Testing a (not-quite) necessary condition for parallel trends in difference-in-differences using a CCC test
A Program for Stata

Sunny Karim

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CCC test

- Karim, 2026 develops a test to detect whether the **Common Causality of Covariates (CCC)** assumption holds.
- CCC is an assumption on the **untreated potential outcome** $Y_{i,s,t}(0)$
- Under **linearity**, the untreated potential outcome model for region s in period t:

$$Y_{i,s,t}(0) = \theta^{\circ}_{s,t} + \gamma^{\circ}_{s,t} X_{i,s,t} + \epsilon_{i,s,t}.$$

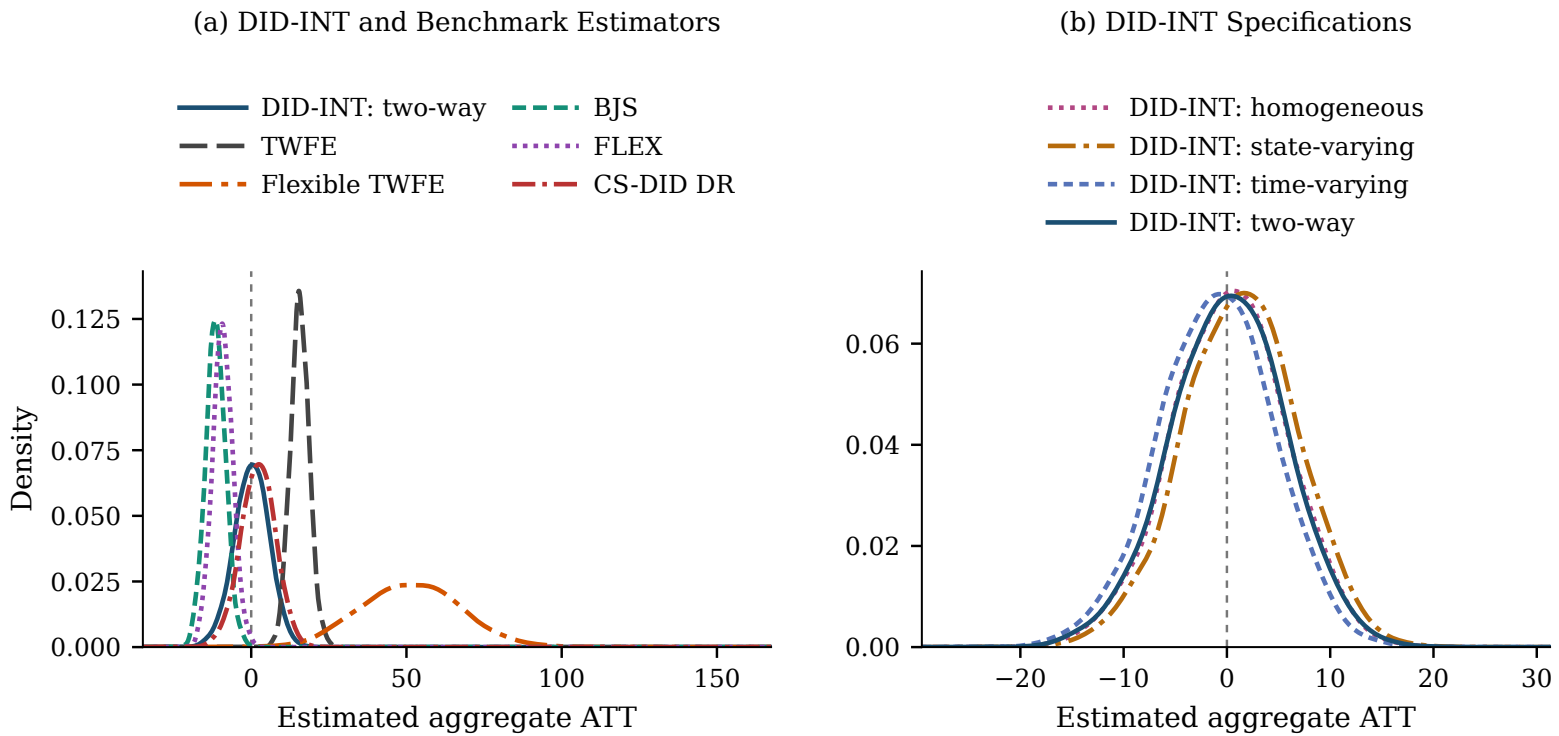
- i is an index for the individual, s is an index for region and t is an index for time.
- Many DID estimators implicitly assume that the effect of the covariate $X_{i,s,t}$ on the untreated potential outcome outcome $Y_{i,s,t}(0)$ is **common across regions and periods**:

