External Quality Assurance of Cost Estimates in Major Public Projects: Empirical Evidence on Cost Performance

Research paper

[Author details removed for anonymous review]

Purpose

Value creation for society from public projects requires that the overall benefits exceed the use of taxpayers' money. At the same time, cost overruns in public projects are a well-documented feature in the literature, but practical guidance on reducing the extent and magnitude of overruns is rare. In 2000, Norway introduced a governance regime that includes mandatory external quality assurance (QA) of cost estimates for major public projects. This paper compares the cost performance of public projects on each side of this QA scheme.

Methodology

We use an original dataset covering 1,704 projects from 2000 to 2021, reported first-hand from Norwegian public agencies. We apply quantitative methods in the form of descriptive statistics, regression models, and statistical testing of hypotheses to answer our research questions.

Findings

The mean cost overrun across projects in our dataset is smaller than several previous international studies have reported. We find no statistical support for different cost performances between QA and non-QA projects. Secondly, cost overruns seem to vary between different public sectors. A third finding is a small development with lower cost overruns over time for the non-QA projects, and we raise the question of whether the QA scheme has contributed to overall learning effects. The fourth finding is that cost deviations are quite independent of project size.

Originality

The paper offers novel insights for decision-makers and researchers on the effects of external quality assurance on cost performance in public projects.

Keywords: Cost performance, Cost overrun, Public sector, Learning effects, Project Cost Management

1. Introduction

The strategic impact of public investment projects in the form of value creation for society is something that is given increased attention by scholars and practitioners in the project management community (Haavaldsen *et al.*, 2014; Ika and Pinto, 2022; Morris, 2013; Volden, 2019). Within this shift in focus from the traditional "iron triangle" of project management (Pinto, 2010; Pollack *et al.*, 2018), the

identified cost and benefits of the proposed business case remain crucial for ensuring positive net value through both cost and benefits management in the project (Musawir *et al.*, 2017; Serra and Kunc, 2015). The choice to proceed with a public investment is often formed based on a cost-benefit analysis (CBA) of the effects (Volden, 2019). The relationship between costs (public resources invested) and benefits in the CBA determines if the investment is profitable for society through a positive net value and thus should proceed (Samset and Volden, 2014a; Volden, 2019). Hence, high-quality cost performance remains one of the key success criteria in government investment projects (Flyvbjerg, 2014; Ika and Feeny, 2022).

After many negative experiences with cost overruns, delays, and lack of realization of benefits in government projects, the Norwegian Ministry of Finance introduced the scheme with external quality assurance of cost estimates for the largest government investment projects in 2000 (Samset and Volden, 2014a). The scheme is also known as the external quality assurance or Quality Assurance (QA) scheme. It was later expanded with quality assurance of the earlier conceptual solution in the pre-project phase (QA1). QA means that project documentation on cost estimates and management basis must go through quality assurance by independent external consultants specialized in cost estimation and risk analysis before parliamentary proceedings. In addition, the independent consultants must carry out their analysis of success factors and pitfalls, as well as an analysis of the overall uncertainty of the project. They must then recommend the estimated project's cost and the necessary provisions for uncertainty and budget for

Figure 1 QA2 for large public projects in Norway, figure from Samset and Volden (2014)

the executing public agency.

The Norwegian government's project model includes all government investments with an expected cost of more than NOK 1 billion.[1] This paper will focus on final cost estimates before project approval in the QA2, illustrated in Figure 1.

Among the important results from a cost and uncertainty process for QA projects are the probabilistic P50 and P85 estimates. The budget for the public entity is often set equivalent to or close to P50 (the median of the cost outcome distribution), while P85 constitutes the upper-cost level (85% chance of no overrun) adopted by politicians for obtaining a portfolio-level budget (Jorgensen *et al.*, 2021).

1.1 The research gap

In the project management literature, there are several proposed explanations as well as measures proposed to mitigate the challenge of cost overruns in public projects (Flyvbjerg *et al.*, 2002, 2004; Love *et al.*, 2022; Welde and Klakegg, 2022). The formal involvement of an external party for quality assurance of cost estimates for major public projects is one measure decision-makers can adopt to ensure realistic budgeting (Flyvbjerg, 2009; Lovallo and Kahneman, 2003; Mackie and Preston, 1998; Volden, 2019; Welde and Klakegg, 2022). The QA scheme in Norway has been the subject of several previous studies, for example, cost-benefit analyses (Volden, 2019), challenges in the front-end of projects (Samset and Volden, 2014b, 2016), as well as studies on cost performance (Andersen *et al.*, 2016; Samset and Volden, 2014a; Welde and Klakegg, 2022). Previous studies have documented that the cost performance for the Norwegian projects undergoing QA is good in terms of low deviations from budget (Welde, 2017; Welde *et al.*, 2019; Welde and Klakegg, 2022). However, the cost overruns in QA scheme projects have not previously been compared to major projects outside the QA scheme. In order to capture other factors that can explain cost overrun, there is a need to extend the empirical knowledge to include data from other major projects to allow a comparison of cost overruns of the QA projects, as well as project data across different sectors to a larger extent than what has been done previously.

1.2 This study

The purpose of introducing QA2 was to improve cost performance and ensure successful implementation of projects. In this paper, we will focus on cost performance from the quality assurance before final project approval in the QA2-projects (henceforward “QA-projects”). We take previous analyses further by comparing QA projects with other major public projects that have not been through QA. This could potentially add more knowledge to any impact from QA on cost

[1] Approximately equivalent to EUR 100 million. This has been the threshold since 2019. For ICT projects, the threshold is NOK 300 million. At implementation, the threshold was NOK 500 million, before it was raised to NOK 750 millions in the period 2011-2018.

performance. The empirical results in this study are based on first-hand quality data on budgets and final costs from Norwegian public projects. To account for the fact that final costs can vary from the initial budget in both directions (i.e. both cost *under*run and *overrun*), we use the term "cost deviations". We define the following four research questions (RQs) that together aim to increase knowledge on the effect of introducing an external quality assurance scheme on cost performance in public projects:

- RQ 1. Do QA projects have smaller relative cost deviations than non-QA projects?
- RQ 2. Do any sectors stand out regarding relative cost deviations between QA and non-QA projects?
- RQ 3. Have the relative cost deviations changed over time? If so, is this change different between QA and non-QA projects?
- RQ 4. Can the monetary size of the projects explain differences in relative cost deviations?

This paper is organized as follows. Section 2 presents extant literature on cost performance. The methodology and data are described in section 3. The empirical results are given in section 4. Section 5 addresses limitations and further work before conclusions are drawn in Section 6.

2. Extant literature on cost performance

2.1 Cost overruns pose a substantial challenge in public projects

Cost overruns in public projects have been the topic of many empirical studies. Morris and Hough (Morris and Hough, 1987) reviewed international studies of cost overruns from the 1970s to the 1980s. In total, these studies covered close to 4,000 projects and several countries. The results showed that 40-200 percent overruns were the rule rather than the exception. Flyvbjerg et al. examined cost overruns in 258 infrastructure projects from 20 countries between 1910 and 1998 (Flyvbjerg *et al.*, 2002). Nearly 90 percent of the projects in the sample had cost overruns, and on average, the final cost was 28 percent higher than the original budget. Large cost overruns were the case in all the countries surveyed, and there was no sign that there had been any improvement in the situation over time. Recent studies suggest that large cost overruns are still widespread in public investment projects worldwide. For example, Sarmento and Renneboog found an average cost overrun of 24 percent in a sample of 243 public infrastructure projects in Portugal, whereas Cantarelli et al. documented an average cost overrun of 16.5 percent in a sample of 78 Dutch infrastructure projects (Cantarelli *et al.*, 2010; Sarmento and Renneboog, 2017). Similarly, Love et al. found an average overrun of 23 percent among 16 Australian railway projects (Love *et al.*, 2017). Given differences in reporting, organization, and estimation methodology, it is not surprising that one finds different sizes of cost variances across studies. In addition, the basis for comparison compared to the final cost is also relevant, for example, whether it is an early estimate or an approved budget. Odeck finds in his meta-study that the average percentage cost overrun varies across study-specific characteristics such as project type or world region. One key finding was that overruns rather than underconsumption are widespread (34 percent on average) but that overruns have decreased over time (Odeck, 2019).

Studies and public reports have documented that cost overruns were the rule rather than the exception for public investment projects also in Norway before the introduction of QA in 2000 (Berg, 1999; Odeck, 2004). After 2000 and the introduction of the QA scheme, several studies were carried out to analyze cost performance (Aas, 2013; Odeck and Welde, 2015). The latest study of cost performance in QA projects is Welde et al. (2019), with data from 85 completed QA projects show that 75 percent of the projects were within the upper-cost level adopted by politicians (p85) and 42 percent within the budget for the public entity (p50). Concerning our research question 3 on change in cost deviations over time, a previous study by Samset and Volden (Samset and Volden, 2013) has argued that QA has contributed to learning effects in the agencies that prepare the basis for QA.

