

# An Introductory Guide to Event Study Models

Douglas L. Miller

**T**he event study model is a powerful econometric tool used for the purpose of estimating dynamic treatment effects. One of its most appealing features is that it creates a built-in graphical summary of results. In one of the earliest papers in labor economics to use an event study model, Jacobson, LaLonde, and Sullivan (1993) sought to estimate the loss of income after being displaced from a job. Figure 1 reproduces a graph from that paper.

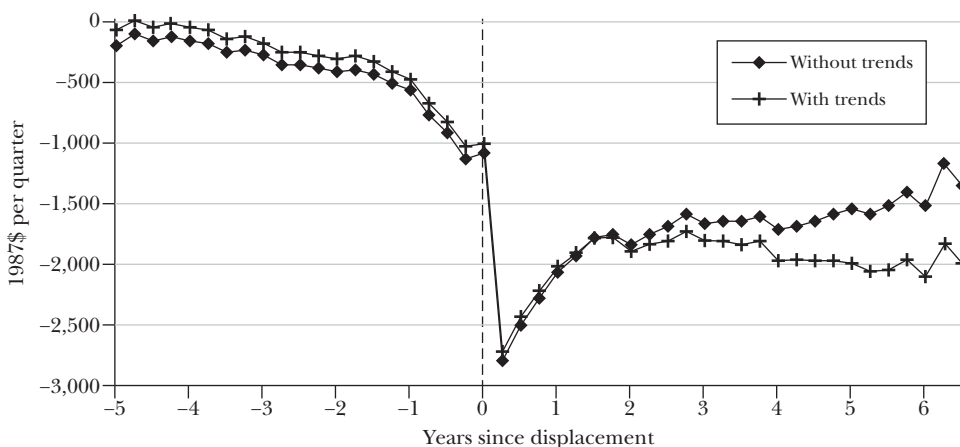
The  $x$ -axis is measured in “event time,” meaning that for each person, the time of job displacement is treated as zero. The time-zero event is often referred to as the “treatment”—that is, the event or policy that changed what otherwise would have happened. The  $y$ -axis of the picture shows income for each period relative to a baseline comparison period. In this example, the baseline is more than five years prior to the job displacement.

The change after the event time of zero is the key takeaway from an event study picture, but the picture also reveals other rich patterns of behavior. For example, it also shows patterns before the event. Ideally, we hope that the line before the event is trendless, and deviations from that pattern alert us to a potential problem with our model; in particular, a trend suggests that the treatment may have been expected or that other factors are in play. In Figure 1, we see a modest deterioration in earnings in advance of the layoffs. This may reflect the presence of third factors—say, perhaps declines in demand for the output of a certain industry—that affect earnings prior to the event and that ultimately contribute to the displacement.

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For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at <https://doi.org/10.1257/jep.37.2.203>.

Figure 1

**An Event Study Example: Loss of Income after Being Displaced from a Job**

Source: Jacobson, LaLonde, and Sullivan (1993).

Note: Figure reproduced from Jacobson, LaLonde, and Sullivan (1993). The x-axis is measured in “event time.” The y-axis show income for each period relative to a baseline comparison period more than five years prior to the job displacement.

Alternatively, if displacement was anticipated and resulted in discouragement, this could lead to a pre-event trend through reductions in labor supply. The figure shows a modest pre-event trend, but also shows a sharp drop in earnings at the time of displacement, followed by a bounce back over the next two years that levels off at an earnings decline of about \$500 to \$1,000 per quarter compared to the pre-event level.

Event study models in economics started with finance applications: for a survey of earlier event studies in finance, see MacKinlay (1997). His earliest example is Dolley (1933a, b), who examines the effect of stock splits on trading activity, dividend payout rates, and market returns. In recent years, event study models have been growing in popularity. Currie, Kleven, and Zwiers (2020, Figure 4c) summarize trends in working papers from the National Bureau of Economic Research (1980–2018) and papers published in top economics journals (2004–2019). They document a sharply increasing share of papers using event study approaches, with an inflection point around 2012. Typically, event study models are estimated in a reduced-form “treatment effects” context.<sup>1</sup> Applications of event study models vary broadly, from job displacement (as in Figure 1), to school finance reform

<sup>1</sup>They can also be used to estimate statistical moments, which in turn can be used to estimate a structural model, as in Finkelstein et al. (2022).

(Lafortune, Rothstein, and Schanzenbach 2018), to the effect of trade liberalization (Braun and Raddatz 2008).

Behind the scenes of the easily digestible event study picture, a researcher needs to make a number of choices. Some choices are as obvious as the question of how (or when) to deal with pre-existing trends like those shown in Figure 1—and indeed that figure shows different estimates if the pre-event trend is taken into account—and some are more subtle, but researchers are often insufficiently clear about the choices they have made. In this essay, I discuss the range of decisions that go into an event study model, and in this way I aim to improve the understanding of these models for researchers, teachers, and consumers of this research.

For those who wish to dig a few layers deeper, a set of online Appendices provide more detail along with graphic examples and underlying code on related topics, such as connections from event study to difference-in-difference models, showing event study results in a way that is closer to raw data, pooling event study coefficients or using splines over event times to improve efficiency, additional considerations when controlling for pre-event trends, and other topics.

## Core Features of Event Study Models

An event study model has two key elements: the estimating equation and the structure of the data.

### Estimating Equation

The traditional approach to estimating an event study model is shown in this equation. We have units  $i$  and calendar time periods  $t$ ; in the original example, the units are workers and the time period is calendar time (for example, earnings in the first quarter of calendar year 1982).

$$y_{it} = \underbrace{\left( \sum_{j \in \{-m, \dots, 0, \dots, n\}} \gamma_j \cdot D_{i,t-j} \right)}_{\text{Event Study Terms}} + \underbrace{\alpha_i + \delta_t}_{\text{Panel Fixed Effects}} + \underbrace{\beta \cdot X_{it}}_{\text{(Optional) Control Variables}} + \epsilon_{it}.$$

On the left-hand side, the  $y$  variable shows the outcome. On the right-hand side,  $D_{i,t-j}$  is an indicator variable for event time  $j$ , meaning that the event took place  $j$  periods before this observation's calendar time. A separate term is included for each event time. The key features of this specification are the  $\gamma_j \cdot D_{i,t-j}$  terms. The coefficients after the event has occurred ( $\gamma_j$  for  $j \geq 0$ ) capture the dynamic effects of the treatment as these effects manifest over time since the event. The terms  $\gamma_j$  for before the event has occurred (for  $j < 0$ ) provide a placebo or falsification test. In the absence of anticipation effects, model misspecification, or omitted confounding variables, these pre-event terms should not have a trend in  $j$ . Together, this part of the regression equation terms will trace out a graph similar in appearance to Figure 1, measured in event time.

The index  $t$  represents the “calendar time” in which we observe the outcomes. The index  $j$  represents time-since-event, or “event time.” In Jacobson, LaLonde, and Sullivan (1993), event time would be interpreted as, for example, “two quarters after job displacement” (for  $j = 2$ ). In many applications, with at most one event per unit, we can designate the “Event Date”  $E_i$ , which is the date that the event occurs. The connection between these three variables is  $j = t - E_i$ . However, names and labels for the  $\{t, j, E_i\}$  variables are not standardized across the literature. As you read event study papers, take care to check your understanding of what names and labels are used for each time concept. The constants  $m$  and  $n$  determine the endpoints for the estimated event study terms.<sup>2</sup>

Event study models are estimated on data that have a panel structure. It is conventional to add two sets of fixed effects,  $\alpha_i$  and  $\delta_t$ , for unit and time fixed effects. These serve the role of controlling for confounding omitted variables that vary at the unit or time level. Using this two-way fixed events approach helps to isolate the effect of the event. The outcome variable  $y_{i,t}$  may also be influenced by other underlying factors. Thus, some event studies add other control variables  $X_{i,t}$ .

