

Supplemental Content

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Approaches: Modeling strategy

G-computation model

G-computation is a robust causal inference method for use with data containing time-dependent confounding. In particular, g-computation is able to account for time-varying confounders in cases where the exposure affects future values of confounders and vice-versa.

Causal pathway

Let S_t denote the value of the SNAP policy index at year t , D_t denote diabetes prevalence at year t , and W_t denote confounding variables collected at time t . For simplicity, let W_t contain information from both time-varying and time-stable confounders. For a random variable X , let $\bar{X}_t = (X_0, X_1, \dots, X_t)$ denote the covariate history up to and including interval t . We assume a causal model in which, within each interval, (1) W_t affects both S_t and D_t and (2) S_t affects D_t . We also assume that all variables collected in a given year, indexed by t , affects all variables collected in the following year, indexed by $t + 1$.

In our assumed causal model, the SNAP policy index affects county-level diabetes prevalence through multiple pathways. For example, the diabetes percentage during the first year of follow-up, D_1 , is affected by the SNAP policy indices S_0 and S_1 through the “front-door” paths:

- $S_1 \rightarrow D_1$
- $S_0 \rightarrow D_1$
- $S_0 \rightarrow S_1 \rightarrow D_1$
- $S_0 \rightarrow D_0 \rightarrow D_1$
- $S_0 \rightarrow W_1 \rightarrow D_1$
- $S_0 \rightarrow D_0 \rightarrow S_1 \rightarrow D_1$
- $S_0 \rightarrow D_0 \rightarrow W_1 \rightarrow D_1$
- $S_0 \rightarrow W_1 \rightarrow S_1 \rightarrow D_1$
- $S_0 \rightarrow D_0 \rightarrow W_1 \rightarrow S_1 \rightarrow D_1$

And the “back-door” paths:

- $S_1 \leftarrow W_1 \rightarrow D_1$
- $S_1 \leftarrow W_0 \rightarrow D_1$
- $S_0 \leftarrow W_0 \rightarrow W_1 \rightarrow D_1$
- $S_0 \leftarrow W_0 \rightarrow D_0 \rightarrow D_1$
- etc.

The causal effect of $\bar{S}_1 = (S_0, S_1)$ on D_1 , consists of the effects of \bar{S}_1 on D_1 through the front-door paths alone. In a typical regression analysis, D_1 may be regressed on exposure history, \bar{S}_1 , and confounder history, \bar{W}_1 . Because all backdoor paths from \bar{S}_1 to D_1 pass through the confounders, \bar{W}_1 , this regression analysis removes the confounding effects of the back-door paths. However, part of the causal effect of \bar{S}_1 on D_1 is through the effect of \bar{S}_1 on the confounders \bar{W}_1 (e.g. the path $S_0 \rightarrow W_1 \rightarrow D_1$). Blocking these pathways by conditioning on the confounding variables can bias estimates of the causal effect. Under the causal assumptions of positivity, sequentially ignorable treatment assignment, and consistency, the g-computation procedure samples from a causal model in which the back-door paths are eliminated, but all front-door paths are left intact, allowing us to use standard regression techniques to measure the effect of exposure.

Longitudinal g-computation model

Let $X_t(\bar{s}_t)$ be the potential outcome of X_t if we intervene to set $\bar{S}_t = \bar{s}_t$. The g-computation estimator consists of a two-step procedure. In the first step, a Monte Carlo simulation of the potential outcomes $D_t(\bar{s}_t)$ is performed for time points $t = 1, \dots, T$. In the second step, the simulated potential outcomes are regressed on the corresponding trajectories of the SNAP policy index, \bar{S}_t . Because we are interested in the causal effect of changing the SNAP policy index on the change in diabetes prevalence within a county, our final regression model is given by:

$$E[D_t(\bar{s}_t)] = \beta_0 + \beta_1 s_0 + \beta_2 * t + \beta_3 (s_t - s_0) + \beta_4 (s_t - s_0) * t.$$

The Monte Carlo algorithm used in the first step draws samples from a proposed causal model where all causal pathways between \bar{S}_t and D_t are intact while all backdoor paths have been eliminated (i.e. the relationship between \bar{S}_t and D_t is unconfounded). The data generation process under this causal model, consists of two components. The first component consists of the conditional distributions of intermediate outcomes, D_t , and confounders W_t conditional on past covariate histories, while the second is made up of the marginal distribution of \bar{S}_t . If we have maximum likelihood estimates of the conditional distributions in the first component, called the Q-functions, and the marginal exposure distribution, then we can randomly sample from the unconfounded causal model.