$$\gamma^{\circ}_{s,t} = \gamma^{\circ}, \qquad \forall s, t.$$

- We call this the **Common Causality of Covariates (CCC)** assumption.
- My paper focuses on cases where **the CCC assumption is violated**.

Why Is CCC Important?

- **Ignoring CCC violations** can lead to inconsistent estimates from many DID estimators.



- The **CCC test** helps researchers identify the appropriate **functional form for covariates**.

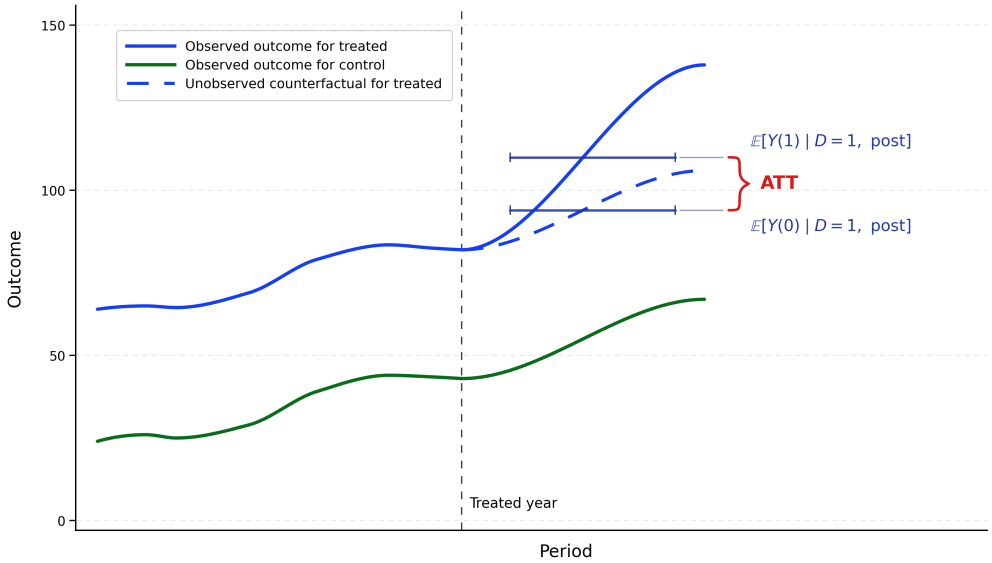
Motivation

- **Why do we need covariates?**
- Our parameter of interest is the **Average Treatment Effect on the Treated (ATT)**.

$$ATT = \mathbb{E}\left[Y_{i,s,t}(1) - \underbrace{Y_{i,s,t}(0)}_{\text{Unobserved}} \mid D_{i,s,t} = 1 \right]$$

- Here, $Y_{i,s,t}(1)$ is the treated potential outcome, $Y_{i,s,t}(0)$ is the untreated potential outcome, and $D_{i,s,t}$ is a treatment dummy.
- $Y_{i,s,t}(0)$ is **unobserved** for treated individuals.
- With **random assignment**, the control group provides a valid counterfactual on average.
- However, treatment assignment is rarely random for **region-based policies**.
- Therefore, identifying the ATT requires **strong assumptions**.

A Key Identifying Assumption of DID



- Requires a **control group** and a **pre-treatment period**.
- Requires the **Parallel Trends (PT)** assumption.

