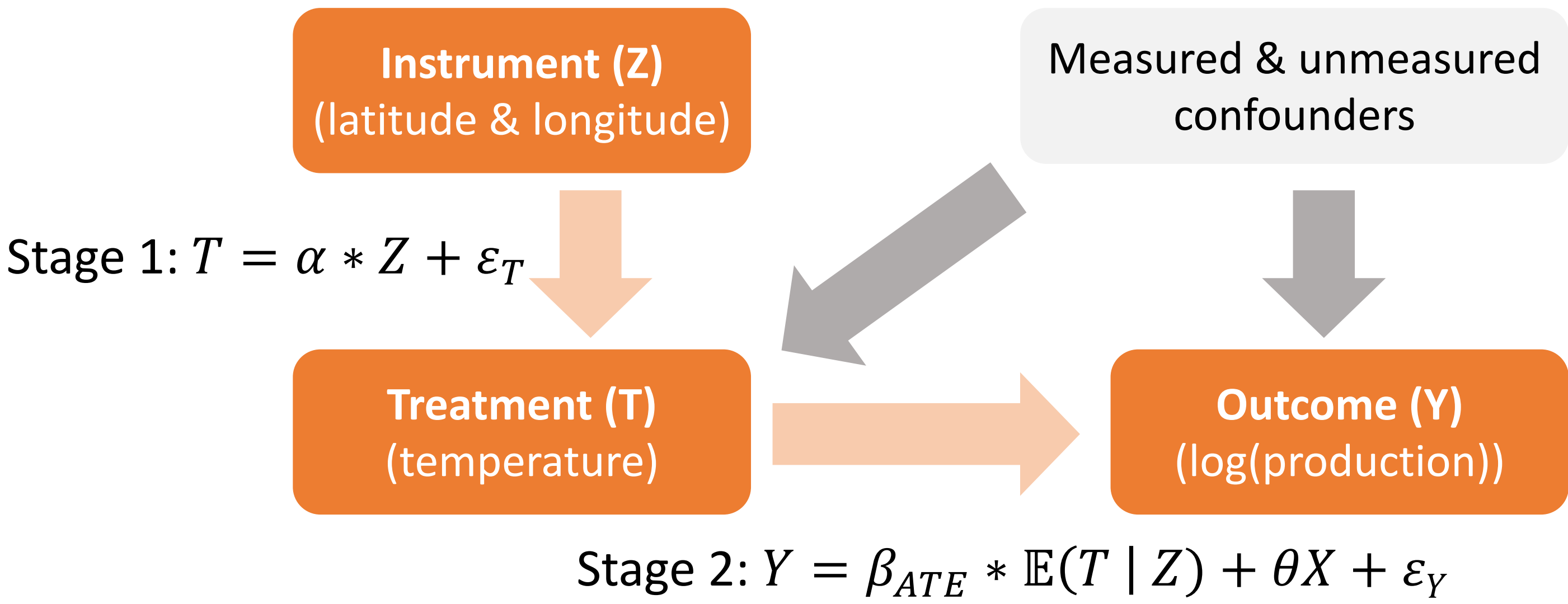




Motivation

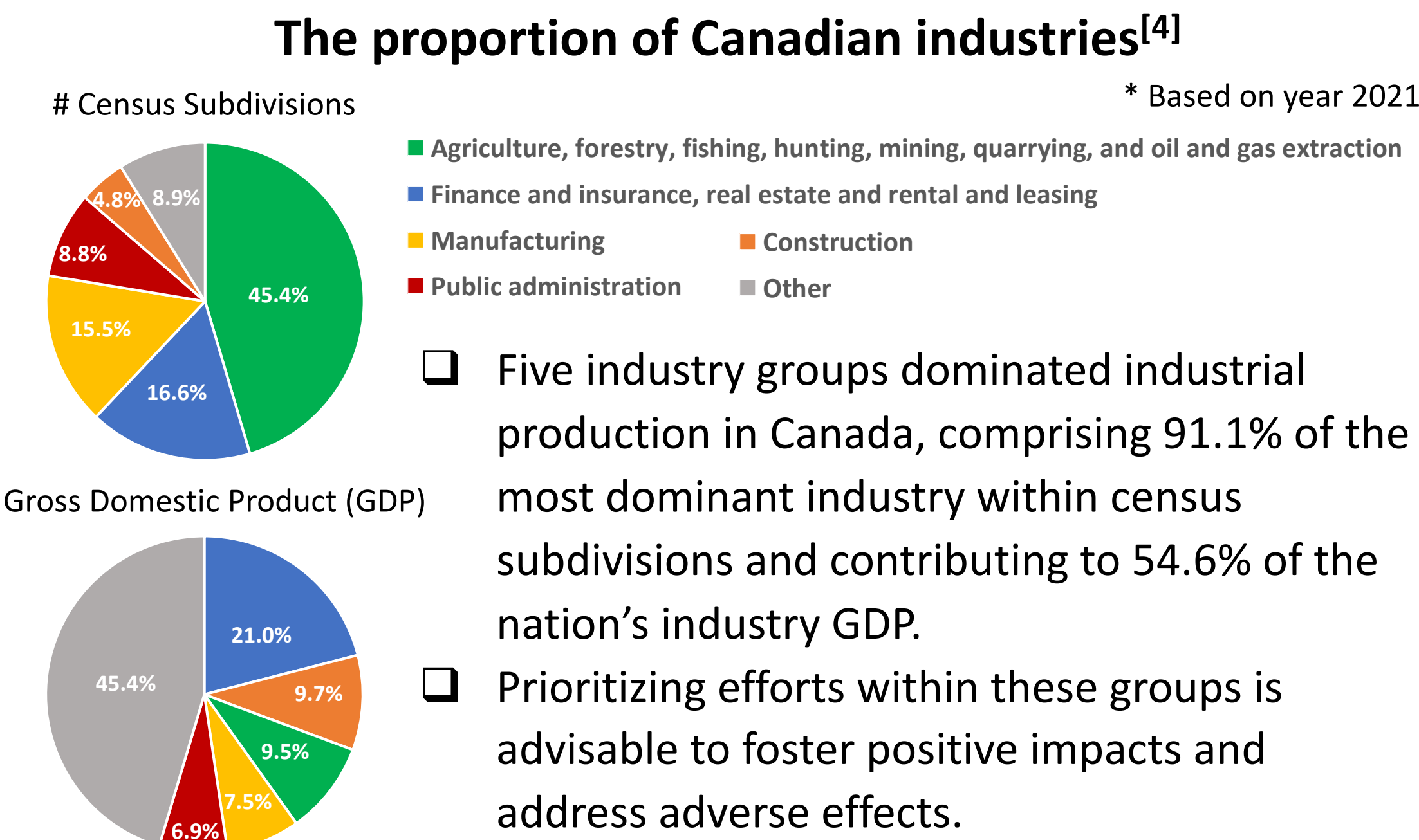
- To prepare for climate change, we must understand the impact of climate change on Canadian industry.
- Conventional regression methods have limitations due to biases from unmeasured confounders, and a randomized controlled trial (RCT) is unfeasible.
- This project employed instrumental variable (IV) analysis to establish causal impacts of temperature factors on economic productivity in Canadian census subdivisions.

