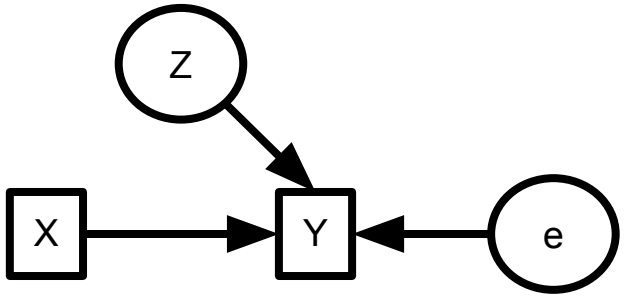
A. Uncorrelated Unmeasured Driver Causing Only Additional Error




B. Correlated Driver Causing Omitted Variable Bias

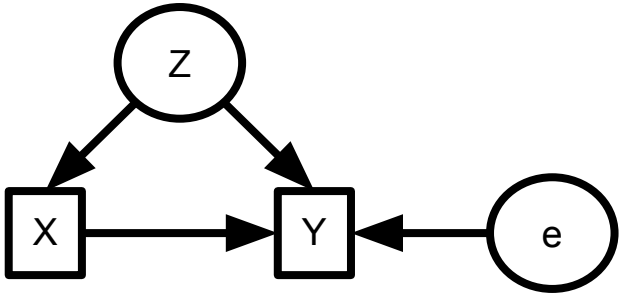



**Figure 1:** A response variable of interest (Y) is driven by both a measured variable (X) and an unmeasured variable (Z) as well as other uncorrelated sources of residual variability (e). In one scenario, X and Z are uncorrelated, and thus the lack of inclusion of Z in a statistical model increases the standard error of the estimate of the effect of X on Y, but does not alter the causal identification of the statistical model. If Z drives X, however (or if Z and X are driven by a common unmeasured driver), the omission of Z from a statistical model causes bias in the estimate of X on Y in a direction that depends on the effect of Z on Y. The results of the model are no longer causally identified.