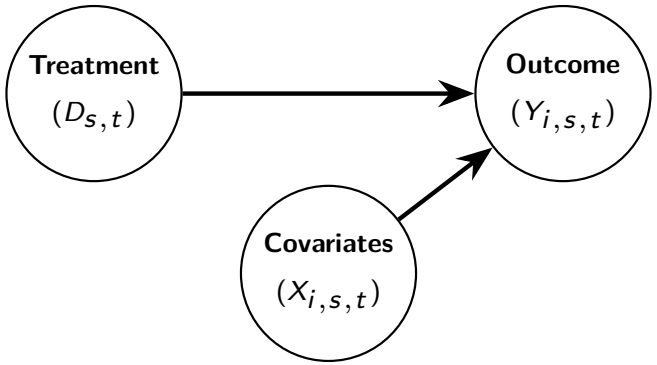
Parallel Trends (PT) Assumption

Assumption: The average outcome trends between the treated and control regions would be the same in the absence of treatment

$$\mathbb{E}\left[Y_{i,s,t}(0) - Y_{i,s,t-1}(0) \mid D_{i,s,t} = 1\right] = \mathbb{E}\left[Y_{i,s,t}(0) - Y_{i,s,t-1}(0) \mid D_{i,s,t} = 0\right].$$

- This is a **strong assumption**: **All other factors affecting the outcome** must not generate different untreated trends between the treated and control groups.

Why Do We Need Covariates?



- Observable characteristics, or **covariates**, affect outcomes and may exhibit **different trends** across groups.
- These differences can cause outcome trends to diverge, violating **Parallel Trends (PT)**.
- Controlling for covariates can make **Conditional Parallel Trends (CPT)** more plausible.

Conditional Parallel Trends (CPT) Assumption

The average outcome trends between the treated and control regions would be the same in the absence of treatment, **conditional on covariates**.

$$\mathbb{E}\left[Y_{i,s,t}(0) - Y_{i,s,t-1}(0) \mid D_{i,s,t} = 1, X_{i,s,t} = x\right] = \mathbb{E}\left[Y_{i,s,t}(0) - Y_{i,s,t-1}(0) \mid D_{i,s,t} = 0, X_{i,s,t} = x\right], \quad \forall x.$$

Contributions

- **Good Controls Gone Bad: Difference-in-Differences with Covariates** (Karim and Webb, 2024)
  - We establish the relationship between **CCC violations and CPT**.
  - We show that CPT can hold even when CCC is violated.
    - CCC is **not necessary** for CPT.
  - This possibility has received limited attention in the existing DID literature.
  - As a result, many DID estimators impose CCC while modelling covarites.
  - For example, the Two-way Fixed Effects (TWFE) models covariates with a common coefficient:

$$Y_{i,s,t} = \alpha_s + \delta_t + \tau D_{i,s,t} + \gamma X_{i,s,t} + \epsilon_{i,s,t}.$$

- Estimators become **inconsistent**.
- The **CCC test** helps researchers determine **how covariates should enter the model** to recover consistent ATT estimates.
- CPT is not testable, but CCC is.

Relationship between CCC and CPT

- Assume a simple setup with two regions, and two periods:
  - Region A is treated, B is not.
  - Period 1 is the pre-intervention period, and period 2 is the post-intervention period.
- We substitute the untreated potential outcome model $Y_{i,s,t}(0) = \theta^{\circ}_{s,t} + \gamma^{\circ}_{s,t} X_{i,s,t} + \epsilon_{i,s,t}$ into the expression for conditional parallel trends, and simplify to derive the jointly necessary and sufficient conditions for CPT.
- **Jointly necessary and sufficient conditions:**

$$\text{Condition 1 (Parallel trends in intercepts):} \quad \theta^{\circ}_{A,2} - \theta^{\circ}_{A,1} = \theta^{\circ}_{B,2} - \theta^{\circ}_{B,1},$$