Sometimes our events occur at a different level of aggregation than our data. For example, perhaps an event occurs at the state-year level and we are working with a repeated cross section of individual-level data. It is okay to define the event dummies based on the state-year variation and to keep our regressions at the individual level (incorporating cluster-robust standard errors so that inference accounts for the more aggregated level of the event study dummies and their correlation over time within a state). This approach can be useful if we want to control for individual-level covariates; that is, even though we are working with a repeated cross section of individual-level data, we still conceptually have a panel at the state-year level. It can also be okay to first aggregate our data up to the state-year level and then run the model at that level. This makes the dataset more manageable. If we do this, I think it makes sense to weight our aggregated observations by the population represented in each state-year cell in order to get closer to results we would have obtained from the micro data.

### Event Study Data Structures

In the panel data used by event studies, units may have an event (in the basic model) or else multiple events (in a more complex model) that occur at certain dates. An event study data structure can be defined based on an understanding of the unit types in your dataset. Two key questions are: (1) Are there “never treated” units or not? (2) Is there (a lot of) variation in the treatment date across units? A researcher needs for the answer to one or both of these questions to be “yes.” The combined answers to these two questions represent different data structures, with corresponding differences in the thought experiment behind identification of the treatment effect coefficients. A key theme in this paper is that the options,

<sup>2</sup>In some applications, the time variable  $t$  is based on birth cohorts instead of calendar time. This possibility is discussed further later in the paper.

*Table 1*  
**Data Structures for Event Study Estimation**

	<i>Only Ever-Treated Units</i>	<i>There are Never-Treated Units</i>
Common Event Date	N/A	DiD-type
Varying Event Date	Timing-based	Hybrid

*Note:* Author’s proposed labels for event study data structures, based on whether the analysis data sample uses never treated units or not, and on whether treated units have a common event date or varying event dates. “DiD-type” = “Difference in Difference type.”

guidance, and conclusions for an event study can depend on the data structure with which we are working.

Table 1 lists the possibilities. In the top-left corner, if we answer both questions with “no” we have only treated units and they share a common event date. In this setting, we cannot separate the effects of the event from other confounders that occur in calendar time, and so cannot identify treatment effects.

If we answer “yes” to the first question and “no” to the second question, then the data include both treated and untreated units, while all treated units share a common event date. The never-treated units help to identify the change in counterfactual outcomes across calendar times. Then the treatment effects can be estimated. In the canonical event studies graph, the treatment effects line represents allowing for over-time changes in the treated group and over-time changes in the untreated group and then looking at the differences between these changes.<sup>3</sup>

In the timing-based data structure, there are only treated units and the event dates vary. A leading example is when different geographic units (or perhaps individuals) all experience the same policy change or treatment, but they experience the change at different (event) dates. Here, the underlying thought experiment is that the timing of the event is as good as random, and so those treated earlier or later can serve as controls for one another. Dobkin et al. (2018) have a timing-based data structure in their study of the effects of hospitalizations on expenditures and labor supply. All of the individuals in their study experience a hospitalization, but they do so at different times.

Sometimes with this data structure, researchers make descriptive event study graphs that omit calendar-time fixed effects and unit fixed effects. For example, Card, Heining, and Kline (2013) track German workers who transition jobs across firms, based on the quartile of wages at the old and new firm. In a

<sup>3</sup>Indeed, the event study specification is a generalization of a standard two-way fixed effects difference-in-difference specification:

$$y_{it} = \gamma \cdot Treated_i \cdot Post_{it} + \alpha_i + \delta_t + \beta \cdot X_{it} + E_{it}$$

Here  $Treated_i$  is a binary variable for units that ever receive treatment, and  $Post_{it}$  is a binary variable that indicates that treatment has occurred. If we restrict the pretreatment coefficients from the earlier equation to be zero, ( $\gamma_j = 0$  for  $j < 0$ ), and restrict the post-treatment coefficients to have the same value ( $\gamma_j = \gamma$  for  $j \geq 0$ ), then the traditional equation approach shown earlier and this regression here are equivalent.

separate example, Chetty et al. (2014) track Danish workers who transition to jobs with greater defined contribution pension shares. The event study graphs shown in these two examples are essentially expanded pre-post designs. Their credibility comes from three factors: (1) an a priori expectation that the pre-move outcome provides a reasonable counterfactual, (2) the visibly flat pre-trend in the raw data, and (3) the stark jumps at the time of job transition. These graphs have no unit or calendar-time fixed effects and are based on balancing the dataset in event time rather than calendar time.

The data structure might combine variation in event dates and both treated and untreated units. I label this the “hybrid” data structure, and it will include both sources of identification: the comparing of treated and control units and timing-of-event. This data structure is common in event studies. One application that employs a hybrid data structure is the Jacobson, LaLonde, and Sullivan (1993) study mentioned above. They pool data on workers who were displaced at different dates from their jobs as well as workers who were never displaced. Another example is Lafortune, Rothstein, and Schanzenbach (2018), who examine the impact of state-level school finance reforms on funding and test scores. They have 26 states which implement reforms, across a wide range of implementation dates spanning 1990–2011. They also incorporate states without reforms in this period into their analysis.

Estimates from the hybrid data structure can be (informally) compared to estimates relying solely on the timing-based subset of the data (estimated using only ever-treated units) to see whether the different sources of variation are producing similar estimates. So far, I have not seen a formal approach or recipe for making this type of comparison, but I think it could be a useful addition to our standard practice.

When carrying out or interpreting an event study, it is important to be explicit with your reader about the data structure. It is also best practice to show your reader the distribution of observations across event times in your sample. In Appendix A, I place these data structures in the context of related difference-in-difference models. I also illustrate a couple of graphical ways of showing the variation in your unit types and other key aspects of your data structure.

### Parameter Restrictions

The basic event studies model includes more parameters to estimate than is possible. Remember, the total number of parameters comes not just from the  $\gamma$  parameters for the treatment effects over each time period, but also from the  $\alpha$  and  $\delta$  fixed effects parameters on units and times and potentially from more parameters if the researcher decides to include additional control variables. More important than a simple count of parameters is the fact that the event-time dummies are multicollinear with the combination of unit (for example, state-level) and time (for example, calendar year) fixed effects.<sup>4</sup> To proceed, we need some restrictions

<sup>4</sup>This multicollinearity is due to the fact that event time, calendar time, and event date are connected by  $j = t - E_p$  and that event dates can be defined by unit dummies.

on these parameters. It is useful to group these restrictions into three (potentially overlapping) categories: (1) standard restrictions on panel fixed effects parameters; (2) restrictions that help to define our desired counterfactual; and (3) potential additional restrictions that are required to address concerns about multicollinearity.