2.2 Causes behind cost overruns

The reasons for cost overruns can be many and complex, and the literature points to a number of different causes. Flyvbjerg et al. (2002) and Cantarelli et al. (2010) divided the reasons into four categories: technical, economic, psychological, and political:

1) Technical reasons include errors in the forecasts, insufficient data, "honest errors", inherent problems predicting the future, and lack of experience and competence. If technical reasons are the dominant explanation, one would expect that the deviations between actual and estimated cost would be around zero and that an improvement in the situation could be observed over time due to learning.

Of other literature that falls under this category, Morris and Hough (1987) found that scope changes during project implementation, increased security requirements, and land acquisition costs were all possible explanations for large cost overruns observed in the international literature. The authors believed that the exceedances were mainly due to circumstances "outside" the project and, to a lesser extent, to conditions during the project implementation. Scope changes has also been pointed to as a cause by later studies (Love *et al.*, 2014).

In contrast, Adam et al. (2017) found that management-related reasons were the most prominent. Management-related reasons include poor construction management, insufficient leadership skills, poor monitoring and control during project implementation, slow decisions, user-initiated changes, and poor work planning.

2) Economic reasons behind cost overruns concern deliberate underestimation based on lack of incentives or resources but can also originate in strategic motives.

3) Psychological reasons concern the inherent over-optimism of those who plan and promote the project (tendency to ignore problems that may arise) and will also result in underestimated costs. Suppose psychological reasons and over-optimism had been the dominant reason. In that case, one would, like for technical reasons, expect to see an improvement over time as learning would lead to a reduction, or possibly elimination, of the bias in the estimates.

4) Political reasons are about deliberate underestimation of costs to get a project started. This means that costs are knowingly and willfully underestimated to ensure project implementation and financing. Flyvbjerg et al. (2002) believed that such strategic underestimation of the estimates was the most likely explanation for the systematic cost overrun they observed in their data set. A substantial part of the causes behind cost overruns documented in the literature fall outside these four categories. In a recent work by Asiedu and Adaku (2019), the authors propose further causes for cost overruns seen from a developing country's perspective. The four main causes suggested are poor contract planning and supervision, change orders, weak institutional and economic environment of projects, and lack of effective coordination among the contracting parties. Another recent study on cost overruns in 43 projects in the Kingdom of Saudi Arabia found that change orders has an effect on public projects budget, and that approximately 75 % of these could have been prevented with better project planning and management (Alkhattabi *et al.*, 2023). Durdyev (2020) conducted a literature review on the causes of cost overruns as reposted in the project management literature since 1985, and 79 different causes were identified. Out of these 79, the author list a top.10 from the papers that have received the most attention in form of citation and discussion; design problems, inaccurate estimation, poor planning, weather, poor communication, stakeholder's skill, experience and competence, financial problems, price fluctuations, contract management issues and ground/soil conditions (Durdyev, 2020).

External quality assurance of cost estimates can be a way to overcome several of the challenges faced to set realistic budget for public projects. When a neutral external consultant is responsible for ensuring the quality of the calculations and carrying out new analyses, additional competence and the bias behind several causes for cost overruns can be mitigated. It can also help to reduce the risk of several technical reasons, from access to more data to competence from the QA. If these listed causes behind cost overruns from Flyvbjerg et al. (2002) and Cantarelli et al. (2010) are dominant in our data set, one would expect a better cost performance in the projects that are in the QA scheme compared to those outside the QA scheme.

How cost overruns develop over time has also been subject to empirical studies. A natural starting point is the work of Flyvbjerg et al. (2002), who studied if underestimation of public project costs has decreased over time as better methods were developed and more experience gained. The authors cannot find support for learning effects in the data and conclude that the underestimation of costs has not been reduced over time (Flyvbjerg *et al.*, 2002). Dahl et al. (2017) investigated the development of cost overruns between 2000-2013 among Norwegian oil sector projects. The authors aim to capture the macroeconomic cyclical effects on cost overrun and document a statistically significant positive relationship between oil price developments and cost overruns. Other parameters affecting cost overruns are changes in the number of employees and unexpected price changes in the project implementation phase. In another study on Norwegian development projects in the oil and gas sector aiming to explain cost overruns by looking at underlying macroeconomic drivers over time, Lorentzen et al. (2017) find that cost overruns in offshore oil and gas projects tend to increase when economic activity increases (Lorentzen *et al.*, 2017). The authors also build upon the question Flyvbjerg et al. (2002) raised on the development of underestimation over time. However, analyses of the time dimension in cost overrun fail to produce any significant relationship.

Regarding the importance of project size, the literature provides somewhat contradictory results. Cantarelli et al. (2012) found that the percentage overrun was greatest in medium-sized projects (€50-112.5 million). For this group of projects, the average overrun was 23.2 percent. However, Odeck (2004) found that the percentage overrun was greatest in the smallest projects (under NOK 100 million). Similar results occur in Lundberg et al. (2011), who found that the average overruns were far greater in the smallest projects (under SEK 100 million). On the other hand, Flyvbjerg et al. (2004) found no relationship between the project's size and the percentage cost overrun.

3. Methodology

This study aims to investigate how the External Quality Assurance (QA) scheme influences cost overruns. Following the structured framework on causes behind cost overruns presented in the literature, we apply a deductive approach to test a set of hypotheses derived from theory (Saunders *et al.*, 2019). This methodological stance is grounded in the positivist tradition, which emphasizes the importance of hypothesis testing to validate and refine theoretical constructs (Popper, 2005). By starting with a general theory and moving toward specific observations, researchers can employ statistical methods to rigorously assess the validity of their predictions (Bryman, 2016). Deductive reasoning allows for the operationalization of variables and the establishment of clear, measurable outcomes, facilitating the replication of studies and the accumulation of knowledge across different contexts (Hempel, 1965). Moreover, the deductive approach aligns with the scientific method's emphasis on falsifiability, ensuring that research findings are subjected to empirical scrutiny and can be disproven if they do not hold true (Popper, 2005). This approach is particularly effective in established fields such as research on cost overruns, where we have a strong theoretical foundation for hypothesis-driven research, leading to a deeper understanding of causal relationships and contributing to the predictive power of scientific inquiry (Babbie, 2020).

3.1 The projects

The dataset used in this study consists of budget, final costs, and project start and end (opening year) for completed projects. The monetary value of the projects presented amounts to NOK 340,3 billion. The starting point is the entire population of projects that have undergone QA and where there is a final cost. These data are supplemented by data from the three major public sectors in Norway: 1) the Norwegian Public Roads Administration (Statens vegvesen), 2) the Norwegian government's building commissioner, property manager and developer (Statsbygg), and 3) the procurement agencies of the Armed Forces, for the years 2000-2020. The project budgets range from NOK 1 million to NOK 16 billion, with the average budget being approximately NOK 200 million. Data is reported first-hand from the agencies. The QA projects include a few below the threshold value that triggers quality assurance requirements but have nevertheless been the subject of QA since they have been sub-projects of a major investment. Together with the quantitative data on project costs, we gathered documentation from the agencies on quality assurance practices for cost estimates for projects below the threshold for QA. Budget and final costs are indexed to a common reference year to account for inflation.

3.2 Definition of cost deviation and analysis

When we study deviations between the final cost and the project's budget, we take the budget as our starting point, which in most cases is based on the P50 estimates. Although P85 is the formal upper-cost level, there are several reasons why we use the agencies' budgets based on the P50 estimate. One main reason is that the budget has been reported for most projects in the data set. Furthermore, smaller projects often have a budget closer to P50 than P85, for example, setting the uncertainty provision as 10 percent of P50 when the estimation process is not as extensive and formalized. Thus, comparing QA and smaller projects will make the most sense when using the budget based on the P50 estimate.

Cost performance in the form of relative deviation between final cost and budget for project *i* is defined as follows:

$$Relative\ cost\ deviation_i = \left(\frac{Final\ cost_i - Budget_i}{Budget_i}\right) = \left(\frac{Final\ cost_i}{Budget_i} - 1\right) \quad (1)$$

A deviation in the form of a final cost higher or lower than the budget will be defined as different from 0. A negative value indicates that costs are lower than P50, while a positive value suggests cost overruns compared to P50. If the cost deviation is calculated as 0.1, the costs have exceeded the P50 budget by 10 percent.

$$Average\ cost\ deviation = \frac{1}{n}\sum_{i=1}^{n} Relative\ cost\ deviation_i \quad (2)$$

In order to select projects where cost estimates naturally can be compared according to project size, the analysis in this paper will mainly focus on projects over NOK 100 million. In addition to graphical representations, we will use ordinary least squares (OLS) to evaluate various issues with regression models. Hypothesis testing is based on an estimate and variance measure to say how precisely an estimate is calculated and whether the point estimate is statistically significant. The OLS method is the most common method for estimating unknown parameters in a linear regression model. The method involves minimizing the sum of the squared difference between the actual value of the dependent variable and the value predicted with the product of estimated parameters and independent variable values (Wooldrige, 2020).

