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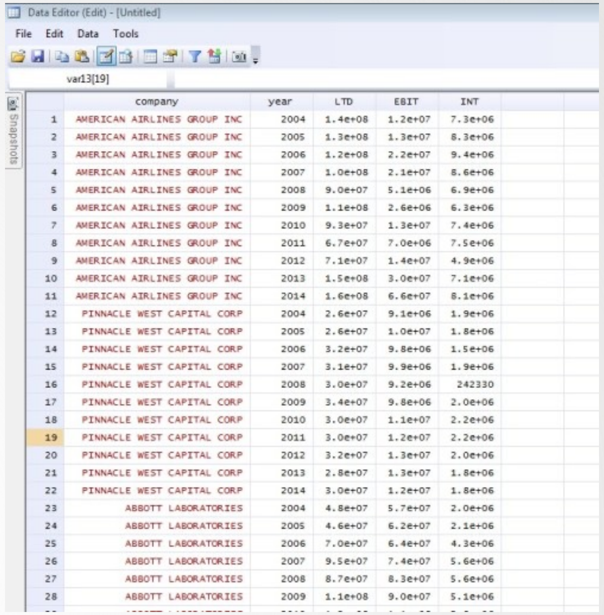
8 – PANEL DATA

SECTION 8 – PANEL DATA
THE PLAN

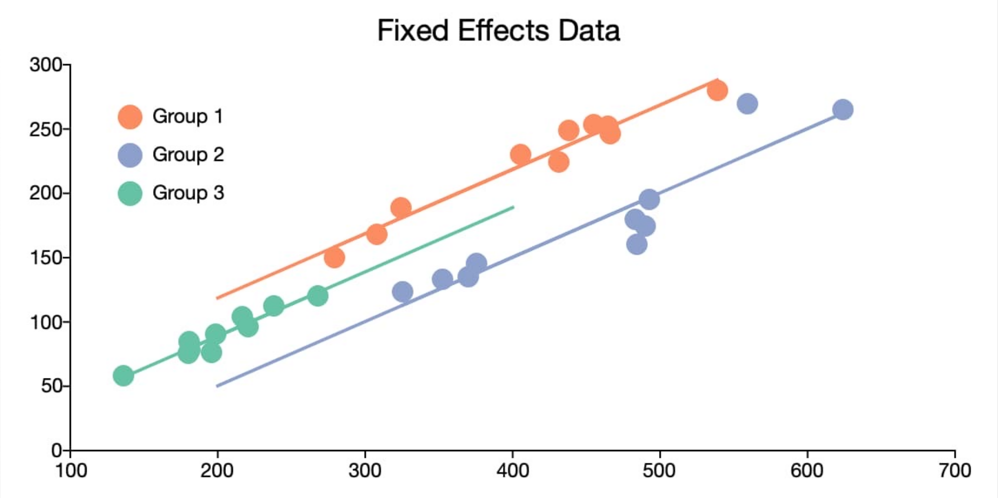
1. Panel Data Structure.
2. Panel Data with Two Time Periods.
3. Fixed Effects Regression.
4. Time Effects & the TWFE model.
5. The Fixed Effects Model's Assumptions for Causal Inference.
6. Standard Errors in Panel Data.
7. Application: Drunk Driving Laws & Traffic Deaths.

OVERVIEW: WHY PANEL DATA?



	company	year	LTD	EBIT	INT
1	AMERICAN AIRLINES GROUP INC	2004	1.4e+08	1.2e+07	7.3e+06
2	AMERICAN AIRLINES GROUP INC	2005	1.3e+08	1.3e+07	8.3e+06
3	AMERICAN AIRLINES GROUP INC	2006	1.2e+08	2.2e+07	9.4e+06
4	AMERICAN AIRLINES GROUP INC	2007	1.0e+08	2.1e+07	8.6e+06
5	AMERICAN AIRLINES GROUP INC	2008	9.0e+07	5.1e+06	6.9e+06
6	AMERICAN AIRLINES GROUP INC	2009	1.1e+08	2.6e+06	6.3e+06
7	AMERICAN AIRLINES GROUP INC	2010	9.3e+07	1.3e+07	7.4e+06
8	AMERICAN AIRLINES GROUP INC	2011	6.7e+07	7.0e+06	7.5e+06
9	AMERICAN AIRLINES GROUP INC	2012	7.1e+07	1.4e+07	4.9e+06
10	AMERICAN AIRLINES GROUP INC	2013	1.5e+08	3.0e+07	7.1e+06
11	AMERICAN AIRLINES GROUP INC	2014	1.6e+08	6.6e+07	8.1e+06
12	PINNACLE WEST CAPITAL CORP	2004	2.6e+07	9.1e+06	1.9e+06
13	PINNACLE WEST CAPITAL CORP	2005	2.6e+07	1.0e+07	1.8e+06
14	PINNACLE WEST CAPITAL CORP	2006	3.2e+07	9.8e+06	1.5e+06
15	PINNACLE WEST CAPITAL CORP	2007	3.1e+07	9.9e+06	1.9e+06
16	PINNACLE WEST CAPITAL CORP	2008	3.0e+07	9.2e+06	242330
17	PINNACLE WEST CAPITAL CORP	2009	3.4e+07	9.8e+06	2.0e+06
18	PINNACLE WEST CAPITAL CORP	2010	3.0e+07	1.1e+07	2.2e+06
19	PINNACLE WEST CAPITAL CORP	2011	3.0e+07	1.2e+07	2.2e+06
20	PINNACLE WEST CAPITAL CORP	2012	3.2e+07	1.3e+07	2.0e+06
21	PINNACLE WEST CAPITAL CORP	2013	2.8e+07	1.3e+07	1.8e+06
22	PINNACLE WEST CAPITAL CORP	2014	3.0e+07	1.2e+07	1.8e+06
23	ABBOTT LABORATORIES	2004	4.8e+07	5.7e+07	2.0e+06
24	ABBOTT LABORATORIES	2005	4.6e+07	6.2e+07	2.1e+06
25	ABBOTT LABORATORIES	2006	7.0e+07	6.4e+07	4.3e+06
26	ABBOTT LABORATORIES	2007	9.5e+07	7.4e+07	5.6e+06
27	ABBOTT LABORATORIES	2008	8.7e+07	8.3e+07	5.6e+06
28	ABBOTT LABORATORIES	2009	1.1e+08	9.0e+07	5.1e+06

- Tracking multiple individuals over time
- Can compare *changes* in *X* & *Y* over time across units.
- Allows to control for (some) unobservable factors.
- But requires different ("clustered") standard errors.