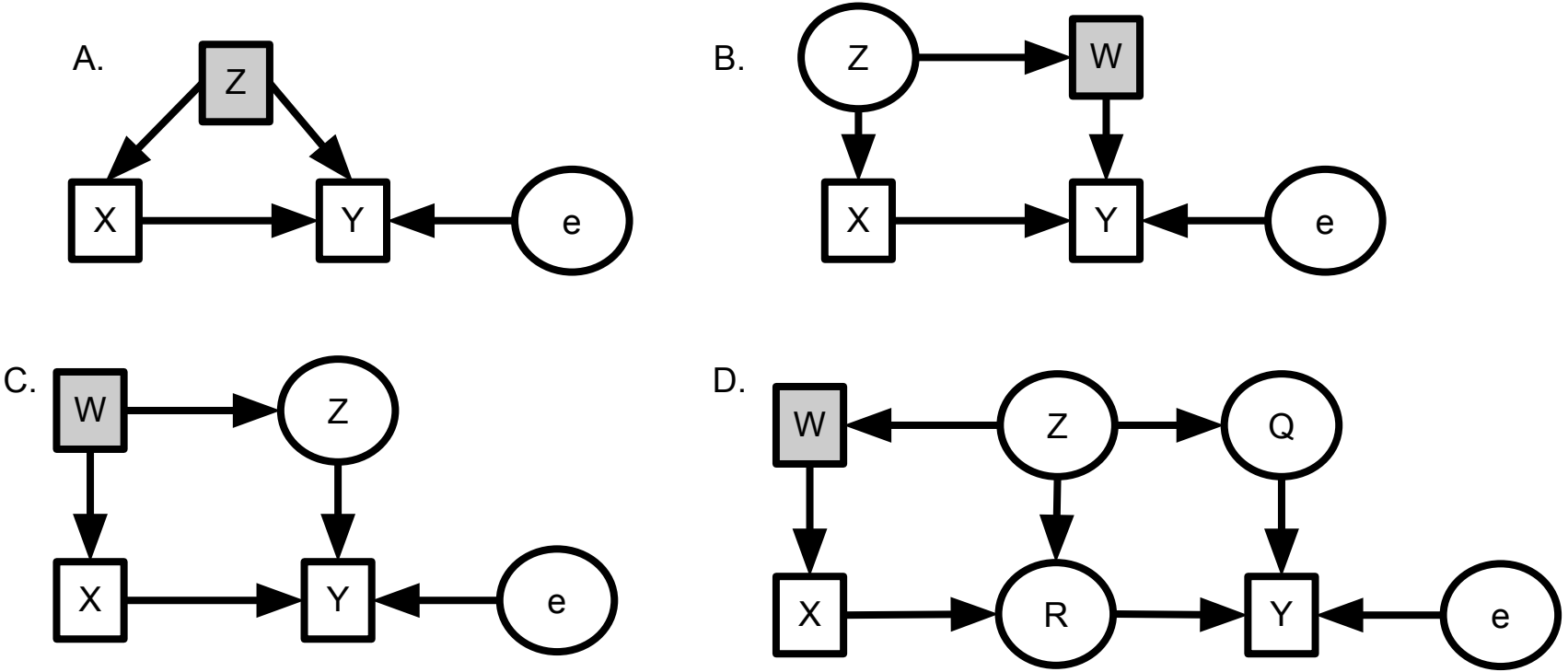



**Figure 2:** Examples of satisfying the back-door criterion with control variables. By including shaded observed variables, either Z or W, in a statistical analysis of the effects of X on Y, omitted variable bias is controlled for the results have a causal interpretation. The relationship between the control variable and Y might (A and B) or might (C and D) not have a causal interpretation, depending on the structure of the system. Note, in (D), Q would have also served as an adequate control instead of W. R would have been a bad control.

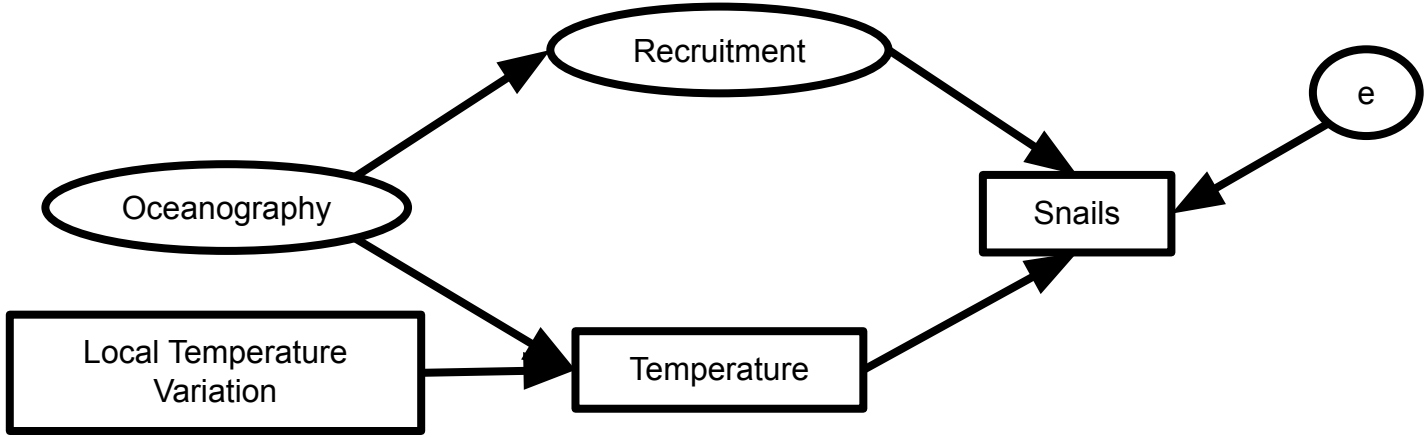



**Figure 3:** A system describing the controls of snail abundance in the intertidal. Oceanography regulates both temperature and recruitment, both of which drive snail abundance. Temperature, however, is also driven by local influences as well. This could be variability in plot-level temperature within a site or site-level temperature variability between years uncorrelated with local oceanography and recruitment.