For the intermediate outcomes, we use the following Q-function for $t = 0$:

$$D_0 = \gamma_0 + \gamma_1 S_0 + \gamma_2 W_0$$

And for $t > 0$:

$$D_t = \eta_0 + \eta_1 S_t + \eta_2 W_t + \eta_3 S_{t-1} + \eta_4 W_{t-1} + \eta_5 * t + \eta_6 * t^2 + \eta_7 (S_t * t) + \eta_8 (S_t * t^2)$$

For each of the confounding variables, we fit a linear model conditional on all variables measured in the previous year. Because the nonparametric maximum likelihood estimator for the marginal distribution of \bar{S}_t is given by the empirical distribution, random draws of SNAP policy index trajectories are taken from the observed data distribution. After we have sampled from this unconfounded causal model, we may perform the desired regression analysis.

Random effects model

As an alternative to the primary g-computation model, we also fit linear random effects models to assess whether the results of our analysis were robust to the analytic technique used.

Variables:

- D_{ijt} = Diabetes prevalence for county j , within state i , at year t
- S_{it} = Unweighted SNAP policy Index for state i during year t
- W_{ijt} = Set of time-varying county level covariates measured for county j , within state i , at year t
- X_{ij} = Set of fixed county level covariates measured for county j , within state i

Model:

$$D_{ijt} = \beta_{0ij} + \beta_{1ij} * t + \beta_2 S_{i0} + \beta_3 (S_{it} - S_{i0}) + \beta_4^T W_{ijt} + \beta_5^T X_{ij} + \beta_6 (S_{it} - S_{i0}) * t$$

Where:

$$\beta_{0ij} = \gamma_{0i} + \epsilon_{0ij}$$

$$\gamma_{0i} = \eta_0 + \omega_{0i}$$

And:

$$\beta_{1ij} = \gamma_{1i} + \epsilon_{1ij}$$

$$\gamma_{1i} = \eta_1 + \omega_{1i}$$

Specifically:

W_{ijt} consists of the variables:

- Poverty rate
- Unemployment rate
- Median house-hold income
- Proportion of residents who are female
- Proportion of residents who are non-Hispanic Black
- Proportion of residents who are Hispanic (any race)
- Proportion of residents who are without health insurance

- Number of primary care providers per 100,000 residents
- Physical inactivity rate

X_{ij} consists of the variables:

- County metropolitan status

Table 1: Components of the SNAP policy index

Eligibility	Increases or decreases index
Exempts at least one (but not all) vehicles from SNAP asset test	Increase
Exempts all vehicles from SNAP asset test	Increase
SNAP eligibility extended to all households that are authorized to receive a noncash benefit or service financed out of Temporary Assistance for Needy Families (TANF) or State maintenance of effort (MOE) funds	Increase
Eligibility restrictions for all legal noncitizen adults	Decrease
Transaction costs	
Proportion of working households who are required to recertify over short periods of time (1-3 months)	Decrease
Simplified reporting related to changes in income	Increase
Availability of online application	Increase
Stigma	
Proportion of state benefits issued through electronic benefits transfer (EBT) card	Increase
Fingerprinting required during application	Decrease
Outreach	
Federally funded radio or TV advertisement campaign present	Increase

Table 2: Number of counties with missing data in each year from 2004 to 2018 *

Covariates	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
County metropolitan status	0	0	0	0	0	0	0	0	0	0	0
Proportion of county residents who are:											
Female	0	0	0	0	0	0	0	0	0	0	0
Male	0	0	0	0	0	0	0	0	0	0	0
Non-Hispanic White	0	0	0	0	0	0	0	0	0	0	0
Non-Hispanic Black	0	0	0	0	0	0	0	0	0	0	0
Non-Hispanic Other	0	0	0	0	0	0	0	0	0	0	0
Hispanic (Any race)	0	0	0	0	0	0	0	0	0	0	0
Poverty rate	1	1	1	1	1	1	1	1	1	1	1
Median household income	1	1	1	1	1	1	1	1	1	1	1
Unemployment rate	1	8	8	1	1	1	1	1	1	1	1
Physically inactive prevalence	0	0	0	0	0	0	0	0	0	0	0
Obesity prevalence	0	0	0	0	0	0	0	0	0	0	0
Smoking prevalence	0	0	0	0	0	0	0	0	0	3,135	3,135
Number of primary care providers per capita	3,135	3,135	3,135	3,135	3,135	3,135	0	0	0	0	0
Health insurance coverage	3,135	1	1	1	1	1	1	1	1	1	1

* N=3,135 counties (8 counties excluded due to lack of diabetes prevalence data)

Table 3: Counties excluded due to lack of diabetes prevalence data from 2004 to 2014