In an event study model, the event-time coefficients  $\gamma_j$  in the traditional equation approach shown earlier are our main coefficients of interest. They estimate the treatment impact  $j$  periods after receiving treatment. This treatment impact needs to be defined in reference to a specific counterfactual. That definition is embodied in parameter restrictions. For example, we might think of a difference-in-difference-type counterfactual as “compared to a pretreatment period, how much change we would have expected to have occurred in the absence of treatment.” Thus, probably the most common normalization is to choose a specific pretreatment event time and normalize the corresponding coefficients to average to zero. For example it is a common choice to set  $\gamma_{-1} = 0$ , by excluding the dummy variable for the  $j = -1$  event time from the regression. Alternatively, we might have experimental assignment to treatment and control unit types. In this case, our normalizing assumption might be that those in the untreated group can serve as a control group for those who are treated. We would, therefore, have all of the event-time dummy variables but omit the unit fixed effects, setting  $\alpha_i = 0$ .

Multicollinearities abound in event study models. At a basic level, the sum of the unit dummies is equal to one, and the sum of the calendar-time dummies is equal to one. This introduces a multicollinearity between these two sets of dummies as well as the intercept, typically requiring dropping one from each set. There is also an additional multicollinearity between the event-time dummies  $D_{i,t-j}$  and the unit and calendar-time dummies. Sometimes, once we have made basic restrictions on fixed effects and to define the counterfactual, the remaining parameters in the model can be identified and we are good to go. But this is not always the case. The problem of multicollinearity is especially prevalent in a “timing-based” data structure, where all units are treated but their event date  $E_i$  varies. In this data structure, the event-time dummy variables, unit dummy variables, and calendar-time dummy variables will have one or more additional multicollinearities, and so additional restrictions are needed in order to proceed.<sup>5</sup> The problems of multicollinearity also compound when we directly add in unit-specific time trend controls.

How should we implement our additional required parameter restrictions? In current practice, a common approach is to let the software (like Stata) automatically choose some collinear variables to drop, with unknown and possibly problematic implications. This approach should be avoided, and my recommendation is to check your regression output carefully to ensure that no variables are being unexpectedly dropped.

<sup>5</sup>See Proposition 1 in Borusyak, Jaravel, and Spiess (2022) and section 2.4.2 of Schmidheiny and Siegloch (2023). I discuss the number of needed parameter restrictions further in online Appendix B.1 and different examples are illustrated in online Appendix C.2.

Another common approach is to pool some of the data by grouping several of the treatment variable  $\gamma$ 's in the tails to be equal. In the traditional event study equation, this would mean including an “end-cap” dummy variable such as  $D_{i,t \leq E_i - m}$ , indicating “the event will happen  $m$  or more periods in the future.” This approach can sometimes be okay, but it can be problematic if there are uncontrolled-for underlying trends or (for a posttreatment end cap) if the treatment effects themselves are trending. It should only be used if these concerns seem unlikely to be important. As an alternative, it is possible to apply milder but still-useful constraints. For example, you can focus your parameter restrictions on the pre-event coefficients. I discuss “end caps” more in the next section.<sup>6</sup>

It's not always obvious when our model is okay as is or when additional restrictions are needed. When researchers need to impose additional restrictions to identify the model, we should keep in mind the following: (1) these are not merely formalities—the treatment effect coefficients  $\gamma_j$  we estimate are directly dependent on the restrictions imposed; (2) these restrictions are untestable, at least in part; and so (3) we want for these to be as uncontroversial and “obviously true” as possible. Indeed, (4) because of the “multicollinearities abound” nature of some event study data structures, our main estimates of interest can be unexpectedly sensitive to these extra restrictions. This can result in (5) “small bits of noise” propagating through our model in unexpected ways. This last fact can sometimes argue for employing additional restrictions beyond what would be minimally necessary.

My main recommendation is to be clear and explicit about what restrictions are being imposed. Going forward, it would be useful if all event studies would clearly report (1) the number of categories for each group (time, unit-type, or unit) of dummies and/or event study coefficients, both the total possible as well as those that are included in our actually estimated specification (after variables are dropped due to collinearity); (2) the constraints we (or our statistical package) impose on the estimation, either directly or through dropped terms; and (3) a direct assessment of the identifying variation in your data structure (for example, by computing the rank of the relevant proportion of your X matrix).

## Event Study Specification Choices

This section outlines some of the main specification choices to be made when estimating event study models and discusses the trade-offs involved.

### Choice of Pre-event Reference Period

When estimating an event study model, a common choice is to use “one period before treatment” as a normalization, so that the  $\gamma_{-1}$  coefficient is set equal to zero

<sup>6</sup>In online Appendix B.2, I offer more detail and examples for parameter restrictions, including some discussion of useful Stata commands.



in the time period immediately before the event. In the traditional event study equation presented earlier, this is implemented by dropping the  $-1$  event-time dummy variable. But instead of blindly choosing the period immediately before the event for the normalization, it is better practice to make a judgment call as to what is a reasonable pre-event window, balancing considerations of “close enough to be the appropriate counterfactual baseline” and “more data allows for more precision.” Then all of the event dummies can be included and the  $\gamma_j$  coefficients constrained to average to zero within the pre-period window.

How long of a pre-event window should a researcher choose? There is no hard-and-fast rule. I think it is useful to consider the pre-event window you would choose if you were estimating a simple difference-in-difference model. If you chose just one pre-event-time period, you might be worried about the extra statistical noise this would bring. As your pre-event window extends farther back, at some point you might get increasingly worried that those time periods become less appropriate for your counterfactual. In the end, for your difference-in-difference model you would make a judgment call, trading off these two considerations. It seems sensible to have this same judgement call inform your choice of the pre-event reference period.

Normalizing to zero over several event times, rather than just the period immediately before the event, has two effects on the canonical event studies graph. Choosing a longer time period has the effect of shifting the whole pattern of coefficients up or down—while retaining the same shape. The other effect is that when a more extended reference period is used for normalizing to zero, the standard errors can be noticeably smaller. The reason is that when using a single reference time period there is additional uncertainty driven by the noise in this term on its own, which tends to make the standard errors larger.<sup>7</sup>

If we normalize to a broader reference period, our search for a trend before the event will manifest itself differently than if we had normalized the  $-1$  coefficient to zero. We need to assess the overall trend in coefficients rather than examine point-wise coefficients and their difference from zero. (This is also illustrated in online Appendix C.1.)

When we suspect (or see) a dip in outcomes shortly before the event, we might speculate that this is driven by some process that is bundled with the event and which is playing out shortly before the event as it is recognized in our dataset. In this case, we probably do not want to use the period of the dip as our counterfactual baseline because it is actually part of the treated period, even though nominally it's before treatment.<sup>8</sup> Instead we could define our baseline counterfactual to be a period prior to the beginning of the dip. For example, in Figure 1 we see a dip in

<sup>7</sup>This is illustrated in online Appendix C.1. Also, online Appendix C.2 illustrates the potential impact of different normalizations within a timing-based data structure.

<sup>8</sup>A dip that occurs just before the event is sometimes called “Ashenfelter’s dip,” after Ashenfelter (1978), who studied the impact of job training on earnings. Ashenfelter’s models were not presented in the now-traditional event study graphical format, but his table’s results have an event study framing, including showing a pretraining drop in earnings.

earnings prior to the layoff. Inspection of the figure suggests that we would want to have our reference period be at least one year prior to the layoff. In Jacobson, LaLonde, and Sullivan (1993), the authors chose “5 or more years prior to the layoff” as the reference period.

