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Climate exposure and cost overruns in transport infrastructure across bidding, construction, and delivery in Québec

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ABSTRACT

This paper investigates how climate-related disruptions influence cost overruns in Québec, using an administrative dataset of 3,134 transport construction projects delivered between 2014 and 2021. Rather than treating cost overrun as a single metric, we develop three complementary measures aligned with key stages of the project cycle: the gap between the engineer's estimate and the awarded contract price, the difference between final costs and the contract price, and the lifecycle overrun relative to the initial estimate. This approach allows us to pinpoint when cost pressures emerge. The results show that winter climatic exposure proxy during execution significantly increases post-award and lifecycle overruns but is not priced at the bidding stage. Project type, project size, geographical location, and the number of bidders also systematically drive cost growth. Generalized Moment Method and Logit models confirm the robustness of these findings, highlighting the need for climate-responsive budgeting, bid screening, and contract design.

Keywords: bad weather, transport, Quebec, cost overruns, project cycle, construction project

INTRODUCTION

The effects of climate change have become a major global concern, affecting economic systems, infrastructure, and public finances worldwide (Abbass et al., 2022). Beyond physical damage, climate-related disruptions generate financial consequences that are increasingly salient but remain difficult to quantify and to incorporate into economic decision-making frameworks (Barnett, 2023). In the infrastructure sector, this challenge is amplified by long planning horizons. Investment decisions are often made years before projects are delivered, when exposure and vulnerability are still imperfectly understood. Despite growing awareness of climate risk, empirical evidence remains limited on how these risks are priced and how they materialize in large infrastructure investments. Moreover, little is known about when and how climate exposure translates into cost overruns along the project lifecycle.

Construction projects, particularly in the transport sector, are characterized by high capital intensity, long implementation horizons, and complex coordination requirements. These features make them inherently vulnerable to delays and cost escalation (Berihu et al., 2023; Eliasson, 2025). A substantial body of empirical literature documents the persistence of cost overruns across countries and project types (Cantarelli et al., 2012; Eliasson, 2025; Flyvbjerg et al., 2002; Love et al., 2016; Molinari et al., 2025). Flyvbjerg et al. (2002) show that cost overruns are widespread in major transport infrastructure projects. However, much of the existing literature relies on a single aggregate indicator comparing final outturn costs with early-stage estimates (Andrić et al., 2019; Odeck, 2004). This static approach obscures the timing and dynamics of cost escalation over the project life cycle, thereby limiting our understanding of the mechanisms through which cost overruns materialize (Flyvbjerg et al., 2003).

Climate change adds a further source of uncertainty to infrastructure delivery by disrupting productivity, logistics, and contractual arrangements, thereby increasing the risk of delays and cost escalation (Dong et al., 2025; Šopić et al., 2025). Because transport construction is largely conducted outdoors, it is highly exposed to adverse conditions such as heavy precipitation, freeze–thaw cycles, snow accumulation, and strong winds. These disruptions can reduce labor productivity, damage incomplete works, and generate change orders and compensation claims (Schuldt et al., 2021). Yet, existing studies mainly focus on schedule delays or aggregate cost outcomes, providing limited insight into how climate exposure affects project costs across different delivery stages.

This limitation is particularly relevant in Québec, which is characterized by strong seasonal variability, frequent freeze–thaw cycles, and substantial regional heterogeneity. As one of Canada's largest public infrastructure owners, the Ministère des Transports du Québec manages thousands of contracts annually, making even modest forecasting errors financially significant. However, systematic evidence on how climate-related risks affect cost performance across project phases in this context remains scarce.

To address these gaps, this paper adopts a phase-specific approach that distinguishes three complementary measures of cost overruns: (i) a bidding-stage overrun, defined as the ratio of the awarded contract price to the engineer's estimate (V2–1); (ii) a lifecycle overrun, measured as the ratio of final outturn cost to the initial estimate (V3–1); and (iii) a post-award overrun, defined as the ratio of final cost to the awarded contract price (V3–2). By analyzing these indicators jointly, we identify whether cost pressures are embedded in bids at tender or primarily emerge during execution.

Using administrative data on 3,134 transport projects delivered in Québec between 2014 and 2021, combined with detailed information on winter climatic exposure, procurement characteristics, and project attributes, we examine how climate exposure and market conditions shape cost escalation. We show that adverse weather significantly increases post-award and lifecycle overruns but does not affect bidding-stage misalignment, indicating incomplete ex ante pricing of climate risk. We also find that competition intensity and project scale are important drivers of escalation.

By linking phase-specific cost indicators to climate exposure within a single institutional setting, this study contributes to the literature on infrastructure, governance, and public procurement. Our findings provide actionable insights for contingency budgeting, bid screening, and contract design. This framework enables public agencies to identify whether cost risks originate at tender or during construction and to adapt procurement rules and contingency provisions accordingly.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature and motivates the use of phase-specific overrun measures. Section 3 presents the data and descriptive evidence. Section 4 outlines the empirical strategy and reports the main results. Section 5 concludes with policy implications for procurement design and climate adaptation in public transport infrastructure.

LITERATURE REVIEW

Measuring Cost Overruns: Three Phase-Consistent Ratios

Comparative research indicates that meaningful comparisons across projects require clearly defined time benchmarks: the decision to build, contract award, and construction/completion stages (Cantarelli et al., 2010; Flyvbjerg et al., 2003; Love et al., 2016; Odeck, 2004). We therefore adopt three complementary ratios.

(i) Contract-award ratio (ACP/EE), which measures cost overruns at the bidding stage: the ratio of the awarded contract price (ACP) to the engineer's/owner's estimate (EE) at tender (V2–1). This procurement-phase metric reflects how bidders price anticipated risks, market conditions, and expected project complexity before execution, and it is sensitive to competition intensity and bid dispersion (Bordat et al., 2004).

(ii) Lifecycle cost-overrun ratio (AOC/EE): the ratio of actual outturn cost (AOC) at completion to the decision-stage estimate (EE), computed in constant prices (V3–1). This is the standard benchmark because it links outturn costs to the budget used to justify the project and, over the project lifecycle, captures forecasting accuracy, scope stability, governance quality, and exogenous shocks (Cantarelli et al., 2010; Flyvbjerg et al., 2003; Odeck, 2004).

(iii) Post-award (implementation) overrun ratio (AOC/ACP): the ratio of AOC to ACP (V3–2). By conditioning on the award price, this measure isolates delivery-phase performance, capturing change orders, on-site efficiency, supply-chain shocks, and exposure to adverse climatic conditions during execution, from pre-award estimating errors and market influences (Ahsan & Gunawan, 2010; Bordat et al., 2004; Park & Papadopoulou, 2012).