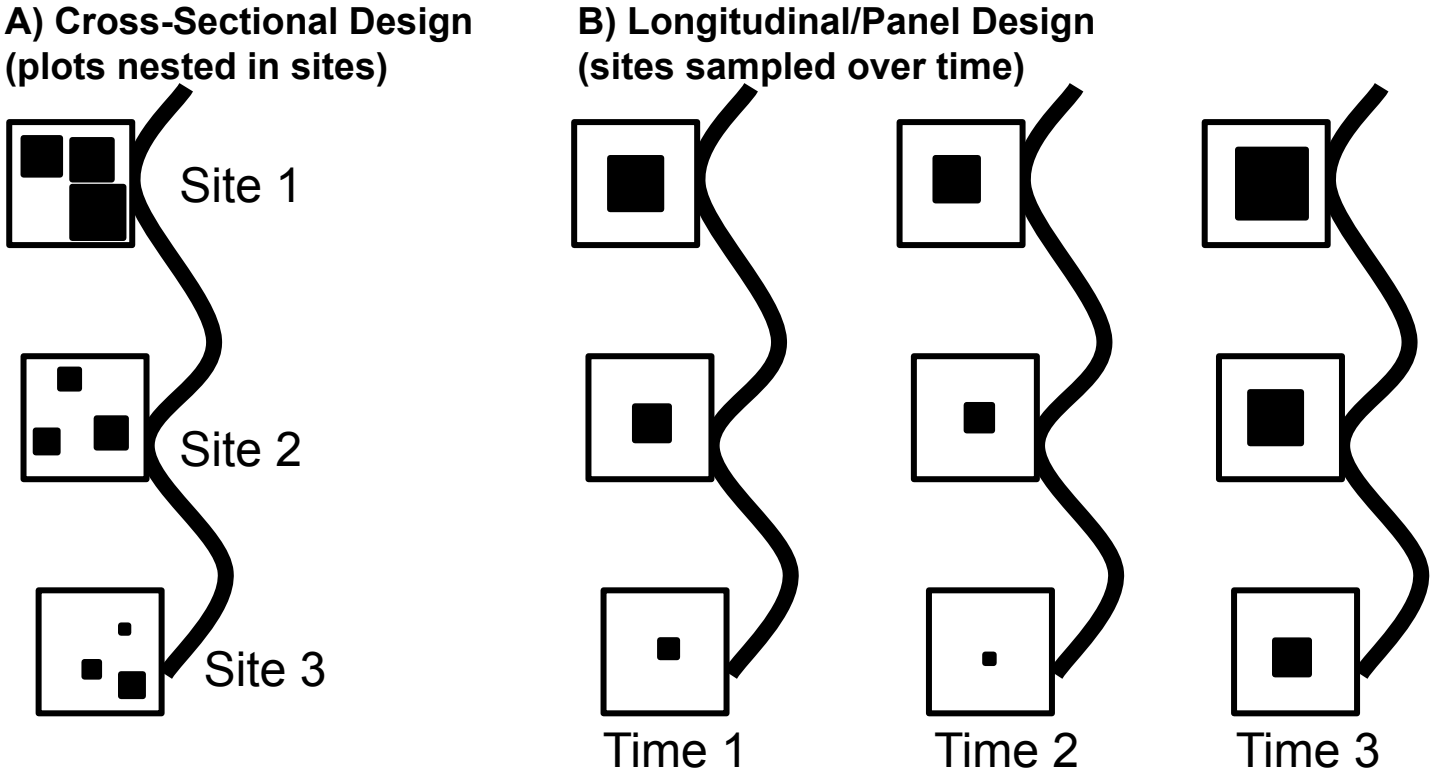



**Figure 4:** Visual examples of clustered/nested/hierarchical study designs with n = 3 per site. In these studies, sites are distributed along a coastline with a corresponding thermal gradient. However, they leverage spatial or temporal clusters to take advantage of temperature variation within sites in a cross-sectional study design (A) or temperature variation across time for a longitudinal (a.k.a. panel) design. Open squares are sites. Closed squares are plots within sites. Size of square is proportional to temperature.