### **Show More than the Estimated Treatment Effects**

An event study provides a treatment estimate as a single set of numbers. However, it is good practice to get closer to the raw data by also reporting a combination of actual and counterfactual average outcomes separately for each unit type. These graphs will complement each other in terms of the information provided. For example, when the event study allows comparison of treated and untreated units, this presentation allows readers to assess whether the unit types experience parallel trends during periods when treatment status is unchanging. Both the difference in levels and in the trends can provide important context for interpreting the treatment effects.

We can also add to this plot a line for the counterfactual untreated prediction that applies to the treated units. To generate this, here are the appropriate steps: (1) estimate the event study model; (2) “zero out” the event-time dummies and make predictions; (3) average these predictions within calendar time for the treated units; and (4) plot out this counterfactual. This calculation lets us see both the raw data and the estimated treatment effects. It also implicitly shows the content of the normalizing restrictions of the model. For example, if we are normalizing the pre-trend in event studies coefficients to be zero and are controlling for unit-type trends, this will show up in a trending counterfactual line. For timing-based or hybrid data structures, this lesson is slightly more complicated to apply. However, the researcher can still plot the average time series for each unit type and then supplement this by adding the counterfactuals for each unit type. (These ideas are illustrated in Appendix D.)

### **Choices with Control Units: Selection and Re-weighting**

Suppose that we are carrying out an event study that includes both treated and untreated units (for example, individuals or states), with untreated units as the control group. However, sometimes we might worry that the never-treated units could be problematic comparisons for the treated units. For example, Krolikowski (2018) reconsiders the Jacobson, LaLonde, and Sullivan (1993) example that generated Figure 1 presented earlier. In the 1993 paper, the event is “first observed layoff”; never-treated units are therefore individuals who never experienced a layoff. However, subsequent layoffs can only occur for the treated group. Thus, there is a mechanical difference in the future earnings potential of the treated group compared to the control observations, above and beyond the effect of the first layoff under consideration. In addition, the control group may be positively selected with regard to unobservable skill, labor force attachment, and/or job match quality. In this setting, those who are never laid off may not provide a good counterfactual for outcome for treated individuals; indeed, the use of this control group could make the impacts of the layoff look worse than they actually are.

There are a range of options to have the control units (for example, individuals who did not experience job displacement) offer better counterfactuals, with the overall goal of making the assumption that “the control units tell us the counterfactual over-time changes” more plausible. First, a researcher might exclude a subset of the control units because they are in some way unrepresentative or because they experienced unusual shocks. For example, if you are working with a city-year panel, and your treated cities are all medium- or large-sized, then you might consider excluding small cities from the control units that you use. Second, for the time periods before the event, it is possible to check for parallel trends between the control and treated units. Third, one can look at the degree of similarity between treated and control units along a number of dimensions, using covariates.

Finally, the researcher might use a reweighting or matching procedure prior to estimation of the event study. A reweighting procedure would apply different weights to the never-treated units so that the covariates match the treated units. In a study of the impact of the introduction of the Legal Services Program (during the 1960s) on demographic outcomes, Goodman-Bacon and Cunningham (2019) observe that untreated counties are different in their observables compared to treated counties. To address this, they estimate a cross-county first stage model to obtain propensity scores (specifically, the probability of being a treated county). They then re-weight the control counties to be more representative of those treated.<sup>9</sup>

An alternative is to choose one or more never-treated “matches” for each treated unit. These matches would typically be made based on observable covariates, possibly including some values of pre-event outcomes. Some practitioners choose to combine these approaches with assigning a pseudo-event time to each control unit, in an effort to present a more plausible counterfactual outcome path. I am not aware of a systematic look at possible trade-offs involved in the choice to use pseudo-event times for the control units.

If an event study has a hybrid data structure, a researcher has the option of discarding the data from untreated units and focusing instead on a timing-based strategy. This approach that would be based on the belief that “among those treated, timing of treatment is as good as random” is more believable than the assumption that “control units tell us the counterfactual over-time changes.” On the other side, using never-treated units will bring in more data, usually improving statistical power and requiring fewer parameter restrictions in order to identify the model. The trade-off between these two considerations will vary on a case-by-case basis. Whatever approach is chosen for dealing with never-treated units, it is useful to show sensitivity of the results to alternate approaches.

<sup>9</sup>This approach could in principle also be used in situations that use only ever-treated units. If there is reason for concern over possible differences between, say, earlier-treated and later-treated events, We could use reweighting to balance covariates across “early event date” and “late event date” units prior to estimating the model.

### Choice of Event Window

In some cases, data availability will limit what endpoints  $m$  and  $n$  can be used for the event-time window; otherwise, you need to make an explicit decision. On one hand, making the event window as wide as possible allows us to see a long path of dynamic treatment effects, and for the pre-event coefficients it gives us a long window to detect troublesome patterns. This consideration pushes toward including as many event-time lags as possible.

The main competing consideration is that we would ideally like for the event-time coefficients  $\gamma_j$  to all be estimated off of the same set of units. For example, in Jacobson, LaLonde, and Sullivan (1993) the events (job displacements) occur between 1980 and 1986, and the outcome (earnings) data are observed for the period 1974–1986. The event-time coefficients for “zero years since displacement” in Figure 1 are based off of all displacements. But the coefficients for “five years since displacement” can only be estimated for displacements that occur in 1980 or 1981. This means that the event-time coefficients post-displacement are estimated off of different sets of individuals. If there is something systematically different about the early- or late-displacement individuals, that could challenge interpretation of the coefficients. Even without a systematic difference, there will be a loss of statistical power as fewer units are available to identify the more remote coefficients further from the event itself. These considerations suggest if possible choosing the endpoints of the event window so that most or all coefficients are identified off of a balanced set of units. It also reinforces the need to show your reader the distribution of data across event times (as illustrated in Appendix A).

Depending on your data setup, there may be a straightforward resolution of these competing concerns. Suppose that the span of event dates lies within a ten-year window and that you have data for at least 20 years on either side of that window. Then it might be easy to focus on event-time endpoints that are within 20 years and have a fully balanced set of units for each event-time coefficient. But even in this case, if you observed that the interesting dynamics in terms of treatment effects are resolved within the first five years of treatment, it might make sense to limit the event window to eight to ten years, to bring more visual attention to the period of interest and show the leveling off.

If your data setup does not allow for a straightforward resolution, then you need to make a judgment call. In this case, it will be useful to offer a “robustness check” specification, in which you choose an alternate approach (such as a wider event window).

Finally, it will be important for readers of an event study to know the degree of balance or imbalance in the number of units available to identify the event coefficients. This could be discussed in the text or presented as an appendix table showing the count of units, by event time  $j$ .

### Special Attention for the Endpoints?

In event studies, it will be common to have data for some units that occur before or after the event window. In the notation of the traditional event study

equation, these would be observations for which  $j \leq -m$  or  $j \geq n$ . We need to decide how to address this issue.

One natural option is to create and include as many event dummies as possible. By directly estimating a  $\gamma_j$  for each event time, this removes the problem. This approach is natural and appropriate when the data structure has both treated and untreated units that are balanced in calendar time (for example, all US states are observed over the period 1980–2020).