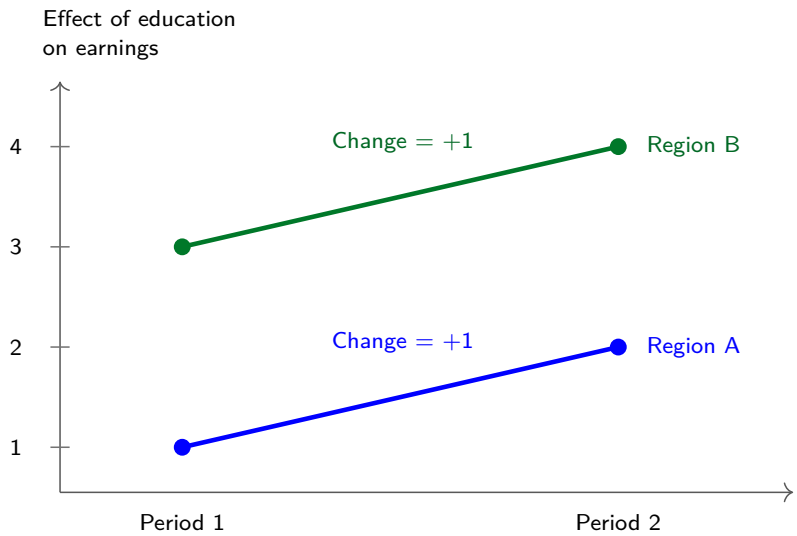
$$\text{Condition 2 (Parallel trends in coefficients):} \quad \gamma^{\circ}_{A,2} - \gamma^{\circ}_{A,1} = \gamma^{\circ}_{B,2} - \gamma^{\circ}_{B,1}.$$

- **Condition 1:** The component of the untreated potential outcomes not explained by $X_{i,s,t}$'s follow the same trends.
- **Condition 2:** Covariate coefficients follow the same trend.
- **Our contribution:** Condition 2 reveals a previously overlooked possibility: **CCC can be violated while CPT still holds**.

When Condition 2 Holds

- **Parallel changes in covariate effects**:

$$\underbrace{\gamma^{\circ}_{A,2} - \gamma^{\circ}_{A,1}}_{+1} = \underbrace{\gamma^{\circ}_{B,2} - \gamma^{\circ}_{B,1}}_{+1}.$$

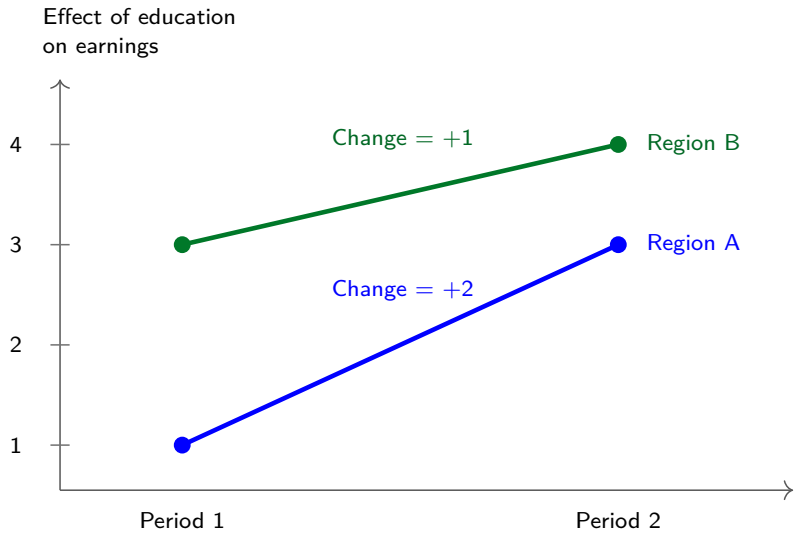


- CCC is violated because effects differ across regions and periods, but **CPT can hold** when intercept trends are also parallel.

When Condition 2 Is Violated

- **Nonparallel changes in covariate effects**:

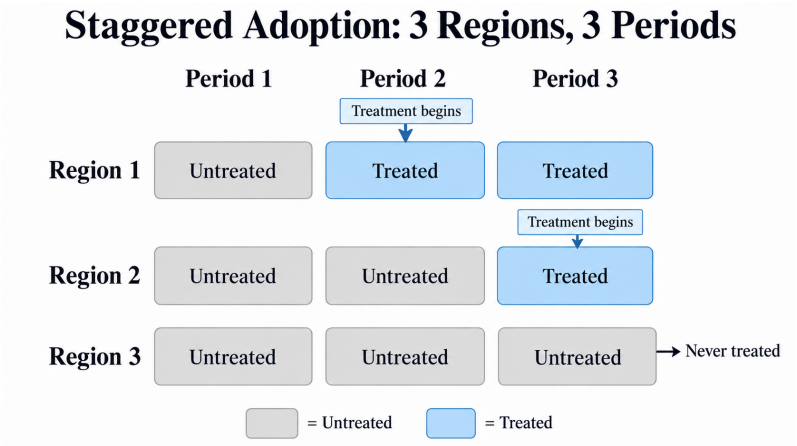
$$\underbrace{\gamma^{\circ}_{A,2} - \gamma^{\circ}_{A,1}}_{+2} \neq \underbrace{\gamma^{\circ}_{B,2} - \gamma^{\circ}_{B,1}}_{+1}.$$