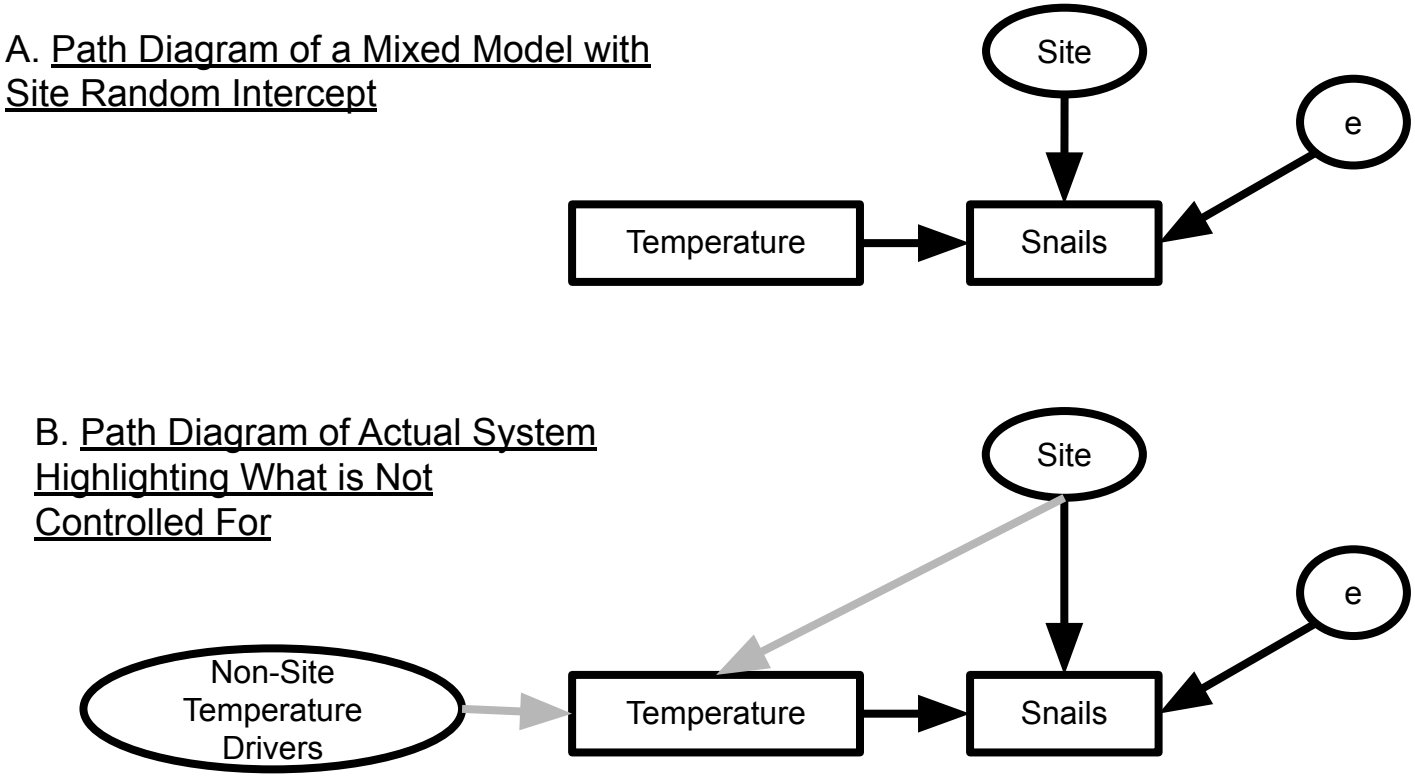



**Figure 5:** The system assumed underlying a mixed model (A) versus the system as it is (B). Note that a mixed model does not account for the correlation between site and temperature nor does it separate out the non-site drivers of temperature. Instead, the effect of temperature on snails is confounded by any correlated site-level drivers that correlate with temperature at the site level.

