Effect of expedited payments on project delays: Evidence from the QuickPay reform

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Contractors are usually not paid immediately after an invoice is submitted. Payment delays affect the value of projects to contractors, which, in turn, affects their financing costs, decisions about project acceptance and sequencing, and competition among contractors. We examine how payment delays affect project completion times. We develop several theories that link payment delays to project delays and test our theories using the U.S. government's project data, taking advantage of an exogenous shock from the QuickPay reform that expedited payments to certain federal contractors. Surprisingly, our results show that faster payments led to *greater* project delays. Compared with the pre-QuickPay delay rate per quarter, there is a 26% increase, on average, in the delay rate for projects subject to the QuickPay reform. Both the likelihood of a project delay and the expected delay magnitude conditional on it being positive are significantly higher for the affected projects after QuickPay. We present evidence indicating that project delays can be explained by the contractor's liquidity constraints and competition among contractors. We identify other factors that moderate the effect of QuickPay. For example, the delays are not as severe if a treated project is in the portfolio with projects that do not receive faster payments or if it is at an early stage in its life. We show that the delay is not caused by contractors taking on more projects in response to the reform.

Key words: Government procurement, Payment timing, Interface of OM and finance, Empirical operations management, Project management

History: This version: January 24, 2025

1. Introduction

Contractors are not paid promptly upon completing project tasks and submitting an invoice. Long payment delays are the norm in several industries. In the construction sector, for example, contractors wait an average of 50 to 75 days to receive payments on their invoices (For Construction Pros 2019). Furthermore, according to recent surveys, contractors spent an average of 4.81 hours per week chasing late payments, and one in three contractors had to stop or postpone work because of payment delays (Kinal 2015, Rabbet 2019).

The issue of delayed payments has caught the attention of policymakers. To aid small businesses, several countries have restricted maximum payment delays. The U.S. government, for example, initiated the QuickPay reform, which accelerated payments on federal projects awarded to small businesses. Similar initiatives have also been launched in Europe and Canada.[1] The QuickPay reform's goals were to "improve cash flow for small businesses and provide them with a more predictable stream of resources" to "give small businesses the flexibility they need to invest and hire."[2] Findings in Barrot and Nanda (2020) indicate that these intended goals were achieved. However, any law or policy could have positive or negative unintended consequences.

While the reduction in payment delays benefits contractors, as intended, this reduction may have unanticipated operational consequences, e.g., affecting project completion delays. This is an especially relevant concern, given that projects are often late and over budget. According to a 2019 survey by the Project Management Institute, 47% of the projects globally were reported to be behind schedule, and 41% were over budget.[3] In this paper, we address the research question: what role do payment delays play in project delays?

We answer this question both theoretically and empirically. We develop several theories that link payment delays with project completion and, based on those theories, formulate testable hypotheses (§4). The theories highlight a baseline economic link between payment delays and project completion times, as well as additional moderating roles of contractors' liquidity constraints, competition for projects, project sequencing decisions, contractor workload, and the project stage.

Our baseline theory explains that if payment happens sooner, then the project becomes more valuable to a contractor who then exerts effort to accelerate the completion. We augment this theory by incorporating liquidity constraints that force contractors to accelerate projects so as to collect payments in time for their own liquidity needs. When payment delay is shorter, projects do not need to be rushed, leading to longer completion times and project delays. Recognizing that a contractor holds multiple projects, we next theorize that contractors may sequence projects based on payment delays, prioritizing projects with shorter payment delays and postponing the ones with longer payment delays. Faster payments may also result in project delays due to congestion, as contractors may be motivated to accept more projects. For competitively-awarded projects, we point out that faster payments make projects more attractive, which pushes contractors to bid aggressively and promise shorter project completion times. When these optimistic promises cannot be fulfilled, this results in apparent project delays. Finally, we argue that if projects and

[1] See the UK Prompt Payment Code, the EU Late Payment Directive, and the Canadian Federal Prompt Payment for Construction Work Act.

