Social Science & Medicine 272 (2021) 113732

Contents lists available at ScienceDirect

Social Science & Medicine

journal homepage: http://www.elsevier.com/locate/socscimed

What is the causal effect of income gains on youth obesity? Leveraging the economic boom created by the Marcellus Shale development☆,☆☆,☆☆☆

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A R T I C L E I N F O

An earlier version of this manuscript was presented at the 2016 Annual Meetings of the Population Association of America, Washington, D.C., and the 2016 Annual Meeting of the Association for Public Policy Analysis & Management, Washington, D.C.

Keywords:
Youth obesity
Income
Health disparities
Natural experiment

A B S T R A C T

Low family income is frequently assumed to be a primary social determinant of youth obesity in the U.S. But while the observed correlation between family income and youth obesity is consistently negative, the true causal relationship is unclear. I take advantage of a natural experiment – the boom economy created by development of the Marcellus Shale geological formation for natural gas extraction – to study whether income gains affect youth obesity rates among Pennsylvania students. To test this relationship, I compile data from geological, administrative, Census and other governmental sources and estimate cross-sectional OLS regression models, longitudinal fixed effects models, and two-stage instrumental variable models within a difference-in-differences framework. Falsification tests indicate that children's location relative to the Marcellus Shale's geological boundaries is a valid instrument for income gains. Yet plausibly exogenous income gains do not alter youth obesity rates, regardless of the community's initial level of poverty or affluence and regardless of the child's grade level. Thus, the observed disparities in youth obesity by area income in Pennsylvania do not result from simple differences in disposable income and the relative cost of "healthy" versus "unhealthy" goods and services.

Once researchers documented the profound long-term consequences of rising youth obesity rates (Deckelbaum and Williams, 2001; Ogden and Carroll, 2010; Tsiros et al., 2009), health professionals worked diligently to put youth obesity on America's policy agenda. Numerous health organizations launched educational campaigns and built private-public partnerships (Deardorff, 2012; Squires, 2007). Key among government responses was the federal Child Nutrition and WIC Reauthorization Act of 2004, which required all public school districts to develop and adopt wellness policies (Probart et al., 2010), and First Lady Obama's *Let's Move* initiatives, which focused heavily on school district reforms (The Whitehouse, 2016). As such, the 2000s witnessed a multifactorial policy response to reverse youth obesity trends and improve school wellness environments. Some studies find these policies had no effect on youth obesity rates (Gee, 2018; Phillips et al., 2013), but others suggest they helped slow the historic rise in youth obesity (Coffield et al., 2011; Ryan et al., 2006).

While policy prescriptions targeted school districts, analysts diagnosed family income as critical given that rates of youth obesity are lowest among high-income families (Ogden, 2018). Many scholars and public officials presumed that families with higher incomes could better protect their children in America's obesogenic environment given that "healthy" food is relatively expensive (Drewnowski and Specter, 2004) and most physical activity opportunities are family financed (McNeal, 1998). The public emphasis on family income is reflected in the federal government's websites: Although the social determinants of obesity are numerous, family income is the only social determinant explicitly mentioned on both the CDC and Healthy People 2020 youth obesity websites. Thus, many view youth obesity in the U.S. as embodied economic disadvantage (Moffat, 2010).

Income-based disparities in youth obesity comport with Fundamental Cause Theory, which argues that high-status individuals are better able to learn about and apply their flexible resources to respond to

☆ The author can be reached at the Department of Sociology, Pennsylvania State University, 211 Oswald Tower, University Park, PA 16802.☆☆ I am grateful for support from the Russell Sage Foundation (#83-14-16), seed grant funding from the Penn State Social Science Research Institute, and the Penn State Population Research Institute, which received center grant funding from the National Institutes of Health (P2CHD041025; PI: Glick).☆☆☆ I sincerely thank Arthur Friedson of the New York State Department of Taxation & Finance, Lisa Bailey-Davis of Geisinger Health, and Beth Anne Bahn of the Pennsylvania Department of Health for providing access to data utilized in this project. I am indebted to Elizabeth Ananat for her guidance about the research design and Yosef Bodovski for his tremendous skills as a geographic information analyst. Finally, I thank Alexander Chapman, Sarah Cowan, Glenn Firebaugh, Michelle Frisco, David Kindig, Thomas Loughran, John McCarthy, Diane McLaughlin, and Wayne Osgood for their comments and advice on this project.

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https://doi.org/10.1016/j.socscimed.2021.113732
Received in revised form 21 January 2021; Accepted 27 January 2021
Available online 2 February 2021
0277-9536/

new health information, technologies and treatments (Link and Phelan, 1995). The implication is that, once the risks of youth obesity became widely known, high-status parents deployed their resources to help their children maintain a healthy weight. Yet the causal question remains: Does high family income reduce the risk of youth obesity?

Because Fundamental Cause Theory focuses on an individual's or family's relatively stable and flexible composite of resources – akin to the notions of "socioeconomic status" in sociology or "permanent income" in economics, Fundamental Cause Theory does not predict the marginal effect of changing any particular component (Glymour et al., 2014). Further, it is neutral about which stratified resource high-status individuals utilize to achieve better health (Link and Phelan, 1995). On the one hand, income could causally affect youth obesity directly and indirectly given income also influences families' residential location decisions (Logan et al., 1996), migration patterns (Borjas 2014), and children's educational achievement (Dahl and Lochner, 2012). On the other hand, the income gradient in youth obesity could be spurious and stem from inequalities in parents' education or cultural capital. These other stratified resources predict family income (Becker, 1993; Bourdieu, 1986), while adults' health-related knowledge and time constraints predict body weight (Cawley and Liu, 2012; Mirowsky and Ross, 2015). Finally, unequal community resources could fuel the observed obesity differentials given distressed neighborhoods have lower access to high-quality food and health care, but higher rates of violence and social disorganization (Diez Roux and Mair, 2010). In sum, numerous structural resources, correlated with family income, could create the observed disparities in youth obesity.

The true causal relationship between income and youth obesity is complex and difficult to demonstrate. For example, scholars view macroeconomic growth as undergirding the population increase in obesity because it accelerates agricultural production and processing, while lowering food prices and the demand for physical labor (Popkin, 2002). Further, improved worker productivity increases wages, which helps people afford better nutrition (Firebaugh and Beck, 1994). Yet, after the risk of famine recedes, continued economic growth is predicted to increase obesity risks (Popkin, 2002). Prior research seeking to identify the causal effect of macroeconomic growth arrives at mixed conclusions. Leveraging the timing and geographic variability of recessions, scholars find economic downturns increased childhood obesity in California (You and Davis, 2010), but lowered it in Spain (Bellés-Obrero et al., 2016).

Within high- and middle-income countries like the U.S., family income and youth obesity are negatively correlated (Lakdawalla and Philipson, 2009). The hypothesized mediating factors are families' stress exposure (Garasky et al., 2009), parents' time use (Cawley and Liu, 2012), and families' consumption of weight-related goods and services (Cawley, 2004).

Families' consumption practices are generally prioritized within the literature as particularly important, yet the effects of families' consumption on youth obesity depend on the relative balance of health-promoting versus health-depleting purchases (Cawley, 2004). In fact, Lakdawalla and Philipson (2009) theorize an inverted U-shaped relationship, wherein increasing income for poor families would lead to weight gain because poor families are predicted to increase their total food consumption, but increasing income for affluent families would foster weight loss because wealthy families are predicted to purchase more nutritious foods and become more active. In essence, Lakdawalla and Philipson (2009) propose that poor and wealthy families have different preferences that generate different behavioral responses to increasing income. Further, economists argue that permanent income – one's expected, long-term average income – affects consumption behavior more than their transitory income (Friedman, 1957). Yet Catalano et al. (2011) have argued that, regardless of their initial economic status, families will consume more unhealthy goods during economic booms versus recessions. Thus, the causal effect of income gains on youth obesity could be positive, negative, or even zero if opposing theoretical mechanisms cancel each other out. Alternatively, the causal effect of income gains could be nonlinear and depend on families' initial income (Lakdawalla and Philipson, 2009).