County name	County FIPS code
Hoonah Angoon Census Area, Alaska	02105
Petersburg Census Area, Alaska	02195
Prince of Wales-Hyder Census Area, Alaska	02198
Skagway Municipality, Alaska	02230
Wade Hampton Census Area, Alaska	02270
Wrangell City and Borough, Alaska	02275
Oglala Lakota County, South Dakota	46102
Bedford City, Virginia	51515

Table 4 : Yearly SNAP, and component, policy index values by quartile of absolute change in SNAP policy index from 2004 to 2014 *†

Quartile for change in SNAP policy index (from 2004 to 2014) ‡		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
First quartile	SNAP Policy Index	7.3 (0.6)	7.5 (0.5)	7.5 (0.8)	7.5 (0.7)	7.5 (0.8)	7.6 (0.9)	7.7 (0.9)	7.8 (0.8)	7.9 (0.8)	7.9 (0.8)	7.9 (0.8)
	Eligibility Index	2.5 (0.4)	2.5 (0.4)	2.5 (0.4)	2.5 (0.4)	2.6 (0.4)	2.7 (0.5)	2.8 (0.5)	2.8 (0.5)	2.8 (0.5)	2.8 (0.5)	2.8 (0.5)
	Transaction cost Index	2.2 (0.5)	2.4 (0.4)	2.4 (0.6)	2.4 (0.6)	2.4 (0.5)	2.5 (0.6)	2.6 (0.6)	2.7 (0.5)	2.7 (0.5)	2.8 (0.5)	2.8 (0.6)
	Stigma Index	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)
	Outreach Index	0.2 (0.2)	0.3 (0.1)	0.3 (0.2)	0.2 (0.2)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.03 (0.1)	0.0 (0.0)	0.0 (0.0)
Second quartile	SNAP Policy Index	6.7 (0.6)	6.8 (0.5)	6.9 (0.8)	7.1 (0.7)	7.2 (0.8)	7.3 (0.9)	7.8 (0.9)	8.0 (0.8)	8.1 (0.8)	8.1 (0.8)	8.1 (0.8)
	Eligibility Index	2.5 (0.4)	2.6 (0.4)	2.6 (0.4)	2.6 (0.4)	2.7 (0.4)	2.8 (0.5)	3.0 (0.5)	3.2 (0.5)	3.2 (0.5)	3.2 (0.5)	3.2 (0.5)
	Transaction cost Index	1.7 (0.5)	1.8 (0.4)	1.9 (0.6)	2.0 (0.6)	2.1 (0.5)	2.2 (0.6)	2.4 (0.6)	2.5 (0.5)	2.6 (0.5)	2.6 (0.5)	2.6 (0.6)
	Stigma Index	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)
	Outreach Index	0.2 (0.2)	0.2 (0.1)	0.2 (0.2)	0.2 (0.2)	0.2 (0.2)	0.1 (0.1)	0.02 (0.0)	0.04 (0.0)	0.04 (0.1)	0.0 (0.0)	0.0 (0.0)
Third quartile	SNAP Policy Index	6.0 (0.6)	6.6 (0.5)	6.7 (0.8)	7.0 (0.7)	7.1 (0.8)	7.4 (0.9)	7.6 (0.9)	8.0 (0.8)	8.1 (0.8)	8.3 (0.8)	8.3 (0.8)
	Eligibility Index	2.3 (0.4)	2.4 (0.4)	2.4 (0.4)	2.5 (0.4)	2.5 (0.4)	2.8 (0.5)	3.0 (0.5)	3.2 (0.5)	3.2 (0.5)	3.2 (0.5)	3.2 (0.5)
	Transaction cost Index	1.4 (0.5)	1.7 (0.4)	1.8 (0.6)	2.0 (0.6)	2.1 (0.5)	2.2 (0.6)	2.3 (0.6)	2.5 (0.5)	2.6 (0.5)	2.8 (0.5)	2.8 (0.6)