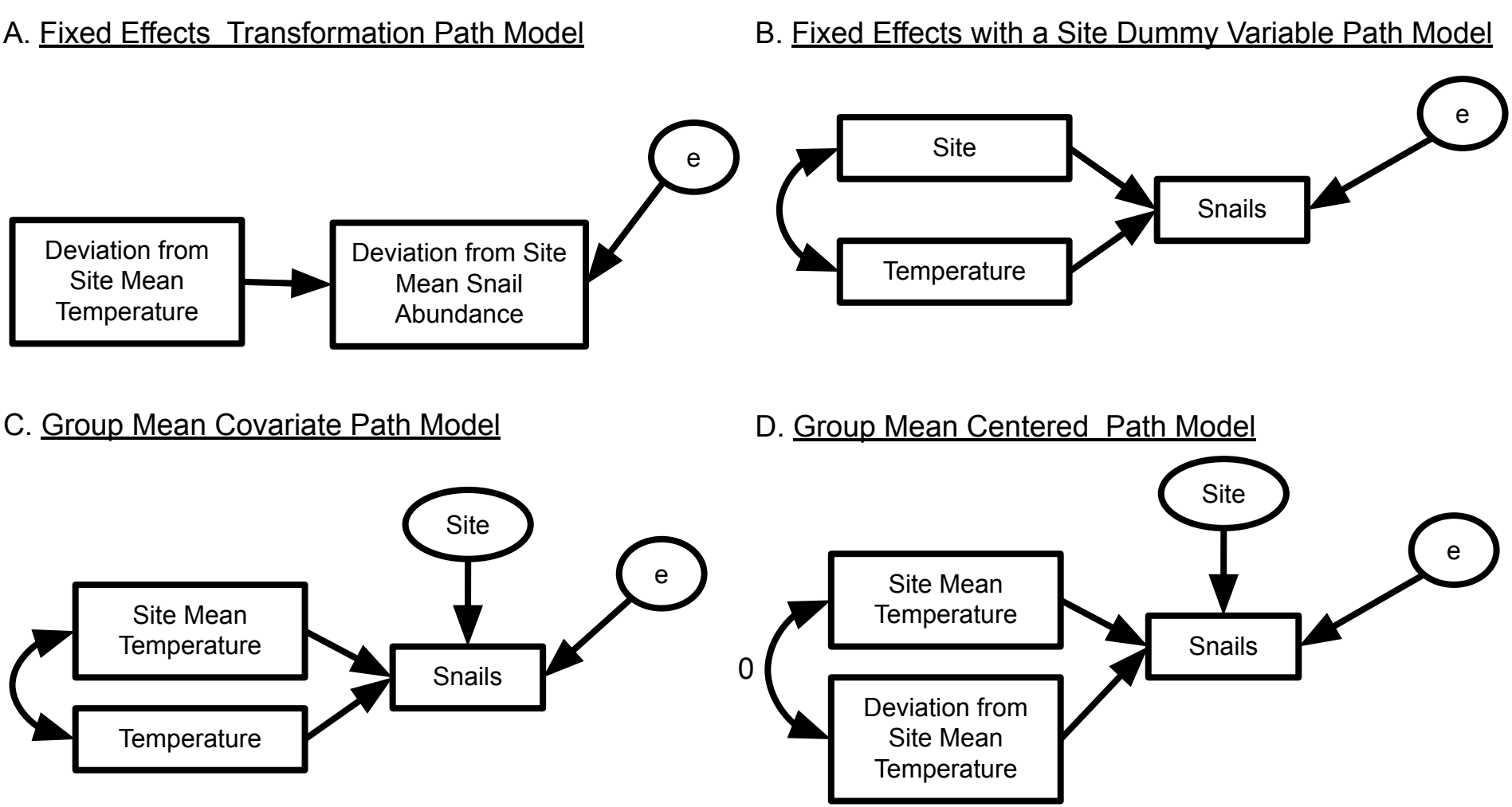



**Figure 6:** Path model representations of different statistical models handling spatial omitted variables in the text.

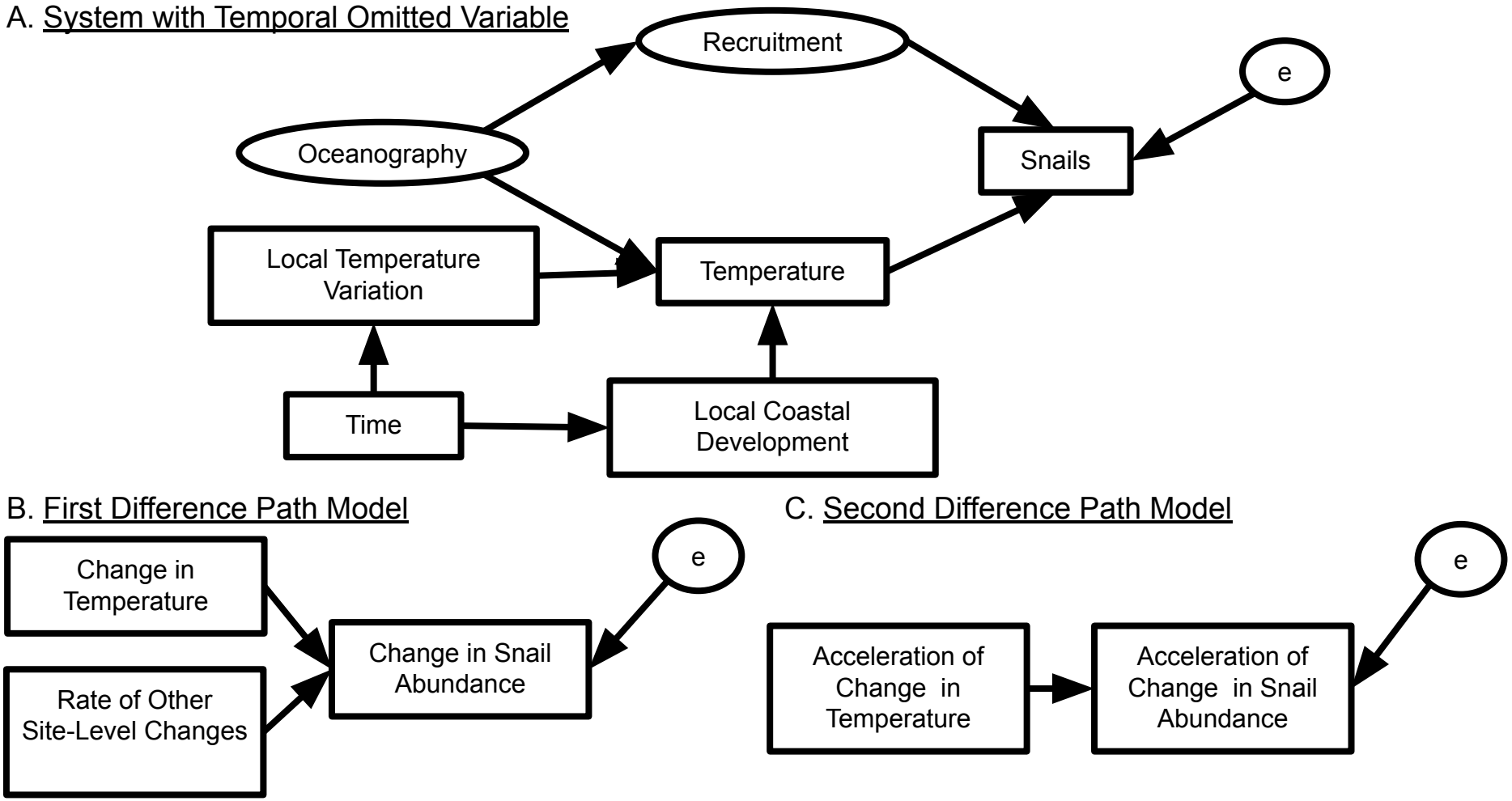



**Figure 7:** Path model representations of different models handling spatial and temporal omitted variables.

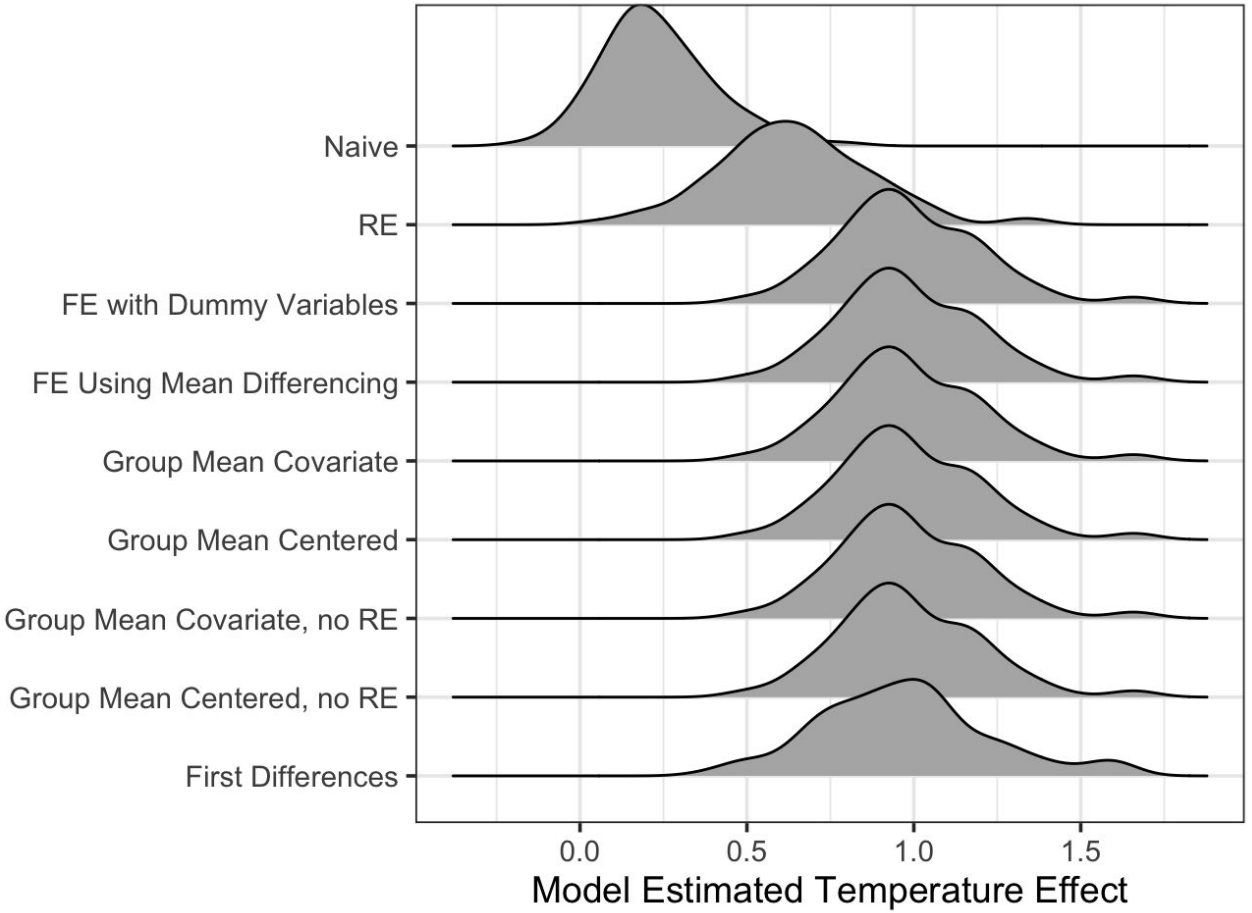



**Figure 8:** Distribution of point estimates of temperature effects from different models.