These measures are complements rather than substitutes: V2–1 (ACP/EE) captures procurement-stage pricing at award; V3–1 (AOC/EE) provides the standard lifecycle benchmark for accountability and international comparability by relating outturn cost to the decision-stage estimate; and V3–2 (AOC/ACP) isolates post-award delivery performance by measuring cost growth during implementation relative to the awarded contract price.

Determinants of Cost Overruns

Environmental and climate conditions

Because transport construction is performed largely in open-air conditions, adverse or anomalous weather can directly disrupt project execution. It reduces labor and equipment productivity, causes work stoppages, damages work in progress, and increases change orders and claims, thereby raising realized costs. Empirical studies commonly measure weather exposure by the number or share of "bad-weather days" during the contract period, such as days with sub-zero temperatures, measurable precipitation, or snow cover, and typically find a positive relationship with cost overruns. Using U.S. highway contracts, Gkritza and Labi (2008) show that a higher proportion of snow-cover days is associated with higher costs. Bhargava et al. (2010) similarly find that a greater share of adverse-weather days increases the likelihood of overruns, while project-level evidence suggests that unexpected conditions, rather than merely seasonal patterns, are the main drivers of delays and cost increases (Akinci & Fischer, 1998). Šopić et al. (2025) also document a positive relationship between adverse weather and construction outcomes, using monthly estimates of expected low-productivity days derived from detailed weather-event data, including precipitation, wind, extreme temperatures, snow cover, and high humidity. Sector-level benchmarking is consistent with these project-level findings and links greater climate variability to higher cost overruns in transport infrastructure (Flyvbjerg et al., 2003). In the context of climate change, the IPCC Sixth Assessment Report indicates that heavy precipitation, heatwaves, and compound extremes have intensified and are projected to become more frequent and severe. At the same time, uncertainty, both variance and tail risk around weather conditions, is rising. This dual channel of more adverse weather and greater unpredictability widens the gap between ex ante allowances embedded in estimates and bids and ex post cost realizations, especially for long-duration or weather-sensitive projects (IPCC, 2022). Consistent with this logic, realized adverse weather should not systematically affect award-phase pricing relative to the engineer's estimate (ACP/EE), which primarily reflects anticipated seasonal conditions. By contrast, it is expected to increase post-award overruns conditional on the award price (AOC/ACP) and, cumulatively, lifecycle overruns relative to the decision-stage estimate (AOC/EE) (Love et al., 2016).

Project and procurement determinants of cost overruns

A growing body of research shows that cost overruns in transport infrastructure projects arise from the interaction between project design, implementation conditions, and procurement practices. Cost escalation reflects cumulative risks that emerge at different stages of the project lifecycle. Previous studies highlight the role of project duration, location, size, technical complexity, and market conditions in shaping cost performance (see, among others, Andrić et al., 2019; Eliasson, 2025; Molinari et al., 2023)

Project duration has received particular attention in the literature as a fundamental source of cost uncertainty. Longer implementation periods increase exposure to unexpected events including adverse weather, input price volatility, scope changes, and coordination failures (Andrić et al., 2019; Flyvbjerg et al., 2003). Over time, these disturbances tend to accumulate and generate efficiency losses. As a result, longer projects are more likely to experience higher post-award and lifecycle overruns (AOC/ACP and AOC/EE). At the bidding stage, however, the effect on ACP/EE remains ambiguous, because bidders may partially anticipate duration-related risks while competitive pressure constrains price adjustments.

While duration captures the temporal dimension of risk exposure, project location reflects its spatial dimension. Geographic conditions affect transportation costs, mobilization requirements, supply-chain reliability, terrain constraints, and climate exposure. Empirical evidence consistently documents substantial regional heterogeneity in cost overruns (Cantarelli et al., 2012; Flyvbjerg et al., 2003; Molinari et al., 2023). In large territories such as Québec, projects located in remote areas tend to face greater logistical and coordination challenges, which can increase post-award and lifecycle overruns. At the same time, projects in dense urban environments may also incur higher costs due to traffic management, utility conflicts, and permitting requirements.

Beyond temporal and spatial factors, project size captures the organizational and managerial complexity of project delivery. The relationship between size and cost overruns is often non-linear and context dependent. Smaller projects may suffer from weaker planning and governance structures, resulting in relatively higher proportional overruns (Odeck, 2004). Larger projects may benefit from economies of scale (Chong & Hopkins, 2016), yet very large and interface-intensive projects reintroduce coordination and contractual risks. Recent studies suggest a possible U-shaped relationship (Molinari et al., 2023). At the bidding stage, large contracts may either increase ACP/EE through higher risk premia or reduce it through stronger competition, depending on market depth. To account for these heterogeneous effects, we adopt a size-interval specification.

Project type and technical complexity further shape engineering tasks and coordination requirements. More complex projects are associated with greater design uncertainty, higher risks of change orders, and more frequent contractual disputes (Bordat et al., 2004; Park & Papadopoulou, 2012). Standardized projects, such as asphalt works, are generally completed more efficiently and tend to exhibit lower post-award and lifecycle overruns, despite their sensitivity to weather conditions. By contrast, complex structures such as major bridges and interchanges involve higher technical and coordination risks, leading to systematically larger cost overruns. Differences observed at the award stage mainly reflect risk premia embedded in bids. While large projects may benefit from stronger managerial attention and economies of scale (Chong & Hopkins, 2016; Odeck, 2004), recent evidence suggests that medium-sized projects often display the highest cost deviations (Molinari et al., 2025).

In addition to intrinsic project characteristics, procurement and market conditions shape how risks are allocated and priced. Competition intensity, measured by the number of bidders, directly affects bidding strategies and award prices. Greater competition typically compresses bids relative to engineer estimates, resulting in lower ACP/EE (Hinze et al., 1992). However, intense competition may also encourage strategic underpricing, which is subsequently recovered through change orders and claims (Bordat et al., 2004). Consequently, competition is expected to reduce award-stage misalignment while potentially increasing post-award overruns, with lifecycle effects reflecting the interaction between these two phases.

Finally, bid dispersion provides additional information on bidding behavior and risk-taking incentives. A large spread between the lowest and second-lowest bids may indicate an aggressive or unrealistic winning bid. Empirical studies consistently link large bid spreads to higher probabilities of change orders and cost overruns (Bordat et al., 2004; Hinze et al., 1992). Reviews further suggest heightened risk when spreads exceed conventional thresholds (Park & Papadopoulou, 2012). Accordingly, larger bid spreads are expected to be positively associated with post-award and lifecycle overruns, while their effect on ACP/EE remains indirect.