Two-stage least squares (IV-2SLS) method



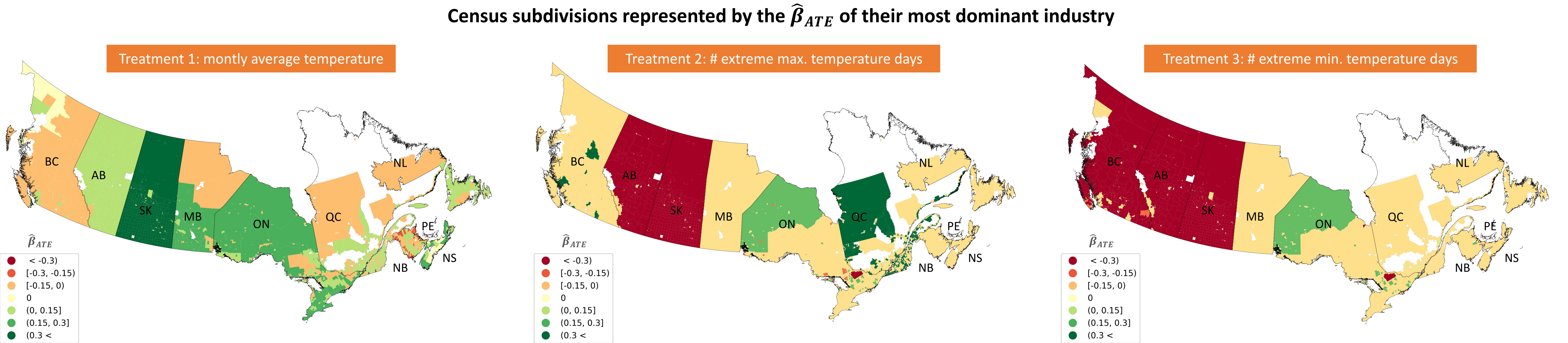
- Instrumental variable analysis** is a method used to estimate causal effects for cases where randomized controlled trials are not feasible<sup>[1]</sup>.
- The two-stage least squares** method (IV-2SLS)<sup>[2]</sup>:
  - Stage 1:** Fit regression from the IVs( $Z$ ) to the treatment, get  $\hat{T} = \mathbb{E}[T | Z]$ .
  - Stage 2:** Fit regression of  $Y$  on  $\hat{T}$  and measured confounders  $X$  (year, season, commodity prices (metal, oil, etc), and CAD-USD rate. We took the first 5 principal components of these covariates)
    - Unmeasured confounders influencing  $Y$  through  $T$  are controlled for by replacing  $T$  with  $\mathbb{E}[T | Z]$ .
  - The **average treatment effect (ATE)** is then the coefficient for  $\hat{T}$ , namely  $\hat{\beta}_{ATE}$ .
- It has been shown that latitude and longitude can serve as robust IVs for the effect of temperature changes<sup>[3]</sup>.
- We estimated the ATE of three different treatment variables on log(production) using IV-2SLS.

Canadian economic productivity



- Five industry groups dominated industrial production in Canada, comprising 91.1% of the most dominant industry within census subdivisions and contributing to 54.6% of the nation's industry GDP.
- Prioritizing efforts within these groups is advisable to foster positive impacts and address adverse effects.