Furthermore, regression models have a clear advantage in that more variables can be included to explain the variation in the studied dependent variable. In our case, the connection between cost deviations and which sector the project belongs to may also depend on project size. Such conditions can be controlled for in regression models so that conditional relationships are demonstrated.

An estimated coefficient of 0 in the linear probability model indicates no relationship between the dependent and the independent variable. The dependent variable will be the relative deviation between the final cost and frame measured as (final cost/frame – 1). A value of, for example, 0.1 thus indicates that the final cost is 10% higher than the limit. An estimated coefficient of a dummy variable, for example, a variable that takes the value 1 for QA projects and 0 for others, can thus be interpreted as how many percentage points higher or lower the relative cost deviation is for QA projects compared to the reference category of other projects.

3.3 Descriptive statistics

Table 1 presents descriptive statistics regarding the projects in our dataset. We have collected information on budgets and cost performance for 1,704 investment projects. There are 373 projects with a budget frame above 100 MNOKs, whereas 71, 235, 51, and 16 projects are within construction (buildings), road, defense, and other sectors, respectively. The monetary value of these projects amounts to NOK 70,5 billion. The total number of quality assurance (QA) projects amounts to 123, with a monetary value of NOK 233,6 billion. All projects grouped as “Other” are QA projects, whereas this is the case for 20, 70, and 17 projects categorized as construction, road, and defense, respectively.

The projects under NOK 100 million follow the procedures for cost estimation and budget decision (p50) according to the current guidelines of the respective agency (Berg *et al.*, 2022). Since these are smaller projects, they are not subjects to the external QA model, and thus not governed directly by the Norwegian Ministry of Finance. The monetary value of these projects in our dataset amounts to approximately NOK 37 billion.

Panel B shows descriptive statistics regarding relative cost deviations. For the entire dataset, including the projects under NOK 100 million, the average relative cost deviation calculated using equation (2) is 10.8 percent. The standard deviation is 37.6 percent. By applying the budget frame as weight, the average cost deviation is 4.3 percent (not reported in the table), indicating that cost deviation is most severe among smaller projects. This is confirmed in the second column, where projects with a budget frame under NOK 100 million are excluded. We observe an average cost deviation of 3.7 percent among the larger projects. Since we measure cost deviation relative to the p50 budget, it is natural to expect that close to 50% of the projects should have a positive cost deviation (cost higher than budget). This is also observed in the data, where the share with costs higher than the p50 budget is 54.1% for all the 1,704 projects and 47.7% for the projects with a budget above NOK 100 million.

[Table I here]

The last four columns in Table 1 show descriptive statistics across the four sectors. For the construction projects, we observe a negative relative cost deviation on average (costs lower than the budget), whereas the relative cost deviation in the other sectors varies between 4.5-8.4 percent. The reported standard deviations suggest that it is among defense projects where cost deviation varies the most. The 16 projects categorized as "Other" are typically larger ICT projects. Regarding the share of projects with costs higher than the p50 budget, we observe that the share is quite low among the construction (buildings) projects, whereas the shares are almost 70% among the projects grouped in the "other" category.

Descriptive statistics on project size are reported in Panel C in Table 1. For all the 1,704 projects, the average budget frame is about NOK 200 million. The standard deviation is NOK 709.2 million, which documents substantial variation in size. The smallest road projects in the dataset have a budget frame of only NOK 0.6 million, whereas the largest defense project amounts to NOK 16,200 million. When excluding the projects with a budget below NOK 100 million, the average size is NOK 828 million. Generally, the defense projects are somewhat larger on average than the construction and road projects, whereas the projects categorized as "other" are the largest, with an average of NOK 2,326 million.

3.4 Qualitative information from the agencies on quality assurance practices

In addition to quantitative data on cost performance, we gathered documentation on guidelines for cost estimation from the agencies represented in our dataset. This documentation revealed that all projects, including those under the threshold for QA, were subject to internal processes for quality assurance. The comprehensiveness of the process was divided according to the monetary size of the project. Typical divisions were into the most simplified process for projects under NOK 15-20 million, a more comprehensive process for projects between NOK 20-50 million, and finally, for projects over NOK 50 or 100 million, a full process containing, for example, several group processes on risk assessment, as well as a more formal quality assurance on the final cost estimate within the entity. An earlier survey of cost estimation in large QA projects by Welde and Torp (2016) found that the way cost estimates are prepared is relatively similar between the agencies. The agencies within the three sectors in this study use a stochastic cost estimate where the uncertainty in the various elements of the estimate is estimated through group processes. The researchers also found that the methods used mainly align with international best practices. This information on quality assurance practices within public agencies forms an important background when interpreting the following results on the distribution of cost deviation across project sizes.

4. Presentation of empirical results and discussion

This section presents the findings from our quantitative analysis of cost data from public projects. In the previous section, we included all 1,704 projects to describe how cost overruns materialize in a larger and representative sample of the populations of public projects in Norway. To answer our research questions, we will in the following mainly focus on the subset containing large projects over NOK 100 million. The results presented in this section are divided according to our four research questions.

4.1 RQ1: Do QA projects have smaller relative cost deviations than non-QA projects?

To answer RQ1, we will look at deviations between the final cost and the p50 budget for large projects above and below the threshold value for external QA. The QA projects will be compared with different comparison groups. Large projects over NOK 100 million are assumed to be a favorable comparison group due to similarities in the comprehensiveness of the cost-estimating process.

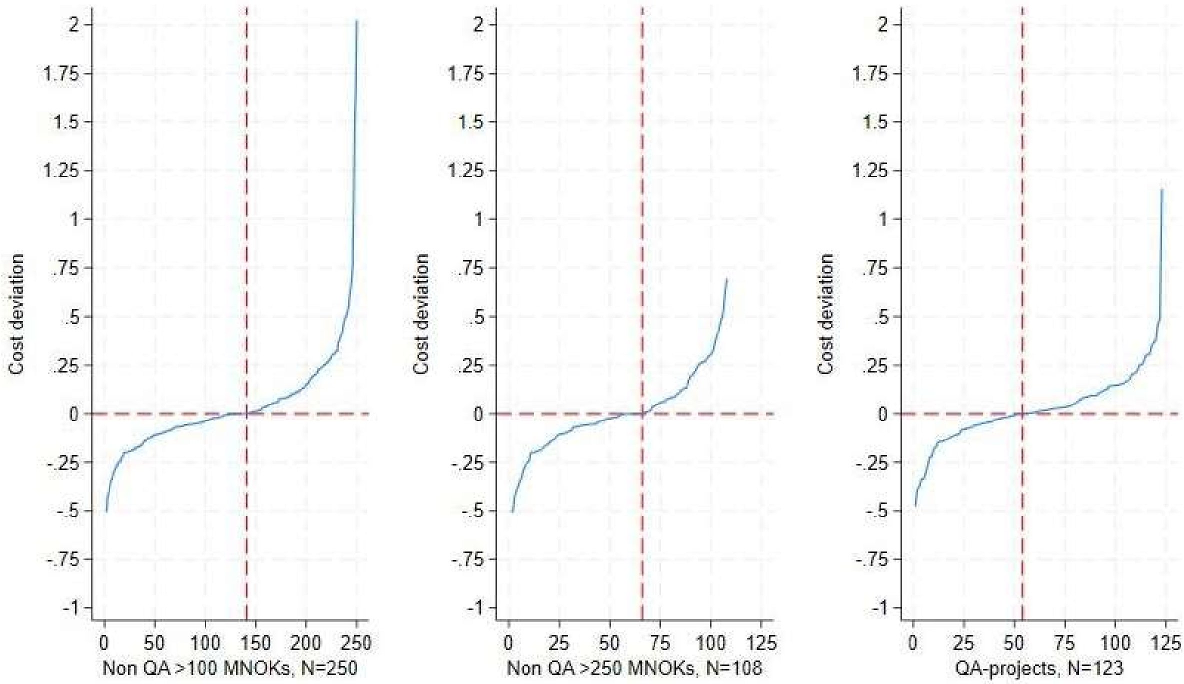

Figure 2 Distribution of cost deviation among projects grouped across project size

A graphic presentation of the relative cost deviation for different groups of projects is shown in Figure 2. Here, we can observe a fairly similar distribution of relative deviations across the different groups of projects. The graph on the left shows the distribution for projects with an initial budget of more than 100 million but have not completed QA. There are a total of 250 current projects in the data set. Of these, 141 projects are to the left of the red vertical line (56.4%). As we also saw in Chapter 4.1, there are relatively large relative deviations for many projects. Those to the left in the graph have a relative deviation of about -0.5, which indicates that the final cost only makes up half of the initial budget. However, there are more significant relative deviations to the right of the red vertical line where 12 of the 109 projects (corresponding to 11%) have a final cost at least 50% higher than the budget. The project with the largest deviation has a final cost twice as large as the budget.