8.1 PANEL DATA STRUCTURE

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THREE TYPES OF DATA

- **Cross-Sectional.**
  - *"Screenshot" of different entities in a single time-period.*
- **Time-Series.**
  - *A single entity followed for multiple time-periods.*
- **Panel (or longitudinal)**
  - *Multiple entities followed for two or more time periods.*

PANEL DATA

- n different entities, each observed at T different periods.

Notation:

- i = one (generic) entity.
- n = *total* number of entities.
- t = one (generic) time period.
- T = total number of time periods.
- Y_{it} = variable Y for unit *i* at time *t.*
- $i = 1,\ldots, n$ → the list of entities.
- $T = 1, \ldots, T$ → the list of time periods.
- A panel dataset can be *balanced* or *unbalanced*.

	unit	time	Y	X1	X2
1	1	1	202.5588	-19.22264	129.2636
2	1	2	104.2631	-8.070382	125.4709
3	1	3	29.77124	61.50526	147.9711
4	1	4	-172.2132	-135.8765	-183.4996
5	1	5	-72.91995	9.291389	-1.059095
6	2	1	-61.89822	-130.0697	-77.89272
7	2	2	-95.60616	-111.8378	-160.6753
8	2	3	71.0319	-192.2037	86.28811
9	2	4	-1.714685	-115.199	136.7121
10	2	5	179.3087	117.5241	-86.32957
11	3	1	208.0849	-136.4253	78.39323
12	3	2	-65.77222	128.4241	79.56686
13	3	3	-.3863547	-89.31672	-16.51904
14	3	4	-33.60559	154.7801	-103.5521
15	3	5	-226.0383	37.95787	-43.9291
16	4	1	-70.60056	7.230512	-108.6402
17	4	2	5.290823	150.3593	259.3312
18	4	3	-29.76007	-74.51495	5.438204
19	4	4	-21.65111	51.5759	-140.877
20	4	5	129.9809	21.44303	11.02391
21	5	1	-268.5881	-35.96759	56.76199
22	5	2	-127.7903	-141.1225	38.18351
23	5	3	-52.39587	29.19638	-8.14588
24	5	4	86.98702	56.08614	-166.6773
25	5	5	104.0118	73.22259	-169.8337
26	6	1	-209.6827	-114.1686	240.1911
27	6	2	-5.266198	-7.821132	226.6435

A PANEL DATASET: TRAFFIC DEATHS AND ALCOHOL TAXES

Observational unit: a year in a U.S. state.

- 48 U.S. states → $n = 48$
- 7 years (1982,…, 1988) → $T = 7$
- Balanced panel, so total observations = $n \times T = 7 \times 48 = 336$

Variables:

- Traffic fatality rate (# traffic deaths per 10,000 state residents)
- Tax on a case of beer
- Other (legal driving age, drunk driving laws, etc.)