DATA, VARIABLES, AND DESCRIPTIVE ANALYSIS

Data and Variable Definitions

Our empirical analysis is based on a dataset of 3,134 transport construction projects contracted by the Ministry of Transport of Québec (MTQ) between 2014 and 2021. However, the econometric analysis of cost overruns requires a sufficiently complete and stabilized actual outturn cost (AOC)

Table 1. Descriptive statistics

Variable	Mean	St.dev	Min	Max
Cost overruns1(V2-1)	0.95	0.16	0.30	2.44
Cost overruns2 (V3-1)	0.93	0.24	0.008	3.21
Cost overruns3 (V3-2)	0.98	0.19	0.006	3.42
Bad weather	6.17	5.41	0	34.53
Duration	470.05	377.08	10	2434
Distance	207.66	136.20	0	706
BidGap	100.40	34.26	0	504.42
Contracting Experience	97.09	128.82	1	373
Number of bidders	4.77	3.11	1	27
Size	3.30	1.47	1	6
Type	2.14	0.95	1	4
	Frequency			
	1		0	
COVID-19	0.22		0.77	

in order to compute the overrun ratios (AOC/EE and AOC/ACP). At the time of data collection, a substantial number of projects were either still ongoing or had not yet reached a stage where execution costs were fully recorded and finalized. The dataset covers road construction, asphalt manufacturing and laying, non-complex structures, and complex structures. For each contract, we observe: (i) the engineer's ex ante cost estimate, (ii) the awarded contract price, and (iii) the final outturn cost at completion, along with project-type information, project size and duration, procurement characteristics (number of bidders, bid dispersion, and award method), geographical location, and seasonal exposure to adverse climatic conditions during execution.

MTQ is one of the main public contracting authorities in Québec, awarding thousands of construction contracts per year and managing multi-billion-dollar transport investments. Cost discrepancies between initial estimates, awarded prices, and realized costs are therefore financially significant. Projects in our sample are dominated by non-complex structures and road construction, followed by asphalt works and a smaller share of complex structures, which reflects the composition of provincial transport spending. For regional analysis, we group Québec's 17 administrative regions into 12 operational regions (e.g., Laurentides–Lanaudière; Bas-Saint-Laurent and Gaspésie–Îles-de-la-Madeleine; Mauricie–Centre-du-Québec; Saguenay and Lac-Saint-Jean–Chibougamau).

Cost Overrun Measures

We distinguish three complementary measures of cost overrun, each aligned with a different stage of the project cycle:

1. Bidding-stage overrun (V2–1): ratio of the awarded contract price to the engineer's estimate. This measures whether contractors bid above the original estimate, and therefore whether perceived risks and complexities are already priced in at award.
2. Lifecycle overrun (V3–1): ratio of the final outturn cost to the initial estimate. This is the traditional "cost overrun" definition used in most of the infrastructure literature, because it links what was politically/financially justified at the planning stage to what was ultimately paid.
3. Post-award overrun (V3–2): ratio of the final outturn cost to the awarded contract price. This isolates escalation that occurs strictly after the contract is awarded, during execution (e.g., changing orders, claims, productivity losses due to weather).

Treating these three ratios separately allows us to identify when escalation occurs. High V2–1 with low V3–2 suggests that risks were priced up front at award. Low V2–1 with high V3–2 suggests unanticipated overrun emerging on site. V3–1 captures the net financial impact over the full life of the project.

Explanatory Variables

In line with the determinants discussed in the literature review, we group them into four categories: (A) climate exposure, (B) project characteristics, (C) procurement and market conditions, and (D) geographical context. All variables are defined in Appendix, and summary statistics are reported in **Table 1**.

Climate exposure

We construct a weather variable to capture the intensity of adverse climatic conditions ("bad weather") during project execution. This measure reflects periods in which site activities are more likely to be disrupted by snow accumulation, freeze–thaw cycles, heavy precipitation, and low temperatures. Because project-level meteorological observations are unavailable, climate exposure is proxied by the number of winter months (November–March) included in the contract period. In Québec, these months are consistently associated with snow cover, freeze–thaw cycles, and reduced construction productivity. Prior studies show that winter conditions in cold-climate regions are systematically associated with work interruptions, productivity losses, and increased change orders (Bhargava et al., 2010; Gkritza & Labi, 2008). Accordingly, this indicator captures the relative intensity of climate-related execution constraints faced by each project.

Project characteristics

We include several variables that describe the technical and operational profile of the project:

Table 2. Frequency of cost overruns for four types of projects

Types	V3-2	V3-1	V2-1
Road construction	45.80%	38.02%	39.88%
Asphalt manufacturing and laying	45.91%	32.68%	30.74%
Non-complex structures	49.60%	34.59%	36.48%
Complex structures	49.11%	21.43%	23.21%
Total	47.61%	35.04%	36.29%

- Type of project. Each contract is assigned to one of four mutually exclusive categories: (1) road construction; (2) asphalt manufacturing and laying; (3) non-complex structures; (4) complex structures. These types proxy scope complexity, the number of technical interfaces, and sensitivity to on-site uncertainty. Prior studies suggest that more complex structures are subject to higher technical risk and more negotiation during delivery, while asphalt works tend to be more standardized and shorter in duration. We include type dummies to allow these differences to affect all three overrun measures.
- Project size. We use the estimated cost at planning stage as a proxy for scale. The literature does not find a simple linear pattern: smaller projects may face looser planning and weaker oversight, while very large projects face coordination and interface risk but may also attract tighter management structures. We allow project size to influence all phases of escalation both at award (V2–1) and during execution (V3–2) and, by extension, lifecycle overruns (V3–1).
- Project duration. We measure the planned execution window. Longer projects are exposed to more sources of shock (input price changes, labour constraints, seasonal shutdowns, bad weather) and have more opportunities for scope adjustment, so we expect duration to be positively associated with post-award (V3–2) and lifecycle (V3–1) overruns.

Procurement and market conditions

We characterize the competitive environment and pricing dynamics at tender:

- Number of bidders. This is the count of valid bids submitted for a given contract. More bidders typically increase competitive pressure and should, in principle, reduce the probability that the awarded contract price exceeds the engineer's estimate (i.e. lower V2–1). However, very aggressive bidding can reappear later as renegotiation, which may increase the likelihood of post-award escalation (V3–2). We therefore allow this variable to affect all three ratios.
- Bid spread. We compute the spread between the lowest bid and the second-lowest bid. A large spread suggests that the winning bid may be unusually low relative to the rest of the market, which procurement agencies often view as a red flag for later change orders and claims. In that case, we would expect higher post-award overruns (V3–2), and, through accumulation, higher lifecycle overruns (V3–1), even if the bidding-stage ratio (V2–1) initially appears favorable.
- Award method. We distinguish contracts awarded through public/open tender from those awarded through more restrictive procedures (e.g. invitation to tender). This captures potential differences in screening, negotiation, and ex ante risk pricing.
- Contracting (contractor) experience. We measure contractor experience as the total number of contracts awarded to each winning firm over the analysis period. This variable captures cumulative learning effects that may reduce optimism bias and improve the management of implementation complexity in transport infrastructure projects. Firms with greater contracting experience are therefore expected to exercise better control over execution risks and to exhibit lower post-award and lifecycle cost overruns.