Most studies relying on observational U.S. data find no statistically significant association between family income and the risk of overweight and obesity for children (e.g., Anderson et al., 2003; Classen and Hokayem, 2005) or adolescents (e.g., Goodman et al., 2003; Martin et al., 2012; Wang and Zhang, 2006) after controlling for measured family traits, particularly parents' education (for the few exceptions, see Goodman, 1999; Haas et al., 2003; Strauss and Knight, 1999). Yet the estimated association between observed family income and youth obesity could be downwardly biased due to the omission of difficult-to-measure family and community traits (MacKinnon et al., 2000) or nonlinearities in the true income effect.

The results from U.S.-based, quasi-experimental microeconomic studies are mixed. Rising family income led to small increases in childhood obesity rates among EITC-eligible families nationwide (Jo, 2018), but small declines in children's BMI and overweight/obesity rates among American Indian children in California (Jones-Smith et al., 2014) and modest declines in obesity rates among Alaskan children (Watson et al., 2019). Other quasi-experimental studies have leveraged exogenous changes in families' in-kind benefits, which could affect children's weight if recipients divert their financial resources to weight-related goods and services. Exogenous variation in means-tested childcare subsidies increased preschool children's obesity rates (Herbst and Tekin, 2012), while long-term Supplemental Nutrition Assistance Program participation reduced the likelihood of being overweight or obese for children aged five to eleven (Schmeiser, 2012).

Despite its notable strengths, the existing quasi-experimental literature has several limitations. First, I am not aware of any previous research estimating the causal effects of macroeconomic growth – only recessions. Second, to my knowledge, most quasi-experimental studies of family income gains have examined the effects among initially low-income Americans, which limits their generalizability (for the exception, see Watson et al., 2019). Given Lakdawalla and Philipson's (2009) theory of nonlinear income effects, it is important to explore whether initial income levels moderate the hypothesized income effect. Finally, quasi-experimental studies of family income gains with national samples do not account for sample members' differential exposure to local, anti-obesity intervention efforts and their expansion across this period. In this study, I seek to build on prior research by [1] estimating the effects of a boom economy, [2] examining possible differences across places with initially greater family poverty or affluence, and [3] utilizing a detailed geographically-informed design to account for policy variation across school districts – the site of most youth obesity interventions during the 2000s.

1. Capitalizing on the Marcellus shale natural gas boom

I leverage a sudden, but uneven boom economy to examine whether income gains altered the risks of youth obesity. Between 2008 and 2011, the development of the Marcellus Shale geological formation for natural gas production offset the Great Recession in areas of Pennsylvania. This geographically-bounded economic boom was countercyclical and, thus, cannot be mistaken for a generally rising economy. Natural gas trapped in microscopic pockets thousands of feet below the surface is now profitable to extract due to new technology that combines hydraulic fracturing and horizontal drilling. The first productive well was drilled in 2005 but drilling escalated after 2008.

Families who own their property's mineral rights can sign a lease to allow gas companies to drill and extract the gas beneath their property. Companies then compensate families for signing a lease and provide royalty payments upon the sale of the gas from their parcel (based on the contracted royalty rate, the price of natural gas upon its sale, and the per acre volume of gas extracted). Contracted royalty rates vary, but the PA state-mandated minimum is 12.5% and the average was 13.4% (Ward et al., 2011). Leasing payments arrive in either one or multiple payments, whereas royalties arrive repeatedly while the well is active. In 2010 in PA, natural gas companies paid $2.07 billion in Marcellus Shale lease and royalty payments (Considine et al., 2011).

Yet more families financially benefited from the local hiring and wage increases related to the Marcellus Shale boom (Cruz et al., 2014; Kelsey et al., 2011). For example, between 2007 and 2012, PA employment in the oil and gas industry increased by 259.3% and average industry wages increased by 36.3% (Cruz et al., 2014). Employment and wages in other industries also improved as gas production increased demand for several services (Kelsey et al., 2011). The most common expanded opportunities for local residents were in truck driving, subcontracted construction and manufacturing work, and within the service sector (e.g., restaurants and hotels) to support the out-of-state employees working directly in the specialized drilling process (Brasier et al., 2011; Kelsey and Hardy, 2015; Wrenn et al., 2015).

The intensity of this economic stimulus varied geographically. As determined by gas industry experts prior to development, some areas are more economically-productive given the rock's known depth, thickness, porosity, thermal maturity, and silica content (Dell et al., 2008). My "treatment" areas are those above the pre-determined economically-viable "Core" in Pennsylvania (see Fig. 1). I make multiple comparisons in these analyses, though the primary comparison is to Pennsylvania areas pre-determined as above the not economically viable Shale, or "non-Core." Supplemental analyses make comparisons to Pennsylvania areas located entirely outside the Marcellus Shale geological formation. Finally, I leverage parallel income tax data from New York (NY) to test the validity of the instrument. Areas of NY lie above the Marcellus Shale, but NY has a statewide ban on hydraulic fracturing. Thus, I can examine whether location above the "Core" predicts income gains in Pennsylvania, but not New York. Although the Marcellus Shale formation extends into Ohio, Virginia, West Virginia and Maryland, I exclude these states because [1] the Core of the Marcellus Shale does not extend into Virginia and Maryland and only slightly extends into Ohio, [2] few West Virginian property owners can receive royalty and lease payments due to the state's history of extensive corporate landownership and detached mineral rights (West Virginia Center on Budget & Policy and American Friends Service Committee, 2013), and [3] West Virginia has a severance tax on natural gas extraction (generating roughly $4 million revenue in 2010 distributed to local governments (O'Leary, 2012)) which could indirectly alter the risks of youth obesity.

Based on past theoretical (Friedman, 1957) and empirical work (for a review see Glymour et al., 2014), Marcellus Shale income is more likely to alter families' consumption behavior if the income gains – and Marcellus Shale development more generally – were viewed as long-term shifts. For example, the reliable annual casino dividends paid to tribe members led to increased obesity rates among Native American adolescents from initially poor families (Akee et al., 2013), while increased payments from Alaska's Permanent Fund Dividend – a universal basic income program in operation for 35 years – reduced early childhood obesity rates (Watson et al., 2019). As such, it is important to know whether PA Marcellus Shale residents viewed their income gains as permanent or temporary. Unfortunately, the evidence is mixed. On the one hand, local political leaders and industry representatives predicted decades-long Marcellus Shale growth (Considine et al., 2009) and several residents internalized these exaggerated prognostications