- The covariate effects change by different amounts. Even if intercept trends are parallel, **CPT fails**.
- **Accounting for CCC violations can recover obscured PT.**

Setup

- For the remainder of the talk, let's consider a more realistic setup with staggered adoption.
- Assume there are S regions observed over T time periods.
- Staggered treatment adoption:
  - Different regions adopt treatment at different times.
  - Once treated, regions remain treated.
  - Some regions may never receive treatment.



Four Possible Covariate Specifications

- Depending on which **CCC restrictions** hold or are violated, we can consider four different covariate specifications.

- **Homogeneous:**
  Common covariate effects across regions and periods.
  $$f(X_{i,s,t}) = \gamma X_{i,s,t}.$$

- **Region-varying:**
  Covariate effects vary across regions.
  $$f(X_{i,s,t}) = \sum_{s} \gamma_s I(s) X_{i,s,t}.$$

- **Time-varying:**
  Covariate effects vary over time.
  $$f(X_{i,s,t}) = \sum_{t} \gamma_t I(t) X_{i,s,t}.$$

- **Two-way:**
  Covariate effects vary across regions and periods.
  $$f(X_{i,s,t}) = \sum_{s} \sum_{t} \gamma_{s,t} I(s) I(t) X_{i,s,t}.$$

- We do not observe the true specification in real data.
- **Key question:** Which covariate specification should we use?

Why not use the most saturated model by default?

True covariate effects	Identifies ATT? Hom.	Region	Time	Two-way	Most efficient specification
Common: $\gamma_{s,t} = \gamma$	✓	✓	✓	✓	**Homogeneous**
Region-varying: $\gamma_{s,t} = \gamma_s$	✗	✓	✗	✓	**Region-varying**
Time-varying: $\gamma_{s,t} = \gamma_t$	✗	✗	✓	✓	**Time-varying**
Two-way: $\gamma_{s,t}$ unrestricted	✗	✗	✗	✓	**Two-way**

✓ Identifies ATT ✗ Generally does not identify ATT

- **Too restrictive:** Misspecification can lead to inconsistent ATT estimates.
- **Too flexible:** Unnecessary parameters can increase estimator variance.