The second graph in Figure 2 shows a corresponding distribution where we have excluded projects with a budget of less than NOK 250 million. The number of projects here is 108. Of these, 66 have a final cost that does not exceed the budget, which amounts to 61.1% of the projects. In this sense, the distribution is fairly similar to the graph that included all projects over 100 million that have not undergone QA, except for the biggest deviations being far smaller when projects between 100-250 million are excluded. In the graph, only three projects have a deviation greater than 50%, while the largest deviation is 70%.

The graph on the right in Figure 2 shows the distribution of deviations for the projects that have been the subject of external quality assurance (QA). In total, this applies to 123 projects in our dataset. For 54 of the projects, negative values for relative deviation are observed. The share is 43.9% and, in comparison, somewhat lower than what we observe in the graphs on the left, where projects that have not undergone external quality assurance are included. Otherwise, we see that the distribution of relative deviations is fairly similar as in the other two graphs but that the largest positive values (final cost higher than the initial budget) lie somewhere in the middle of what was the case for the projects in the two graphs on the left, where the maximum estimates of the deviation are measured at 1.16, which indicates that the final cost is 116% higher than the budget.

In summary, it appears that the deviations between the final cost and the budget are equally distributed for projects that have undergone QA and those that have not been subject to external quality assurance.

The mean percentage cost deviations for the three groups illustrated in Figure 2 are 4.1 for non-QA above NOK 100 million, 0.6 for non-QA projects above NOK 250 million, and 2.9 for QA projects. The relative deviation between budget and final costs is further analyzed using regression in Table 2. The interest variable in these analyses is the dummy variable QA, taking the value of 1 for projects that have undergone QA. The interpretation of the estimated coefficient for that variable is how much higher or lower the relative deviation on average is for the QA projects compared with the projects that make up the reference category/comparison basis, i.e., projects that have not been the subject of QA. An estimated coefficient of 0.1 will thus indicate that the final cost is 10 percentage points higher than the final cost for QA projects compared with projects outside the scheme.

[Table II here]

The first column of Table 2 shows results for all 1,704 projects in our dataset. The calculated coefficient of the QA dummy here is -0.085 and statistically significant at the 5 percent level. The estimate thus indicates that the QA projects have a deviation of 8.5 percentage points lower than other projects. However, the analysis sample in column (1) includes many small projects. In column (2), we include a dummy variable for projects under NOK 25 million. Then, we observe that the effect of the QA dummy is more than halved and that the estimate is no longer statistically significantly different from zero. This finding suggests that the average relative cost deviation is prominent and highest for smaller projects. In columns (3)-(6), we reduce the samples by only including large projects over NOK 100 million in the reference group, in addition to utilizing weights in the regression in column (4). The point estimates for the QA dummy are always close to zero and never statistically significant, indicating that the external quality assessed projects do not differ from the reference group regarding cost deviations.

In the literature on cost overruns, it is consistently found that final costs are, on average, higher than the original budget. See, for example, Flyvbjerg (2002), Cantarelli et al. (2012), and Love et al. (2017). The cost overruns in this study are generally lower than those found in the international literature and are thus more consistent with findings from Norwegian studies, for example, Aass (2013), Welde et al. (2019) and Welde and Klakegg (2022). However, this is unsurprising as much of our QA-based data is the same as in previous studies. What is new about this study, however, is that we have discovered that the good results with low deviations also apply to smaller projects.

Furthermore, Flyvbjerg et al. (2002)(Flyvbjerg *et al.*, 2002) and Cantarelli et al. (2010)(Cantarelli *et al.*, 2010) divided causes of cost overruns into the categories of technical, economic, psychological, and political. In the literature chapter, we advanced the possibility that a regime with quality assurance by a neutral third party would be able to overcome several of these causes (Flyvbjerg, 2009; Lovallo and Kahneman, 2003). We could thus expect a sharp difference in the size of the cost deviations between the projects in and outside the KS scheme. When our results do not show that such a distinction is the case and that the deviations are on average lower than findings from the international literature, it may point in the direction that these ratios are not prominent for the average project in the Norwegian context. Here there are several other factors that can come into play, such as estimation methods and quality assurance practices. For example, the document review of the public agencies' processes in Section 3.4 showed that a form of internal processes for quality assurance of the cost estimates is also the case for smaller projects.

4.2 RQ2: Do any sectors stand out regarding relative cost deviations between QA and non-QA projects?

To answer RQ2, we will expand the analyses from the first research question by grouping the projects into three sectors: construction, roads, and defense. Figure 3 shows no apparent difference in relative cost deviations across the sectors represented. However, we observe the highest deviations within non-QA in the road and defense sectors, with cost deviations seeming relatively small in the building construction sector. The examples of outliers with large cost deviations in the defense sector can be explained by risk and complexity from the substantial proportion of new development projects in the Norwegian defense sector (Berg et al., 2019).

Figure 3 Distribution of cost deviation among projects > NOK 100 million grouped across QA and sector

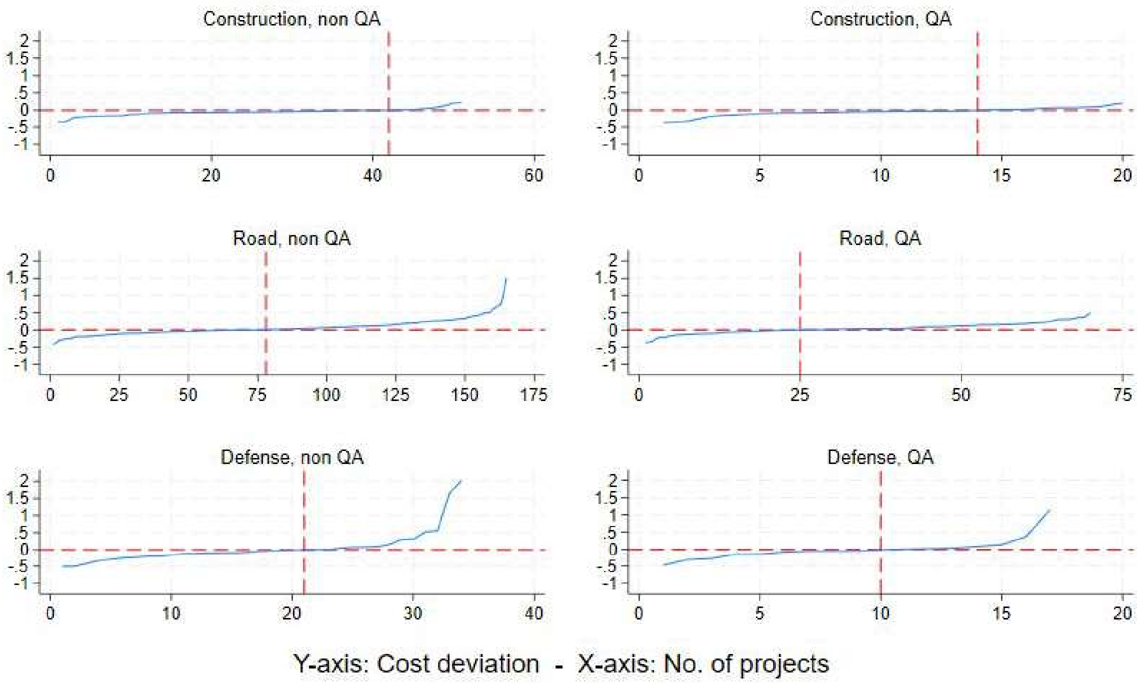

Table 3 presents the results from sector-level regression analyses where relative cost deviation is the dependent variable. We chose to focus on the projects over NOK 100 million. We have included all projects in column (1), controlling for sector by including dummy variables (construction is then the reference category). These dummy variables control for potential systematic differences in average cost deviations across the sectors.

[Table III here]

The coefficient for QA in column (1) indicates that the relative cost deviation is slightly lower (2.2 percentage points) among the QA projects, but the point estimate is not statistically significant. The dummies for roads and defense are positive and reflect that relative cost deviations are smaller for buildings, as suggested in Figure 3. When we split the sample by sector into columns (2)-(4), the point estimates for QA are always quite close to zero and never statistically significant. However, it is worth mentioning that the QA point estimates for roads and defense are negative.

The results on cost deviations across the sectors represented in our dataset illustrate some differences.