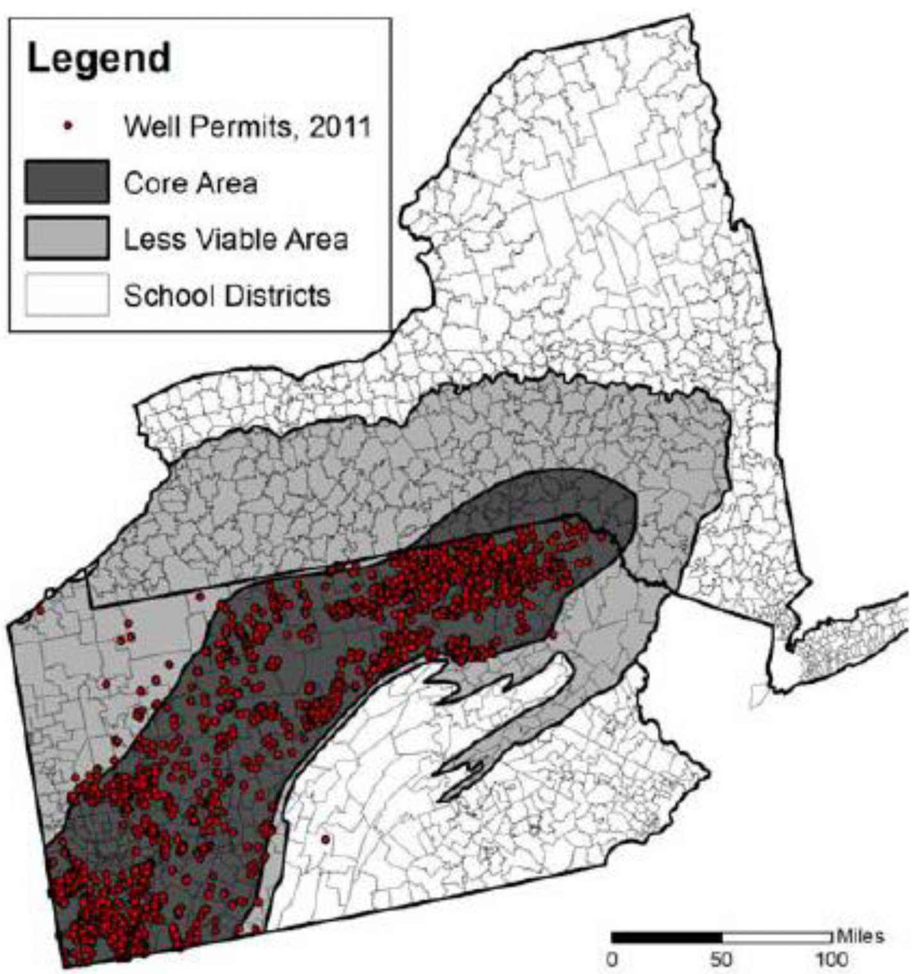

Fig. 1. Map of Marcellus Shale Formation overlaying Pennsylvania and New York School District Boundaries.

(McGraw, 2011). On the other hand, PA residents were less optimistic than the full U.S. population about the long-term economic impacts of Marcellus Shale development (Evensen and Stedman, 2016). In addition, many respondents participating in a 2010 mixed methods project fielded in four PA Marcellus Shale communities questioned whether the boom would last more than 5 years (unpublished data). If PA residents viewed the boom as short-lived, then Marcellus Shale income gains would not likely affect youth obesity via consumption shifts.

Beyond consumption, Marcellus Shale income gains could operate via the other two mechanisms proposed in the literature – chronic stress and parents' time use. Obesity risk are greater for those experiencing chronic stress and economic distress (Björntorp, 2001; Garasky et al., 2009). In the same unpublished study referenced above, the most frequently stated plan for spending leasing and royalty income among shale leaseholders was paying off debts, which would lower the family's economic distress. Simultaneously, the income effects could be heterogeneous given some of the income gains from the Marcellus Shale boom economy could come at the cost of declines in parents' time with children (Glymour et al., 2014). Although a 1-hour increase in parents' paid work hours does not translate into a 1-hour decline in children's time with parents (Bianchi, 2000), parents are critically important for monitoring and structuring youth's time (Larson and Richards, 1994) and influencing children's food choices (Birch and Davison, 2001). Interestingly, the quasi-experimental study predicting childhood obesity leveraging income gains garnered via EITC and, thus, increases in parents increased labor force participation still found income gains led to declines in childhood obesity. I try to address these heterogeneous effects by examining separate models for gains in royalty income and earned income in supplemental models.

Beyond its effect on income, Marcellus development could affect youth obesity risks through other channels. Specifically, youth obesity rates could increase due to [1] the hydraulic fracturing process and children's increased exposure to water or air pollution (Colborn et al., 2011; Goetz et al., 2015; Jackson et al., 2013), [2] the stress of living through a "boom" economy (i.e., the increased strains on infrastructure, heightened risk perceptions, restrictions on routines and outdoor activities, and weakened social ties) (England and Albrecht, 1984), [3] changes in the quality or quantity of food outlets and recreational facilities in the local area (Betz and Clark, 2015), or [4] changes to children's caregiver's health that then limits their time and ability to care for youth. I take several approaches to address these risks. First, some models include controls for these potential development sequela (Table 3). Second, I predict changes in many of these indicators as a function of the area's location relative to the shale's Core (Appendix Table 4 and Appendix Fig. 1). Finally, I estimate supplemental models where I stratify districts according to some of these indicators (Appendix Table 5).

My unit of analysis is school districts because youth obesity data are not available at the individual-level. Thus, I rely on data aggregated from individuals to the school district-level, combined with other data sources. To estimate the causal effect of plausibly-exogenous increasing income on youth obesity, I use a two-sample instrumental variable method, instrumenting for income with the proportion of land in the child's school district that is located above the economically-productive Core of the shale. I use a difference-in-differences framework, examining patterns before and after Marcellus Shale development between treatment and control areas. I study the entire youth population but test whether these potential income effects differ depending on the area's initial levels of poverty or affluence. Finally, I estimate separate models by children's developmental stage because I expect it is harder to alter adolescents' versus children's weight-related habits. Together, this geographically-informed analysis allows us to generate strong evidence about whether there is a causal relationship between income gains and youth obesity, while controlling for the simultaneous, but inconsistent implementation of wellness policies aimed at reducing youth obesity in school districts.

2. Study data and methods

2.1. Data

I study the 321 PA and 272 NY public school districts above the Marcellus Shale. I omit two PA school districts that merged in 2009, and the resulting district. I also drop 1 PA district and 38 NY districts that lack student obesity or income tax data. The final sample is 317 PA and 234 NY school districts.

2.2. Measures

All indicators are district-level measures. Given the Marcellus Shale boom occurred between 2008 and 2010, the "pre-development" indicators are measured in 2007 and the "post-development" indicators are from 2011. Descriptions of key variables are provided below but see Appendix Table 1 for more information on all study measures, including those used only in supplemental analyses, and their sources.

Youth Obesity Rates, which districts calculated separately for elementary and middle/high school students, are based on [1] students' body mass index (BMI) measured by trained professionals at the school and [2] CDC standards for evaluating children's BMI relative to age- and sex-standardized growth charts. A child is classified as obese when their BMI is greater than or equal to the 95th percentile in the standardized population (Ogden et al., 2002). I acquired the PA obesity data through personal contacts, while the NY obesity data are available online.

To measure income for families living in a district's catchment area, I calculate the following inflation-adjusted (Stewart and Reed, 2000) per capita income measures aggregated from state income tax filings: *Mean Area Income* (i.e., annual household-adjusted gross income), *Mean Royalty Income* (i.e., income earned via "royalties, rents, patents, and copyrights"), *Mean Earnings*, and *Mean Property Sales*. New York only provides data on district-level mean area income, not specific income sources. To measure district income post-Marcellus Shale development, I average 2010 and 2011 tax data. To instrument for income, I calculate the proportion of each district's land area above the *Core* and *non-Core* area of the Marcellus Shale. To explore whether the district's general economic standing prior to Marcellus development moderates the subsequent income effect, I categorize districts by [1] their *Initial Poverty Level* based on whether districts' 2007 poverty rate for children enrolled in school is above the PA Marcellus district median (i.e., 16.1%) and [2] their *Initial Affluence Level* based on whether 20% or more of district households have incomes four times the poverty threshold for a family of four in 2007.

Demographic control variables are districts' unemployment rate, the proportion of families living with minor children, the population proportion identifying as white, the proportion of adults aged 25 and older with a college degree, and the proportion of the labor force working in the agriculture, forestry and fishing industry. Potential Marcellus Shale development sequela are measured with indicators for traffic volume, the addition of local roads, crime rates, air pollution, and gas companies' environmental violations.