TWFE When CCC Holds

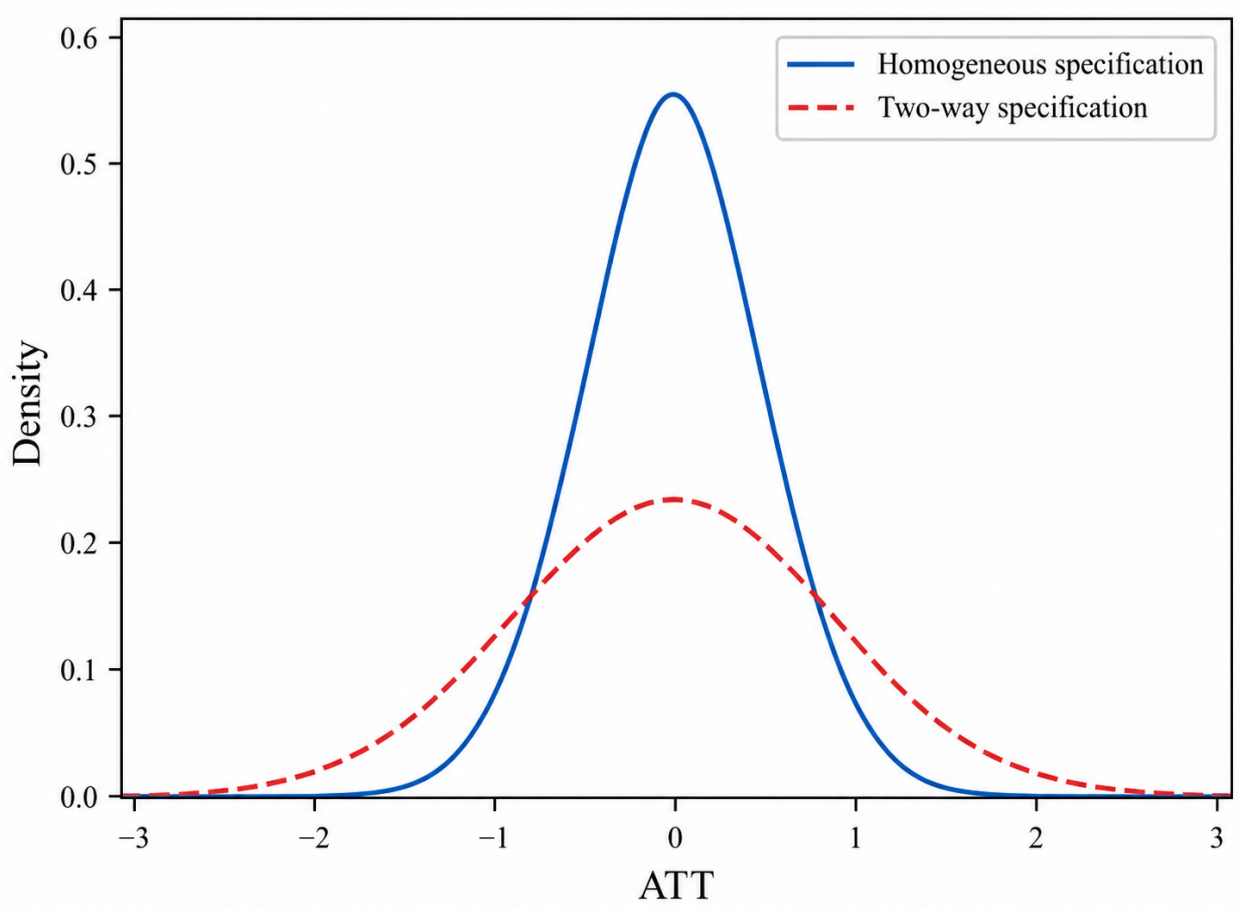


Illustration of efficiency: When CCC holds, the homogeneous specification yields a more concentrated sampling distribution of the ATT than the unnecessarily flexible two-way specification.

The CCC Test Algorithm

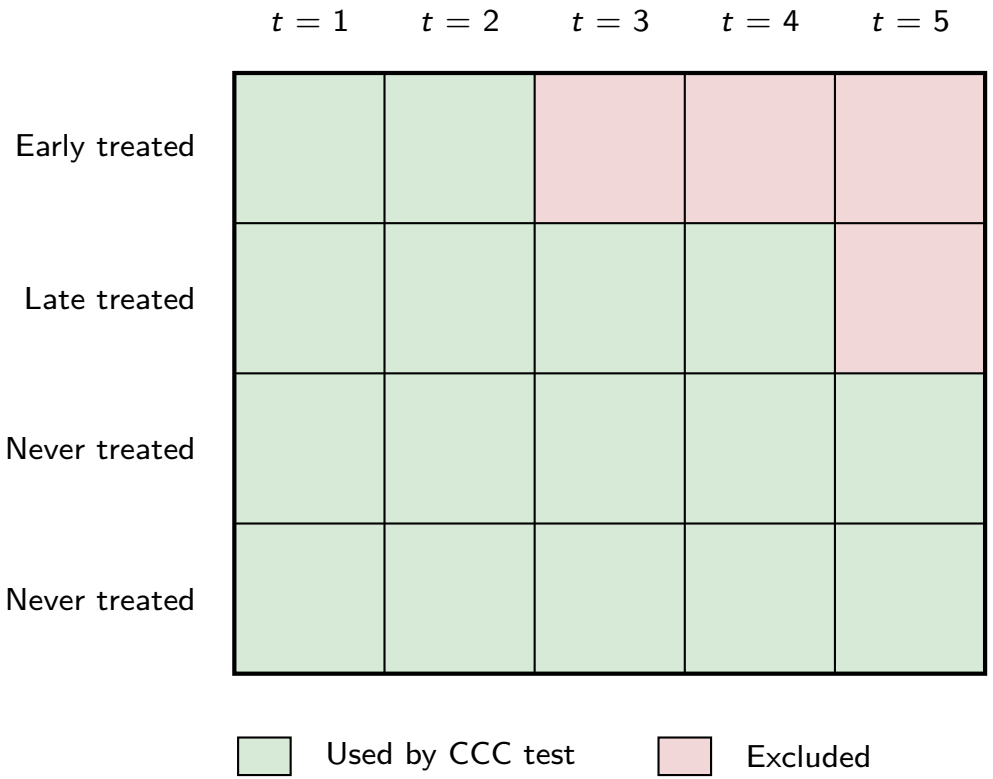
- CCC test is two step test.
- **Step 1:** Do the covariates vary across both region and time.