A second option involves creating “end-cap” variables in the traditional event study equation. For example, the data before and including the “pre” endpoint might be given a common dummy variable,  $D_{i,t \leq E_i - m}$ . Similarly the data points after the “post” endpoint can share a common dummy variable. I think this choice is the most common one, and often it is a good one. Schmidheiny and Siegloch (2023) recommend this approach (which they call “binning”). They note that it can provide a natural identifying restriction for timing-based data structures, that it creates a natural connection to distributed lag models, and that it can lead to a straightforward way to model multiple events per unit.

The main risks to creating “end caps” arise with trending counterfactuals or trending treatment effects. These risks are discussed further in the next main section of the paper on trends. That section argues that we might be hesitant about including “post” end caps if we think that there is a chance that treatment effects are changing over event time.

Another possible approach is just to drop observations that have event dates outside of our main window of interest. This option keeps the specification simple and creates a balance in event time in our analysis sample (for example, all US states are observed from three periods before their event to five periods after). One possible trade-off is that the loss of data can weaken statistical power. An additional consideration arises when using only ever-treated units: with this data structure you can be balanced in calendar time or balanced in event time, but not both. If you limit your sample to be balanced in event time, then this creates an imbalance in calendar time. This in turn means that the time dummies at the extremes will be estimated off of strangely selected units. Because the time dummies play a fundamental role in the identification of treatment effects, this approach seems risky to me.

A final option is not to include an event-time variable that is turned on for these faraway observations. In this way, the faraway observations are pooled together as part of the reference group for when the event did not happen. For example, the reference group in Figure 1 appears to be “more than five years before job displacement.” This choice can be acceptable, but you should not include both “before the first endpoint” ( $j \leq j_{min}$ ) as well as “after the final endpoint” ( $j \geq j_{max}$ ) in the same reference group. Also, you should not combine “before the first endpoint” with the time period before the event in the same reference group. For example, in Figure 1 event time  $-1$  is not part of the reference group.

A related choice when presenting a graph of the event-time coefficients concerns whether and how to plot endpoint coefficients. When the endpoint has its own dummy variable, it will capture different averaging than the “interior” terms and will

sometimes appear to be offset a bit from the rest of the graph. This can distract the reader from the main story about what is going on closer to event time zero. On the other hand, including such endpoints in the graph gives a fuller picture of the model; indeed, including them can sometimes help to diagnose problems with the specification or the data. I think best practice should typically be to plot the endpoint coefficients and to indicate in the figure (whether with a distinct symbol and/or in the figure notes) that these are differently estimated from the other event study coefficients.

Overall, you need to explicitly decide how you will deal with the endpoints and inform your readers about your decision.

### **Pooling Event Times for Statistical Power**

With so many “key coefficients” to estimate, event study specifications can ask a lot of the data. Many event study models have pretty wide confidence intervals around each of the main  $\gamma_j$  coefficients. One strategy to regain some statistical power is to estimate models that pool together two or more adjacent event-time dummies, and then include these pooled variables in the model instead of the single-year event-time dummies. This approach strives for a balance between flexibility and statistical power. The main risk is that the pooling might obscure features of the empirical results. If you do this pooling, it is probably best to also show results from the unpooled model as a robustness check.

There are a variety of ways to pool event-time data. For example, one can restrict the model so that the coefficients will be the same in, say, periods 1 and 2, periods 3 and 4, and so on. Goodman-Bacon (2018) uses pooled event-time dummies to present results in table format. A more complex alternative is to restrict the event study coefficients to lie on a spline function between the points—essentially forcing a kind of averaging across points, but allowing for a flexible functional form (in a piecewise linear spline, the event study coefficients are forced to lie on a connected set of straight lines). For example, Bailey et al. (2020) and Lafortune, Rothstein, and Schanzenbach (2018) use spline restrictions for improved statistical power. However, this approach comes with some risk of mischaracterizing the pattern of treatment effects, in particular if the imposed model is not flexible enough to reflect reality. When using splines, it can make sense to allow for a jump or break in the splines in the transition from pretreatment to posttreatment periods. Lafortune, Rothstein, and Schanzenbach (2018) implement a model with a linear trend in event time, a jump at event time 0, and then a separate linear trend for event times after the event. As with pooling, it is best practice to also show the unconstrained model as a robustness check. Appendix E offers examples of pooling coefficients and spline models.

### **The Problem of Trends in Event Studies**

Trends can cause problems for event studies in two distinct ways. First, treated unit types might follow a different trend than untreated types in terms of their

untreated potential (and unobserved) outcomes, which can confound the estimated treatment effects. As illustrated by Figure 1 at the start of the paper, if a trend is already apparent before the event, it calls into question how to interpret patterns after the event. Second, treatment effects themselves may be trending in time-since-treatment. This second possibility is not necessarily a problem for event study models: after all, the point of these models is to allow for treatment effects that vary over time. But trending treatment effects can cause problems for the estimates from certain specification choices. In this section, I lay out these issues and some possible approaches in more detail. (Appendix F has an expanded discussion and graphical illustrations for several of the main points.)

### Pre-event Coefficients as a Diagnostic Tool

The estimated pre-event terms can serve as a tool for diagnosing trends. This is often done informally by inspecting the graph of the pre-event coefficients. This tool is most appropriate when working with difference-in-difference or hybrid data structures, which include never-treated units.

An additional consideration arises if we are working with a timing-based data structure with no control units. In this setting, Borusyak, Jaravel, and Spiess (2022) show that due to the multicollinearity of event-time, calendar-time, and unit fixed effects it is impossible to identify a linear trend in the set of treatment effects (or in the pretreatment coefficients). In this case, the best we can do is to look for nonlinear pre-trends. For this data structure, they recommend the normalization of setting an additional pretreatment  $\gamma_{-a}$  coefficient to be zero. This step imposes a zero pre-trend, and allows for visual or statistical inspection of the other pretreatment coefficients as a check for nonlinear pre-trends. Schmidheiny and Siegloch (2023) argue that using end caps can provide identification of the event-time coefficients in a timing-based data structure. This would restore the ability to examine pre-event trends.

A separate difficulty is that if you have too few pretreatment periods, it can be hard to distinguish between actual pre-trends and statistical noise. This limits the comfort a researcher can take from “passing” a test of no visible pre-trend. There is no hard and fast rule for “how few is too few.” When looking at a graph of event study coefficient estimates, I find it useful to mentally visualize the range of possible pre-trends that could be consistent with the pretreatment estimates. Across papers that I see, this approach often leaves me feeling skeptical if I see three or fewer pre-event terms. But this depends on both the variability and the apparent trends among those pretreatment coefficients. If you are concerned about this issue, a simple additional step here is to add more pretreatment periods, extending further back in event time. In a more structured approach, Dobkin et al. (2018) plot the linear pre-trend from a parametric model on the figures that show event study coefficients.

Recent econometric work identifies some potential problems with using pre-trends as a diagnostic tool. Roth (2022) notes that the widespread, informal practice of “rounding insignificant pre-trends to zero” can lead to “pre-test bias.”



Even a mild pre-trend, which cannot be visually or statistically detected, can still meaningfully influence the estimated posttreatment impacts. Roth argues that if we are confident of the functional form of the trends (for example, that the trends are linear in time) we should plan always to control for trends regardless of whether or not there is not a strongly apparent pre-trend. He also presents more sophisticated extensions to methods of controlling for trends, based on Freyaldenhoven, Hansen, and Shapiro (2019) and Rambachan and Roth (2023), that allow a researcher to proceed under weaker assumptions about the functional form of the trends.