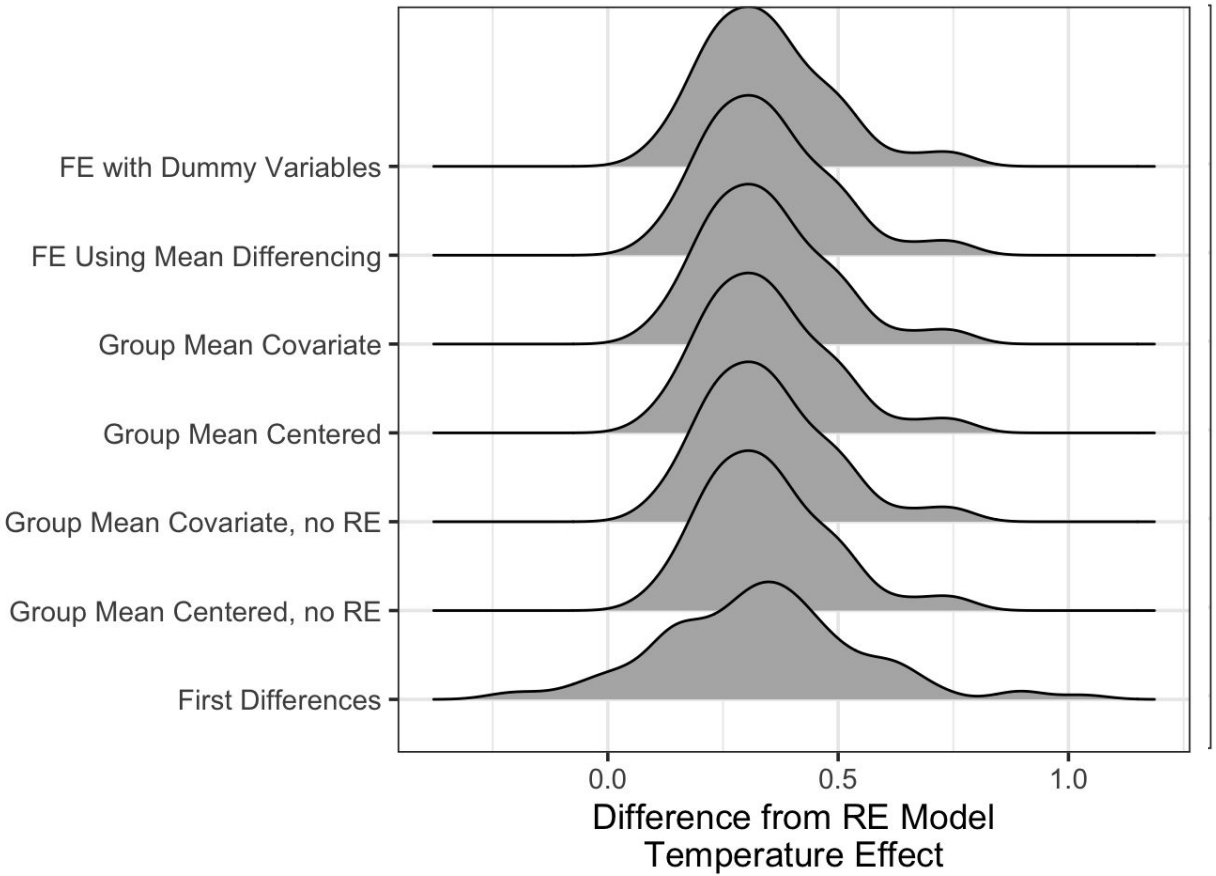



**Figure 9:** Distribution of difference between point estimate of temperature effect in the RE model versus all other models demonstrating clear bias in the estimand of the RE model.

**Table 1:** Mean and SD of point estimates of temperature effects from different models.

| Model Type | Mean Estimate | SD Estimate |
|---|---|---|
| Naive | 0.231 | 0.165 |
| RE | 0.640 | 0.232 |
| FE with Dummy Variables | 0.985 | 0.215 |
| FE Using Mean Differencing | 0.985 | 0.215 |
| Group Mean Covariate | 0.985 | 0.215 |
| Group Mean Centered | 0.985 | 0.215 |
| Group Mean Covariate, no RE | 0.985 | 0.215 |
| Group Mean Centered, no RE | 0.985 | 0.215 |

**Table 2:** Fraction of simulated runs where the mean +/- 2 SE of the temperature effect either overlapped 0 (i.e., high likelihood of committing a type II error) or did *not* contain the true effect of temperature.

| Model Type | 95% CI Contains 0 | 95% CI does Not Contain 1 |
|---|---|---|
| RE | 0.08 | 0.54 |
| FE with Dummy Variables | 0.00 | 0.05 |
| FE Using Mean Differencing | 0.00 | 0.05 |
| Group Mean Covariate | 0.00 | 0.05 |
| Group Mean Centered | 0.00 | 0.05 |
| Group Mean Covariate, no RE | 0.01 | 0.04 |
| Group Mean Centered, no RE | 0.01 | 0.04 |