Fail to reject common effects	Reject common effects
Homogeneous specification	**Proceed to Step 2**

- **Step 2:** Where do the covariate effects vary?

Across regions only	Over time only	Both or inconclusive
Region-varying	**Time-varying**	**Two-way**

Which Observations Enter the CCC Test?



- The test uses **untreated observations only**.
- This includes **never-treated** and **not-yet-treated** observations.
- Observations **after treatment begins** are excluded.

Why? We want to learn how covariates affect outcomes *without* the policy.

Step 1: Are Covariate Effects Common?

Unrestricted model: Allow covariate effects to differ across untreated region-period cells.

$$Y_{i,s,t} = \sum_{u=1}^{U} \theta_u^{\circ} Z_{i,u} + \sum_{k=1}^{K} \sum_{u=1}^{U} \gamma_u^{\circ,k} I(s) I(t) X_{i,s,t}^{k} + \epsilon_{i,s,t}.$$

$Z_{i,u}$ identifies untreated region-period cell u; U is the number of such cells.

Null hypothesis: Covariate effects are common across all regions and periods.

$$\boxed{H_0^{TW}: \quad \gamma_1^{\circ,k} = \cdots = \gamma_U^{\circ,k} = \gamma^{\circ,k}, \qquad \forall k.}$$

Wald statistic: Test each restriction using

$$W_j = (R_j \widehat{\beta})' \left[R_j \widehat{V} R_j' \right]^{-1} (R_j \widehat{\beta}) \xrightarrow{d} \chi^2_{q_j}, \qquad j \in \{R, T\}.$$

- **Fail to reject:** Select homogeneous specification.
- **Reject:** Proceed to Step 2.

Step 2: What Type of CCC Violation?

Unrestricted model: Allow covariate effects to vary **additively** across regions and time.

$$Y_{i,s,t} = \sum_{u=1}^{U} \theta_u^{\circ} Z_{i,u} + \sum_{k=1}^{K} \sum_{r=1}^{S^u} \gamma_r^{\circ,k} I(s=r) X_{i,s,t}^k + \sum_{k=1}^{K} \sum_{\ell=2}^{T^u} \gamma_\ell^{\circ,k} I(t=\ell) X_{i,s,t}^k + \epsilon_{i,s,t}.$$

Two null hypotheses:

Region-invariant CCC: No differences across regions.

$$H_0^R: \quad \gamma_1^{\circ,k} = \cdots = \gamma_{S^u}^{\circ,k} = \gamma_R^{\circ,k}, \qquad \forall k.$$

Time-invariant CCC: No changes over time.

$$H_0^T: \quad \gamma_2^{\circ,k} = \cdots = \gamma_{T^u}^{\circ,k} = 0, \qquad \forall k.$$

Multiple testing: Since Stage 2 tests two hypotheses, we apply **Holm's step-down correction** to control the family-wise error rate (FWER) at level α.

S^u and T^u count regions and periods in the untreated sample; period 1 is the reference period.