[2] Source: https://obamawhitehouse.archives.gov/blog/2011/09/14/getting-money-small-businesses-faster.

[3] See PMI Pulse of the Profession Report 2020

payments are made in stages, then contractors with an earlier-stage project have a greater incentive to accelerate it to expedite payments for all subsequent stages.

We test our hypotheses using data on the U.S. federal government's projects. To estimate the causal effect of expedited payments on project delays, we use a difference-in-differences design with the QuickPay reform as an exogenous shock. Launched in 2011, this reform accelerated payments to federal projects awarded to small businesses, reducing the time between their invoice approval and payment from 30 days to 15 days. §3 discusses this reform and §5 describes the data.

We find that the QuickPay reform had an unintended and unanticipated adverse effect on project delays. The *reduced* payment delays significantly *increased* project delays, which is defined to be a project's reported delay each quarter as a percentage of the project's last reported duration (see §6). We estimate that QuickPay increased the quarterly percentage delay of treated projects, i.e., small business projects, by 1.1 percentage points. Compared with their pre-QuickPay quarterly delay of 3.51 percentage points, this represents a 26% increase, corresponding to an additional delay rate of 2.56 days per quarter on average.

Faster payment under QuickPay increased average project delays by increasing both the likelihood and the magnitude of delay. The odds of a positive delay rate per quarter increased for treated projects by approximately 0.26. Conditional on observing a positive delay rate, the delay rate reported for a treated project is 28 percentage points higher than for the non-treated project, corresponding to an increase of 71.7 days in the estimated project completion time.

The empirical evidence supports several of our theories (§7). A part of the increase in delay rates can be explained by the contractors' liquidity constraints. Eligible projects held by financially weaker contractors had greater delays after the reform than those held by financially stronger firms.

We found evidence that the QuickPay reform made treated projects more attractive to prospective bidders. Specifically, competitively-awarded, treated projects signed after the reform received more bids and the winning bids were more aggressive, with contractors quoting shorter duration by approximately 3 days and lower budget by approximately $27,800, on average. As a result, quarterly percentage delay on competitively awarded projects increased by 0.75 percentage points after QuickPay (which is 75% of the 1.01 percentage points in the baseline specification).

We also found empirical support for the existence of forces that reduce delays. For instance, treated projects that belong to a contractor with additional untreated projects were delayed less than treated projects that belong to a contractor with no additional untreated projects. The formers' quarterly delay rates are 0.38 percentage points lower, a 38% decrease from the baseline treatment effect. This is consistent with the theory that contractors may change the sequence of untreated and treated projects in response to faster payments on treated projects.

Finally, we did not find empirical support for the congestion theory that links payment delays with project delays through a contractor's workload. The data indicates that QuickPay reform did not increase any one of the three metrics of contractors' workload: number of projects, number of tasks, and total budget (see Appendix 7.3 for details).

We performed several robustness tests to establish the validity of our findings, including analysis on a matched sample of treated and control projects, using alternative definitions of the dependent variable, placebo tests with respect to treatment timing and treatment group, and using a more restrictive sample. We also verified that our findings are specific to the QuickPay policy and are not caused by other contemporaneous government policies affecting small businesses. All robustness tests confirm our results.

Our findings have significant consequences for public and private sector procurement. First, the scope of the problem is significant. The proposed 2025 U.S. Federal budget is almost $7.3 trillion of dollars.[4] and the proposed 2025 U.S. Department of Defense budget is almost $850 billion.[5] According to Barrot and Nanda (2020), the QuickPay reform accelerated payments of $70 billion in annual contract value. Second, the U.S. QuickPay reform is not the only law that expedites contract payments. There are government policies in Europe and Canada that aim to achieve the same goal. Our paper illuminates the unintended consequence of such policies. Third, the theories that we develop and test extend beyond government contracts. However, empirically studying general contract settings is difficult because of the endogeneity problem. To the best of our knowledge, ours is the first paper to use the exogenous shock of the QuickPay reform to understand the effect of expediting payments on project delays.