A PANEL DATASET: TRAFFIC DEATHS AND ALCOHOL TAXES

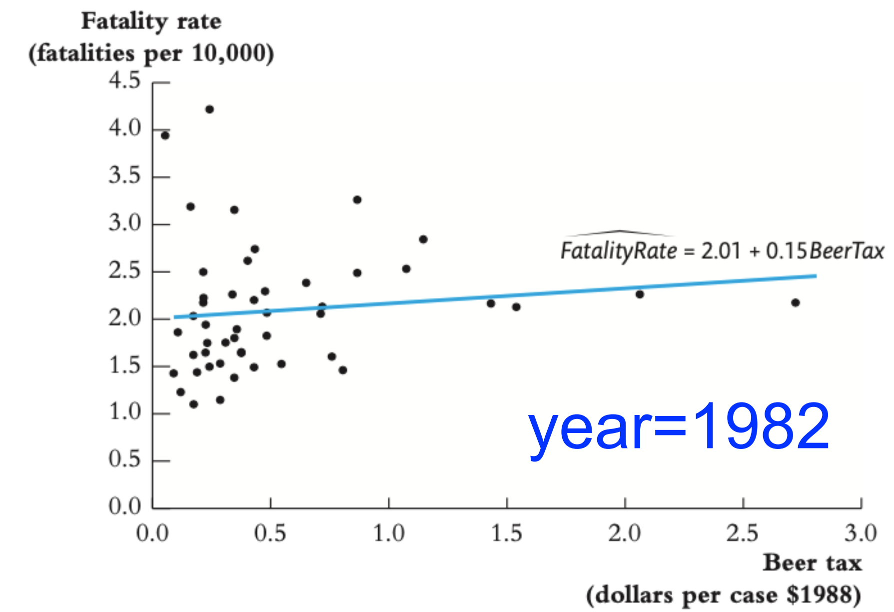
Data Editor (Browse) — fatality.dta

state[1] | 1

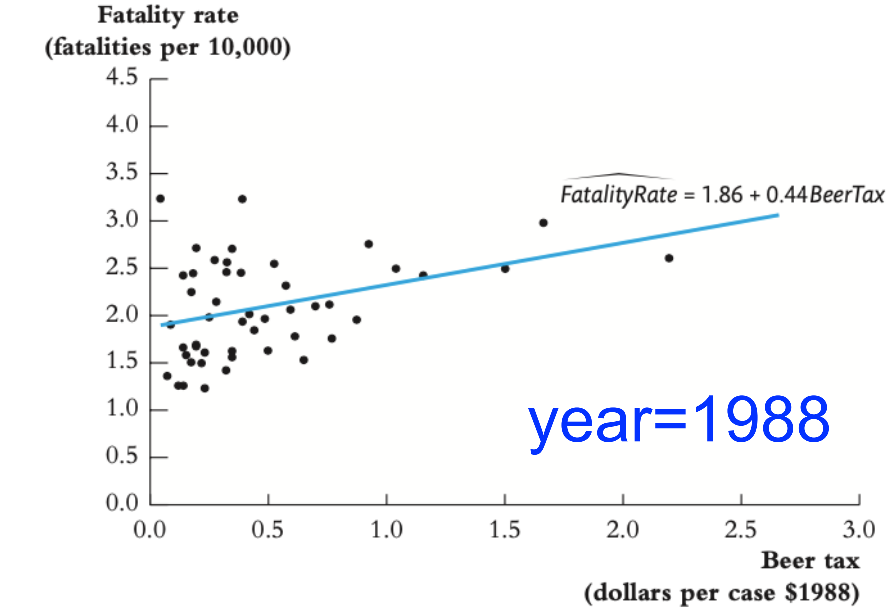
	state	year	beertax	vfrall
1	AL	1982	1.539379	2.12836
2	AL	1983	1.788991	2.34848
3	AL	1984	1.714286	2.33643
4	AL	1985	1.652542	2.19348
5	AL	1986	1.609907	2.66914
6	AL	1987	1.56	2.71859
7	AL	1988	1.501444	2.49391
8	AZ	1982	.2147971	2.49914
9	AZ	1983	.206422	2.26738
10	AZ	1984	.2967033	2.82878
11	AZ	1985	.3813559	2.80201
12	AZ	1986	.371517	3.07106
13	AZ	1987	.36	2.76728
14	AZ	1988	.346487	2.70565
15	AR	1982	.650358	2.38405
16	AR	1983	.6754587	2.3957
17	AR	1984	.5989011	2.23785
18	AR	1985	.5773305	2.26367
19	AR	1986	.5624355	2.54323
20	AR	1987	.545	2.67588
21	AR	1988	.5245429	2.54697
22	CA	1982	.1073986	1.86194
23	CA	1983	.103211	1.80672
24	CA	1984	.0989011	1.94611
25	CA	1985	.095339	1.88128
26	CA	1986	.0928793	1.94548
27	CA	1987	.09	1.98966
28	CA	1988	.0866218	1.90365

The dataset in STATA

A PANEL DATASET: TRAFFIC DEATHS AND ALCOHOL TAXES



(a) 1982 data

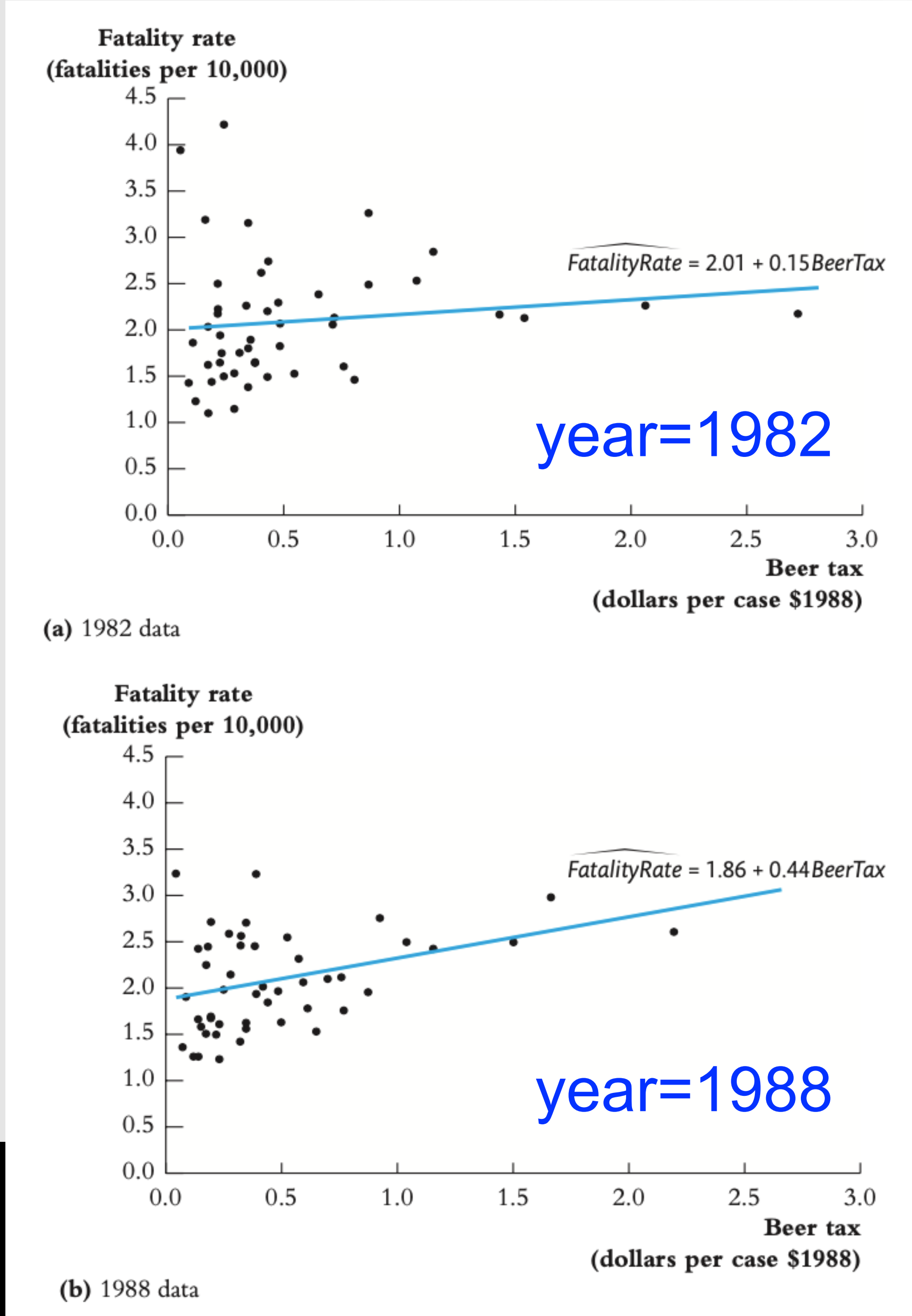


(b) 1988 data

- Consider a *cross-section* of the 48 States in a single year.
- In each single year, we can estimate

$$FatalityRate_i = \beta_0 + \beta_1 BeerTax_i + u_i$$

- Higher alcohol taxes, more traffic deaths??



A PANEL DATASET: TRAFFIC DEATHS AND ALCOHOL TAXES

Why?

