

Day 2 exercise

James Thorson

2025-05-20

Arrow-and-lag interface for simultaneous and lagged effects

Agenda section E: Exercise Goal:

1. Understand arrow-and-lag notation
2. Fit simultaneous and lagged effects in a time-series model

Structure:

1. Students are to self-organize into groups of 2-3 people, and work in a group on step-1 for 20 minutes.
2. For Step-0, we will walk through code as a group;
3. For later steps, the instructor will then share code for that step on github, and groups will continue with step-2 for 20 minutes, then repeating for step-3.

Step 0: Try fitting a linear model (20 minutes)

Try simulating data from a linear model:

$$\begin{aligned}x_i &\sim \text{Normal}(2, \sigma_X^2) \\ y_i &\sim \text{Normal}(1 + 0.5x_i, \sigma_Y^2)\end{aligned}$$

Where:

- $i \in 1, 2, \dots, 100$, x and y are vectors with length 100
- $\sigma_X^2 = 1$ is the variance in the predictor variable x and $\sigma_Y^2 = 1$ is the residual variance in the response variable y
- $E(x_i) = 2$ and $E(y_i) = 1 + 0.5x_i$
- $x_i \sim \text{Normal}(2, \sigma_X^2)$ indicates that x_i is simulated from a normal distribution, which can be done in R using `rnorm(n = 100, mean = 2, sd = 1)`

```
# Simulate x and y
x = rnorm( n = 100, mean = 2, sd = 1 )
y = rnorm( n = 100, mean = 1 + 0.5*x, sd = 1 )
```

Then try fitting in `dsem`:

```

#install.packages("dsem")
library(dsem)

# Define arrow-and-lag notation
time_term = "
# predictor -> response, lag, parameter_name, start_value
x -> y, 0, slope, 1
x <-> x, 0, sd_x, 1
y <-> y, 0, sd_y, 1
"

# format data into ts object
tsdata = ts(data.frame(x=x, y=y))

# fit in dsem
dsem_fit = dsem(
  tsdata = tsdata,
  sem = time_term,
  control = dsem_control(quiet = TRUE)
)

# Summarize dsem output
summary(dsem_fit)

```

```

##      path lag  name start parameter first second direction Estimate Std_Error
## 1  x -> y   0 slope     1         1      x      y         1 0.4350437 0.11379065
## 2  x <-> x   0 sd_x     1         2      x      x         2 1.0086589 0.07168210
## 3  y <-> y   0 sd_y     1         3      y      y         2 1.1420062 0.08115871
##      z_value      p_value
## 1  3.823194 1.317343e-04
## 2 14.071278 5.702907e-45
## 3 14.071272 5.703458e-45

```

You can then compare this with a linear model

```

# linear model
lm_fit = lm( y ~ 1 + x )
summary(lm_fit)

```

```

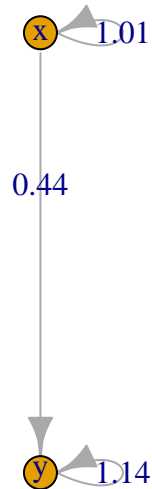
##
## Call:
## lm(formula = y ~ 1 + x)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -2.65066 -0.84710 -0.04157  0.93396  2.63541
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.1418     0.2574   4.435 2.41e-05 ***
## x              0.4350     0.1144   3.804 0.000248 ***
## ---

```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.148 on 98 degrees of freedom
## Multiple R-squared:  0.1287, Adjusted R-squared:  0.1198
## F-statistic: 14.47 on 1 and 98 DF,  p-value: 0.0002479
```

You can also plot output to see the graphical model

```
# plot dsem
plot( dsem_fit,
      edge_label = "value",
      style = "igraph" )
```



Step 1: Simulate data (20 minutes)

Please write an R script that simulates abundance at age $n_{a,t}$ for ages $a \in 1, 2, \dots, 10$ and years $t \in 1, 2, \dots, 40$ with the following simplified dynamics:

$$n_{a,t} = \begin{cases} \mu_R \times e^{\sigma_1 \epsilon_{a,t} - m a} & \text{if } a = 1 \text{ \& } t = 1 \\ n_{a-1,t-1} \times e^{\sigma_2 \epsilon_{a,t} - m} & \text{otherwise} \end{cases}$$

Where process errors $\epsilon_{a,t} \sim \text{Normal}(0, \sigma^2)$, median age-0 recruitment $\mu_R = 10^9$ [individuals], recruitment variation $\sigma_1 = 0.6$ [dimensionless], demographic variation $\sigma_2 = 0.1$ [dimensionless], and natural mortality $m = 0.4$ [per year].

Now imagine that we can only sample abundance-at-age from a sampling gear with logistic selectivity:

$$s_a = \frac{1}{1 + e^{-\theta_2(a-\theta_1)}}$$

Where age at 50% selection $\theta_1 = 3$ [years] and the logit-slope $\theta_2 = 1$ [year⁻¹]. We then observe:

$$n_{a,t}^* = n_{a,t} s_a$$

Step 2: Fit model using dsem (20 minutes)

Write out the arrow-and-lag notation whereby $n_{a,t}$ is caused by abundance $n_{a-1,t-1}$ the preceding age and year. This will presumably involve several one-headed arrows:

```
X -> Y, 1, parameter
```

Where **X** is the predictor, **Y** the response, **1** represents a time-lag, and **parameter** is a parameter name (you can use the same name multiple times to force a single parameter value to be estimated and shared across lines)

Next, modify this arrow-and-lag notation to represent the assumption that exogenous variation at age1 (representing recruitment deviations) will be different than subsequent ages (representing demographic variation). This will presumably involve several two-headed arrows:

```
X <-> X, 0, parameter
```

where these always have a lag of zero.

Step 3: Retrospective skill testing (20 minutes)

Finally, conduct a “leave-future-out” crossvalidation by dropping the final five years of simulated data. To do so, modify **tsdata** by replacing values (measurements) with NAs (representing missing data). This will ensure that the model still predicts those missing values.