2.3. Statistical analysis

I explore the association between income and obesity across increasingly sophisticated analytic models. All models are weighted by the district's student population size. First, I assess the cross-sectional, bivariate relationship between districts' mean area incomes and youth obesity rates after Marcellus Shale development (i.e., 2011) with an OLS regression model (using Stata's "reg" command). I then add theoretically exogenous demographic control variables and Marcellus development sequela that could affect youth obesity through non-income pathways.

Second, to examine this association longitudinally and account for unobserved district traits that could influence both mean area incomes and youth obesity rates, I examine the association between changes in observed mean area incomes and changes in youth obesity rates before and after development (i.e., 2007 and 2011) with a difference-in-differences, fixed effects (FE) regression model (using Stata's "xtreg, fe" command with clustered standard errors). The FE model specified is as follows:

$$\text{Obesity}_{dt} = b_0 + b_1\text{MeanIncome}_{dt} + b_2\text{Post}_t + b_3\text{MeanIncome}_{dt}{*}\text{Post}_t + b_4\text{District}_d + b_5\text{Controls}_t + e_{dt} \quad (1)$$

where *d* references school district units, *t* references period, *MeanIncome* is the observed average area income, *District* is a vector of dummy variables to capture time-invariant district-level traits, *Post* is a dichotomous variable equal to one for the 2011 period, and *Controls* is a vector of time-varying demographic and Marcellus development sequela variables. The key estimate, b_3, is the coefficient for the interaction of observed mean area income and the dichotomous variable for the 2011 period.

Third, I estimate the causal effect of income gains on youth obesity using a two-sample instrumental variable approach and a difference-in-differences framework, leveraging differential income change across Core and non-Core Pennsylvania school districts pre and post Marcellus Shale development (with Stata's "ivreg" command). The instrument for family income is the percentage of the district's area in the Core of the Marcellus Shale formation interacted with an indicator for the post period. The system of two-stage least squares (2SLS) equations can be represented as follows:

$$\text{MeanIncome}_{dt} = b_0 + b_1\text{District}_d + b_2\text{Post}_t + b_3\text{Post}_t{*}\%\text{Core} + e_{dt} \quad (2)$$

$$\text{Obesity}_{dt} = b_0 + b_1\ \widehat{MeanIncome}_d + b_2\text{District}_d + b_3\text{Post}_t + b_4\text{DevelopmentSequela}_{dt} + \gamma dt \quad (3)$$

where the new term, *%Core,* is the proportion of the district's land area in the Core of the Marcellus Shale and $DevelopmentSequela_{dt}$ is a vector of time-varying, non-income Marcellus Shale sequela that could influence youth obesity rates; all other variables are defined as above. Equation (2) uses a difference-in-differences model predicting mean area income per capita in school district *d,* before and after Marcellus development, based on Marcellus Shale quality (*%Core*). The predicted mean area income per capita, $\widehat{MeanIncome}_{dt}$, estimated in Equation (2), becomes the key predictor for the prevalence of youth obesity ($Obesity_d$) in school district *d* in Equation (3), controlling for district fixed effects ($District_d$) and whether the data are from the post period ($Post_t$). The identifying exclusion restriction is that any differential change in youth obesity between the pre- and post-period reflecting the percentage of the district's area that lies above the Marcellus Core is due to income from Marcellus development, not other effects of Marcellus Shale development. Additionally, I test for potential nonlinearities in the effects of income gains by stratifying districts according to their initial (2007) levels of poverty and affluence.

Supplemental analyses include [1] a series of falsification tests examining whether there were any income differences over time between Core and non-Core areas in New York, or for Pennsylvania districts located only in the non-Core area of the Marcellus Shale (n = 96) (see Table 2); and [2] a series of falsification tests to assess the assumption that the effects of the instrumental variable (*%Core*) are fully mediated by household income and not due to changes in school funding, selective in- or out-migration and/or the social and environmental risks of Marcellus Shale development itself (see Appendix Tables 4 and 5 and Appendix Fig. 1).

2.4. Limitations

This natural experiment has several limitations. First, the results largely reflect the experiences of non-Hispanic whites given the limited racial diversity in this area. Second, the findings are most applicable to children in modest-sized cities and rural communities, where food outlets and recreational facilities are less common and more dispersed than in urban areas (Powell et al., 2006; Yeager and Gatrell, 2014). Third, the analysis is vulnerable to an ecological fallacy. Fourth, I cannot stratify the results according to the child's sex or initial family income because schools did not collect this information. Finally, I do not have data to test plausible mechanisms of the hypothesized income effect.

3. Results

As shown in Table 1, Pennsylvania districts located primarily above the Marcellus Shale Core have similar initial youth obesity rates and demographic profiles as districts primarily above the less productive or "non-Core" areas of the Marcellus Shale. Yet, by 2010–2011, PA districts located primarily above the Core had significantly greater mean area income, royalty income, earnings, and property sales income. PA districts with no land area above the Marcellus Shale have lower rates of youth of obesity and greater mean area incomes. Finally, New York districts above the Marcellus Shale have similar youth obesity rates ($\text{Elementary}_{2010\text{-}11} = 18\%$, $\text{Middle/High school}_{2010\text{-}11} = 21\%$) as Pennsylvania Marcellus districts, though New York Marcellus districts have greater mean area incomes ($\bar{x}_{2010\text{-}11} = \$53{,}189$).

Table 2 demonstrates the validity of the instrument. I predict changes in districts' mean area incomes and various income sources after Marcellus development based on the proportion of the district's land area above the Core. Each cell is a separate regression and each row indicates the sample utilized. Among all PA Marcellus Shale districts (row I), we see that those that lie entirely above the Core have, on average, an additional \$2249 in mean area income per household compared to districts that lie entirely outside it ($b = 22.49$; $p < .01$; 95% CI: 7.53–37.46) by 2010–2011. Location above the Core in PA also led to significant gains in the average earnings ($b = 16.80$; $p < .01$; 95% CI: 7.30–26.30) and royalty income ($b = 6.36$; $p < .01$; 95% CI: 2.46–10.26) per household, but not property sales income. Using Census data, Appendix Table 2 demonstrates that this earnings increase was particularly concentrated among those with a high school degree (column 4). Further, to assess whether these earnings gains reflect improvements in wages, I examine changes in earnings among those working full-time, full-year and find that wages increased among all full-time, full-year workers (column 6), and especially men (column 8). Appendix Table 3 displays results predicting changes in work hours over time. After Marcellus development, there were fewer adults who did not work for pay (columns 1–3) and more working full-time, full year (column 4), though the gains in full-time employment were larger and only statistically significant among men (column 6).

Rows II – V in Table 2 assess the scope of these income gains across PA Marcellus districts categorized according to their initial poverty and affluence. The gains in mean area income were significantly greater in high-poverty and low-affluence districts, while the gains in mean earnings and royalty income increased across all PA Marcellus districts. Lastly, I conducted two falsification tests in rows V and VI. First, the percentage of the district's land area above the Core in NY – where hydraulic fracturing is banned – does not predict increases in mean area income (row VI). Likewise, there is no significant income growth among PA districts located entirely above the non-Core area of the Marcellus Shale (row VII). Together, these results provide good evidence that the proportion of a PA district's land area above the Core, conditional on initial income, is a powerful instrument for income post-Marcellus development.

Table 3 presents the association between a \$1000 increase in observed, mean area income and youth obesity rates (measured in percentage points) in PA Marcellus districts, where each cell is a separate multivariate model. Results from cross-sectional OLS regression models, where all variables are measured in 2011, are presented in columns 1–4, while results from longitudinal fixed effects models, are

Table 1
Descriptive statistics for Pennsylvania districts.