Some possible omitted factors:

- Income level.
- Urban vs. Rural.
- Culture around alcohol & driving.
- Reverse causality.
- …

PANEL DATA & FIXED EFFECTS

- Panel data allows to control for some omitted variables *even without explicitly including them in the regression.*

1. Factors that are constant over time for a given unit
   → *entity (or unit) fixed effects*

2. Factors that vary over time but are common to all units
   → *time fixed effects*

8.2 PANEL DATA WITH TWO TIME PERIODS

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PANEL DATA WITH 2 PERIODS

- Consider only the data for 1982 and 1988
- → T=2.
- We can estimate a regression comparing *changes*:

$$\Delta FatalityRate_i = \beta_0 + \beta_1 \Delta BeerTax_i + u_i$$

  - with $\Delta X_i = X_{i1988} - X_{i1982}$
- "Differenced" regression model
- Implicitly controls for all factors that vary across States but not over time.

DERIVATION OF THE "DIFFERENCED" MODEL

- Assume that fatality rate in 1982 and 1988 is determined as

$$FatalityRate_{1982i} = \beta_{0,1982} + \beta_1 BeerTax_{i1982} + \beta_2 Z_i + u_{1982i}$$

$$FatalityRate_{1988i} = \beta_{0,1988} + \beta_1 BeerTax_{i1988} + \beta_2 Z_i + u_{1988i}$$

- Subtracting:

$$\Delta FatalityRate_i = (\beta_{0,1988} - \beta_{0,1982}) + \beta_1 \Delta BeerTax_i + (u_{1988i} - u_{1982i})$$

$$= \beta_0 + \beta_1 \Delta BeerTax_i + u_i$$

- → "Filters out" the effect of Z_i

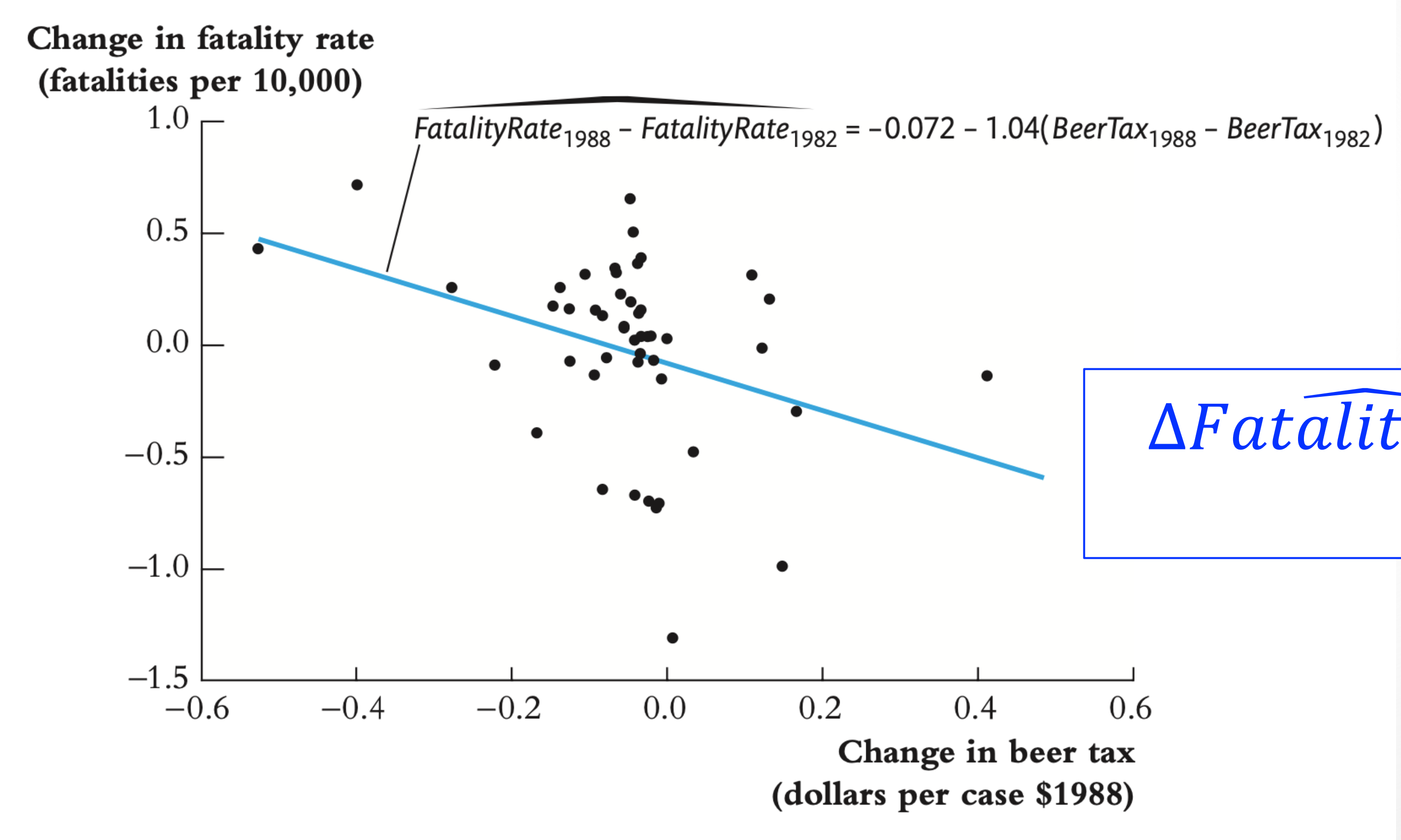
THE "DIFFERENCED" MODEL IN GENERAL

- In general, with T=2, the differenced model is

$$\Delta Y_i = \beta_0 + \beta_1 \Delta X_i + u_i$$

- Statistical inference (SEs, hypothesis testing) is as usual.

A DIFFERENCED MODEL FOR THE EFFECT OF ALCOHOL TAXES



- Only consider 1982 and 1988.
- Estimate a "differenced" model

$$\Delta \widehat{FatalityRate_i} = \underset{(0.065)}{-0.07} - \underset{(0.36)}{1.04}\, \Delta BeerTax_i$$

8.3 FIXED EFFECTS REGRESSION

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THE FIXED EFFECT MODEL

$$Y_{it} = \alpha_i + \beta_1 X_{it} + u_{it}$$

- α_i = *unit fixed effect* (or *unit-specific intercept*)
- Can be used with any T>2.