Geographical context

Finally, we control the region in which the project is delivered. We group Québec's 17 administrative regions into 12 operational regions (for example, Laurentides–Lanaudière; Bas-Saint-Laurent & Gaspésie–Îles-de-la-Madeleine; Mauricie–Centre-du-Québec; Saguenay & Lac-Saint-Jean–Chibougamau). These regional indicators absorb systematic heterogeneity in logistics (remoteness, access to materials and labour), regulatory and administrative practices, and climatic conditions. In descriptive analysis, we observe that some regions are characterized by systematically higher post-award overrun, whereas others display higher disagreement already at the bidding stage. Including region fixed effects therefore allows us to separate region-specific operating environments from project-level attributes. All variables enter the regression alongside the three dependent variables described in Section 3.2. **Table 1** reports their means, dispersion, and ranges, showing substantial variation across projects in weather exposure, competition, duration, size, and regional context.

Descriptive Evidence

Table 2 reports how often each type of cost overrun occurs, by project type. In the full sample:

- Post-award overruns (V3–2) occur in 47.61% of projects.
- Lifecycle overruns (V3–1) occur in 35.04% of projects.
- Bidding-stage overruns (V2–1) occur in 36.29% of projects.

This indicates that nearly half of all projects end with a final cost above the awarded contract price, confirming that overrun during execution is widespread. Patterns differ by project type. Road construction shows relatively high frequencies for lifecycle and bidding-stage overruns, suggesting pressure both at award and over the entire life of the project. Asphalt manufacturing and laying displays lower-

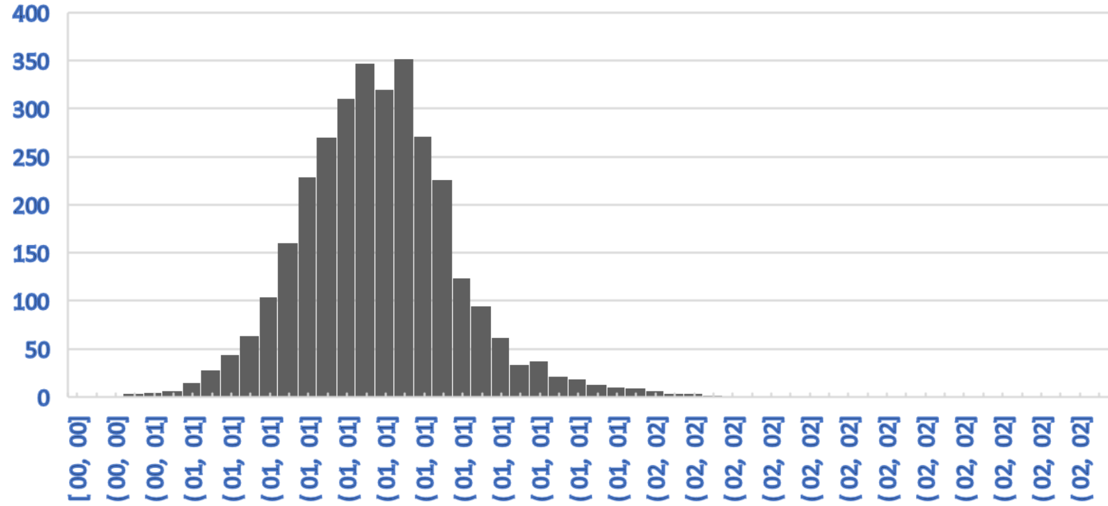

Figure 1. Distribution of cost overruns in the bidding stage V2-1 (Source: Authors' own elaboration, based on data from the Ministry of Transport of Québec)

Table 3. Frequency of overruns in the different regions of Québec

Region	V3-2	V3-1	V2-1
1: Abitibi-Témiscamingue	50.68%	50.68%	53.42%
2 : Bas-Saint-Laurent and Gaspésie–Îles-de-la-Madeleine	51.52%	37.88%	34.85%
3: Chaudière-Appalaches	38.67%	38.67%	38.67%
4: Côte-Nord	57.59%	39.27%	36.65%
5: Capitale-Nationale	53.65%	34.31%	33.21%
6: Estrie	48.55%	32.15%	34.08%
7: Laurentides-Lanaudière	45.12%	24.19%	21.86%
8: Montérégie	43.01%	31.54%	32.26%
9: Mauricie–Centre-du-Québec	48.45%	35.09%	36.02%
10: Outaouais	53.57%	46.43%	42.86%
11: Montréal	43.60%	35.47%	52.91%
12: Saguenay and Lac-Saint-Jean–Chibougamau	47.60%	39.60%	47.60%

than-average bidding-stage and lifecycle overruns, consistent with standardized, shorter-duration work. Non-complex structures exhibit the highest post-award overrun frequency, indicating that much of the escalation emerges during execution. Complex structures still show frequent post-award adjustments, but much lower lifecycle and bidding-stage overruns, suggesting that higher risk is partially priced in or managed up front.

Figure 1 plots the distribution of the bidding-stage cost-overrun ratio V2–1 (Awarded Contract /Engineer's Estimate). The distribution is unimodal and centered near 1, with a slight right-skew: most projects are awarded at prices close to the estimate, but upward deviations (award > estimate) are somewhat larger in magnitude than downward ones. In the full sample, 36.29% of projects exhibit V2–1 > 1.

Table 3 shows that the three ratios exhibit heterogeneous regional patterns. Côte-Nord, Capitale-Nationale, and Bas-Saint-Laurent and Gaspésie–Îles-de-la-Madeleine have the highest post-award incidence (V3–2 ≈ 52–58%), while their bidding-stage and lifecycle frequencies are only moderate, pointing to risks that materialize mainly after award. Abitibi-Témiscamingue and Outaouais are high on all three metrics, indicating pressure both at award and during execution. Montréal stands out as front-loaded (V2–1 ≈ 53%) with comparatively lower V3–2 and V3–1, consistent with conservative estimating buffers or tighter cost control in delivery. In contrast, Laurentides–Lanaudière, Montérégie, and Chaudière-Appalaches show relatively low bidding-stage and lifecycle overruns (the latter uniformly ≈ 38.7% in Chaudière-Appalaches), suggesting more balanced front-end estimates and execution performance. Saguenay and Lac-Saint-Jean–Chibougamau displays similar magnitudes at award and post-award, producing a mid-range lifecycle rate. Overall, these contrasts justify including regional controls and suggest that the balance between estimating accuracy and execution risk varies meaningfully across Québec.