	Any Land above the Marcellus Shale		50+% above Core Shale		50+% above Non-Core Shale		Not Above Marcellus Shale	
	(N = 317)		(N = 188)		(N = 99)		(N = 180)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Proportion Obese								
Elementary school								
SY 2006-07	0.187	(0.041)	0.184	(0.043)	0.193	(0.040)	0.157	(0.040)
SY 2010-11	0.193	(0.047)	0.193	(0.053)	0.194	(0.038)	0.155	(0.038)
Middle/High school								
SY 2006-07	0.196	(0.045)	0.194	(0.048)	0.198	(0.043)	0.168	(0.040)
SY 2010-11	0.205	(0.058)	0.206	(0.068)	0.204	(0.041)	0.174	(0.038)
Income per Household, in $2010								
Total Mean Area Income								
2006	50,734	(24,521)	52,136	(29,674)	47,801	(13,991)	82,731	(44,625)
2010–2011, avg.	49,559	(24,532)	52,010	(29,757)	45,176	(13,036)	75,627	(39,386)
Mean Area Royalty Income								
2006	626	(449)	655	(497)	592	(388)	934	(801)
2010–2011, avg.	1490	(1974)	1834	(2348)	1077	(1177)	1019	(803)
Mean Area Earnings								
2006	40,744	(15,903)	41,319	(19,003)	39,062	(9594)	62,532	(25,059)
2010–2011, avg.	40,619	(17,228)	41,787	(20,751)	38,026	(9664)	60,987	(25,235)
Mean Area Property Sales								
2006	2338	(3140)	2630	(3806)	1907	(1830)	5911	(9120)
2010–2011, avg.	1641	(2319)	2004	(2720)	1107	(1575)	3048	(4636)
Area relative to Marcellus Shale Formation (as percentage)								
Above Core	59.8	(46.6)	97.4	(8.3)	5.9	(12.8)	0.000	0.000
Above Non-Core	31.4	(41.5)	2.3	(7.8)	90.2	(14.8)	0.000	0.000
	Any Land above the Marcellus Shale		50+% above Core Shale		50+% above Non-Core Shale		Not Above Marcellus Shale	
	(N = 317)		(N = 188)		(N = 99)		(N = 180)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Demographic Controls								
Proportion Unemployed								
2007	0.066	(0.019)	0.065	(0.021)	0.068	(0.016)	0.055	(0.022)
2011	0.049	(0.015)	0.048	(0.014)	0.052	(0.016)	0.051	(0.017)
Proportion of families with minor children								
2007	0.432	(0.040)	0.428	(0.040)	0.436	(0.042)	0.468	(0.051)
2011	0.252	(0.036)	0.248	(0.037)	0.254	(0.034)	0.289	(0.039)
Proportion white								
2007	0.936	(0.084)	0.937	(0.090)	0.934	(0.081)	0.873	(0.135)
2011	0.937	(0.089)	0.935	(0.098)	0.938	(0.079)	0.880	(0.128)
Proportion of adults aged 25+ with college degree								
2007	0.192	(0.099)	0.205	(0.115)	0.174	(0.061)	0.274	(0.147)
2011	0.206	(0.103)	0.220	(0.120)	0.187	(0.065)	0.287	(0.151)
Proportion of labor force in agriculture, fishing and forestry industry								
2007	0.014	(0.017)	0.014	(0.018)	0.012	(0.013)	0.015	(0.021)
2011	0.012	(0.015)	0.011	(0.016)	0.012	(0.013)	0.016	(0.022)
Development Sequela Controls								
Formaldehyde (lbs/m3)								
2007	453.5	(4251)	271.5	(2778)	935.7	(6571)	472.4	(4898)
2011	479.9	(7571)	806.3	(9828)	4.7	(46)	645.4	(7050)
Environmental Compliance Violations								
2007	2.8	(10.2)	2.7	(6.3)	3.8	(16.0)	0.0	(0.0)
2011	8.5	(24.4)	9.7	(22.0)	8.8	(31.0)	0.0	(0.4)
Traffic in 1000 miles per capita								
2007	21.9	(13.2)	20.1	(12.4)	23.0	(12.7)	21.9	(15.5)
2011	23.4	(14.1)	21.2	(12.9)	24.8	(13.9)	23.6	(14.8)
Local roads added (in miles)								
2007	78.4	(129.0)	66.2	(113.2)	106.2	(158.8)	120.8	(184.1)
2011	29.1	(75.0)	34.7	(87.6)	23.3	(56.5)	10.9	(20.4)
Average commute (in minutes)								
2007	25.5	(4.5)	26.0	(4.0)	24.8	(5.4)	26.7	(4.2)
2011	24.9	(4.7)	25.5	(4.0)	24.2	(5.6)	26.2	(4.3)
	Any Land above the Marcellus Shale		50+% above Core Shale		50+% above Non-Core Shale		Not Above Marcellus Shale	
	(N = 317)		(N = 188)		(N = 99)		(N = 180)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Stratifying Variables								
Prop. enrolled children in poverty, 2007	0.168	(0.088)	0.169	(0.094)	0.171	(0.080)	0.105	(0.088)
20+ pct. of HHs with incomes > 4xs poverty line for family of 4, 2007	0.404	(0.491)	0.399	(0.491)	0.394	(0.491)	0.839	(0.369)
Prop. population with public water, 2011	0.617	(0.314)	0.673	(0.308)	0.535	(0.325)	0.698	(0.308)

(continued on next page)

Table 1 (*continued*)

	Any Land above the Marcellus Shale		50+% above Core Shale		50+% above Non-Core Shale		Not Above Marcellus Shale	
	(N = 317)		(N = 188)		(N = 99)		(N = 180)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Alternative Shale Development Mechanisms								
Child population								
2007	3661	(4098)	3632	(4406)	3583	(3508)	9143	(27,360)
2011	3548	(3987)	3488	(4190)	3487	(3466)	9056	(25,681)
Prop. children aged 5–17 enrolled in public K-12 school								
2007	0.693	(0.081)	0.693	(0.086)	0.698	(0.074)	0.633	(0.087)
2011	0.670	(0.078)	0.672	(0.084)	0.671	(0.074)	0.614	(0.089)
Total local tax revenue per pupil (in $2010)								
2007	5885	(2292)	6104	(2583)	5531	(1781)	9112	(3345)
2011	6577	(2654)	6785	(2877)	6197	(2338)	10,410	(3669)
Total current instructional expenditures per pupil (in $2010)								
2007	6036	(832)	6192	(867)	5854	(774)	6382	(1207)
2011	7244	(1119)	7407	(1163)	7078	(1094)	7641	(1338)

Abbreviations: "SD": Standard deviation; "Prop.": proportion of; "HH": households; "avg.": average.
Note: All values are adjusted for inflation to 2010$ using CPI-U-RS.

Table 2
Predicted growth in mean area income per household based on the proportion of the District's area above the marcellus shale core.

