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**The Estimation of  
Causal Effects by  
Difference-in-Difference  
Methods**

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# The Estimation of Causal Effects by Difference-in-Difference Methods

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## The Estimation of Causal Effects by Difference-in-Difference Methods\*

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### Abstract

This survey gives a brief overview of the literature on the difference-in-difference (DiD) estimation strategy and discusses major issues using a treatment effects perspective. In this sense, this survey gives a somewhat different view on DiD than the standard textbook discussion of the DiD model, but it will not be as complete as the latter. It contains some extensions of the literature, for example, a discussion of, and suggestions for nonlinear DiD estimators as well as DiD estimators based on propensity-score type matching methods.

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*Keywords:* Causal inference, counterfactual analysis, before-after-treatment-control design, control group design with pretest and posttest.

*JEL Codes:* C21, C23, C31, C33

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# 1

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## Introduction

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The Difference-in-Difference (DiD) approach is a research design for estimating causal effects. It is popular in empirical economics, for example, to estimate the effects of certain policy interventions and policy changes that do not affect everybody at the same time and in the same way. It is used in other social sciences as well.<sup>1</sup> DiD could be an attractive choice when using research designs based on controlling for confounding variables or using instrumental variables is deemed unsuitable, and at the same time, pre-treatment information is available.<sup>2</sup> The DiD design is usually based on comparing *de facto* four different groups of objects. Three of these groups are not affected by the treatment. In many applications, “time” is an important variable to

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<sup>1</sup>In other social sciences the DiD approach is also denoted as “untreated control group design with independent pretest and posttest samples” or “control group design with pretest and posttest.” See, for example, Cook and Campbell (1979), Rosenbaum (2001), and Shadish et al. (2002) for further references.

<sup>2</sup>Following the literature, the event for which we want to estimate the causal effect is called the *treatment*. The *outcome* denotes the variable that will be used to measure the effect of the treatment. Outcomes that would be realised if a specific treatment has, or would have been applied, are called *potential outcomes*. A variable is called *confounding* if it is related to the treatment and the potential outcomes. A variable is called an *instrument* if it influences the treatment but not the potential outcomes.

## 2 Introduction

distinguish the groups.<sup>3</sup> Besides the group which already received the treatment (post-treatment treated), these groups are the treated prior to their treatment (pre-treatment treated), the nontreated in the period before the treatment occurs to the treated (pre-treatment nontreated), and the nontreated in the current period (post-treatment nontreated).<sup>4</sup> The idea of this empirical strategy is that if the two treated and the two nontreated groups are subject to the same time trends, and if the treatment has had no effect in the pre-treatment period, then an estimate of the “effect” of the treatment in a period in which it is known to have none, can be used to remove the effect of confounding factors to which a comparison of post-treatment outcomes of treated and nontreated may be subject to. This is to say that we use the mean changes of the outcome variables for the nontreated over time and add them to the mean level of the outcome variable for the treated prior to treatment to obtain the mean outcome the treated would have experienced if they had not been subjected to the treatment.

This survey presents a brief overview of the literature on the difference-in-difference estimation strategy and discusses major issues mainly using a treatment effect perspective (and language) that allows, in our opinion, more general considerations than the classical regression formulation that still dominates the applied work. In this sense, this survey might give a somewhat different perspective than the standard text book discussion of the DiD design, but it will not be as complete as the latter. Thus, this review is more of a complement than a substitute to the excellent text type discussions of the DiD approach that are already available in the literature (e.g., Angrist and Pischke, 2009; Blundell and Costa Dias, 2009; Imbens and Wooldridge, 2009).

This review focuses on the case of only two differences although the basic ideas of DiD estimation could be extended to more than

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<sup>3</sup> As the concept of time is only used to define a group that is similar to the treated group with respect to relevant unobservable variables and whose members have not (yet) participated, any other characteristic may be used instead of time as well, as long as the formal conditions given below are fulfilled.

<sup>4</sup> When a data set is available in which everybody is observed in all periods, there will be just two groups with outcomes measured before and after the treatment.

two dimensions to create difference-in-difference-in-difference-in- ... estimators.<sup>5</sup> However, the basic ideas of the approach of taking multiple differences are already apparent with two dimensions. Thus, we refrain from addressing these higher dimensions to keep the discussion as focused as possible.

The outline of this survey is as follows: The next section gives a historical perspective and discusses some interesting applications. Section 3, which is the main part of this survey, discusses identification issues at length. Section 4 concerns DiD specific issues related to estimation, including a discussion of propensity score matching estimation of DiD models. Section 5 discusses some specific issues related to inference, and Section 6 considers important practical extensions to the basic approach. Section 7 concludes. Some short proofs are relegated to a technical appendix.

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<sup>5</sup>For example, Yelowitz (1995) analyzes the effects of losing public health insurance on labor market decisions in the United States by using Medicaid eligibility that varies over time, state and age (of the child in the household). Another example for a triple difference is the paper by Ravallion et al. (2005) who analyze the effects of a social programme based on a comparison of participants with nonparticipants and ex-participants.

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