These descriptive results motivate the multivariate analysis that follows. First, the three overrun definitions do not behave identically, which justifies estimating separate models for V2–1, V3–1, and V3–2 rather than collapsing them. Second, overrun is not uniform across project types or regions, which supports the inclusion of detailed type dummies, region dummies, and weather exposure in the regression framework.

Table 4 shows the correlations among all variables. The correlations among the independent variables are within acceptable limits, suggesting that severe multicollinearity is unlikely. Therefore, multicollinearity does not appear to be a major concern in this study. In this regard, Gujarati and Porter (2009) assert that the coefficient of correlation that is less than 0.8 may not be subject to a serious multicollinearity problem. We also computed the variation inflation factor (VIF) to test the multicollinearity problem for the three regressions. VIF

Table 4. Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Cost overrunsV2-1 (1)	1											
Cost overruns V3-1 (2)	0.62	1										
Cost overruns V3-2 (3)	-0.03	0.74	1									
Bad Weather (4)	0.08*	0.01*	0.09*	1								
COVID (5)	0.30*	0.07*	-0.24*	-0.24*	1							
Number of bidders(6)	-0.29*	-0.14	0.06	0.14*	-019*	1						
Distance (7)	0.04*	0.04	0.02	0.07	0.02	-0.08*	1					
Duration (8)	0.06	0.07	0.09	0.49*	-0.24	0.18*	0.05*	1				
Contracting Experience (9)	0.04*	0.04	0.05	-0.10*	-0.01	-0.34	0.04*	-0.11*	1			
Size (10)	0.14*	-0.04	-0.11	0.23*	0.21	0.04*	0.04*	0.25*	0.12*	1		
BidGap (11)	-0.18*	-0.12	-0.09	-0.01	-0.07	-0.04*	-0.04*	0.01	-0.29*	-0.04*	1	
Type of contract (12)	-0.06*	-0.04	-0.02	0.13*	-0.12	0.02	0.02	0.14*	-0.34*	-0.17*	0.15*	1

*Indicate the significance at 5% thresholds

values range between 1.02 and 1.26, which is below 10 (Neter et al., 1996) and the average of VIF is equal to 1.11 which is below 2 (Chatterjee & Hadi, 2012), confirming that severe multicollinearity is unlikely.

METHODOLOGY AND RESULTS

Methodology

This study begins with OLS estimations to examine the average relationship between climate exposure and continuous cost overrun ratios. OLS provides an intuitive benchmark and allows for direct interpretation of marginal effects under standard assumptions.

$$Cost\ overruns_{ji} = \beta_0 + \beta_1 X_i + \beta_2 W_i + \varepsilon_i \qquad (1)$$

Where cost overruns ji is a dependent variable representing the j cost overruns of project i. j ∈ {V2−1, V3−1, V3−2} and represents the three measures of cost overruns. Xi denotes the independent variable is defined by the number of months with bad weather. Wi is a set of control variables, which describe market conditions and characteristics of the projects, εi is the error term.

Empirical Results

Basic model

Table 5 reports the baseline OLS regressions linking each of the three cost overrun ratios to climate exposure (bad weather), project characteristics, procurement conditions, and geography. All regressions are estimated using heteroskedasticity-robust standard errors clustered at the regional level to account for potential spatial correlation and unobserved heterogeneity. The three dependent variables are: (i) V2−1, (ii) V3−1, and (iii) V3−2, as defined above.

Weather exposure: The climate proxy has no statistically significant effect on the bidding-stage ratio (column 1, **Table 5**), suggesting that contractors do not systematically price adverse climatic conditions at tender. By contrast, winter climatic exposure proxy is positive and statistically significant for both lifecycle overruns and post-award overruns (columns 2 and 3, **Table 5**), indicating that climate-related disruptions materialize primarily during execution rather than being fully anticipated ex ante. Consistent with this interpretation, the OLS estimates imply that one additional month of potential adverse weather exposure increases post-award overruns (V3–2) by approximately 11% on average. This pattern is consistent with prior evidence showing that severe weather shocks affect project performance mainly through productivity losses, schedule slippage, and compensable claims during construction, rather than through systematic risk loading in bid prices (Akinci & Fischer, 1998; Bhargava et al., 2010; Gkritza & Labi, 2008). Overall, these phase-specific results support the view that climate risk is only imperfectly internalized at tender and instead emerges as ex post budget pressure, especially through post-award escalation (V3–2).

COVID-19: The COVID-19 indicator is positive and statistically significant across all three cost-overrun definitions, indicating that contracts awarded and/or executed after the onset of the pandemic were systematically more likely to deviate from planned cost levels. The effect is observed at the bidding, post-award, and lifecycle stages, suggesting that pandemic-related disruptions affected project performance throughout the delivery process.

Social-distance requirements, health protocols, and illness-related absenteeism reduced on-site labor availability, slowed construction activities, and increased labor costs per unit of output. In parallel, supply-chain disruptions and input-price volatility further intensified budgetary pressures, leading to contract amendments and additional claims during execution. These findings are consistent with prior evidence documenting project suspensions, labor shortages, and financial stress in the construction sector during the pandemic (Gamil & Alhagar, 2020), as well as more recent work highlighting increased post-shock cost variability in transport infrastructure (Molinari et al., 2023).

Procurement conditions: The number of bidders is positive and statistically significant across all three cost overrun measures, indicating that greater competition is associated with larger cost deviations at the award stage (V2–1), during execution (V3–2), and over the project lifecycle (V3–1). Specifically, one additional bidder is associated with an average increase of approximately 6% in post-award cost overruns, highlighting the practical relevance of competitive pressure for cost performance. By contrast, bid spread (BidGap) is not statistically significant in any specification.

Project characteristics: Project size emerges as a robust driver of cost escalation. Larger contracts exhibit significantly

Table 5. The impact of bad weather conditions on cost overruns: regression results