2. Related literature

Although the effect of payment timing on project delays specifically has not been studied, our work relates to three streams of literature: (1) project delays, (2) the effect of payment timing on agent's incentives in a principal-agent framework, and (3) trade credit (i.e., payment delays) in supply chains. We briefly review the literature in each of these areas and draw connections with our work.

Researchers have identified several reasons for project delays. Coviello and Mariniello (2014) and Bajari and Tadelis (2001) look at poor hiring and contracting decisions that lead to negative project outcomes. Baucells et al. (2024) develop a model to show that behavioral biases of a project leader can result in inadequate adjustments in both the estimated cost and scope of a

[4] Table S–1. Budget Totals in `https://www.govinfo.gov/content/pkg/BUDGET-2025-BUD/pdf/BUDGET-2025-BUD.pdf`

[5] `https://www.defense.gov/News/Releases/Release/Article/3703410/department-of-defense-releases-the-presidents-fiscal-year-2025-defense-budget/#:~:text=On%20March%2011%2C%202024%2C%20the,Act%20(FRA)%20of%202023.`

project. Further, the authors demonstrate how certain progress metrics, such as planned scope or actual cost, can help alleviate this issue, whereas others, such as "earned value management" consistently underperform. Lovallo and Kahneman (2003), Grushka-Cockayne et al. (2012), Flyvbjerg and Gardner (2023), and Grushka-Cockayne (2020) provide a comprehensive discussion of the issues arising in project management. Other researchers have used U.S. government-projects data to study operational causes of project delays. Examples include Calvo et al. (2019), who study the impact of government oversight on project performance, and Dhingra et al. (2024), who study how exogenous disruptions to one project affect the on-time performance of connected projects. We contribute to this research area by studying the timing of payments to the contractor as a cause of project delays and explaining the mechanisms at work.

Researchers have also studied how to design contracts with time-dependent incentives to improve project performance. Babich and Tang (2012) show that delaying payments until inspections are complete or until customers evaluate the products can deter suppliers from producing poor-quality products. Kwon et al. (2010) study a payment regime where a supplier gets paid when all suppliers have finished their tasks. They identify conditions under which such delayed payments are profitable for the client. Similarly, Chen and Lee (2017) propose a "delivery-schedule based contract" to improve project performance. In this contract, the client sets the price, the target delivery schedule, and incentivizes or penalizes the contractor for early or late completion. In addition, Dayanand and Padman (2001) study the optimal payment structure when clients control both payments and project activity times. They show that clients are better off paying contractors at the beginning or at the end of the project rather than continually. Further, Szmerekovsky (2005) shows that these insights need not be true when contractors determine the activity schedules.

These studies focus on the timing of payment relative to task completion. In contrast, we are interested in how the delay between invoice approval and payment receipt affects project value and outcomes. In other words, the payment delay in our setting is not tied to task completion and occurs *after* the client has approved payments.

Our research is also related to the vast literature on trade credit. Similar to us, papers in this research stream study the delay in payments from buyers to suppliers. On the theoretical side, several papers highlight the operational benefits of trade credit, such as managing inventory (Beranek 1967, Haley and Higgins 1973, Chapman et al. 1984), deterring moral hazard (Kim and Shin 2012, Babich and Tang 2012, Devalkar and Krishnan 2019), signaling product quality (Lee and Stowe 1993, Long et al. 1993), sharing demand risk in newsvendor settings (Kouvelis and Zhao 2012, Yang and Birge 2018), softening price competition among suppliers (Peura et al. 2017), or increasing quantity competition among buyers (Ning 2022). The empirical literature has examined the impact of trade credit on the corporate default rate (Barrot 2016), investment levels (Murfin and Njoroge 2015), profit (Lee et al. 2018), sales and inventory (Breza and Liberman 2017, Chen et al. 2022).

Our paper contributes to this literature in two ways. First, we develop theories to explain how payment delays can affect the time it takes to complete the delivery of a product or service. Second, we empirically test the operational effect of payment timings by examining the performance of projects whose payments were expedited under the QuickPay reform.