Separately, pre-trends can be biased if our underlying model is misspecified. Sun and Abraham (2021) examine the case where the misspecification arises from different unit types having different treatment effects—say, if those treated earlier in calendar time have larger treatment effects than those treated later in time. For example, suppose that in Jacobson, LaLonde, and Sullivan (1993) the individuals facing job displacement early in the sample (1980–1982) have greater impacts than those displaced later in the sample (1983–1986), perhaps due to changes in the macroeconomic environment. This difference in treatment effects can lead to a (spurious) apparent trend in the estimated pre-event coefficients. In this case, the appearance of a pre-trend is an indication that something is wrong with the specification of our model.<sup>10</sup> De Chaisemartin and D’Haultfœuille (2022) propose alternative pre-trend estimators that are robust to different unit types having different treatment effects.

### **Controlling for Unit-Specific Trends**

Rather than focusing on pre-trends as a diagnostic measure, an alternative is to control for unit-specific trends, by including a (continuous) time variable interacted with unit (for example, state) dummies. This approach is suitable if we believe that pre-trends reflect trending omitted variables that could bias the main estimates of the treatment. Controlling for unit-specific trends aims to eliminate this omitted variables bias.

For example, Alsan and Goldin (2019) use an event study to examine the historical introduction of clean water and sewer projects across municipalities during 1880–1920. In their specification they control for municipality-specific time trends. In a separate example, Bostwick, Fischer, and Lang (2022) study the impacts of a university switching from a quarter-based to a semester-based schedule. They want to make sure their estimates are not confounded by outcomes trending differently across universities, so they control for university-specific time trends.

What are the main trade-offs between using pre-trends as a diagnostic and controlling for unit-specific trends? First, controlling for unit trends changes the counterfactual thought experiment. Our treatment effect estimates now have an

<sup>10</sup>The specification error here is the assumption of treatment effects that are the same for both early and late treated units. This contrasts with our usual interpretation of pre-trends as indicating anticipation effects or different underlying trends in untreated potential outcomes.



interpretation of “my outcome compared to the reference period, and net of underlying linear trends in the counterfactual between that period and now.” Second, because the counterfactual now controls for these trends, our pre-trends should look flat by construction. Thus, we lose the basic falsification test that the pre-trends provide in the basic model. However, one can still use the pre-event coefficients to look for nonlinear violations of the parallel trends assumption.

Adding unit trend controls may also interact uncomfortably with the “too many variables” and “multicollinearities abound” challenges of event studies. A unit-specific time trend term will be multicollinear with the unit dummies, time dummies, and event-time variables. This means that it will be necessary to add (at least) one more additional parameter restriction. As noted earlier, it is imprudent to just let our software address the collinearity problem by dropping a variable on its own, because what it drops might undermine our interpretation of the resulting estimates. The choice of which restriction to apply is guided by the same principle as before: the additional restrictions are untestable, but estimated coefficients on the trend terms will be affected by the restrictions we place, so we want it to be as “obviously true” as possible. Our additional restriction should be applied to the event study coefficients  $\gamma_j$  so that we do not undermine the panel fixed effects controls in the estimation. A common choice is to impose a restriction that two event coefficients are equal. The trend estimates will be estimated in the context of those restrictions; in particular, the later treatment estimates may “pivot” as a result of imposing this restriction. (This is illustrated in online Appendix F.)

### Trends versus Pre-trends

The estimated parameters for unit-specific trends will seek to capture trending behavior both before and after the event. But what if treatment effects are also trending? Suppose that in our traditional event study equation, treatment effects are increasing in event time:  $\gamma_0 < \gamma_1 < \gamma_2 \dots$ . Then, an estimate of unit-specific trends might try to fit both pre-event trends *and* the treatment effect pattern. This in turn can bias the estimated event study coefficients. This problem can occur if our parameter restrictions include post-event terms, such as a post-event end cap. The post-event end cap (for example, “six or more periods after the event”) forces all the estimated event-time effects  $\gamma_j$  within the end cap to be the same. If instead they are truly trending, this can cause problems. An extreme version of this is a difference-in-difference specification, which restricts all post-event treatment effects to be the same.

This is the main argument in the Wolfers (2006) critique of prior difference-in-difference approaches examining the impact of unilateral divorce laws on divorce rates. Much of this work used state trend controls. Wolfers argues that these laws will have dynamic impacts—that is, trending  $\gamma_j$  for  $j \geq 0$ . Because of this, the estimated state-specific time trends will be contaminated by trying to also fit the trending treatment impacts. This in turn will bias the main estimates. Wolfers proposes as an improvement a variation of an event study specification for the post-event periods. (I present a stylized illustration of this phenomenon in online Appendix G.2.)

One option to prevent this problem is to focus on controlling for “pre-trends” only. However, this may require custom programming (online Appendix F.4 presents one approach). Another option is to model your event study terms (the  $\gamma_j \cdot D_{i,t-j}$  terms in the traditional event study equation) so that the unit-specific time trends will not be confounded by trending treatment effects. For example, one can drop all constraints on the event study parameters for posttreatment by including all “post” event-time dummies and having no “post” end cap. This step will ensure that the trend coefficients are estimated based only on pre-event data.

### Recommendations in Controlling for Trends

These considerations lead to guidelines for researchers who are controlling for trends. First, don’t let post-event parameter restrictions influence your estimated trends, unless you are highly confident that the treatment effects are not trending in that range. Otherwise, your control for trends may be picking up part of the trending treatment event.

Second, if one of your extra parameter restrictions is in the form of equality of two event coefficients, consider spacing those coefficients further apart, because the impact of any statistical “noise” between the two coefficients will be larger if they are closer together. As an alternative, focus the restrictions on event study parameters that allow for more averaging across units.

One restriction that accommodates the considerations above—at least for the difference-in-differences and the hybrid data structures—is to constrain the trend in the “reference period” event study coefficients to be zero. This approach has the advantage of averaging across several coefficients, and reducing the impact of noise from any one or two of them. It also respects the notion of having a reference period embodied in the normalizing restriction (as discussed earlier), and offers a natural counterfactual interpretation: “Compared to the level and trend in the reference period, and the over-calendar-time changes from control units, what would my expected outcome be?”<sup>11</sup>

Finally, if we are working with a timing-based data structure, controlling for trends has potential to create surprising and severe problems. Adding *linear* trend controls (and the required additional parameter restriction) can induce *quadratic* trends into our estimated event study coefficients. This arises from a subtle way in which the event dummies are collinear with the other variables in the model (as illustrated in online Appendix F.2). The key lesson is to be extra cautious about the combination of trend controls and a timing-based data structure.

There is one way in which adjustments for trends can often be simplified compared to common practice: we can focus on unit-type trends, rather than

<sup>11</sup> Given a reference period  $(k_1, k_2)$ , this is implemented with the following linear restriction on the event study parameters:  $\sum_{j=k_1}^{k_2} \left( j - \frac{k_1 + k_2}{2} \right) \cdot \gamma_j = 0$ . To derive this, consider a bivariate regression  $\gamma_j = \phi_0 + \phi_1 \cdot j$ . To impose a zero trend, we want  $\hat{\phi}_1 = 0$ . The left hand side of the proposed restriction is the numerator for the coefficient  $\hat{\phi}_1$ .

unit-specific trends. That is, we can allow for one shared trend parameter for each group of units that share an event date. This is because the event study variables depend only on unit type and time. Once we condition on unit-type trends, any remaining unit-specific trends will be orthogonal to the event study dummies and will not influence their coefficients.