- An equivalent way to represent it:

$$Y_{it} = \beta_1 X_{it} + \gamma_1 D1_i + \gamma_2 D2_i + \cdots + \gamma_n Dn_i + u_{it}$$

- $D1_i$ = 1 for unit 1 (*i=1*);
= 0 for other units (*i≠1*).

THE FIXED EFFECT MODEL: DERIVATION

- Where does the fixed-effects model come from?
- Start from the following regression model:

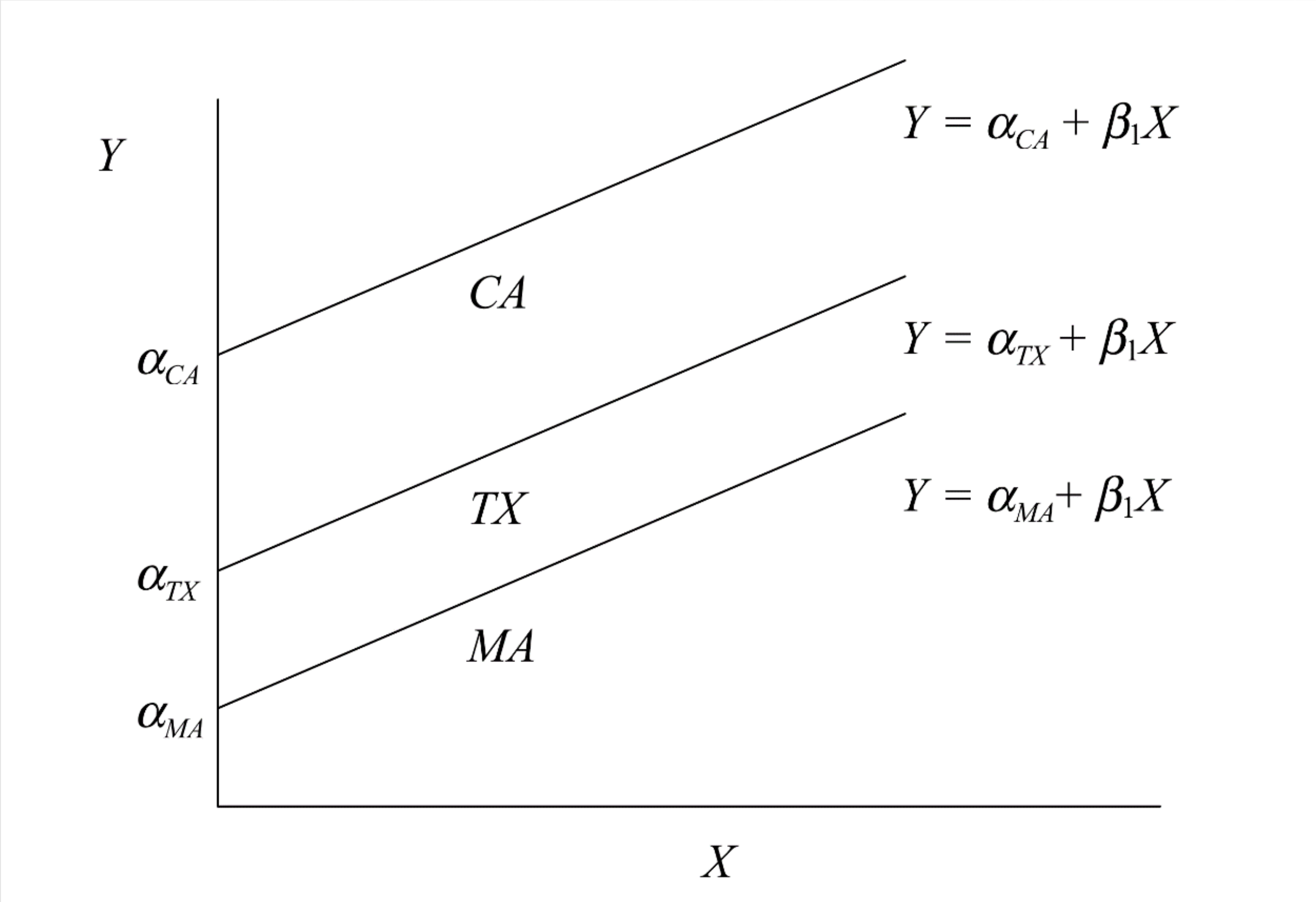
$$Y_{it} = \beta_0 + \beta_2 Z_i + \beta_1 X_{it} + u_{it}$$

  - Z_i = unit-specific fixed variable.

- Define α_i= $\beta_0 + \beta_2 Z_i$
- So we have:

$$Y_{it} = \alpha_i + \beta_1 X_{it} + u_{it}$$

THE FIXED EFFECT MODEL



- Consider 3 states: CA, TX, MA.
- Their regression lines are:

$$\hat{Y}_{CA,t} = \alpha_{CA} + \beta_1 X_{CA,t}$$
$$\hat{Y}_{TX,t} = \alpha_{TX} + \beta_1 X_{TX,t}$$
$$\hat{Y}_{MA,t} = \alpha_{MA} + \beta_1 X_{MA,t}$$

PREVIOUSLY ON ECON 452…

- Panel data: *n* units over *T* periods.
- Differenced regression model (with T=2):

$$\Delta Y_i = \beta_0 + \beta_1 \Delta X_i + u_i$$

- Fixed-effects model:

$$Y_{it} = \alpha_i + \beta_1 X_{it} + u_{it}$$

- Both control for any unobserved unit-specific fixed characteristic.

FIXED EFFECTS AS "DEMEANING"

- Fixed-effects model

$$Y_{it} = \alpha_i + \beta_1 X_{it} + u_{it}$$

- Taking averages over time, this implies

$$\bar{Y}_i = \alpha_i + \beta_1 \bar{X}_i + \bar{u}_i$$

- Subtract the 2nd equation from the 1st:

$$(Y_{it} - \bar{Y}_i) = \beta_1 (X_{it} - \bar{X}_i) + (u_{it} - \bar{u}_i)$$

- Defining $\tilde{Y}_{it} = Y_{it} - \bar{Y}_i$ (& similarly for *X* and *u*):

$$\tilde{Y}_{it} = \beta_1 \tilde{X}_{it} + \tilde{u}_{it}$$

- Takeaway:
    - The fixed-effects β_1 estimate can also be obtained by regressing "demeaned" Y on "demeaned" X, where "demeaned" means you subtract the unit-specific average.
    - In other words, we are taking both Y & X in deviations from unit-specific means.