Barrot and Nanda (2020) evaluate the effect of QuickPay reform on the employment growth and financial health of the treated firms. They confirm that the policy was implemented as stated and identified which contract types received faster payments for contractors of the Department of Defense. We built on these findings when constructing our sample. However, our work differs from Barrot and Nanda (2020) in several important dimensions. First, we ask a different research question, i.e., how accelerated payments affect operational performance when measured as project delays. Second, our analysis is at the project level. In federal procurement, eligibility for faster payments varies from project to project for the same firm (see §3). Therefore, there is no ambiguity or researcher discretion in defining the treatment status in our setting. Third, we restrict our sample to 2012 because QuickPay was extended to all federal projects at this time.[6] Finally, fourth, we explore several mechanisms through which faster payments may influence project delays. These analyses show the heterogeneous effect of QuickPay on a range of project and contractor characteristics.

3. QuickPay Reform

The QuickPay reform was initiated as part of a government strategy to support small businesses and promote employment growth after the 2008 financial crisis. Introduced in 2011, the reform directed federal agencies to accelerate payments to their small business contractors. Before the reform, the agencies would pay the contractors approximately 30 days after receiving the invoice.[7]

The QuickPay reform mandated that federal agencies pay their small business contractors as soon as possible, with the goal of processing payments within 15 days of invoice receipt. The policy directed agencies to "ensure expeditious processing throughout (including in inspection and acceptance) to facilitate prompt payment to small businesses, while also maintaining necessary internal controls."[8] The reform affected projects worth \$220 billion in total value for 172,000 small businesses across the U.S., and saved small firms billions of dollars in cost of financing goods and

[6] See `https://obamawhitehouse.archives.gov/sites/default/files/omb/memoranda/2012/m-12-16.pdf`

[7] Federal Acquisition Regulations §52.232-25

[8] Memorandum M-II-32 of the Office of Management and Budget

services (Mandelbaum 2011). The late-payment interest penalties paid by the agencies declined by 97% and they started receiving early payment discounts from the contractors.[9]

Whether a firm is a "small business," and thus a potential beneficiary of the reform is determined by the contracting officer on a given project. It is important to note here that the classification of a firm as a large or a small business can vary across projects. Contractors can be listed under multiple industry codes (NAICS) for federal procurement, and a firm's classification as a small business is determined by its size in a given industry.[10] This classification depends on the firm's revenue or number of employees in a given industry-year. The US Small Business Administration (SBA) provides a detailed explanation on how to determine business size[11] by computing annual revenue/receipts and number of employees.[12] For example, in 2019, a drywall and insulation contracting firm would qualify as a small business if its annual revenue was below $16.5 million. In that same year, an industrial valve manufacturer would qualify if it had fewer than 750 employees.

This means that under the QuickPay reform, a firm may be classified as a "small business" in some projects and as a "large business" in others and could receive faster payments on some projects but not others. Accordingly, the unit of analysis in our paper is a project (to ensure a clear definition of treatment and control groups discussed in §5).

4. Theories

In this section, we present several theories of how payment delays affect project delays. All theories consider a principal who outsources work to contractors and pays (with a delay) after the project is completed. We define a project delay as the difference between the actual time it takes to complete a project and the promised time.

Figure 1 is an influence diagram illustrating various theories all at once. The top node of this figure is the *Payment delay*. The QuickPay reform reduced *Payment delay* for some projects. The bottom node is *Project delay*, which is the difference between the actual and promised time. The arrows connecting the nodes indicate direct influence. Signs '+' and '−' next to arrows indicate whether the influence is positive or negative. For example, longer *Actual time* increases *Project delay*, while longer *Promised time* decreases it. Different theories are captured by different paths from the top node to the bottom one. We will highlight these paths when we discuss particular theories below.