Overall, the deviations stand out as small for the construction projects compared to roads and defense. The final cost is also relatively low on average in construction projects compared to the case for road and defense projects. However, there is relatively weak empirical support for claiming that QA projects have a relative deviation between final cost and initial budget that differs from projects outside the scheme across sectors. Empirical studies on cost overruns are often represented with data from one sector, such as infrastructure (Flyvbjerg *et al.*, 2002; Love *et al.*, 2017; Odeck, 2014; Sarmento and Renneboog, 2017), or the construction sector (Adam *et al.*, 2017; Asiedu and Adaku, 2019). In the meta-study across countries, Odeck (2017) finds difference between type of projects with road projects show significantly lower cost overruns than rail projects.

4.3 RQ3: Have the relative cost deviations changed over time? If so, is this change different between QA and non-QA projects?

If QA provides learning effects within the agencies, as Samset and Volden (2013) suggest, this may also affect projects below the threshold value / outside QA. Thus, one will expect any difference in project cost deviations across the threshold value to be reduced over time. Figure 4 presents the association between cost deviations and opening year across the dimension quality assessment. We observe a large spread over the period for both groups, but this applies especially to the non-QA projects. Although some relatively clear extreme observations exist on high relative cost deviations within the non-QA projects in the last half of the period, the regression line shows that the relative deviation has decreased over time.

One might expect potential learning effects concerning cost performance over time for projects that have undergone QA, but as we see in the right graph in Figure 4, this shows a positive slope for the regression line. This indicates that these projects' final cost over time has increased relative to the budget. A possible learning effect for the quality assurance providers may have been the case in that at the start, they often calculated relatively high estimates (Magnussen and Olsson, 2006), but over time, these estimates came closer to the agencies' estimates. However, when testing the hypothesis that the slope of the two lines in Figure 4 is different from zero through a formal T-test in an OLS regression, we reject this hypothesis (p-value equal to 0.24). Thus, we do not find a statistically significant association of differences in cost deviation development over time between QA and non-QA projects.

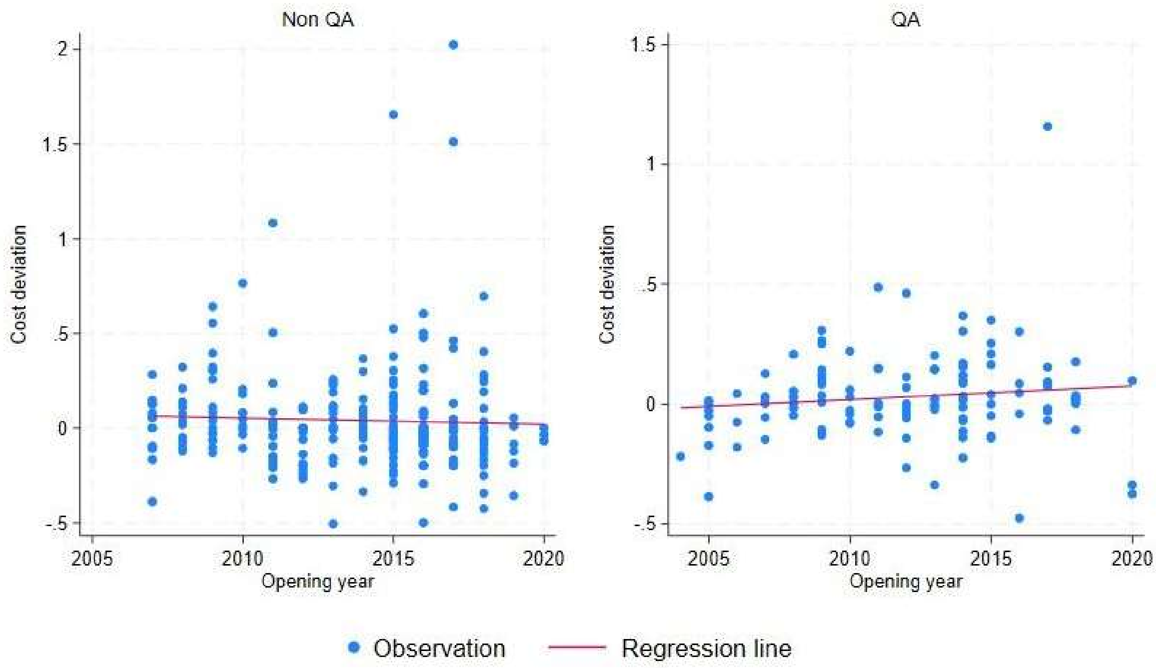

Figure 4 Cost deviations and opening year across non-QA (> NOK 100 million) and QA projects

Samset and Volden (2013) argued that the QA scheme may have positively affected planning work linked to smaller projects outside the KS scheme, as the external quality assurance may have provided internal learning within the agencies. Our finding that it is mainly among projects outside the QA scheme where relative deviations have decreased over time is in line with this hypothesis.

Figure 5 shows the graphic relationship between relative cost deviations and opening year across the three sectors. The visual presentations suggest that relative cost deviations have decreased slightly in the construction sector, where the regression line's slope is somewhat steeper among quality-assured (QA) projects. In contrast, we observe the opposite relationship among quality-assured road projects.

These results add valuable knowledge to the discussion on the development of cost overruns over time across different sectors, as previous studies have focuses on macroeconomic factors such as oil price

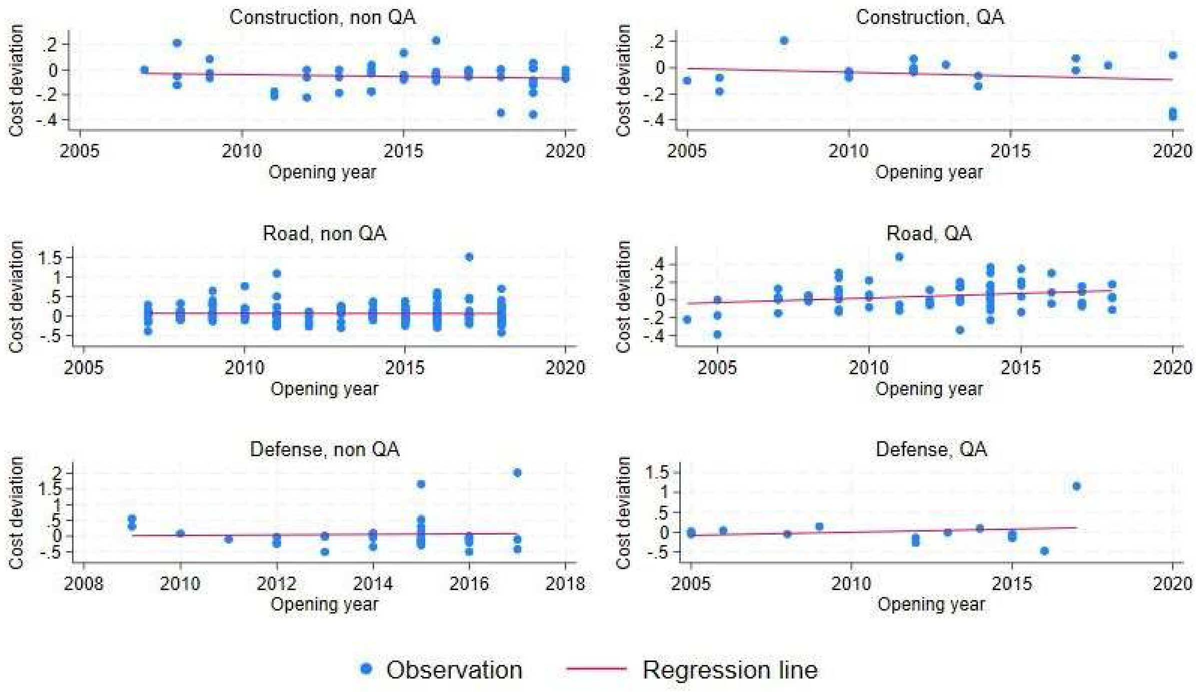

Figure 5 Cost deviations and opening year across non-QA (> NOK 100 million) and QA projects in different sectors

development and overall economic activity (Dahl *et al.*, 2017; Lorentzen *et al.*, 2017).

As our timeline is 2000-2013, we should be able to see traces of possible learning effects. However, among the large QA projects, we observe differences between the sectors in development over time. Flyvbjerg et al. (2002) rejected that cost underestimation had decreased over time based on their statistical findings. In this study, we do not find a statistically significant association between time and cost overrun. However, the difference between non-QA and QA projects is interesting. It suggests that the development of cost overruns over time should be seen in relation to the monetary size of the project as well as type of project (sector).