		Mean Area Income	Earnings	Royalties	Property Sales
		(1)	(2)	(3)	(4)
I.	All districts in PA Shale (n = 317)	22.49**	16.80**	6.36**	0.11
		(7.61)	(4.83)	(3.21)	(3.82)
II.	High-poverty districts in PA Shale (n = 159)	29.70**	14.76*	7.60*	5.61
		(8.44)	(6.88)	(3.52)	(4.55)
III.	Low-poverty districts in PA Shale (n = 158)	16.26	18.16*	5.12*	−4.52
		(11.88)	(7.39)	(2.15)	(5.72)
IV.	Low-affluent districts in PA Shale (n = 189)	27.54**	14.37*	6.86*	5.39
		(7.86)	(5.97)	(3.15)	(4.17)
V.	High-affluent districts in PA Shale (n = 128)	16.85	19.52*	5.79*	−5.81
		(12.98)	(8.24)	(2.32)	(6.26)
Falsification checks					
VI.	All districts in NY Shale (n = 227)	−4.79	–	–	–
		(14.07)			
VII.	Only non-Core PA Shale (n = 96)	−5.33	−4.69	1.29	−4.06
		(10.60)	(8.11)	(1.36)	(3.74)

Cluster-robust standard errors in parentheses. +: $p < .10$; *: $p < .05$; **: $p < .01$; ***: $p < .001$.
Note: Each cell represents a separate, population-weighted regression. For all but row VII, coefficients are difference-in-differences estimates from the interaction of the post period (2011) and percentage of the district's area in the Marcellus Shale Core (i.e., $Post_t$*$\%Core_d$). Data for rows I–V is restricted to PA districts with any land area above the Marcellus Shale geological formation. Data for row VI is restricted to NY districts with any land area above the Marcellus Shale geological formation. Data for row VII is includes all PA districts except those existing entirely above the Marcellus Shale Core. Coefficients in row VII are difference-in-differences estimates from the interaction of the post-period and the percentage of the district's area above the less economically-viable section of the Marcellus Shale (i.e., $Post_t$*$\%non\text{-}Core_d$). All values are adjusted for inflation to 2010$ using CPI-U-RS.

presented in columns 5–8. Column 1 demonstrates the expected cross-sectional significant and negative association between districts' mean area incomes and youth obesity rates. Districts with $1000 more in mean area income have approximately a tenth of a percentage point lower obesity rate for both elementary ($b = -0.103$; $p < .001$; 95% CI: 0.118 to −0.089) and middle/high school students ($b = -0.092$; $p < .001$; 95% CI: 0.114 to −0.069). For middle/high school students, this association declines to zero and becomes statistically non-significant when I control for the percentage of adults in the district with a college degree. A similar shift is observed among elementary school students when I include all demographic control variables (column 2). When I only control for variables hypothesized to reflect non-income pathways by which Marcellus Shale development could affect youth obesity rates (column 3), the association between mean area income is highly statistically significant and of the same magnitude as the estimates from the bivariate association (column 1). With all control variables included (column 4), the cross-sectional association between mean area income and youth obesity is substantively small and statistically zero for the full population of elementary and middle/high school students. In supplemental models (not shown), the observed cross-sectional association between mean area income and obesity rates among elementary school-aged youth remains negative and statistically significant for those living in initially high-poverty ($b = -0.116$; $p < .05$; 95% CI: 0.222 to −0.010) or low-affluence ($b = -0.131$; $p < .05$; 95% CI: 0.255 to −0.007) PA Marcellus districts even when all covariates are included. In contrast, this association is statistically zero for elementary-school children living in initially low-poverty or high-affluence PA Marcellus districts and for all middle/high school youth regardless of the district's initial poverty or affluence.

Using pre- and post-development data, column 5 in Table 3 provides the difference-in-differences fixed effects estimator for observed mean area income (i.e., observed mean area income * post-Marcellus development period). The differential association between mean area income (in thousands of dollars) and youth obesity rates (in percentage points) in the post-Marcellus development period is not statistically significant and estimated to be very small in magnitude for both age groups across all PA Marcellus districts ($b_{Elementary} = -0.010$; $b_{Middle/High\ School} = -0.001$). When I stratify districts by their initial poverty and affluence (columns 6–9), I also arrive at statistically non-significant income coefficients, though the estimated negative coefficients are much larger in high-poverty and low-affluence districts and approach statistical significance for elementary-school children in high-poverty districts (column 6: $b_{Elementary} = -0.007$; $p < .10$).

Yet the preceding income coefficients could be biased because income remains correlated with a host of unobserved factors theorized to

Table 3
Predicted association between youth obesity and $1000 in mean area income: Selected coefficients from various models with observational data.

	Cross-sectional (2011) OLS Models				Longitudinal, Difference-in-Differences Fixed Effects Models				
	All PA Marcellus districts				All PA Marcellus districts	Stratified by Initial Poverty		Stratified by Initial Affluence	
						High-poverty districts	Low-poverty districts	Low-affluence districts	High-affluence districts
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Elementary students:	−0.103***	−0.013	−0.103***	−0.013	−0.010	−0.105+	−0.007	−0.072	−0.004
	(0.007)	(0.017)	(0.007)	(0.017)	(0.010)	(0.057)	(0.010)	(0.063)	(0.009)
Middle & High School students:	−0.092***	0.006	−0.092***	0.000	0.001	−0.074	0.000	−0.124	0.006
	(0.011)	(0.026)	(0.011)	(0.027)	(0.012)	(0.082)	(0.011)	(0.099)	(0.011)
Controls									
Demographic	–	X	–	X	X	X	X	X	X
Non-income shale sequela	–	–	X	X	X	X	X	X	X
N	317	317	317	317	317	159	158	189	128

Cluster-robust standard errors in parentheses. +: $p < .10$; *: $p < .05$; **: $p < .01$; ***: $p < .001$.
Note: Each cell represents a separate, population-weighted regression. Coefficients in columns 1–4 are cross-sectional OLS regression estimates of the association between districts mean area income and youth obesity rates in 2011. All control variables in columns 1–4 derive from the 2011 period. Coefficients in columns 5–9 are the difference-in-differences estimate of the differential association between observed mean area income and youth obesity rates in the post-Shale development period relative to the pre-Shale development period (i.e., Mean Area Income$_{dt}$ * Post$_t$), where time-invariant district-level traits are modeled with a dichotomous variable for n-1 districts. All control variables in columns 5–9 are time varying. Across all models, data are restricted to PA districts with any land area above the Marcellus Shale geological formation. Mean area income is adjusted for inflation to 2010$ using CPI-U-RS.

Table 4
Predicted effect of a plausibly-exogenous $1000 increase in mean area income and youth obesity: Selected coefficients from various models.

	Second Stage of Fixed Effects Instrumental Variable 2SLS Models				
	All PA Marcellus districts	Stratified by Initial Poverty		Stratified by Initial Affluence	
		High-poverty districts	Low-poverty districts	Low-affluence districts	High-affluence districts
	(1)	(2)	(3)	(4)	(5)
Elementary students:	0.310	0.310	0.370	0.400	0.270
	(0.370)	(0.460)	(0.870)	(0.510)	(0.910)
Middle & High School students:	0.240	0.370	0.150	0.370	0.160
	(0.410)	(0.550)	(0.920)	(0.580)	(0.920)
Controls					
Demographic	–	–	–	–	–
Non-income shale sequela	X	X	X	X	X
N	317	159	158	189	128

Cluster-robust standard errors in parentheses. +: $p < .10$; *: $p < .05$; **: $p < .01$; ***: $p < .001$.
Note: Each cell represents a separate, population-weighted regression. Coefficients are difference-in differences second-stage estimates of instrumented mean area income, wherein the instrument for mean area income is the interaction of the percentage of the district's land area in the Marcellus Shale Core and the post-development period (2011) (i.e., *%Core$_d$* Post$_t$*). Across all models, data are restricted to PA districts with any land area above the Marcellus Shale geological formation and all control variables are time varying. Because a district's demographic profile could shift as a function of changing income, time-varying demographic control variables are omitted from these models. Mean area income is adjusted for inflation to 2010$ using CPI-U-RS.

affect obesity (including district-level obesity interventions). To better estimate the causal effect of increasing income, Table 4 presents the second-stage results from the 2SLS models, where districts' mean area income is instrumented by the interaction of the percentage of the district's land area above the Marcellus Shale and the post-development period. I find that plausibly-exogeneous income gains do not significantly alter youth obesity rates for elementary or middle/high school students. Columns 2 through 5 explore whether the district's initial poverty or affluence moderates the income effect. Across initially disadvantaged and initially advantaged districts, youth obesity rates do not significantly change as predicted income increases.