	OLS		
	(V2-1)	**(V3-1)**	**(V3-2)**
	(1)	**(2)**	**(3)**
Bad weather	0.02	0.10**	0.11***
	(0.552)	(0.047)	(0.008)
COVID-19	0.04***	0.04***	0.02**
	(0.000)	(0.001)	(0.050)
Number of bidders	0.05***	0.08***	0.06*
	(0.001)	(0.003)	(0.093)
Duration	-0.06	-0.07	-0.01
	(0.410)	(0.656)	(0.164)
Distance	-0.03	-0.09*	-0.10**
	(0.244)	(0.060)	(0.013)
Contracting Experience	-0.07***	-0.06	0.03
	(0.006)	(0.571)	(0.778)
BidGap	0.06	0.03	0.05
	(0.442)	(0.656)	(0.869)
Size			
2-	0.04***	0.08***	0.32**
	(0.007)	(0.000)	(0.036)
3-	0.05***	0.095***	0.03**
	(0.000)	(0.000)	(0.012)
4-	0.06***	0.11***	0.05***
	(0.000)	(0.000)	(0.000)
5-	0.04***	0.083***	0.05***
	(0.000)	(0.002)	(0.000)
6-	0.03	0.12***	0.07***
	(0.109)	(0.000)	(0.001)
Type of contract			
2-	-0.07	-0.01	-0.004
	(0.517)	(0.569)	(0.731)
3-	0.03***	0.04***	0.01*
	(0.000)	(0.003)	(0.079)
4-	-0.01	-0.03	-0.01
	(0.632)	(0.931)	(0.608)
Constant	1.15***	1.20***	1.00***
	(0.000)	(0.000)	(0.000)
N	1471	1471	1471
R^2	0.11	0.20	0.09

higher overruns across most specifications, reflecting greater technical complexity, coordination challenges, and interface risks. This finding is consistent with the complexity-based explanations emphasized by Flyvbjerg et al. (2003), although it contrasts with evidence from other settings suggesting higher proportional overruns among smaller or medium-sized projects (Molinari et al., 2023; Odeck, 2004). Project duration is not statistically significant once size, weather exposure, and procurement conditions are controlled for. This suggests that duration mainly proxies underlying project complexity rather than constituting an independent source of risk. Regarding project type, non-road and structural works exhibit higher lifecycle overruns (V3–1) than standard road projects, while differences are less pronounced at the bidding and post-award stages. This pattern suggests that technical complexity is primarily underestimated at early planning stages, consistent with Cantarelli et al. (2012). Finally, distance to Québec City is negatively associated with post-award and lifecycle overruns, suggesting that projects in more remote areas are, on average, less prone to execution-phase cost growth. This pattern likely reflects differences in project composition: urban projects face greater coordination, regulatory, and stakeholder constraints, which may lead to more frequent scope adjustments (Flyvbjerg et al., 2003; Love et al., 2016). Taken together, the results suggest that the modest R-squared values reflect the highly idiosyncratic nature of project-level cost outcomes rather than weak model performance. Despite this inherent variability, several systematic mechanisms clearly emerge. In line with Gkritza and Labi (2008), and Bhargava et al. (2010), adverse weather significantly increases realized costs during construction, and our phase-specific approach shows that this effect is concentrated in post-award and lifecycle overruns rather than in bidding-stage misalignment. Similarly, the positive association between the number of bidders and all three overrun measures is consistent with a mechanism of strategic underbidding followed by renegotiation, as discussed by Hinze et al. (1992) and Bordat et al. (2004). Project size also remains a robust predictor of cost escalation, consistent with the complexity- and interface-risk perspective emphasized by Flyvbjerg et al. (2003), even though this contrasts with evidence from settings in which smaller projects receive less managerial attention (Molinari et al., 2023; Odeck, 2004). By contrast, project duration does not emerge as an independent driver once procurement conditions, weather exposure, and project characteristics are controlled for. In the Québec context, this suggests that governance arrangements, scope

Table 6. The impact of bad weather on cost overruns: Logit model

	Logit (V>1)			Logit(V>1.05)		
	(V2-1)	**(V3-1)**	**(V3-2)**	**(V2-1)**	**(V3-1)**	**(V3-2)**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Bad weather	0.77	0.45**	0.16***	0.09	0.03*	0.01**
	(0.703)	(0.030)	(0.009)	(0.134)	(0.070)	(0.032)
COVID-19	0.95***	1.73***	0.78***	0.96***	0.38***	0.64***
	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Number of bidders	0.04***	0.06***	0.05***	0.24***	0.18***	0.04***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.007)
Duration	-0.07***	-0.054	-0.03	-0.01***	-0.02	-0.03
	(0.023)	(0.209)	(0.417)	(0.007)	(0.662)	(0.164)
Distance	-0.09	-0.05	-0.08***	-0.08	-0.05	-0.03***
	(0.203)	(0.107)	(0.001)	(0.766)	(0.497)	(0.010)
Contracting Experience	-0.06***	-0.34	-0.04	-0.01***	-0.472	-0.04
	(0.001)	(0.709)	(0.185)	(0.008)	(0.211)	(0.911)
BidGap	-0.01	-0.07	-0.01	-0.03	-0.06	-0.01
	(0.124)	(0.328)	(0.432)	(0.137)	(0.190)	(0.618)
Size						
-2	0.20	0.34	0.09***	0.11	0.02	0.13
	(0.185)	(0.608)	(0.000)	(0.509)	(0.855)	(0.371)
-3	0.39***	0.15*	0.04**	0.28*	0.15***	0.16**
	(0.000)	(0.070)	(0.020)	(0.089)	(0.000)	(0.050)
-4						
	0.43***	0.23***	0.21***	0.36**	0.21***	0.01**
-5	(0.003)	(0.008)	(0.000)	(0.025)	(0.000)	(0.023)
	0.68***	0.64*	0.52***	0.56***	0.47**	0.27**
-6	(0.000)	(0.054)	(0.000)	(0.003)	(0.034)	(0.045)
	0.54**	0.88	0.07	0.68***	0.26	0.05
	(0.019)	(0.176)	(0.701)	(0.005)	(0.258)	(0.822)
Type of contract						
2-	-0.40	-1.29	-0.01	-0.61	-1.57	-0.19
	(0.230)	(0.118)	(0.395)	(0.306)	(0.239)	(0.382)
3-	0.42***	0.31**	0.26*	0.45***	0.43**	0.31***
	(0.000)	(0.013)	(0.100)	(0.000)	(0.013)	(0.006)
4-	-0.53	-0.18	-0.09	-0.80	-0.49	-0.090
	(0.123)	(0.695)	(0.690)	(0.200)	(0.133)	(0.743)
Constant	0.66***	1.56***	0.09	0.23	0.07	0.69***
	(0.002)	(0.000)	(0.109)	(0.307)	(0.738)	(0.000)
Pseudo-R^2	0.126	0.291	0.280	0.127	0.09	0.05
N	1471	1471	1471	1471	1471	1471

management, and environmental conditions dominate pure time exposure. Overall, these findings indicate that cost escalation is driven primarily by execution-phase shocks and institutional incentives rather than by project duration alone.

The results further show that contractor experience is negatively associated with cost overruns only when using the V2–1 measure. The significant coefficient (–0.07) indicates that more experienced firms tend to submit bids that are closer to, or below, the owner's estimate, reflecting greater bidding discipline and better risk anticipation at the procurement stage.