	Stigma Index	2.1 (0.0)	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)
	Outreach Index	0.2 (0.2)	0.2 (0.1)	0.2 (0.2)	0.3 (0.2)	0.2 (0.2)	0.1 (0.1)	0.03 (0.0)	0.1 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
Fourth quartile	SNAP Policy Index	5.5 (0.6)	6.0 (0.5)	6.3 (0.8)	6.6 (0.7)	6.9 (0.8)	7.4 (0.9)	7.8 (0.9)	8.3 (0.8)	8.4 (0.8)	8.5 (0.8)	8.6 (0.8)
	Eligibility Index	1.8 (0.4)	1.8 (0.4)	1.9 (0.4)	2.2 (0.4)	2.4 (0.4)	2.8 (0.5)	3.0 (0.5)	3.1 (0.5)	3.2 (0.5)	3.2 (0.5)	3.2 (0.5)
	Transaction cost Index	1.4 (0.5)	1.7 (0.4)	1.9 (0.6)	1.9 (0.6)	2.1 (0.5)	2.3 (0.6)	2.5 (0.6)	2.7 (0.5)	2.9 (0.5)	3.0 (0.5)	3.1 (0.6)
	Stigma Index	2.0 (0.0)	2.2 (0.0)	2.2 (0.0)	2.2 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)	2.3 (0.0)
	Outreach Index	0.3 (0.2)	0.3 (0.1)	0.3 (0.2)	0.3 (0.2)	0.2 (0.2)	0.1 (0.1)	0.1 (0.0)	0.2 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)

* SNAP policy index is scaled to be from 1 to 10 and is the sum of the eligibility, transaction cost, stigma and outreach indices.

† All data presented as means (standard deviations)

‡ Absolute change in SNAP policy index from 2004 to 2014. First quartile: 0 to 0.9 (N=834 counties), second quartile: 0.9 to 1.9 (N=746 counties), third quartile: 2.0 to 2.6 (N=876 counties), fourth quartile: 2.7 to 4.2 (N=679 counties).

Table 5: States in quartiles of absolute change in SNAP policy index from 2004 to 2014 *†

First quartile (N=834 counties)	Second quartile (N=746 counties)	Third quartile (N=876 counties)	Fourth quartile (N=679 counties)
Alaska Arkansas Delaware Indiana Kansas Kentucky Missouri Pennsylvania South Carolina Virginia West Virginia	Arizona Colorado Connecticut District of Columbia Hawaii Louisiana Maine Maryland Massachusetts Michigan New Hampshire New Mexico North Carolina Oklahoma South Dakota Tennessee Wisconsin	Idaho Illinois Iowa Mississippi Montana North Dakota Ohio Oregon Texas Washington Wyoming	Alabama California Florida Georgia Minnesota Nebraska Nevada New Jersey New York Rhode Island Utah Vermont

* Quartiles calculated at the county level. 8 counties were excluded due to lack of diabetes prevalence data.

† Absolute change in SNAP policy index from 2004 to 2014. First quartile: 0 to 0.9, second quartile: 0.9 to 1.9, third quartile: 2.0 to 2.6, fourth quartile: 2.7 to 4.2.

Table 6: Annual, age-adjusted adult diabetes prevalence from 2004 to 2014 *†

	Total	Male	Female
2004	7.3 (1.3)	7.8 (1.1)	6.8 (1.4)
2005	7.5 (1.3)	8.2 (1.2)	7.0 (1.5)
2006	8.0 (1.5)	8.7 (1.4)	7.4 (1.6)
2007	8.3 (1.6)	9.0 (1.5)	7.7 (1.7)
2008	8.5 (1.6)	9.3 (1.5)	7.9 (1.7)
2009	8.7 (1.6)	9.5 (1.5)	8.1 (1.7)
2010	8.9 (1.6)	9.6 (1.6)	8.3 (1.8)
2011	9.0 (1.7)	9.7 (1.6)	8.4 (1.8)
2012	9.1 (1.7)	9.7 (1.6)	8.5 (1.9)
2013	9.1 (1.7)	9.8 (1.6)	8.6 (1.9)
2014	9.1 (1.8)	9.8 (1.6)	8.6 (2.0)

* Age-adjusted prevalence of diagnosed diabetes for all adults 20 years of age and older obtained from the Centers for Disease Control and Prevention's US Diabetes Surveillance System derived from the Behavioral Risk Factor Surveillance System

† All data presented as means (standard deviations)

Table 7: Annual, age-adjusted adult diabetes prevalence by quartile of absolute change in SNAP policy index from 2004 to 2014 *†‡

	First quartile (N=834 counties)	Second quartile (N=746 counties)	Third quartile (N=876 counties)	Fourth quartile (N=679 counties)
2004	7.8 (1.2)	7.3 (1.5)	7.4 (1.1)	6.9 (1.1)
2005	8.0 (1.3)	7.6 (1.6)	7.6 (1.1)	7.2 (1.2)
2006	8.4 (1.4)	8.1 (1.7)	8.3 (1.3)	7.7 (1.4)
2007	8.7 (1.5)	8.4 (1.9)	8.5 (1.4)	7.9 (1.5)
2008	9.1 (1.5)	8.5 (1.9)	8.7 (1.4)	8.2 (1.4)
2009	9.4 (1.4)	8.7 (1.8)	8.8 (1.4)	8.4 (1.5)
2010	9.6 (1.5)	8.9 (1.9)	9.0 (1.4)	8.5 (1.5)
2011	9.7 (1.7)	9.0 (2.0)	9.1 (1.4)	8.6 (1.5)
2012	9.7 (1.7)	9.1 (2.0)	9.1 (1.4)	8.7 (1.6)
2013	9.8 (1.8)	9.1 (1.9)	9.1 (1.4)	8.8 (1.6)
2014	10.0 (1.8)	9.1 (1.9)	9.2 (1.4)	8.7 (1.7)