4.4 RQ 4. Can the monetary size of the projects explain differences in relative cost deviations?

In this section, we will study whether the correspondence between final costs and budget varies with the size of the projects. As the descriptive statistics in Chapter 3.3 show, there is quite a large variation in the size of the projects. A factor that makes project size somewhat challenging to test is that the QA projects are, on average, much larger than the projects we have as a comparison group, as project size is a characteristic that mainly determines whether the project will undergo external quality assurance. In this part, we will conduct regression analyses with relative deviation as the dependent variable and various functional forms of project size as variables of interest. We analyze projects within and outside the scheme separately. In addition, we will make a distinction by sector.

Table 5.3 presents relevant regression results with relative cost deviation as the dependent variable. We have only included projects outside the QA scheme in the first three columns. In column (1), we have only included the budget measured in billions of kroner as an independent variable. The coefficient of -0.094 indicates that when the project size increases by 1 billion, the final cost among projects outside QA will, on average, be reduced by 9.4 percentage points relative to the budget. It may indicate that cost control is better in relatively large projects outside the KS scheme. However, the coefficient is not statistically significant.

[Table IV here]

In column (2) in Table 4, we have included a logarithmic functional form for project size as an independent variable. The point estimate points in the same direction as we saw in column (1), but the relationship is still not significant. In column (3), we have also tried to include the third-degree polynomial of the project size measured in billion NOKs. None of the polynomials are statistically significant, but the point estimates indicate a negative correlation up to 0.5bn before the estimate on cost deviation increases for project sizes between NOK 0.5 to 1.6 billions. For project sizes above 2.15bn, the estimates indicate a negative cost deviation, meaning that costs would be lower than the budget frame.

In columns (4)-(6) in Table 4, we do the same exercise for the QA projects in the data set. We here find the opposite sign for the linear association compared to the projects outside the scheme, which suggests that the final cost increases relative to the budget the larger the project. This finding is supported by the earlier study by Welde et al. (2019). However, the estimate in column (4) is very close to 0 and far from being statistically significant, which is also substantiated in column (5). In column (6), the third-degree polynomial of size is tested. We do not observe any statistical correlation between the current functional form of size and relative deviation from the budget (p50). However, the point estimates indicate a positive slope up to a project size of about 8 billion.

In Table 5, we tested whether there is a linear relationship between project size and relative deviation within each sector. Briefly summarized, the findings here indicate that it is primarily for QA projects related to buildings and roads as well as projects outside the QA scheme in the defense sector where size statistically contributes to explaining the variation in relative deviation. The point estimate is positive within the buildings and road sector, indicating that the final cost is higher on average relative to the budget for larger projects. For the defense projects outside the QA scheme, however, we observe the opposite effect, where it may appear that the relative deviation is greatest for smaller projects.

[Table V here]

In short, there is little empirical support that project size can explain parts of the variation in relative deviation between final cost and budget when we look at all projects. By dividing by sector, however, the analyses indicate that it is primarily for QA projects – in other words, very large projects – related to construction and roads where relative deviations correlate positively with project size. This means the final costs are relatively high among the largest projects. For projects outside the QA scheme, we mainly find traces of the opposite relationship among defense projects and larger overruns for the smallest projects in our sample.

The literature is somewhat divided on the relationship between monetary size and cost overruns. Our finding that deviations between final cost and budget are quite independent of project size is in line with some previous research findings (Flyvbjerg *et al.*, 2004). At the same time, we find that among the very smallest projects (those under NOK 25 million), the overruns are highest. This finding aligns with Lundberg et al. (2011) and Odeck (2004). Lorentzen et al (2017) found that the size of investment had a positive impact on the cost overruns for investments in the oil sector of Norway.

Divided by sector, it is among buildings and road projects that size statistically contributes to explaining the variation in relative deviation. For defense projects, this is the case for smaller projects outside the QA scheme. This last finding suggests that it might be necessary to consider project type in addition to monetary size in explaining cost deviations.

5. Limitations and further work

Analyzing cost estimates and final costs alone only tells a limited part of the story and is insufficient to evaluate the overall effects of introducing a QA scheme. How public projects create value for society is only partially analyzed by looking at costs, and addressing the benefit side is highly relevant to capturing the full effect of the use of taxpayers' money (Aubry *et al.*, 2021; Musawir *et al.*, 2017; Samset and Volden, 2016).

In this study we use the projects budget to categorize the size of projects, as it is the budget size that determines if there will be an external QA of the estimated costs. An expansion of the analysis could be to categorize project size according to actual costs to see the effect on cost overrun (Jørgensen *et al.*, 2012). Furthermore, the results of this study is focused on the Norwegian market and model and may not be generalizable across different countries.

This paper focuses on the second QA and does not capture cost performance in the pre-project phase of QA1 (Samset and Volden, 2014b). Here, cost deviations can be more extensive; see Andersen et al. (2016) and Welde and Odeck (2017). For a deeper understanding of the overall effects of external quality assurance, a qualitative research approach, for example, through interviews with the agencies, could produce valuable insights. Capturing accurate results from the transition into the QA scheme can, at the same time, be challenging since the scheme was introduced more than 20 years ago.

Regarding temporal aspects of cost overrun, the literature is scarcer than the general literature quantifying cost overrun and its causes. Although more recent studies exist, one of the most influential and cited studies analyzing cost overruns dates back to 2002 (Flyvbjerg *et al.*, 2002). Estimation techniques and possibilities for using historical data should have been improved since then. Thus, there is room for more recent empirical studies using panel data to enhance the knowledge about the learning effects of cost overruns (Amadi and Ahiaga-Dagbui, 2021; Bodendorf and Franke, 2021; Klakegg and Lichtenberg, 2016; Taihairan and Ismail, 2015). Lorentzen et al. (2017) also ask if the period their data covers might be too short to reveal any significant effect from learning and improvement in cost estimate techniques. Another possibility raised by the same authors is that innovation is so rapid that former experience quickly becomes outdated.

6. Conclusion

Our first RQ asked if QA projects had smaller relative cost deviations than non-QA projects. In general, our results from the descriptive statistics show that the average relative cost deviation is lower in our dataset than often found in other international studies. However, we do not find sufficient evidence in the data to support that relative cost deviations are lower in QA projects compared to non-QA projects. There is, however, one exception: If small projects with budgets below NOK 100 million are included in the comparison group, we find a statistical difference suggesting better cost performance among QA projects. Secondly, we asked in our RQ2 if any sectors stood out regarding relative cost deviations between QA and non-QA projects. We found little empirical support to claim that QA projects have lower relative cost deviations than non-QA projects between the three sectors represented in our dataset. However, we observe larger general deviations in the defense and road projects compared to construction.

In our third RQ, we asked if the relative cost deviations had changed over time and whether there was a difference between QA and non-QA projects. Although neither of the associations over the time dimension proved to be statistically different from zero, our results suggest that the development has been most favorable among non-QA projects. This suggestion corresponds with Samset and Volden (2013) in that the agencies' projects below the threshold values for the QA scheme have had learning effects through the quality assurance done on larger projects. Possible learning effects are supported by first-hand information from the agencies on internal processes for cost estimate quality assurance for projects below the threshold for QA.

In our RQ4, we asked if the monetary size of the projects of the projects could explain differences in relative cost deviations. We find little empirical support that project size, measured by cost, can explain the variation in relative deviation between final cost and budget when we look at all projects. By dividing by sector, the analyses indicate that it is primarily for QA projects related to building and roads and projects outside the QA scheme in the defense sector where size statistically contributes to explaining the variation in relative deviation. Among the QA projects within construction and roads, the deviation increases somewhat with size. In contrast, we see the opposite relationship among the slightly smaller defense projects that have not been externally quality-assured. These findings suggest that one must consider other project features together with the monetary size to understand cost deviations.

Finally, it is important to point out that the analyses in this report are not designed to allow conclusions on direct causal relationships between QA and non-QA projects. Although we partly find some indications that cost deviations have developed differently across the QA scheme, this can potentially be explained directly by something other than external quality assurance. One element is, for example, that the work on external quality assurance can also affect the agencies' work with smaller projects. Furthermore, the agencies probably have the opportunity to adapt the projects in a way that does not make it random whether they are quality assured or not. For example, adjustments can be made to create several smaller projects with estimated costs below the thresholds for whether the project should undergo external quality assurance (Ofstad Presterud and Øhrn, 2015).

Declaration of interest

No conflicts of interest

Funding

[Removed for anonymous review]

Acknowledgments

[Removed for anonymous review]

References

Aas, T. (2013), "Kostnadskontroll i prosjekter som har vært underlagt ekstern kvalitetssikring KS2/Cost performance in large public projects within the quality assurance scheme", Concept working report.

Adam, A., Josephson, P.-E.B. and Lindahl, G. (2017), "Aggregation of factors causing cost overruns and time delays in large public construction projects: Trends and implications", *Engineering,* *Construction and Architectural Management*, Emerald Publishing Limited, Vol. 24 No. 3, pp. 393–406, doi: 10.1108/ECAM-09-2015-0135.

