood as one common cause of both increased substance use and behavior problems among low-income adolescent boys.

Interestingly, MTO did change social connectedness for boys, reducing the likelihood that youth had friends from their baseline neighborhood. Social connectedness had a marginal mediation effect for the harmful effect of treatment on boys' psychological distress, increasing the harmful effect by 26.9%. Although this effect was not robust to unmeasured confounding, this is a potential avenue for future investigation. Maternal mental health did not mediate treatment effects on boys' own mental health.

For girls in the treatment group, MTO significantly reduced substance use and improved aspects of non-family social networks vs. controls. Yet none of the potential mediators significantly accounted for the causal effects of MTO on girls' psychological distress. Perhaps we are not testing the most relevant mechanisms. Qualitative work suggests that girls who moved with the voucher escaped sexual harassment in their baseline neighborhoods (Popkin et al., 2008), but we do not have such measures in the interim survey. We expected that reductions in substance use (negative coping/escaping sexual trauma) or increases in mothers' mental health (positive coping/increased emotional support) would have accounted for some of the improvement in girls' mental health, although this was not the case.

Our results suggest that future housing policies should consider building in components to ease some of the potential negative repercussions of this widespread affordable housing policy, including the integration of components outside the housing sector. For example, housing voucher programs could integrate resident supportive services as in the HOPE VI housing relocation program (e.g., case management, linkage to health care access or educational services tailored to residents' needs) (Engdahl, 2009; Popkin et al., 2002). Integrating these components, or other supportive services, like substance use prevention, could mitigate the harmful effects of the MTO policy on boys' substance use and behavior problems. Finally, future housing policies may benefit from measuring baseline mental health and substance use to target services to health-vulnerable populations.

4.1. Limitations

We leverage a strong experimental design and apply a novel mediation method, but our study does exhibit limitations. Since mediators are not randomized, the mediator-outcome relationship may be confounded. Moreover, simultaneous measurement of our mediators and outcomes may inflate mediation effects and violate the ignorability assumption. To mitigate potential confounding and assess potential threats to ignorability, we adjusted for a range of baseline variables, and conducted bias sensitivity analyses to test how unmeasured confounding may influence results (Nguyen et al., 2015; Tchetgen Tchetgen & Shpitser, 2012). We also directly estimated first-stage equations to establish unbiased associations between MTO treatment and the mediators, as an upper bound effect, which is necessary for mediation (Valeri & VanderWeele, 2013). Measurement error of mediators may be another source of bias. We have non-differential measurement error, with error independent of exposure, thus our direct effect estimates may be biased away from the null and indirect effects biased toward the null (Ogburn & VanderWeele, 2012).

Here, we analyzed the effects of being offered a voucher (ITT), rather than of actually moving with the voucher. With perfect compliance, these two effects are identical (Angrist, Imbens, & Rubin, 1996), but since only half of the MTO treatment group moved with the voucher, ITT effects are watered down. Testing mediation adjusting for compliance is complex, and although we cannot adapt the IOW method to do so, we did test the total effect and the first-leg models using instrumental variable (IV) analysis to assess potentially differential uptake. The IV total effect and treatment effect on mediators showed identical patterns as ITT but twice as large, suggesting that our ITT effects are conservative and differential uptake is not biasing our results. Notably, although IV effects assessing the actual effects of moving may be more etiologically relevant, from a policy standpoint, the ITT effect provides important information on the impacts of offering services since policy makers can only offer services and not enforce compliance.

To mitigate that we tested many mediators, we grouped them into 8 domains. This resulted in 24 tests across outcomes/genders. Four mediators had significant or marginally significant indirect effects (16.6%) when you would expect only 1–2 (5–10%) by chance. Since the trial was not powered to test mediation (or effect modification),

these results can be interpreted as exploratory, to identify promising pathways to investigate in future evaluations (Rothman, 1990). Finally, MTO is a bundled treatment, thus represents a combination of neighborhood, mobility, and/or housing effects, rather than strictly neighborhood effects. Nonetheless, MTO substantially improved neighborhood context, and remains a very policy-relevant treatment since housing vouchers represent the primary form of federal affordable housing dollars (National Low Income Housing Coalition, 2011).

4.2. Conclusions

Although MTO was conceived and delivered as a housing program, and health outcomes were not considered a priori, the MTO program worsened boys' mental health. Substance use emerged as a robust, promising mediator of housing mobility effects on boys' behavior problems. The contributions of this paper are three-fold: we focus on a policy-relevant exposure (Glymour et al., 2013), we explore the mechanisms underlying causes of mental health (Galea & Link, 2013), and we contribute a methodologically-rigorous analysis, combining an experimental design with causal mediation methods and bias sensitivity analysis. Leveraging these three components provides an important opportunity to identify realistic points of intervention, with strong internal validity, that can maximize the impact of policies on population health (Galea, 2013).

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ssmph.2017.03.004.

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