[9] `https://obamawhitehouse.archives.gov/the-press-office/2014/07/11/president-obama-announces-new-partnership-private-sector-strengthen-amer` and `https://www.sba.gov/sites/default/files/files/FY15_CBJ_FY%202013_APR.pdf`

[10] See `https://www.naics.com/hrf_faq/can-a-business-have-more-than-one-naics-code/`

[11] `https://www.sba.gov/document/support-table-size-standards`

[12] `https://www.ecfr.gov/current/title-13/chapter-I/part-121`

In response to changes in payment delays, some theories predict a decrease in project delays and others predict an increase. The theories allow us to generate testable hypotheses that form the foundation for the empirical analysis. Although we present theories one at a time, what we observe empirically and what is shown in Figure 1 is the net effect of all of them. Depending on which of the forces described in these theories dominate, the net effect of the QuickPay reform on project delays can be positive or negative.

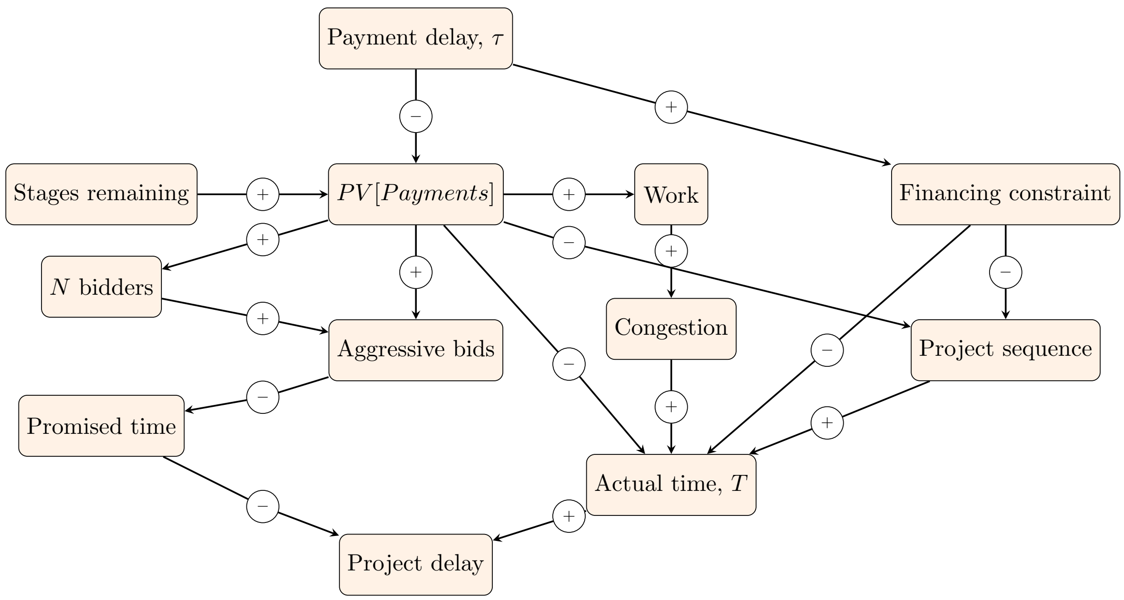


Figure 1 **Summary of theories**

Note: This figure illustrates multiple mechanisms by which expedited payments affect project delays. '+' above an arrow indicates that the quantity to which the arrow points is increasing in the variable from which the arrow originates. '−' indicates that the quantity is decreasing. PV in $PV[Payments]$ stands for present value.

4.1. Strategic complementarity between payment delays and project completion times

The main idea of this theory is an intuitive observation that if payment for completed work happens sooner, the project is more valuable to a contractor, who then exerts effort to expedite the completion. The practical implication of this theory is evident in the construction industry. According to a survey by Rabbet (2020), contractors would save 5.93% on a project if payments were made within 30 days. Wolfe Jr (2019) reports that contractors spend significant human resources trying to chase down late payments, and the majority (78%) never charge customers interest on late payments.