Alkhattabi, L., Alkhard, A. and Gouda, A. (2023), “Effects of change orders on the budget of the public sector construction projects in the kingdom of Saudi Arabia”, *Results in Engineering*, Vol. 20, p. 101628, doi: 10.1016/j.rineng.2023.101628.

Amadi, A. and Ahiaga-Dagbui, D.D. (2021), “Transportation infrastructure cost underestimation: investigating the front-end debate”, *International Journal of Project Organisation and Management*, Vol. 13 No. 4.

Andersen, B., Samset, K. and Welde, M. (2016), “Low estimates – high stakes: underestimation of costs at the front-end of projects”, *International Journal of Managing Projects in Business*, Vol. 9 No. 1, pp. 171–193, doi: 10.1108/IJMPB-01-2015-0008.

Asiedu, R.O. and Adaku, E. (2019), “Cost overruns of public sector construction projects: a developing country perspective”, *International Journal of Managing Projects in Business*, Vol. 13 No. 1, pp. 66–84, doi: 10.1108/IJMPB-09-2018-0177.

Aubry, M., Boukri, S.E. and Sergi, V. (2021), “Opening the Black Box of Benefits Management in the Context of Projects”, *Project Management Journal*, Vol. 52 No. 5, pp. 434–452, doi: 10.1177/87569728211020606.

Babbie, E.R. (2020), *The Practice of Social Research*, Cengage AU.

Berg, H., Nyhus, H. and Bukkestein, I. (2022), *Kostnadskontroll i statlige prosjekter med og uten ekstern kvalitetssikring*, Arbeidsrapport, Concept-programmet No. 2022–1.

Berg, H., Ofstad Presterud, A. and Øhrn, M. (2019), “Military Off the Shelf Procurements: A Norwegian Case Study”, *Defence and Peace Economics*, Vol. 30 No. 1, pp. 98–110, doi: 10.1080/10242694.2017.1342182.

Berg, P. (1999), “Styring av statlige investeringer : sluttrapport fra styringsgruppen/Governance of public project, final report”, Norwegian Ministry of Finance.

Bodendorf, F. and Franke, J. (2021), "A machine learning approach to estimate product costs in the early product design phase: a use case from the automotive industry", *Procedia CIRP*, Vol. 100, pp. 643–648, doi: 10.1016/j.procir.2021.05.137.

Bryman, A. (2016), *Social Research Methods*, Oxford university press.

Cantarelli, C.C., Flyvbjerg, B., Molin, E.J.E. and Wee, B.V. (2010), "Cost Overruns in Large-scale Transportation Infrastructure Projects: Explanations and Their Theoretical Embeddedness", *European Journal of Transport and Infrastructure Research*, European Journal of Transport and Infrastructure Research, p. Vol 10 No 1 (2010), doi: 10.18757/EJTIR.2010.10.1.2864.

Dahl, R.E., Lorentzen, S., Oglend, A. and Osmundsen, P. (2017), "Pro-cyclical petroleum investments and cost overruns in Norway", *Energy Policy*, Vol. 100, pp. 68–78, doi: 10.1016/j.enpol.2016.10.004.

Durdyev, S. (2020), "Review of construction journals on causes of project cost overruns", *Engineering, Construction and Architectural Management*, Emerald Publishing Limited, Vol. 28 No. 4, pp. 1241–1260, doi: 10.1108/ECAM-02-2020-0137.

Flyvbjerg, B. (2009), "Survival of the unfittest: why the worst infrastructure gets built—and what we can do about it", *Oxford Review of Economic Policy*, Vol. 25 No. 3, pp. 344–367, doi: 10.1093/oxrep/grp024.

Flyvbjerg, B. (2014), "What you Should Know about Megaprojects and Why: An Overview", *Project Management Journal*, Vol. 45 No. 2, pp. 6–19, doi: 10.1002/pmj.21409.

Flyvbjerg, B., Holm, M.S. and Buhl, S. (2002), "Underestimating Costs in Public Works Projects: *Error or Lie?*", *Journal of the American Planning Association*, Vol. 68 No. 3, pp. 279–295, doi: 10.1080/01944360208976273.

Flyvbjerg, B., Skamris Holm, M.K. and Buhl, S.L. (2004), "What Causes Cost Overrun in Transport Infrastructure Projects?", *Transport Reviews*, Vol. 24 No. 1, pp. 3–18, doi: 10.1080/0144164032000080494a.

Haavaldsen, T., Lædre, O., Volden, G.H. and Lohne, J. (2014), “On the concept of sustainability – assessing the sustainability of large public infrastructure investment projects”, *International Journal of Sustainable Engineering*, Vol. 7 No. 1, pp. 2–12, doi: 10.1080/19397038.2013.811557.

Hempel, C.G. (1965), *Aspects of Scientific Explanation*, Vol. 1, New York: Free press.

Ika, L. and Feeny, S. (2022), “Optimism Bias and World Bank Project Performance”, *The Journal of Development Studies*, Vol. 58 No. 12, pp. 2604–2623, doi: 10.1080/00220388.2022.2102901.

Ika, L.A. and Pinto, J.K. (2022), “The ‘re-meaning’ of project success: Updating and recalibrating for a modern project management”, *International Journal of Project Management*, p. S0263786322000990, doi: 10.1016/j.ijproman.2022.08.001.

Jørgensen, M., Halkjelsvik, T. and Kitchenham, B. (2012), “How does project size affect cost estimation error? Statistical artifacts and methodological challenges”, *International Journal of Project Management*, Vol. 30 No. 7, pp. 839–849, doi: 10.1016/j.ijproman.2012.01.007.

Jorgensen, M., Welde, M. and Halkjelsvik, T. (2021), “Evaluation of Probabilistic Project Cost Estimates”, *IEEE Transactions on Engineering Management*, pp. 1–16, doi: 10.1109/TEM.2021.3067050.

Klakegg, O.J. and Lichtenberg, S. (2016), “Successive Cost Estimation – Successful Budgeting of Major Projects”, *Procedia - Social and Behavioral Sciences*, Vol. 226, pp. 176–183, doi: 10.1016/j.sbspro.2016.06.177.

Lorentzen, S., Oglend, A. and Osmundsen, P. (2017), “Cost overruns on the Norwegian continental shelf: The element of surprise”, *Energy*, Vol. 133, pp. 1094–1107, doi: 10.1016/j.energy.2017.05.106.

Lovallo, D. and Kahneman, D. (2003), “How Optimism Undermines Executives’ Decisions”, *Harvard Business Review*.

Love, P.E.D., Ika, L.A. and Sing, M.C.P. (2022), “Does the Planning Fallacy Prevail in Social Infrastructure Projects? Empirical Evidence and Competing Explanations”, *IEEE Transactions* *on Engineering Management*, Vol. 69 No. 6, pp. 2588–2602, doi: 10.1109/TEM.2019.2944161.

Love, P.E.D., Sing, C.-P., Wang, X., Irani, Z. and Thwala, D.W. (2014), "Overruns in transportation infrastructure projects", *Structure and Infrastructure Engineering*, Vol. 10 No. 2, pp. 141–159, doi: 10.1080/15732479.2012.715173.

Love, P.E.D., Zhou, J., Edwards, D.J., Irani, Z. and Sing, C.-P. (2017), "Off the rails: The cost performance of infrastructure rail projects", *Transportation Research Part A: Policy and Practice*, Vol. 99, pp. 14–29, doi: 10.1016/j.tra.2017.02.008.

Mackie, P. and Preston, J. (1998), "Twenty-one sources of error and bias in transport project appraisal", *Transport Policy*, Vol. 5 No. 1, pp. 1–7, doi: 10.1016/S0967-070X(98)00004-3.

Morris, P. (2013), "Reconstructing Project Management Reprised: A Knowledge Perspective", *Project Management Journal*, Vol. 44 No. 5, pp. 6–23, doi: 10.1002/pmj.21369.

Morris, P.W.G. and Hough, G.H. (1987), "The Anatomy of Major Projects—A Study of the Reality of Project Management.", *John Wiley & Sons Ltd., Chichester.*

Musawir, A. ul, Serra, C.E.M., Zwikael, O. and Ali, I. (2017), "Project governance, benefit management, and project success: Towards a framework for supporting organizational strategy implementation", *International Journal of Project Management*, Vol. 35 No. 8, pp. 1658–1672, doi: 10.1016/j.ijproman.2017.07.007.

Odeck, J. (2004), "Cost overruns in road construction: What are their sizes and determinants?", *Transport Policy*, Vol. 11 No. 1, pp. 43–53, doi: 10.1016/S0967-070X(03)00017-9.

Odeck, J. (2014), "Do reforms reduce the magnitudes of cost overruns in road projects? Statistical evidence from Norway", *Transportation Research Part A: Policy and Practice*, Vol. 65, pp. 68–79, doi: 10.1016/j.tra.2014.04.005.