Causal impacts of climate change on Canadian economic productivity



|  | Average temperature |       |       |       |       |       |       |       |       |       | # Extreme maximum temperature |       |       |      |       |      |      |      |      |      | # Extreme minimum temperature |       |       |      |       |      |      |      |      |      |      |
|--|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------------------------------|-------|-------|------|-------|------|------|------|------|------|-------------------------------|-------|-------|------|-------|------|------|------|------|------|------|
| North American Industry Classification System (NAICS)                                  | BC                  | AB    | SK    | MB    | ON    | QC    | NB    | NS    | PE    | NL    | BC                            | AB    | SK    | MB   | ON    | QC   | NB   | NS   | PE   | NL   | BC                            | AB    | SK    | MB   | ON    | QC   | NB   | NS   | PE   | NL   |      |
| Agriculture, forestry, fishing, hunting, mining, quarrying, and oil and gas extraction | -0.09               | 0.04  | 0.40  | 0.30  | 0.07  | -0.03 | -0.06 | 0.24  | -0.35 | 0.04  | 0.00                          | -1.07 | -1.57 | 0.00 | 0.00  | 0.48 | 0.00 | 0.00 | 0.00 | 0.00 | -0.88                         | -0.65 | -1.65 | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Finance and insurance, real estate and rental and leasing                              | 0.04                | 0.06  | 0.13  | 0.16  | 0.05  | 0.05  | 0.15  | 0.00  | 0.10  | 0.08  | 0.00                          | 0.00  | -2.10 | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | -2.23 | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Manufacturing  | -0.02               | 0.00  | 0.05  | 0.00  | 0.16  | 0.15  | -0.19 | 0.00  | -0.56 | 0.09  | 0.38                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Public administration  | 0.00                | -0.08 | -0.06 | -0.07 | -0.09 | -0.12 | 0.10  | 0.12  | 0.07  | -0.05 | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.57                         | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Construction   | 0.00                | 0.00  | 0.03  | 0.07  | 0.05  | 0.06  | 0.13  | 0.00  | -0.03 | 0.05  | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.15                         | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Utilities  | -0.04               | -0.05 | 0.06  | -0.11 | -0.02 | -0.10 | 0.12  | -0.67 | 0.00  | -0.05 | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Wholesale trade, Retail trade  | 0.01                | 0.05  | 0.06  | 0.10  | 0.03  | 0.03  | 0.04  | 0.00  | 0.12  | 0.00  | 0.00                          | 0.00  | 0.00  | 0.00 | 0.18  | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | 0.00  | 0.24 | 0.08  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Health care and social assistance  | 0.02                | 0.03  | 0.00  | 0.03  | -0.03 | -0.06 | 0.00  | 0.16  | 0.05  | 0.00  | 0.00                          | 0.00  | 0.00  | 0.00 | -0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Educational services   | 0.00                | -0.04 | -0.04 | 0.00  | -0.04 | -0.05 | 0.02  | -0.21 | 0.00  | -0.02 | 0.00                          | 0.00  | 0.26  | 0.00 | -0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.27                         | 0.00  | 0.29  | 0.00 | -0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transportation and warehousing   | -0.01               | 0.00  | 0.00  | 0.05  | 0.01  | 0.01  | 0.11  | -0.07 | 0.17  | 0.05  | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Professional, scientific, and, technical services                                      | 0.03                | 0.05  | 0.00  | 0.07  | 0.06  | 0.08  | 0.25  | 0.08  | 0.39  | 0.03  | 0.00                          | 0.00  | -0.68 | 0.00 | 0.25  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | -0.72 | 0.00 | 0.00  | 0.00 | 0.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| Information, culture, and recreation   | 0.04                | 0.11  | 0.06  | 0.00  | 0.04  | 0.01  | 0.00  | -0.28 | 0.00  | 0.02  | 0.00                          | 0.00  | -1.08 | 0.00 | 0.37  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | 0.00  | 0.53 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Accommodation and food services  | 0.02                | 0.02  | 0.00  | 0.02  | -0.01 | -0.02 | 0.00  | 0.00  | 0.10  | 0.01  | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00                          | 0.00  | 0.00  | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other services except public administration  | 0.00                | 0.00  | 0.06  | 0.07  | 0.02  | 0.00  | 0.04  | 0.20  | 0.11  | 0.01  | 0.00                          | 0.00  | -1.00 | 0.00 | 0.33  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33                          | 0.00  | -1.05 | 0.00 | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

\* Monthly economic productivity, commodity price indices, and geographical data were provided by Statistics Canada<sup>[4]</sup>. Annual CAD-USD currency rates were provided by the Bank of Canada<sup>[5]</sup>. Monthly average and extreme temperature data were provided by Environment and Climate Change Canada<sup>[6]</sup> and Python package *meteostats*<sup>[7]</sup>.

- Increase in average temperature had a positive impact on log(production) in the five main industries, particularly in Saskatchewan (SK) and Manitoba (MB). However, Prince Edward Island (PE) experienced mixed effects.
- While some provinces remained unaffected, SK faced negative impacts from both temperature extremes on two out of the five major industries, and Alberta faced similar effects on one industry.
- These results suggest that a gradual increase in average temperature may have positive impacts, while sudden temperature fluctuations, whether increases or decreases, could impede industrial activities.
- This study focuses on 14 NAICS productions, but a more extensive analysis could be conducted by utilizing finely segmented industrial production data.
- The IV-2SLS method assumes strong linear associations, and employing more flexible estimators may be necessary to achieve more precise estimations of the average treatment effects.
- Nevertheless, our study demonstrates the efficacy of the causal inference method as a tool for uncovering climate change effects and providing a foundation for future research.

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