In Figure 1, this theory is represented as follows. A *Payment delay* has a negative influence on the present value of payments ($PV[Payments]$). $PV[Payments]$ in turn has a negative influence on *Actual time* and *Actual time* has a positive influence on *Project delay*. Accounting for two negative influences (represented by '−' signs) on this path, the overall influence of the payment delay is to increase the project delay. Thus, when QuickPay reduces the payment delay, this should translate into a decrease in project delays. To have a parsimonious theory, we assume here that other links in Figure 1 are inactive. In particular, the promised time to complete the project is not affected.

The following discussion provides mathematical details. Consider a single project with the expected payment P that occurs τ time units after project completion. Thus, at the time the project is completed and the contractor submits the invoice to the principal, the present value of the payment to the contractor is $e^{-r\tau}P$, where r is the continuously compounded discount rate.[13] This is one of the simplest models to capture a relationship between the payment delay and the value of the payment to the contractor.

Before work commences, the contractor decides the project's overall duration T. The contractor's cost $c(T)$ is incurred upfront (which we shall call time $t=0$) and is decreasing and convex in T, i.e., delivering the project faster costs the contractor increasingly more. Thus, at time $t=0$, the expected present value of the project is

$$V(T,\tau) = e^{-r(T+\tau)}P - c(T). \tag{1}$$

The contractor chooses T to maximize $V(T,\tau)$, and we define

$$V^*(\tau) = \max_{T\geq 0} V(T,\tau). \tag{2}$$

To ensure the economic feasibility of the project, assume the domain for function $V^*(\tau)$ is such that this function is positive for all τ in this domain. The key observation is that the function $V(T,\tau)$ is supermodular, i.e., it has increasing differences in (T,τ). The formal statement is in Lemma 1 in Appendix C. The supermodularity property implies a monotone relationship between an optimal decision T and the parameter τ (see Topkis 1998, and Milgrom and Shannon 1994).

Proposition 1. *An optimal project completion time T for problem* (2) *is increasing in the payment delay τ.*

Proposition 1 formalizes the intuitive observation that the marginal benefit of exerting effort to finish the project sooner is greater when the payment delay is smaller. This is because project duration and the payment delay are strategic complements. This leads to the following hypothesis.

Hypothesis 1. *Reducing payment delays will reduce project delays.*

[13] If the payment is deterministic, then r simply captures the time value of money. If the payment is stochastic, then discounting would reflect the correlation between the cash flow and the pricing kernel (see Cochrane 2001 and Babich and Birge 2020).

4.2. Binding financial liquidity constraints

This theory extends the discussion in §4.1 by introducing financing constraints. The main idea is that binding financial liquidity constraints may force the contractor to expedite projects, so as to submit an invoice and collect the payment in time to meet financial obligations. Thus, reducing payment delays could lead to a project "delay" because the contractor has the flexibility to complete the project at a slower pace (which is closer to the optimal time for the contractor).

The link between payment timing and financing constraints is motivated by the following examples. Based on a survey by Levelset, Wolfe Jr (2019) reports that half of U.S. contractors do not get paid on time, which causes cash flow issues, and 42% of contractors often pay for materials and labor on rigid schedule but face long and random delays in payments from customers. To cover the expenses, contractors take on credit card debt or dip into personal and retirement savings (Rabbet 2020). According to a survey in Kinal (2015), 83% of contractors rely on credit to finance their expenses and are concerned that their credit facility was being harmed by late payments. Our theory captures the incentive of contractors to reduce such costs by accelerating projects.

In Figure 1, this theory is represented by the path from the node *Payment delay*, which has a positive influence on *Financing constraint* (meaning that the constraint becomes tighter), which negatively influences *Actual time*, which positively influences *Project delay*. Again, for parsimony, we focus on one part of this influence diagram and deactivate other arrows.