ESTIMATING THE FIXED-EFFECTS MODEL

Two ways to estimate the fixed-effects model:

1. OLS regression with no intercept & n binary variables (D1, D2, …, Dn):

$$Y_{it} = \beta_1 X_{it} + \gamma_1 D1_i + \gamma_2 D2_i + \cdots + \gamma_n Dn_i + u_{it}$$

- It can also have a common intercept but n-1 indicators (as in the textbook).

2. OLS regression of "demeaned" variables:

$$\tilde{Y}_{it} = \beta_1 \tilde{X}_{it} + \tilde{u}_{it}$$

- *STATA xtreg command uses "demeaning".*

A FIXED EFFECTS MODEL FOR THE EFFECT OF ALCOHOL TAXES

We want to estimate β_1 in

$$FatalityRate_{it} = \alpha_i + \beta_1 BeerTax_{it} + u_{it}$$

- How do we do it in STATA?

A FIXED EFFECTS MODEL FOR THE EFFECT OF ALCOHOL TAXES

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← The dataset in STATA

A FIXED EFFECTS MODEL FOR THE EFFECT OF ALCOHOL TAXES

1. Let STATA know you are working with panel data

```
. xtset state year
       panel variable:  state (strongly balanced)
        time variable:  year, 1982 to 1988
                delta:  1 unit
```

```
. xtreg vfrall beertax, fe vce(cluster state)

Fixed-effects (within) regression               Number of obs      =       336
Group variable: state                           Number of groups   =        48
R-sq:  within  = 0.0407                         Obs per group: min =         7
       between = 0.1101                                        avg =       7.0
       overall = 0.0934                                        max =         7
                                                F(1,47)            =      5.05
corr(u_i, Xb)  = -0.6885                        Prob > F           =    0.0294

                                 (Std. Err. adjusted for 48 clusters in state)
------------------------------------------------------------------------------
             |               Robust
      vfrall |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     beertax |  -.6558736   .2918556    -2.25   0.029    -1.243011   -.0687358
       _cons |   2.377075   .1497966    15.87   0.000     2.075723    2.678427
------------------------------------------------------------------------------
```

DIFFERENCED VS. FIXED-EFFECTS: COMPARING RESULTS

- **"Differenced" specification taking the 1982-1988 change:**

$$\Delta \widehat{FatalityRate}_i = -0.07 - 1.04\ \Delta BeerTax_i$$

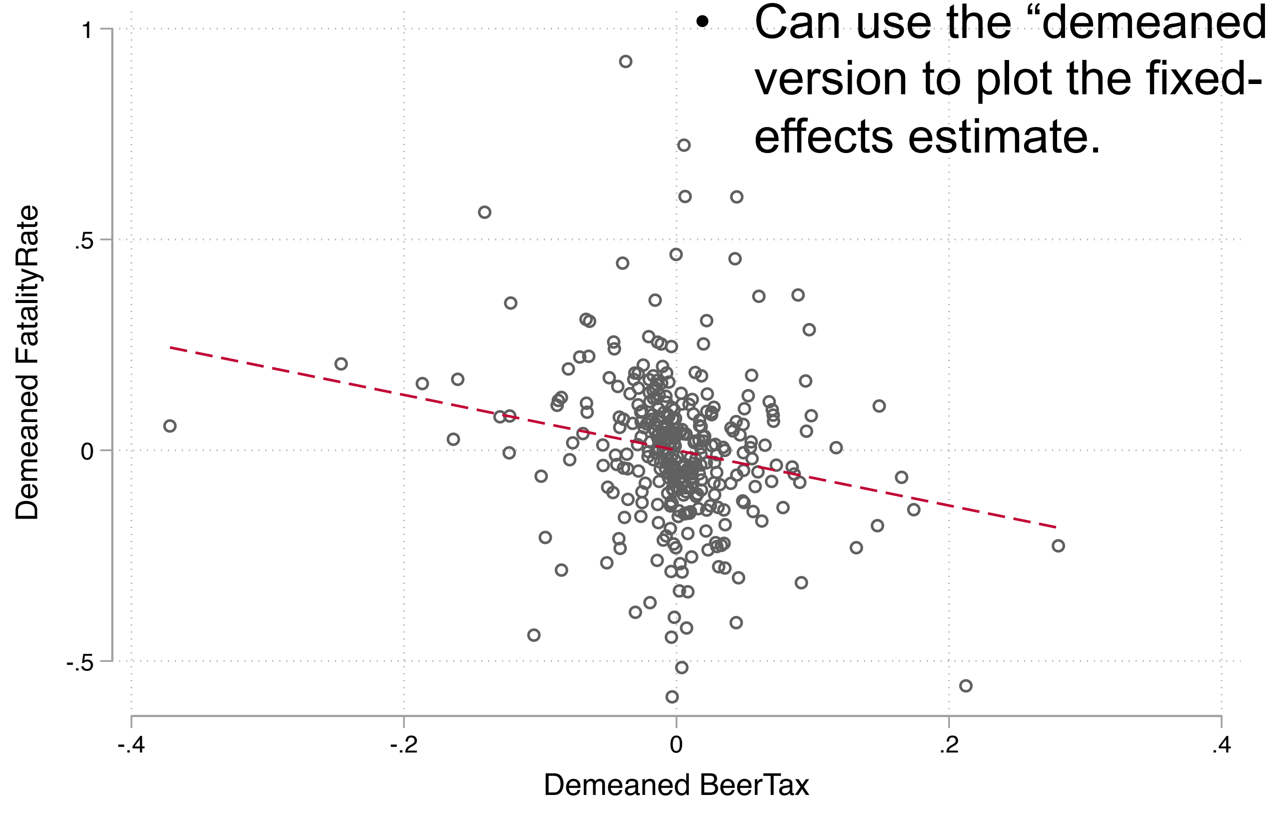
$$(0.065)\quad (0.36)$$

- **Fixed-effects specification:**

$$\widehat{FatalityRate}_{it} = -0.66\ BeerTax_{it} + State\ fixed\ effects$$

$$(0.29)$$

SEEING THROUGH A FIXED EFFECTS REGRESSION



- Can use the "demeaned" version to plot the fixed-effects estimate.