* Age-adjusted prevalence of diagnosed diabetes for all adults 20 years of age and older obtained from the Centers for Disease Control and Prevention’s US Diabetes Surveillance System derived from the Behavioral Risk Factor Surveillance System

† All data presented as means (standard deviations)

‡ Absolute change in SNAP policy index from 2004 to 2014. First quartile: 0 to 0.9, second quartile: 0.9 to 1.9, third quartile: 2.0 to 2.6, fourth quartile: 2.7 to 4.2.

Table 8: States in US Census Regions

Northeast	Midwest	South	West
Connecticut	Illinois	Alabama	Alaska
Maine	Indiana	Arkansas	Arizona
Massachusetts	Iowa	Delaware	California
New Hampshire	Kansas	District of Columbia	Colorado
New Jersey	Michigan	Florida	Hawaii
New York	Minnesota	Georgia	Idaho
Pennsylvania	Missouri	Kentucky	Montana
Rhode Island	Nebraska	Louisiana	Nevada
Vermont	North Dakota	Maryland	New Mexico
	Ohio	Mississippi	Oregon
	South Dakota	North Carolina	Utah
	Wisconsin	Oklahoma	Washington
		South Carolina	Wyoming
		Tennessee	
		Texas	
		Virginia	
		West Virginia	

Table 9: States in quartiles of SNAP policy index in 2004*†

First quartile (N=848 counties)	Second quartile (N=739 counties)	Third quartile (N=845 counties)	Fourth quartile (N=703 counties)
California	Alabama	Alaska	Arkansas
Georgia	Arizona	Colorado	Delaware
Idaho	Connecticut	District of Columbia	Kansas
Minnesota	Florida	Illinois	Maine
Mississippi	Hawaii	Indiana	Maryland
Nebraska	Iowa	Kentucky	Massachusetts
Rhode Island	Nevada	Louisiana	Michigan
Texas	New Jersey	Missouri	New Hampshire
Utah	New York	Montana	Pennsylvania
Vermont	North Dakota	New Mexico	South Carolina
Wyoming	Ohio	North Carolina	Virginia
	Oklahoma	Oregon	West Virginia
	South Dakota	Washington	Wisconsin
	Tennessee		

* Quartiles calculated at the county level. 8 counties were excluded due to lack of diabetes prevalence data.

† Snap policy index range - First quartile: 3.8 to 5.8, second quartile: 5.8 to 6.4, third quartile: 6.4 to 6.9, fourth quartile: 7.0 to 8.1

Table 10: Random effects model – Outcome: Age-adjusted diabetes prevalence *

Variable	Estimate	95% Lower Confidence Limit	95% Upper Confidence Limit	p-value
Intercept	2.05	0.59	3.52	0.006
Baseline SNAP policy index (in 2004)	0.24	0.23	0.26	<0.001
Year	0.32	0.11	0.53	0.004
Absolute change in SNAP policy index from 2004 to 2014	0.35	0.33	0.37	<0.001
Year × Absolute change in SNAP policy index from 2004 to 2014	-0.061	-0.064	-0.058	<0.001
Proportion of residents female	0.009	-0.001	0.019	0.06
Proportion of residents non-Hispanic Black	0.042	0.040	0.045	<0.001
Proportion of residents Hispanic (any race)	-0.006	-0.008	-0.003	<0.001
Poverty rate	0.029	0.024	0.034	<0.001
Median household income	0.012	-0.015	0.039	0.38
Unemployment rate	0.002	-0.002	0.006	0.23
Proportion of residents that are physically inactive	0.081	0.077	0.085	<0.001
Primary care providers per 100,000 residents	-0.001	-0.002	0.0002	0.09
Proportion of residents without health insurance	0.011	0.007	0.015	<0.001
Non-metropolitan county	0.003	-0.047	0.054	0.89

* Age-adjusted prevalence of diagnosed diabetes for all adults 20 years of age and older obtained from the Centers for Disease Control and Prevention's US Diabetes Surveillance System derived from the Behavioral Risk Factor Surveillance System