To complement the baseline analysis, we estimate Logit models using binary indicators that capture whether a project experiences a cost overrun. **Table 6** reports two complementary Logit specifications for each of the three overrun measures. We use two thresholds: an indicator equal to one if the relevant ratio exceeds 1 (any overrun), and an indicator equal to one if it exceeds 1.05 (significant overrun). This approach allows us to distinguish between minor deviations and economically meaningful budget stress. Columns (2) and (3) of **Table 6** show that greater exposure to adverse weather conditions is associated with a significantly higher probability of lifecycle and post-award cost overruns, respectively, while remaining statistically insignificant for bidding-stage misalignment (Column 1). This pattern persists when the higher threshold (>1.05) is used, as shown in Columns (4) to (6) of **Table 6**.

Table 5 reports OLS estimates. p-values based on robust standard errors clustered are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Additional analysis

To complement the baseline analysis, we estimate Logit models using binary indicators that capture whether a project experiences a cost overrun. **Table 6** reports two complementary Logit specifications for each of the three overrun measures. We use two thresholds: an indicator equal to one if the relevant ratio exceeds 1 (any overrun), and an indicator equal to one if it exceeds 1.05 (significant overrun). This approach allows us to distinguish between minor deviations and economically meaningful budget stress. Columns (2) and (3) of **Table 6** show that greater exposure to

Table 7. GMM regression results

	GMM		
	(1)	**(2)**	**(3)**
	(V2-1)	**(V3-1)**	**(V3-2)**
Bad weather	0.06	0.02**	0.11***
	(0.519)	(0.039)	(0.010)
COVID-19	0.04***	0.05***	0.08***
	(0.000)	(0.001)	(0.000)
Number of bidders	0.06***	0.10*	0.002*
	(0.000)	(0.081)	(0.093)
Duration	-0.06	0.07	0.01
	(0.297)	(0.399)	(0.143)
Distance	-0.08	-0.05***	-0.01***
	(0.142)	(0.006)	(0.004)
Contracting experience	-0.05	-0.02	-0.09
	(0.102)	(0.234)	(0.120)
BidGap	0.06	0.003	0.005
	(0.442)	(0.467)	(0.635)
Size			
2-	0.04**	0.08***	0.05
	(0.050)	(0.000)	(0.751)
3-	0.05***	0.09***	0.01**
	(0.004)	(0.000)	(0.012)
4-	0.06**	0.09***	0.04***
	(0.035)	(0.000)	(0.000)
5-	0.04***	0.07***	0.03
	(0.000)	(0.002)	(0.112)
6-	0.03	0.32*	0.07***
	(0.186)	(0.083)	(0.000)
Type of contract			
2-	-0.07	-0.01	-0.01
	(0.412)	(0.461)	(0.257)
3-	0.43***	0.01***	0.01*
	(0.000)	(0.003)	(0.09)
4-	-0.01	-0.03	-0.10
	(0.640)	(0.277)	(0.118)
Constant	1.25***	1.14***	0.99***
	(0.000)	(0.000)	(0.000)
N	1471	1471	1471
R2	0.11	0.14	0.19

adverse weather conditions is associated with a significantly higher probability of lifecycle and post-award cost overruns, respectively, while remaining statistically insignificant for bidding-stage misalignment (Column 1). This pattern persists when the higher threshold (>1.05) is used, as shown in Columns (4) to (6) of **Table 6**.

The COVID-19 indicator is positive and statistically significant across most specifications and thresholds, suggesting that projects executed during the pandemic were more likely to experience both minor and major cost overruns. In particular, the estimates indicate a substantial increase in overrun risk during the construction phase (Column 2, **Table 6**), consistent with supply-chain disruptions, labor shortages, and sanitary constraints affecting construction performance.

Table 6 presents the Logit regression results of the effect of bad weather on cost overruns referring to the phases for project. *, **, and *** are statistical significance at the 10%, 5% and 1% levels, respectively.

Overall, the Logit results confirm that climate exposure, procurement conditions, and project characteristics are key determinants of cost overruns, corroborating the baseline findings. In addition, the control variables retain the same signs across specifications, further supporting the robustness of the main results.

Robust analysis using GMM

GMM is used as an alternative moment-based estimator to assess the robustness of the baseline OLS results under weaker distributional assumptions. GMM allows for heteroskedasticity and potential correlation between regressors and the error term without imposing strict parametric assumptions. In all specifications, standard errors are clustered at the regional level to account for spatial correlation and unobserved regional heterogeneity. The GMM results (**Table 7**) are consistent with the baseline OLS estimates in both sign and statistical significance. Adverse weather remains a significant driver of post-award and lifecycle overruns, while procurement intensity continues to be positively associated with subsequent cost escalation.

Table 7 presents the GMM regression results of the effect of bad weather on cost overruns referring to the phases for project. *, **, and *** are statistical significance at the 10%, 5% and 1% levels, respectively.

CONCLUSION

This paper examines cost overruns in publicly funded transport infrastructure projects in Québec using a large administrative dataset and a phase-specific framework that distinguishes bidding-stage, post-award, and lifecycle cost escalation. By separating these three dimensions, we show that cost growth does not arise uniformly over the project cycle but instead reflects distinct mechanisms operating at different stages.

Three main findings emerge. First, adverse weather significantly increases post-award and lifecycle overruns, while having no systematic effect at the bidding stage. This suggests that climate-related risks are only imperfectly priced at tender and materialize primarily during execution. Second, stronger competition at award is associated with higher cost escalation, consistent with strategic underbidding followed by margin recovery through claims and renegotiation. Third, larger projects are structurally more vulnerable to overruns, reflecting greater technical and organizational complexity, whereas project duration alone does not appear to be an independent source of risk.

These results contribute to the literature by showing that conventional lifecycle measures can conceal important internal dynamics. Some cost escalation is embedded at award, while a substantial share emerges during construction in response to operational shocks and contractual frictions. The findings also highlight the fiscal relevance of climate exposure, showing that adverse weather increases both average cost growth and the probability of large cost deviations.

From a policy perspective, the results point to three main implications. First, budgeting frameworks should explicitly incorporate post-award climate-related risk by strengthening front-end project readiness, including greater design maturity, systematic constructability reviews, and clearer scope definition before tender. Second, procurement systems should complement competition-based mechanisms with more rigorous assessments of bid realism, contractor capacity, and risk allocation in order to limit strategic underpricing. Third, large and complex projects require stronger execution-stage controls, including early-warning indicators, disciplined change-management procedures, and climate-contingent contingency planning to prevent initial disruptions from escalating into major cost overruns.

A limitation of the study is that climate exposure is measured using a winter-season timing proxy rather than geolocated project-level weather realizations. While this proxy is well suited to the Québec context and captures exposure intensity to winter-related constraints, future work could integrate site-level meteorological data to identify realized weather shocks more precisely.

Finally, the proposed phase-specific methodology can be applied in other jurisdictions to better diagnose when and why budgets fail. Moving beyond aggregate overrun indicators toward stage-specific analysis can support more targeted and effective infrastructure governance.