Step 2: Wald Tests and Specification Selection

After Holm's step-down correction, select:

Region test	**Time test**	**Covariate specification**
Reject	Fail to reject	**Region-varying**
Fail to reject	Reject	**Time-varying**
Reject	Reject	**Two-way**
Fail to reject	Fail to reject	**Two-way**

Note: If Step 1 rejects but both Step 2 tests fail to reject, retain the two-way specification.

CCC Test: Installation

- The CCC test is available in **Stata, R, and Python**.
- **GitHub repository:** github.com/SunnyRKarim/ccctest
- **Install directly in Stata:**

```
net install ccctest, ///
  from("https://raw.githubusercontent.com/SunnyRKarim/ccctest/main/stata/") replace
```

- **Verify installation and access documentation:**

```
which ccctest
help ccctest
```

CCC Test: Stata Syntax

- **Basic syntax:**

```
ccctest y c.x, group(group) time(period) gvar(gvar)
```

- **Required inputs:**
  - `y`: Outcome variable.
  - `c.x`: Continuous covariate.
  - `group()`: Region identifier.
  - `time()`: Time-period identifier.
  - `gvar()`: First treatment period; 0 indicates never treated.
- **Optional:** `alpha(0.05)`, `vce(ols)`, `alltests`.
- **Full syntax and documentation:** Stata help file on GitHub.

CCC Test: Output and Interpretation

Example: Saved six-region simulation fixture from the package.

```
ccctest y_state c.x, group(group) time(year) gvar(gvar)
```

Test	Wald W	p-value	Decision
Stage 1: Common effects	37.742	0.0271	Reject
Stage 2: Region restrictions	14.388	0.0266	Reject
Stage 2: Time restrictions	8.705	0.1214	Fail to reject

Stage 1 reports the raw p-value. Stage 2 values use Holm's correction.

- **Selected specification:** `region` (region-varying covariate effects).
- **Access the stored results:**

```
matrix list e(tests)
display "`e(selected)'"
```

The CCC test selects a **covariate specification**; it does not estimate the ATT or test parallel trends.

Source: ccctest presenter guide, saved validation results.

Conclusion

- **The CCC assumption matters:** Covariate effects may differ across regions and over time. Ignoring these differences can lead to **misspecified models and biased ATT estimates**.
- **Link between CCC and CPT:** CCC violations can make CPT less plausible, although they do not necessarily imply its failure.
- **My contribution:** I develop a **two-stage CCC test** to detect violations and distinguish whether covariate effects vary across regions, over time, or both.
- **Practical implications:** The test guides researchers in selecting an appropriate covariate specification, balancing **consistency and efficiency**.

Key takeaway: How we control for covariates matters, not just which covariates we include.

Related Research and Stata Software

Testing Common Causality of Covariates: Evidence from Private-Sector Ban-the-Box Policies
Method: Two-stage Wald test for CCC violations and covariate-specification selection.
HERE

Improved Inference for CSDID Using the Cluster Jackknife
Method: Cluster-jackknife inference for the Callaway–Sant'Anna DID estimator.
HERE

Difference-in-Differences with Unpoolable Data
Method: UN-DID: DID estimation without pooling individual-level data across silos.
HERE

Good Controls Gone Bad: Difference-in-Differences with Covariates
Method: DID-INT: Integrated DID allowing heterogeneous covariate effects.
HERE

Each HERE button opens the corresponding Stata package or its distribution page.

Questions?

Feedback welcome

Please Email: SunnyKarim@cmail.carleton.ca

for any suggestions

References I


Karim, Sunny (2026). *Testing Common Causality of Covariates: Evidence from Private-Sector Ban-the-Box Policies*. Working paper, Carleton University.


Karim, Sunny and Matthew D. Webb (2024). *Good Controls Gone Bad: Difference-in-Differences with Covariates*. arXiv preprint arXiv:2412.14447.


Karim, Sunny Rabiul et al. (2024). *Difference-in-Differences with Unpoolable Data*. arXiv preprint arXiv:2403.15910.


Karim, Sunny Rabiul et al. (2026). *Improved Inference for CSDID Using the Cluster Jackknife*. arXiv preprint arXiv:2602.12043.