## Statistical Inference for Event Study Models

For researchers, the usual primary concern is to have unbiased point estimates. However, we also need to be able to conduct statistical inference to test hypotheses about the true state of the world.

### Cluster-Robust Inference

For event study models, the current practice appears to be to calculate cluster-robust standard errors, with clusters defined as the  $i$ -level units. This starting place is sensible. The key right-hand-side variables in an event study have some degree of autocorrelation and it is plausible to think about the model error term also being positively autocorrelated over time within a unit. Taken together, this argues for clustering at the unit level. The general rule of thumb is that we want to cluster at a level when there is correlation in the scores ( $X_i e_i$ , driven by correlation in the model errors  $e$ ) across units in that cluster (Cameron and Miller 2015, section II.C). If the underlying event is shared across units, then this argues for clustering at a higher level. For example, if our dataset is a panel of individuals, but the event is a state-level policy change, then we likely want to cluster at the level of the state.

However, one potential concern is that standard cluster-robust methods provide accurate standard errors only if the number of clusters is “large enough,” with no hard and fast rule for what that means. Folk wisdom and some simulations offer rules-of-thumb like 42 or 50 clusters, but in some settings this is not enough, and in other settings a smaller number will suffice. When there are too few clusters, traditional cluster-robust methods may over-reject. If we are facing too few clusters, we need to take account of this in our inference procedures (Cameron and Miller 2015, section VI).

The problem of few clusters is exacerbated when the clusters are of asymmetric size or when there are very few treated units. In these settings, our conclusions need to be more tentative. But it is not so bad that you just have to give up. In these settings, the adjustments offered in Imbens and Kolesar (2016), Carter, Schnepel, and Steigerwald (2017), and MacKinnon and Webb (2017) might be a good choice.<sup>12</sup>

<sup>12</sup>Permutation tests are an alternative approach to conducting inference. The idea is to randomly reassign pseudo-event dates across units, and re-estimate the model. Repeat this procedure many times, to construct a distribution of “estimated treatment effects, when there is no actual treatment.” A distribution of test statistics can be constructed from these permutations. The main estimates can be compared

### **The Spatial Correlation Problem**

The basic premise of cluster-robust inference requires that clusters are independent from one another. Spatial correlation in event dates undercuts this premise, and doing so may result in over-rejection of the null hypothesis. When events are the result of a political process or influenced by economic circumstances, neighboring units (say, neighboring states) can be closer in event date than more distant units. Often, economic outcomes are also spatially correlated.

For the most part, the current empirical literature ignores this concern, but there are some potential ways to address it; for example, see Conley (1999) on spatial robust standard errors. However, there is little guidance on how to measure “distance” across some combination of space and time.

Another possibility is to allow for arbitrary correlations in observations within a cluster, and also allow for correlation that decays in calendar time across observations in nearby time periods, regardless of the unit to which they belong (as in Driscoll and Kraay 1998). This approach allows for greater dependence across observations than the current standard. But there is no “button to push” for implementation of these approaches, so it will require custom programming. In addition, allowing for spatial autocorrelation is likely to make the “few clusters” problem even more salient.

For the near term, a basic precaution is to examine your data for the possibility of spatial correlation in event dates, although currently there is no hard-and-fast guidance for what levels of spatial autocorrelation should be a matter of concern. For now, the standard practice of “cluster on the underlying event” seems likely to continue. However, researchers should probably start to pay more attention to spatial correlation in the future.

### **Extensions and Challenges**

My discussion has focused on a basic version of event study models. In this section I briefly note a few of the additional extensions and challenges that may arise.

#### **Events with Variable Intensity**

What should researchers do when events can vary in their magnitude? For example, suppose the event is a cigarette tax hike or an increase in the state minimum wage. We might want to allow for the event to scale proportionally to the size of the shock. This issue can be handled in a straightforward way by pre-multiplying the

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against these distributions, and if they fall in the tails of the distribution, this is evidence against the null hypothesis of no impact. MacKinnon and Webb (2019) study this randomization approach in a difference-in-difference setting with few units, very few treated units, and clusters having different sizes (for example, larger and smaller US states). Young (2019) also shows that randomization procedures (based on t-statistics) perform well. I think it likely that such results would carry over to the event study setting.

event dummy by the magnitude of the event. For example, the event variable  $D_{i,s}$  could be “by what percentage were cigarette taxes hiked?”

One interesting variation is found in Goodman-Bacon (2018), who examines the introduction of Medicaid in the 1960s across US states. The impact of introduction varied state-by-state as a function of the fraction of population that was receiving assistance from the Aid to Families with Dependent Children welfare program at the time when Medicaid was introduced. This setup combines both timing-based and variable-intensity variation in treatment. Concerned about event dates being correlated with preexisting trends, Goodman-Bacon (2018) isolates the variation from variable-intensity of treatment from the timing by including dummies to control for event date by calendar year.

A group of recent papers center event study models within “mover” strategies. These include consumers changing purchase patterns as they move across locations (Bronnenberg, Dubé, and Gentzkow 2012) and either doctors (Molitor 2018) or patients (Finkelstein, Gentzkow, and Williams 2016) moving from one region to another with different patterns of health-care practice. These mover designs often pair with variable intensity of treatment. For example, Finkelstein, Gentzkow, and Williams (2016) track Medicare patients who move across regions with different intensities of medical usage. In this case the event is the move, and the variable intensity reflects the difference in medical usage between the destination and origin locations. Molitor (2018) examines cardiologists’ patterns of practice as they move across regions. Again, the variable intensity of the event is given by the difference in regional patterns of practice across destination and origin locations.

### More than One Event Per Unit

What if there is a possibility of multiple events per unit? For example, the data might include repeated layoffs or repeated state minimum wage hikes.

For the basic case, this can be straightforward to implement. We define the event  $D_{i,s}$  to be one in any period where an event occurs, and we allow this to happen in different time periods for the same unit  $i$ . Thus, more than one of the event-time dummies can be turned on simultaneously. Sandler and Sandler (2014) suggest this approach.<sup>13</sup> However, this approach provides a specific interpretation of the estimated coefficients—a “partial effects” interpretation, holding constant the potential impact of subsequent events (including those whose existence might in turn be impacted by the current event). This can be different from the “total effect,” which includes the impact of today’s event on the likelihood of future events happening. Krolikowski (2018) explores this issue by using a simulation to

<sup>13</sup>A related but alternative approach is to duplicate data around the event. In this approach, each observation is “split” into multiple new observations based on unique combination event-by-underlying-unit. However, Sandler and Sandler (2014) show using Monte Carlo simulations that in some settings this can lead to biased estimates.

propose a weighted average of the partial effect estimates as well as a “first event only” model.<sup>14</sup>

Another approach is to adjust the definition of an event so as to have only one per unit. For example, in the Jacobson, LaLonde, and Sullivan (1993) paper behind Figure 1, the focus is on the first layoff, and subsequent layoffs are not modeled. This approach could be implemented based on “biggest event” or “first big event.” Again, issues will arise in interpreting the resulting coefficient. By bundling subsequent events (and their dynamic impacts) into the definition of “treatment,” we have a potentially nonintuitive definition of treatment—a version of the partial-versus-total effects problem just mentioned. In some cases, this approach is combined with using the “never treated” group as a control group. This combination can introduce the selection issue mentioned earlier—that is, the control group may now differ in unobserved ways, like stronger skills or labor market attachment, so comparisons with them will give biased counterfactuals for the treated. This can make the estimated effects of the displacement look worse than the true causal effects. Separately, it can raise concerns about external validity of the findings to the broader population.