3.1. Falsification tests

I conducted a series of tests of the 2SLS exclusion restriction and explore whether Marcellus Shale development altered youth obesity rates or their measurement through plausible non-income pathways. According to results in Appendix Table 4 and Appendix Fig. 1, it appears that Marcellus Shale development does not systematically affect youth obesity rates through other mechanisms. As shown in Appendix Table 4, per-pupil spending on instruction (column 1) or per-pupil local tax revenue (column 2) did not change as a function of the district's location vis a vis the Core of the Marcellus Shale. This finding is not surprising given that property values are not commonly reassessed in Pennsylvania. The one exception to this overall pattern is that location above the Marcellus Shale Core is associated with a significant, though miniscule decline (≈0.0004 of a standard deviation) in current instructional expenditures per pupil for high-affluence districts ($b = -2.29$; $p < .05$; 95% CI: 4.56 to −0.03). Results from models predicting additional measures of district expenditures and revenues substantively align with the null results and are available upon request. Regarding potential risks resulting from increased air pollution or the stress of living through a boom economy, I find no significant association between the proportion of the district's area above the Core and changes in formaldehyde outdoor pollution (column 3), environmental compliance violations filed with the PA Department of Environmental Protections (column 4), traffic volume per capita (column 5), miles of local road added (column 6), or the arrest rate for adult violent crimes (Column 7) before and after Marcellus development. Regarding the risks of selective in- and out-migration, the evidence is inconsistent and mixed. On the one hand, location above the Core predicts a small, but significant decline in the (natural log of the) total number of children in the district ($b = -0.003$; $p < .05$; 95% CI: 0.0005 to −0.00007). On the other hand, location above the Core does not predict a general shift in the proportion of children attending public school, though the there is a very small, but statistically significant increase in the proportion of children attending public school in low-poverty ($b = 0.0003$; $p < .05$; 95% CI: 0.00007–0.005) and high-affluence ($b = 0.0004$; $p < .01$; 95% CI: 0.0001–0.0006) districts. Given the extremely small magnitudes of these statistically significant changes, I conclude that the overall results are not biased by selective in- or out-migration.

Finally, as shown in Appendix Fig. 1, I find no significant differences in changes in the per capita availability of grocery stores, superstores (e.g., Walmart), or fast food restaurants – the areal amenities most emphasized in prior obesity research – when I compare mean differences across PA Core and other PA counties and use a higher p-value to account for reductions in sample size with the shift to a county-level analysis ($p < .10$). Other changes in the local food environment, however, were significantly different. On the one hand, changes in the relative prices of milk ($p < .01$) and soda ($p < .01$) were more health-promoting in PA Core counties relative to other PA counties. On the other hand, increases in full-service restaurants ($p < .10$) were more detrimental for population health in PA Core counties. In summary, some trends in an area's health-related amenities and prices do differ between PA Core and other PA counties, but the end result seems neutral: the key factors emphasized in the literature – grocery and fast food access – do not differentially shift in PA Core counties, while the improvements in prices and the increased availability of full-service restaurants likely offset each other. Together, the results from Appendix Table 4 and Appendix Fig. 1 validate the exclusion restriction assumption for the 2SLS models.

3.2. Supplemental tests

I also conduct a series of robustness checks. First, I estimate additional 2SLS models wherein I instrumented for specific sources of mean area income – earnings and royalty income. Although the magnitudes of the coefficients for plausibly-exogenous gains in royalty income are greater than that for earnings, the coefficients are never statistically significant ($p \approx 0.4$–0.9), regardless of age group or whether I examine the full population of PA Marcellus districts or stratify districts by their initial poverty or affluence. Second, I predict the prevalence of overweight and the combined prevalence of overweight and obesity per district. Regardless of developmental stage, plausibly-exogenous income gains did not significantly alter overweight prevalence. Third, I utilize a different comparison – PA districts with no land area above the Marcellus Shale and PA districts above the Core of the Marcellus Shale. Again, I find no statistically significant effect of plausibly-exogenous gains in mean area income on youth obesity rates and the estimates become very imprecise ($p \approx 0.8$–0.9). (Results not shown but available upon request).

The remaining supplemental tests are shown in Appendix Table 5. I also explore whether alternate specifications of districts' initial socioeconomic status would generate different conclusions for the stratified models. Yet, I again arrive at null conclusions when I classify districts into terciles of initial poverty rates (columns 1–3) or by the proportion of parents of public school children with a college degree or more (columns 4–5). Finally, I test whether other Marcellus-related factors condition the income effect. Given the weight-related risks of water pollution are lower in communities with greater public water access, I divide districts according to whether 75% or more of the population had access to public water in 2011 (i.e., the earliest year for which data are available). The plausibly-exogenous effect of income gains does not differ by public water access and remains statistically zero (columns 6–7). Next, I test whether the income effects of the Marcellus Shale boom differed by the area's level of farming. I hypothesize weaker income effects in high-farming districts because farmers' larger land plots means they received a greater share of the district's royalty income, but their relatively older age structure means that their households contain fewer children. Again, I find no income effects, regardless of the degree of farming in the district.

4. Discussion

Although youth obesity has been a focus of national policy for several decades, rates of youth obesity and the disparities by family income have not declined. In fact, these disparities have increased, particularly among girls (Ogden, 2018). Despite the consistent negative correlation between family income and youth obesity, causal estimates of the income effect are inconsistent. I build upon prior quasi-experimental research in three ways. First, I estimate the effects of income gains with an economically diverse population of Pennsylvania youth. Second, I examine whether the effect of increasing income operated differently for initially poor or affluent districts. Finally, this geographically-informed approach effectively controls for unmeasured, but simultaneously-occurring policy interventions in PA school districts. Given the intensive obesity interventions occurring at this time across American school districts, estimates would otherwise be biased without this approach.

With this natural experiment design and difference-in-differences approach, I explore whether plausibly-exogenous income gains alter youth obesity rates. My first-stage falsification tests indicate that I have identified an exogenous source of family income. Further, supplemental analyses suggest that Marcellus Shale development has not affected youth obesity through school funding changes and/or other aspects of the Marcellus development process, nor is there evidence of notable selective in- or out-migration from Marcellus districts (see Appendix Table 4).

Despite the strengths of the first-stage, I do not find that plausibly-exogenous income gains significantly altered elementary or middle/high-school students' obesity rates. These analyses are robust to alternative specifications (see Appendix Table 4) and to the area's initial economic status. The results for youth from initially disadvantaged areas are theoretically and empirically interesting given most prior quasi-experimental studies rely on samples of economically-disadvantaged youth (Herbst and Tekin, 2012; Jo, 2018; Jones-Smith et al., 2014; Schmeiser, 2012) and given Lakdawalla and Philipson's (2009) prediction that low-income individuals should gain weight with increased income. Yet the exogenous variation in Marcellus Shale income gains did not significantly alter districts' original youth obesity rankings. In sum, the causal association between income gains and youth obesity is nil in this case.

This null finding situates between prior quasi-experimental studies: some find exogenous gains in income (or in-kind benefits) increase youth obesity (Herbst and Tekin, 2012; Jo, 2018) and some find it reduces youth obesity (Jones-Smith et al., 2014; Schmeiser, 2012; Watson et al., 2019). But while the quasi-experimental evidence is inconsistent, the results from observational studies with individual data is very consistent: Both in the current study and prior research, the observed association between family income and youth obesity is not statistically significant once controls are added (Anderson et al., 2003; Classen and Hokayem, 2005; Goodman et al., 2003; Martin et al., 2012; Wang and Zhang, 2006). In the current study, the observed association between income and youth obesity becomes statistically non-significant when I add controls for the districts' demographic traits, particularly the proportion of adults with a college degree.