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REFERENCES

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the impact of global climate change, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research, 29*(28), 42539-42559. https://doi.org/10.1007/s11356-022-19718-6

Ahsan, K., & Gunawan, I. (2010). Analysis of cost and schedule performance of international development projects. *International Journal of Project Management, 28*(1), 68-78. https://doi.org/10.1016/j.ijproman.2009.03.005

Akinci, B., & Fischer, M. (1998). Factors affecting contractors' risk of cost overburden. *Journal of Management in Engineering, 14*(1), 67-76.

Andrić, J. M., Mahamadu, A. M., Wang, J., Zou, P. X., & Zhong, R. (2019). The cost performance and causes of overruns in infrastructure development projects in Asia. *Journal of Civil Engineering and Management, 25*(3), 203-214. https://doi.org/10.3846/jcem.2019.8646

Barnett, M. (2023). Climate change and uncertainty: An asset pricing perspective. *Management Science, 69*(12), 7562-7584. https://doi.org/10.1287/mnsc.2022.4635

Berihu, L. G., Grum, B., Tariku, Z., & Abebe, B. A. (2023). Causes, effects, and mitigation measures of time and cost overruns in water supply projects: Case of Tigrai Region, Northern Ethiopia. *Advances in Civil Engineering, 2023*(1), Article 7113730. https://doi.org/10.1155/2023/7113730

Bhargava, A., Anastasopoulos, P. C., Labi, S., Sinha, K. C. S., & Mannering, F. L. (2010). Three-stage least-squares analysis of time and cost overruns in construction contracts. *Journal of Construction Engineering and Management, 136*(11), 1207-1218. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000225

Bordat, C., McCullouch, B. G., Labi, S., & Sinha, K. C. (2004). *An analysis of cost overruns and time delays of INDOT projects* [Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana]. https://doi.org/10.5703/1288284313134

Cantarelli, C. C., Van Wee, B., Molin, E. J. E., & Flyvbjerg, B. (2010). Cost overruns in large-scale transport infrastructure projects: Explanations and their theoretical embeddedness. *European Journal of Transport and Infrastructure Research, 10*(1), 5-18. https://doi.org/10.18757/ejtir.2010.10.1.2864

Cantarelli, C., Van Wee, B., Molin, E., Flyvbjerg, B., (2012). Different cost performance: Different determinants? The case of cost overruns in Dutch transport infrastructure projects. *Transport Policy, 22*, 88-95. https://doi.org/10.1016/j.tranpol.2012.04.002

Chatterjee, S., & Hadi, A. S. (2012). *Regression analysis by example* (5th ed.). Wiley.

Chong, U., & Hopkins, O. (2016). An international experience on the evolution of road costs during the project life cycle. *Transport Policy, 48*, 60-66. https://doi.org/10.1016/j.tranpol.2016.02.010

Dong, R., Muhammad, A., & Nauman, U. (2025). The influence of weather conditions on time, cost, and quality in successful construction project delivery. *Buildings*, *15*(3), Article 474. https://doi.org/10.3390/buildings15030474

Eliasson, J. (2025). Cost overruns of infrastructure projects–distributions, causes and remedies. *Transportation Research Part A: Policy and Practice*, *198*, Article 104532. https://doi.org/10.1016/j.tra.2025.104532

Flyvbjerg, B., Skamris Holm, M. K., & Buhl, S. L. (2003). How common and how large are cost overruns in transport infrastructure projects? *Transport Reviews, 23*(1), 71-88. https://doi.org/10.1080/01441640309904

Flyvbjerg, B., Skamris Holm, M. S., & Buhl, S. (2002). Underestimating costs in public works projects: Error or lie? *Journal of the American Planning Association, 68*(3), 279-295. https://doi.org/10.1080/01944360208976273

Gamil, Y., & Alhagar, A. (2020). The impact of pandemic crisis on the survival of construction industry: A case of COVID-19. *Mediterranean Journal of Social Sciences, 11*(4), Article 122. https://doi.org/10.36941/mjss-2020-0047

Gkritza, K., & Labi, S. (2008). Estimating cost discrepancies in highway contracts: Multistep econometric approach. *Journal of Construction Engineering and Management, 134*(12), 953-962. https://doi.org/10.1061/(ASCE)0733-9364(2008)134:12(953)

Gujarati, D. N., & Porter, D. C. (2009). Basic econometrics (5th ed.). McGraw Hill Inc.

Hinze, J., Selstead, G., & Mahoney, J. P. (1992). Cost overruns on State of Washington construction contracts. *Transportation Research Record, 1351*, 87-93. https://onlinepubs.trb.org/Onlinepubs/trr/1992/1351/1351-013.pdf

Intergovernmental Panel on Climate Change (IPCC) (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.)]. Cambridge University Press. https://doi.org/10.1017/9781009325844

Love, P. E., Ahiaga-Dagbui, D. D., & Irani, Z. (2016). Cost overruns in transportation infrastructure projects: Sowing the seeds for a probabilistic theory of causation. *Transportation Research Part A: Policy and Practice, 92*, 184-194. https://doi.org/10.1016/j.tra.2016.08.007

Molinari, L., Haezendonck, E., & Mabillard, V. (2023). Cost overruns of Belgian transport infrastructure projects: Analyzing variations over three land transport modes and two project phases. *Transport Policy, 134*, 167-179. https://doi.org/10.1016/j.tranpol.2023.02.017

Molinari, L., Haezendonck, E., Van Rompay, K., Mabillard, V., & Dooms, M. (2025). Persisting cost overruns in public infrastructure projects: Lessons from the Belgian case. *Public Works Management & Policy*, *30*(1), 36-57. https://doi.org/10.1177/1087724X241252585

Neter, J., Wasserman, W., & Kutner, M. H. (1996). *Applied linear statistical models* (4th ed.). Irwin.

Odeck, J. (2004). Cost overruns in road construction—what are their sizes and determinants? *Transport Policy, 11*(1), 43-53. https://doi.org/10.1016/S0967-070X(03)00017-9

Park, Y. I., & Papadopoulou, T. C. (2012). Causes of cost overruns in transport infrastructure projects in Asia: Their significance and relationship with project size. *Built Environment Project and Asset Management, 2*(2), 195-216. https://doi.org/10.1108/20441241211280873

Schuldt, S. J., Nicholson, M. R., Adams II, Y. A., & Delorit, J. D. (2021). Weather-related construction delays in a changing climate: A systematic state-of-the-art review. *Sustainability, 13*(5), Article 2861. https://doi.org/10.3390/su13052861

Šopić, M., Vranković, A., & Marović, I. (2025). Understanding and quantifying the impact of adverse weather on construction productivity. *Applied Sciences*, *15*(19), Article 10759. https://doi.org/10.3390/app151910759