The possibility of multiple events raises the question of whether the effect of an event depends on the history of other events. A first layoff is one thing, but we can imagine that subsequent layoffs are possibly worse (increasing fragility) or not quite as bad (either toughening up or “floor effects”) as the first. In principle, the basic model could be modified to estimate sensitivity in treatment effects directly, based on the history of prior events, but I have not yet seen this implemented.

### **Heterogeneous Treatment Effects**

What if the effect of treatment does not just vary in “time since event,” but also depends systematically on the unit type, time, or context? For example, the treatment effect might depend on observable variables or on the date of adoption of the event.

Suppose we are interested in how a treatment effect varies across men and women. We can then include one set of event dummies for men and another set of event dummies for women. More generally, we can include a set of interaction terms, based on the covariates that we believe influence the treatment effects. In taking this step, it is important to follow usual best practice for interaction terms in regression models, such as including direct controls for the covariates if they are time-varying. These interactions can use up a lot of variation in the data, and in response, it may be useful to impose a parametric simplification on the interaction terms. For example, the Jacobson, LaLonde, and Sullivan (1993) example

<sup>14</sup> Basso, Miller, and Schaller (2022) label the partial effect “Y channel only (YCO)” and contrast the Event Study approach with a Local Projections approach to estimating dynamic treatment effects. They observe that Local Projections can directly recover the “total effect” (corresponding to the impulse response) and show that it can be transformed into the YCO. Cellini, Ferreira, and Rothstein (2010) also address this distinction in the context of a dynamic regression discontinuity model and estimate both effects. They label the partial effect “Treatment on the Treated” and the total effect “Intent to Treat.”

from Figure 1 used a parsimonious approach of having three periods of treatment effect: the “dip” (the 13 quarters prior to job displacement), the “drop” (the quarter of displacement), and the “recovery” (six quarters following displacement). They allow covariates to produce different slopes (in event time) for these three periods.

In a setting with varying event dates, we might want to model the possibility that the dynamic treatment effects depend on the timing of adoption. For example, US states that are early to adopt a policy might be the ones that benefit the most from that policy; late adopters might have less or even opposite-signed effects. One approach is to treat the actual event date as an observable variable and estimate treatment effects based on the date, or perhaps using an “early”/“late” adopter dummy variable. This approach should work, so long as there are control units or enough variation in event dates.

There is a recent, active, and promising literature on how event study models perform when treatment effects differ across units and when we do not know the functional form of how they differ. This raises issues analogous to those of local average treatment effects (LATE) in the instrumental variables context, in which our main estimates are a weighted average of the underlying treatment effects. Typically these weights might not correspond to our common-sense intuitions or to our desired weighting.<sup>15</sup> This literature typically considers the case where there is (at most) a single event per unit. Sun and Abraham (2021) point out that the overall effect will be a weighted average of the heterogeneous effects for different unit types. They show that an auxiliary regression can calculate the implied weights and also propose an alternative estimation method that works to recover a target average treatment effect. Using a different strategy, de Chaisemartin and D’Haultfœuille (2022) propose relying on using not-yet-treated units and the parallel trends assumption to recover estimates of the treatment effects for each treated unit type, which can then be averaged together.

### **When “Time” Is Not Calendar Time**

What if the time variable is not calendar time? This situation can arise in cohort studies: for example Duflo (2001) studies the life-course impact of childhood exposure to school availability in Indonesia based on district and year of birth, and Bailey, Sun, and Timpe (2021) examine the long run impacts of childhood exposure to Head Start in the United States, with treatment based on county and year of birth. These are standard event study analyses, only the time variable is “year of birth” instead of calendar time.

The challenge here is how best to deal with cohort, age, and time (of survey) effects. The basic event study specification requires fixed effects for cohort. Often the outcomes of interest—such as labor market or demographic outcomes—depend

<sup>15</sup>This theme is addressed for ordinary least squares in Angrist (1998) and Słoczyński (2022); for one way fixed effects models in Gibbons, Suárez Serrato, and Urbancic (2019) and Miller, Shenhav, and Grosz (2021); and for difference-in-difference in Goodman-Bacon (2021a), Callaway and Sant’Anna (2021), de Chaisemartin and D’Haultfœuille (2020), and Borusyak, Jaravel, and Spiess (2022).



importantly on age in nonlinear ways. There can also be important calendar-time effects (for example, if some data is collected in a recession). This raises the challenge of age-cohort-time multicollinearity (as discussed in Deaton 2018, pp. 123–127).

There is no avoiding the fact that the analysis becomes complicated here. If theory suggests all three factors—age, cohort, and time—may be important, I recommend including all three sets of dummies.<sup>16</sup> One leading alternative is instead to include a set of two-way interaction dummies: either *age-by-cohort* fixed effects, *cohort-by-time* fixed effects, or *age-by-time* fixed effects. Any one set of these two-way-interactive fixed effects controls for more, but also “uses up” more variation in the data, which raises its own issues. But it seems like good practice to at least include a specification with these two-way-interactive fixed effects as a robustness check.

A final issue is that in producing an overall estimate, we might want to make sure that each cohort is weighted proportional to its population, because the thought experiment of the model centers on the cohorts. However, our data might not naturally reflect those weights, perhaps especially when we are combining data from different-sized datasets.<sup>17</sup> This can set up a choice between improved statistical power (weighting based on the data in our sample) and improved representativeness (weighting based on size of cohorts), and I do not think there is currently a settled “best practice” for these issues. But we should think carefully about how to weight our observations, and not simply take the weights as they are given by the datasets we are using.

## Conclusion

Event study models are great! But behind that attractive interpretive graph, researchers are necessarily making decisions. This raises risks of bias due to systematic (if perhaps unconscious) model selection processes, committed by either the researcher or the journal review process. Despite these risks, these decisions are unavoidable. There is no “button to push” that can automate the necessary judgment calls. For now, best practice should be to increase transparency through bringing clarity about the specification decisions made (and the reasons for those decisions) and to discuss robustness to alternative decisions, along with providing both estimation code and (whenever possible) data for replication.

<sup>16</sup>Sometimes researchers include only two sets of these three possible sets of dummy variables, such as dummies for age and for cohort. Presumably this is motivated by the collinear relationship: age = cohort + time. However, among the many coefficients for the three sets of dummy variables, there is only one degree of collinearity. So omitting a full block of dummies—say, leaving out the time dummies—imposes many more restrictions than are necessary.

<sup>17</sup>For example, the outcome data in Bailey, Sun, and Timpe (2021) pool observations from the long-form 2000 Census and the 2001–2018 ACS. The relatively large number of observations in the census means that birth cohorts from 1950 to 1965 are weighted more heavily than later cohorts, relative to their population size.



■ I thank Gaetano Basso, Colin Cameron, Hilary Hoynes, Giulia Olivero, Marianne Page, Zhuan Pei, Jessamyn Schaller, my students in my PhD Applied Econometrics classes, and the editors, for many helpful comments and conversations. Special thanks to Liz Cascio, who first explained event study models to me in such a way that I felt like I started to “get it.”

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