STATA code:

- bysort state: egen avg_beertax=mean(beertax)
- bysort state: egen avg_vfrall=mean(vfrall)
- gen beertax_demeaned=beertax-avg_beertax
- gen vfrall_demeaned=vfrall-avg_vfrall
- twoway ///

```
(scatter vfrall_demeaned beertax_demeaned, ytitle("Demeaned FatalityRate") xtitle("Demeaned BeerTax")) ///
(lfit vfrall_demeaned beertax_demeaned, estopts(noconstant) lcolor(cranberry)), scheme(plotplain) legend(off)
```

8.4 TIME EFFECTS AND THE TWFE MODEL

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TIME FIXED EFFECTS

- An omitted variable might vary over time but be common to all units.
  - Federal laws, innovations in car-making, …
- Time fixed effects:

$$Y_{it} = \beta_1 X_{it} + \lambda_t + u_{it}$$

- Estimated by introducing *T* binary variables:

$$Y_{it} = \beta_1 X_{it} + \delta_1 B1_t + \delta_2 B2_t + \cdots + \delta_T BT_t + u_{it}$$

where $B2_t = \begin{cases} 1 \text{ when } t\text{=2 (year \#2)} \\ 0 \text{ otherwise} \end{cases}$, etc.

TIME FIXED EFFECTS AS "TIME DEMEANING"

- Time fixed-effects model

$$Y_{it} = \lambda_t + \beta_1 X_{it} + u_{it}$$

- Taking time-averages across units, this implies

$$\bar{Y}_t = \lambda_t + \beta_1 \bar{X}_t + \bar{u}_{it}$$

- Subtract the 2nd equation from the 1st:

$$(Y_{it} - \bar{Y}_t) = \beta_1 (X_{it} - \bar{X}_t) + (u_{it} - \bar{u}_t)$$

- Defining $\check{Y}_{it} = Y_{it} - \bar{Y}_t$ (& similarly for *X* and *u*):

$$\check{Y}_{it} = \beta_1 \check{X}_{it} + \check{u}_{it}$$

- Takeaway:
  - The time fixed-effects β_1 estimate can also be obtained by regressing "time-demeaned" Y on "time-demeaned" X, where "time-demeaned" means you subtract the time-specific average (=average of all observations for time t).

THE TWFE MODEL

- We usually want both unit & time fixed effects.
- Two Way Fixed Effects (TWFE) model:

$$Y_{it} = \alpha_i + \lambda_t + \beta_1 X_{it} + u_{it}$$

- *3 equivalent ways to estimate it:*

1. Include *n* unit-specific binary variables + T time-specific ones.
2. Subtract unit-specific averages from X & Y. Then regress demeaned Y on demeaned X, including T time-specific binary variables.
3. Subtract unit averages & time averages, and regress "*doubly-demeaned*" Y on "*doubly-demeaned*" X.

A TWFE MODEL FOR THE EFFECT OF ALCOHOL TAXES

We want to estimate β_1 in

$$FatalityRate_{it} = \alpha_i + \lambda_t + \beta_1 BeerTax_{it} + u_{it}$$

- How do we do it in STATA?
  - ‘xtreg’ + time-specific indicators, with “fe” option (option 1 & 2 in the following slides)
  - can also create the unit-specific and time-specific binary variables, and estimate a OLS regression (option 3 below).

```
. gen y83=(year==1983)                    First generate all the time binary variables
. gen y84=(year==1984)
. gen y85=(year==1985)
. gen y86=(year==1986)
. gen y87=(year==1987)
. gen y88=(year==1988)
. global yeardum "y83 y84 y85 y86 y87 y88"
. xtreg vfrall beertax $yeardum, fe vce(cluster state)

Fixed-effects (within) regression               Number of obs      =       336
Group variable: state                           Number of groups   =        48
R-sq:  within  = 0.0803                         Obs per group: min =         7
       between = 0.1101                                        avg =       7.0
       overall = 0.0876                                        max =         7
corr(u_i, Xb)  = -0.6781                        Prob > F           =    0.0009
                                 (Std. Err. adjusted for 48 clusters in state)
------------------------------------------------------------------------------
             |               Robust
      vfrall |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     beertax |  -.6399799   .3570783    -1.79   0.080    -1.358329    .0783691
         y83 |  -.0799029   .0350861    -2.28   0.027    -.1504869   -.0093188
         y84 |  -.0724206   .0438809    -1.65   0.106    -.1606975    .0158564
         y85 |  -.1239763   .0460559    -2.69   0.010    -.2166288   -.0313238
         y86 |  -.0378645   .0570604    -0.66   0.510    -.1526552    .0769262
         y87 |  -.0509021   .0636084    -0.80   0.428    -.1788656    .0770615
         y88 |  -.0518038   .0644023    -0.80   0.425    -.1813645    .0777568
       _cons |    2.42847   .2016885    12.04   0.000     2.022725    2.834215
-------------+----------------------------------------------------------------
```

Option 1: Create "manually" all time binary variables

Then run the fixed-effects regression using xtreg, including those binary variables.

```
. xtreg vfrall beertax i.year, fe vce(cluster state)

Fixed-effects (within) regression               Number of obs     =        336
Group variable: state                           Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.0803                                         min =          7
     Between = 0.1101                                         avg =        7.0
     Overall = 0.0876                                         max =          7

                                                F(7,47)           =       4.36
corr(u_i, Xb) = -0.6781                         Prob > F          =     0.0009

                                  (Std. err. adjusted for 48 clusters in state)
```

vfrall	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
beertax	-.6399799	.3570783	-1.79	0.080	-1.358329	.0783691
year						
1983	-.0799029	.0350861	-2.28	0.027	-.1504869	-.0093188
1984	-.0724206	.0438809	-1.65	0.106	-.1606975	.0158564
1985	-.1239763	.0460559	-2.69	0.010	-.2166288	-.0313238
1986	-.0378645	.0570604	-0.66	0.510	-.1526552	.0769262
1987	-.0509021	.0636084	-0.80	0.428	-.1788656	.0770615
1988	-.0518038	.0644023	-0.80	0.425	-.1813645	.0777568

Option 2:

Run the fixed-effects regression using xtreg, **and** use the i. operator to let STATA generate the time-specific binary variables.

```
. reg vfrall beertax i.state i.year, vce(cluster state)

Linear regression                               Number of obs     =        336
                                                F(6, 47)          =          .
                                                Prob > F          =          .
                                                R-squared         =     0.9089
                                                Root MSE          =     .18788

                                   (Std. err. adjusted for 48 clusters in state)
------------------------------------------------------------------------------
             |               Robust
      vfrall | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
     beertax |  -.6399799   .3857867    -1.66   0.104    -1.416083    .1361229
             |
       state |
         AZ  |  -.5468622   .5064424    -1.08   0.286    -1.565693    .4719685
         AR  |  -.6385298   .3986016    -1.60   0.116    -1.440413    .1633531
         CA  |  -1.485192   .5892726    -2.52   0.015    -2.670655   -.2997283
         CO  |  -1.461534   .5521075    -2.65   0.011    -2.572231   -.3508375
         CT  |  -1.840129   .5371107    -3.43   0.001    -2.920656   -.7596018
```

Option 3:
Use a OLS regression with both unit-specific & time-specific binary variables

8.5 THE FIXED-EFFECTS MODEL'S ASSUMPTIONS FOR CAUSAL INFERENCE

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ASSUMPTIONS FOR CAUSAL INFERENCE

TWFE Model: $Y_{it} = \alpha_i + \lambda_t + \beta_1 X_{it} + u_{it}$

Violated if there are *lagged* effects, where X_t affects not only Y_t but also Y_{t+1}

1. $E(u_{it} | X_{i1,} X_{i2}, \ldots, X_{iT}, \alpha_i, \lambda_t) = E(u_{it} | \alpha_i, \lambda_t) = 0$
2. $(X_{i1,} X_{i2}, \ldots, X_{iT}, u_{i1}, u_{i2}, \ldots, u_{iT})$ are i.i.d. *across units*
3. Large outliers are unlikely.
4. No perfect multicollinearity.

8.6 STANDARD ERRORS WITH PANEL DATA

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CLUSTERED STANDARD ERRORS

- We assume observations are independent *across different units*.
    - → $u_{1982,CA}$ doesn't help predict $u_{1982,MA}$.
- We don't want to assume that observations belonging to the same unit are independent of one another.
    - *autocorrelation*: $u_{1982,CA}$ likely helps predict $u_{1983,CA}$
- **Clustered SEs** assume that variables are i.i.d across units but allow them to be *autocorrelated* within units.

CLUSTERED SEs IN STATA

```
. xtreg vfrall beertax, fe vce(cluster state)

Fixed-effects (within) regression               Number of obs      =       336
Group variable: state                           Number of groups   =        48
R-sq:  within  = 0.0407                         Obs per group: min =         7
       between = 0.1101                                        avg =       7.0
       overall = 0.0934                                        max =         7
                                                F(1,47)            =      5.05
corr(u_i, Xb)  = -0.6885                        Prob > F           =    0.0294

                                 (Std. Err. adjusted for 48 clusters in state)
------------------------------------------------------------------------------
             |               Robust
      vfrall |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     beertax |  -.6558736   .2918556    -2.25   0.029    -1.243011   -.0687358
       _cons |   2.377075   .1497966    15.87   0.000     2.075723    2.678427
------------------------------------------------------------------------------
```

8.7 APPLICATION: DRUNK DRIVING LAWS & TRAFFIC DEATHS

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TABLE 10.1 Regression Analysis of the Effect of Drunk Driving Laws on Traffic Deaths

Dependent variable: traffic fatality rate (deaths per 10,000).

Regressor	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Beer tax	0.36 (0.05) [0.26, 0.46]	−0.66 (0.29) [−1.23, −0.09]	−0.64 (0.36) [−1.35, 0.07]	−0.45 (0.30) [−1.04, 0.14]	−0.69 (0.35) [−1.38, 0.00]	−0.46 (0.31) [−1.07, 0.15]	−0.93 (0.34) [−1.60, −0.26]
Drinking age 18		0.10		0.03 (0.07) [−0.11, 0.17]	−0.01 (0.08) [−0.17, 0.15]		0.04 (0.10) [−0.16, 0.24]
Drinking age 19				−0.02 (0.05) [−0.12, 0.08]	−0.08 (0.07) [−0.21, 0.06]		−0.07 (0.10) [−0.26, 0.13]
Drinking age 20				0.03 (0.05) [−0.07, 0.13]	−0.10 (0.06) [−0.21, 0.01]		−0.11 (0.13) [−0.36, 0.14]
Drinking age						0.00 (0.02) [−0.05, 0.04]	
Mandatory jail or community service?				0.04 (0.10) [−0.17, 0.25]	0.09 (0.11) [−0.14, 0.31]	0.04 (0.10) [−0.17, 0.25]	0.09 (0.16) [−0.24, 0.42]
Average vehicle miles per driver				0.008 (0.007)	0.017 (0.011)	0.009 (0.007)	0.124 (0.049)
Unemployment rate				−0.063 (0.013)		−0.063 (0.013)	−0.091 (0.021)
Real income per capita (logarithm)				1.82 (0.64)		1.79 (0.64)	1.00 (0.68)
Years	1982–88	1982–88	1982–88	1982–88	1982–88	1982–88	1982 & 1988 only
State effects?	no	yes	yes	yes	yes	yes	yes
Time effects?	no	no	yes	yes	yes	yes	yes
Clustered standard errors?	no	yes	yes	yes	yes	yes	yes

Takeaways:

- Fairly large but imprecisely estimated effect of beer taxes.
- In the sample, average beer taxes are 0.50$, and average fatality rate is 2.
- But with all controls, we can't reject the null of no effect at the 5% confidence level.
- Legal drinking age has no or little effect.
- Economic variables have large effects: good economy = more fatalities.

ADDENDUM: THE DYNAMIC TWFE MODEL

- The assumption of *no lagged effects* is often unrealistic
  - No lagged effects means that X_t affects only Y_t and not Y_{t+1}, Y_{t+2}, …

- To allow for lagged effects, can use a *dynamic TWFE model*:

$$Y_{it} = \alpha_i + \lambda_t + \beta_0 X_{it} + \beta_1 X_{it-1} + \beta_2 X_{it-2} + \cdots + \beta_m X_{it-m} + u_{it}$$

- The $\beta_0, \beta_1, \beta_2, \ldots, \beta_m$ coefficients track the time path of the effect, allowing it to play out gradually over time.