Odeck, J. (2019), "Variation in cost overruns of transportation projects: an econometric meta-regression analysis of studies reported in the literature", *Transportation*, doi: 10.1007/s11116-017-9836-5.

Odeck, J. and Welde, M. (2015), "The Impact of External Quality Assurance of Costs Estimates on Cost Overruns: Empirical Evidence from the Norwegian Road Sector", p. 18.

Ofstad Presterud, A. and Øhrn, M. (2015), "Effektive materiellanskaffelser i Forsvaret- en studie av insentiver i investeringsprosessen", *FFI-report*, Vol. 2015/00555.

Pinto, J.K. (2010), "ACHIEVING COMPETITIVE ADVANTAGE".

Pollack, J., Helm, J. and Adler, D. (2018), "What is the Iron Triangle, and how has it changed?", *International Journal of Managing Projects in Business*, Vol. 11 No. 2, pp. 527–547, doi: 10.1108/IJMPB-09-2017-0107.

Popper, K. (2005), *The Logic of Scientific Discovery*, Routledge.

Samset, K. and Volden, G.H. (2013), "Statens prosjektmodell. Bedre kostnadsstyring. Erfaringer med de første investeringstiltakene som har vært gjennom ekstern kvalitetssikring. / Experiences from the first public projects that have been through external quality assurance", *Concept-Rapport n. 35 Ex-Ante Akademisk Forlag*.

Samset, K. and Volden, G.H. (2014a), "Front end Governance of Major Public Projects - Lessons with a Norwegian Quality Assurance Scheme", *International Journal of Architecture, Engineering and Construction*, doi: 10.7492/IJAEC.2014.009.

Samset, K. and Volden, G.H. (2014b), "The impact of external quality assurance up front to improve governance of major public investment projects.", *Paper Presented at Project Management Institute Research and Education Conference, Phoenix, AZ. Newtown Square, PA: Project Management Institute.*

Samset, K. and Volden, G.H. (2016), "Front-end definition of projects: Ten paradoxes and some reflections regarding project management and project governance", *International Journal of Project Management*, Vol. 34 No. 2, pp. 297–313, doi: 10.1016/j.ijproman.2015.01.014.

Sarmento, J.M. and Renneboog, L. (2017), "Cost Overruns in Public Sector Investment Projects", *Public Works Management & Policy*, Vol. 22 No. 2, pp. 140–164, doi: 10.1177/1087724X16668357.

Saunders, M., Lewis, P. and Thornhill, A. (2019), *Research Methods for Business Students*, Vol. 8th edition, Harlow: United Kingdom:Pearson Education Ltd.

Serra, C.E.M. and Kunc, M. (2015), "Benefits Realisation Management and its influence on project success and on the execution of business strategies", *International Journal of Project Management*, Vol. 33 No. 1, pp. 53–66, doi: 10.1016/j.ijproman.2014.03.011.

Taihairan, R.B.R. and Ismail, Z. (2015), "BIM: Integrating Cost Estimates at Initial/Design Stage", Vol. 6 No. 1, p. 13.

Volden, G.H. (2019), "Assessing public projects' value for money: An empirical study of the usefulness of cost–benefit analyses in decision-making", *International Journal of Project Management*, Vol. 37 No. 4, pp. 549–564, doi: 10.1016/j.ijproman.2019.02.007.

Welde, M. (2017), "Kostnadskontroll i store statlige investeringer underlagt ordningen med ekstern kvalitetssikring/cost performance in large public projects within the external quality assurance-scheme", p. 104.

Welde, M., Jørgensen, M., Larsen, P.F. and Halkjelsvik, T. (2019), "Estimering av kostnader i store statlige prosjekter: Hvor gode er estimatene og usikkerhetsanalysene i KS2-rapportene?/Estimation of costs in large public projects: How accurate are the estimates and uncertainty analyzes in the QA2-reports?", *Concept-Report*, Vol. 59.

Welde, M. and Klakegg, O.J. (2022), "Avoiding Cost Overrun Through Stochastic Cost Estimation and External Quality Assurance", *IEEE Transactions on Engineering Management*, pp. 1–14, doi: 10.1109/TEM.2022.3173175.

Wooldrige, J.W. (2020), *Introductory Econometrics: A Modern Approach (Seventh Ed.)*, Cengage, Boston, MA.

External Quality Assurance of Cost Estimates in Major Public Projects: Empirical Evidence on Cost Performance

Tables

Table I Descriptive statistics of average relative cost deviations and project size

Project size	All Projects	Budget > NOK 100 million				
Sector	All	All	Construction	Road	Defense	Other
Panel A – Number of projects						
Total no. of projects	1,704	373	71	235	51	16
No. of QA projects	123	123	20	70	17	16
Panel B - Relative cost deviation:						
Mean	0.108	0.037	-0.052	0.059	0.045	0.084
St.dev.	0.376	0.254	0.116	0.220	0.462	0.147
Minimum	-1.000	-0.505	-0.376	-0.425	-0.505	-0.124
Maximum	6.540	2.025	0.230	1.512	2.025	0.462
Share (%) w/cost>budget	54.1	47.7	21.1	56.2	39.2	68.8
Panel C - Budget frame (in MNOK):						
Mean	198.7	815.8	575.8	752.4	968.52	2,325.9
St.dev.	709.2	1,346.0	827.7	1001.3	2,373.3	2,113.9
Minimum	0.573	101.2	103.0	101.2	117.8	366.0
Maximum	16,211.9	16,211.9	5,580.4	6,029.9	16,211.9	7,340.0

Table II OLS on relative cost deviation as the dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)
Sample	All projects	All projects	Projects >100 MNOK	Same as (3), weighted with project size	Projects >250 MNOK	Projects >500 MNOK
QA	-0.085**	-0.040	-0.012	0.013	0.023	0.014
	(0.0352)	(0.0363)	(0.028)	(0.023)	(0.026)	(0.037)
Dummy <25 million NOK		0.086***				
		(0.0188)				
Constant	0.114***	0.069***	0.041**	0.028	0.006	0.015
	(0.0095)	(0.0136)	(0.0161)	(0.0197)	(0.0192)	(0.0330)
Projects	1,704	1,704	373	373	231	158
R-square	0.003	0.015	0.001	0.001	0.003	0.001

Note: The model is estimated using OLS. The dependent variable in the analysis is the relative deviation between the final cost and the budget. Standard errors are reported in parentheses. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level, respectively.

Table III OLS on relative cost deviation in different sectors

Sector	(1) All	(2) Building construction	(3) Road	(4) Defense
QA	-0.022	0.004	-0.025	-0.043
	(0.0295)	(0.0307)	(0.0314)	(0.1386)
Road (dummy)	0.112***			
	(0.0345)			
Defense (dummy)	0.099**			
	(0.0468)			
Constant	-0.046	-0.053***	0.067***	0.060
	(0.0314)	(0.0163)	(0.0172)	(0.0800)
Projects	357	71	235	51

Note: The model is estimated using OLS. The dependent variable in the analysis is the relative deviation between the final cost and the budget. The samples only include projects over NOK 100 million. Standard errors are reported in parentheses. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level, respectively.

Table IV OLS on relative cost deviation and monetary size of the projects

	(1) Non-QA projects	(2)	(3)	(4) QA projects	(5)	(6)
P50 in bill.NOK	-0,094		-0,558	0,006		-0,037
	(0,0869)		(0,5804)	(0,0090)		(0,0579)
$P50^2$ in bill.NOK			0,704			0,012
			(0,9857)			(0,0126)
$P50^3$ in bill.NOK			-0,220			-0,001
			(0,3525)			(0,0006)
Log (P50 in bill.NOK)		-0,040			0,018	
		(0,0311)			(0,0244)	
Constant	0,069**	0,263	0,135*	0,017	-0,103	0,045
	(0,0309)	(0,1720)	(0,0812)	(0,0243)	(0,1774)	(0,0550)
Observations	250	250	250	123	123	123
R-square	0,005	0,007	0,009	0,004	0,005	0,023

Note: Standard error in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table V OLS on relative cost deviation and monetary size of the projects by sector

	(1)	(2)	(3)	(4)	(5)	(6)
	Construction Non-QA	QA	Roads Non-QA	QA	Defense Non-QA	QA
P50 in bill. NOK	0,054	0,046*	-0.012	0.029**	-1,527***	-0,010
	(0,0518)	(0,0232)	(0.1057)	(0.0144)	(0,5551)	(0,0236)
Constant	-0,070***	-0,108**	0.070*	-0.012	0,472***	0,039
	(0,0217)	(0,0410)	(0.0362)	(0.0322)	(0,1702)	(0,1035)
Observations	51	20	165	70	34	17
R-square	0,022	0,177	0.000	0.057	0,191	0,011

Note: Standard error in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$