What could explain this pattern of [1] non-significant observational results, [2] usually significant but contradictory quasi-experimental results, and [3] the current null quasi-experimental results? Although causation usually implies correlation, this is not always the case. In fact, the most common scenario whereby one arrives at null observational findings despite a true causal relationship is when the causal effect is nonlinear, such as Lakdawalla and Philpson (2009) argue for income and obesity. Most prior quasi-experimental studies cannot test for nonlinearities given their design, but Watson et al. (2019) can and do find a nonlinear relationship. Yet it contradicts Lakdawalla and Philpson's (2009) theory: They find that the obesity-reduction effect of income is present only among middle-income households (i.e., those earning $25,000 - $75,000); it is absent among low- and high-income families (Watson et al., 2019). In supplemental models, I do not find a significant income effect for youth in middle-income districts, but this could reflect limited statistical power to detect a curvilinear relationship or result from variations in family incomes within districts. Unfortunately, I do not have access to individual-level obesity data to explore these potential nonlinearities further.

The tremendous variation in the estimated causal effect of income across quasi-experimental studies suggests that an additional complexity or conditional relationship may exist. Specifically, varying meso-level conditions within high-income countries could condition the income effect. Existing theoretical discussions about the effect of income focus on the importance macro-economic conditions or the micro-economic factors affecting household decision-making (e.g., Popkin, 2002; Cawley, 2004), but the structural conditions of the local context could alter the (likely nonlinear) micro-economic income effect.

In the current study, the context could be important. While there are mid- and small-sized PA cities located above the Marcellus Shale, much of the land area is rural. Further, rural areas have higher rates of youth obesity and severe youth obesity (Ogden et al., 2018) due to rural areas' limited grocery and physical activity opportunities (Powell et al., 2006; Yeager and Gatrell, 2014). This is also true in Pennsylvania: rural PA counties have, on average, more limited grocery store access and higher food prices (https://www.ers.usda.gov/data-products/food-environment-atlas/go-to-the-atlas/). These place-based disparities offer a new lens by which to evaluate the supplementary analyses conducted wherein the models are stratified by the proportion of the labor force engaged in farming, forestry and fishing – an industry more common in rural areas. Based on the proceeding logic, one would expect the effect of plausibly-exogenous income gains to be larger in PA districts with low labor force participation in this industry, but the estimated effect remains zero in those districts as well. Besides looking at variation within areas above the Marcellus Shale, it is worth comparing shale areas to non-shale areas. In supplementary analyses, as another test of the exclusion restriction, I examined whether the trends in county-level weight-related amenities and prices were different between PA Core counties and other PA counties. Yet PA Core counties were significantly different on many of these dimensions before Marcellus development. Specifically, per capita, PA Core counties had more convenience stores ($p < .05$), fewer specialty grocery outlets (i.e., bakeries, butcher shops; $p < .05$), fewer recreational facilities ($p < .05$) and lower soda prices ($p < .01$) than other PA counties in 2007. Thus, the initial limitations on residents' access to healthy goods and services could have blunted the health-promoting effects of increasing family income. To the extent that this explanation is valid, it has important theoretical implications for youth obesity: the causal significance of community-level resources and amenities (which are positively correlated with family income) could exceed the causal importance of family-level income.

Two other factors could also undergird the current null quasi-experimental findings. First, this null effect could reflect limitations in the measurement of youth body weight. Lowering youth obesity rates is a common, but narrow policy target. Youth obesity rates track population change at a singular threshold, not all weight gain. In supplementary analyses, I find no income effects on youth overweight, but I do not have information on districts' median BMI to explore general weight increases.

Second, the null results could reflect complex timing issues. The first timing issue concerns how long it would take for income changes to affect BMI via behavioral shifts in dietary behavior and physical activity. Among the family-based interventions shown to effect children's BMI within a two-year period, the effects generally emerge within 6–12 months (Knowlden and Sharma, 2012). Thus, the three-year window between the pre- and post-Marcellus development period is sufficient to observe effects on BMI, were they present. The second timing issue concerns the time horizon parents originally envisioned for these income gains. Industry analysts and politicians erroneously speculated that the boom would last for decades (Considine et al., 2009), but local residents' expectations are not well documented. Some evidence suggests that PA residents were less optimistic than the full U.S. population about the long-term economic impacts of Marcellus Shale development (Evensen and Stedman, 2016), but journalistic and anecdotal evidence suggests that some lease holders hoped their royalty payments would offer them long-term financial security (McGraw, 2011). I cannot measure parents' time orientations but speculate that parents who expected only a short-term windfall (i.e., an income "shock") would be less likely to alter their consumption behavior (Jappelli and Pistaferri, 2010). The final issue is developmental given weight-related behaviors are generally established early in the life course (Birch and Fisher, 1998). Although the youngest sample members – those in kindergarten through 2nd grade – would have experienced this income gain during their pre-school years when their preferences and behaviors were more malleable, I cannot delineate this more developmentally sensitive group from older elementary school children in the data. The parents' developmental stage, however, could be even more significant. If families' consumption patterns were to change, the hypothesized effects would work primarily through shifts in parents' consumption. Yet parents' weight-related preferences were set decades before this income gain. In summary, while the pre-post window of this study is long enough to observe changes in children's BMI, parents in the study area could have interpreted these income gains as a short-term shock or the income gains could have occurred too late in the children's or parents' life course to affect behavioral change. These timing issues do not undermine the current study and its quasi-experimental design, but instead elucidate the theoretical challenges of the primary mechanism by which family income is hypothesized to affect youth obesity – shifting families' weight-related consumption patterns.

5. Conclusion

Given society's limited public health resources, where do we intervene to affect youth obesity? The WHO argues that we should focus on the social determinants of health (Solar and Irwin, 2010) and low income is frequently viewed as a root cause of multiple public health challenges – including youth obesity. This natural experiment directly speaks to this policy question within a particular context. Further, this study is informative for researchers and policymakers considering a range of income-related interventions, such as price supports for healthy foods, universal electronic benefits transfer cards to reduce food insecurity, and changes in agricultural policy.

In Pennsylvania, the Marcellus Shale economic boom was countercyclical and large, resulting in large gains in employment and wages across industries (Cruz et al., 2014; Kelsey et al., 2011). Simultaneously, the oil and natural gas industry distributed billions in leasing and royalty payments to PA residents (Considine et al., 2011). It is hard to imagine a publicly-funded economic initiative this large in the current political climate. Yet I find no change in youth obesity rates.

The development of the Marcellus Shale for natural gas production offers a unique opportunity to estimate the causal effect of increasing income on youth obesity rates. Although the prevalence of obesity is lower among youth in high-income families across the U.S. (Ogden, 2018) and in Pennsylvania, it appears that the observed disparity in youth obesity by family income does not simply reflect differences in disposable income and the relative cost of "healthy" versus "unhealthy" goods and services in this context. By netting out the effect of income for youth obesity, these analyses suggest that other inequalities undergird the original income-gradient in obesity in Pennsylvania. Where possible, future quasi-experimental studies of youth obesity should explore the causal effects of other stratified resources, like parents' education and communities' weight-related amenities. In addition, future quasi-experimental studies should continue to explore plausible nonlinearities in the income effect and potential moderating effects of community-level factors. Together, this work will increase our understanding of the causal processes generating disparities in youth obesity and help public health organizations design more effective interventions targeting the social determinants of weight.

Author credit statement

Molly A. Martin: Conceptualization, Data curation, Formal analysis, Visualization, Writing, and Editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2021.113732.

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