To elaborate on this theory, suppose that the contractor must meet financial obligations that are due at time $t = L$. For simplicity, assume that the cost of missing the financial deadline is infinite.[14] Therefore, the contractor has the strongest incentive to accelerate the project to reduce cost. This is equivalent to contractors having no access to financial markets and facing a constraint $T + \tau \leq L$. The contractor's problem (2) is modified as follows

$$V^*(\tau, L) = \max_{0 \leq T \leq L-\tau} V(T, \tau), \tag{3}$$

where the value function V is defined in (1). Suppose that T^* is the solution of the unconstrained optimization problem. If the constraint $T \leq L - \tau$ is not binding, then the reduction in the payment delay τ also reduces T^*, according to Proposition 1. But if this constraint is binding, then the optimal project completion time under financial constraints is $T^*_{FC} = \min[T^*, L - \tau] = L - \tau$ and it decreases in the payment delay τ. This motivates the following hypothesis.

Hypothesis 2. *For severely financially constrained firms, reducing payment delay will increase project delays.*

[14] A more refined model with moderate costs produces similar insights but requires more space to develop.

4.3. Project sequencing

The main idea of this theory is that changing payment delays can create an incentive for a contractor to change the project sequence. We consider two channels: the first when financing constraints are not binding and the second channel when they are.

4.3.1. Project sequence when financing constraints are not binding. First, consider the incentives of a contractor who is not financially constrained. Suppose that the contractor holds a portfolio of two projects: project 1 that is subject to the QuickPay reform and project 2 that is not. Using the notation from §4.1, the value of either project k, if it starts immediately, is $V_k^*(\tau_k)$. This value decreases in τ_k, for example, as in equation (2). The optimal time to work on each project is T_k, which increases in τ_k, according to Proposition 1.

The contractor can choose the sequence in which to execute these projects. Define the value of the contractor if project k is executed first and project j second as

$$W_{k,j} \stackrel{\text{def}}{=} V_k^*(\tau_k) + e^{-rT_k} V_j^*(\tau_j). \tag{4}$$

The following proposition states that if project $k=1$ is first in the sequence, then with a reduction of τ_1 this project will remain the first in the sequence.

PROPOSITION 2. *Suppose that for some τ_1^0, the contractor prefers to sequence the project subject to QuickPay reform (i.e., project 1) first, i.e., $W_{1,2} \geq W_{2,1}$, where $W_{k,j}$ is defined in Eq.* (4). *Then for any $\tau_1 \leq \tau_1^0$, the contractor prefers the same sequence.*

From the perspective of the government, because project 1 remains first, the effect of reducing the payment delay τ_1 should expedite the delivery of the completed project because T_1 is increasing in τ_1 (see Proposition 1). Furthermore, if multiple projects are held by the contractor and these projects must wait for project 1, the contractor's incentive to expedite project 1 is even higher.

If the project $k=1$ was scheduled to run second initially, i.e., if $W_{1,2} \leq W_{2,1}$ prior to QuickPay, then reducing τ_1 can make this project attractive enough to reverse the sequence, i.e., it will make $W_{1,2} > W_{2,1}$, and the government will observe even faster delivery, because instead of delivery time $T_2 + T_1$, the new delivery time will be T_1. Combined with the reduction in T_1 due to the strategic complementarity force, the government should observe project 1 being accelerated.

In Figure 1, this theory assumes that reducing *Payment delay* increases $PV[Payments]$ (as there are no financial constraints). This, in turn, encourages earlier sequencing of projects receiving faster payments (a relationship which we mark with the minus sign between the nodes $PV[Payments]$ and *Project sequence*). The node *Project sequence* affects the node *Actual time* as follows: the earlier the project in the sequence, the earlier the actual completion time. This is marked with the plus sign in Figure 1. Defining *treated* projects as those that are subject to the QuickPay reform and *untreated* projects as those that are not, this theory leads to the following hypothesis.

Hypothesis 3. *The treated projects held by contractors that also hold untreated projects are accelerated.*

4.3.2. Project sequence when financing constraints are binding. Next, suppose the contractor's financing constraints are binding, and her objective is to minimize the total time until all projects are paid for. Continuing with the two-project example, if the sequence of projects is $(1,2)$, then the total time until all payments are received is $T_1+T_2+\tau_2$, assuming that $\tau_1 \leq T_2+\tau_2$. The contractor works on project 2 while waiting for the payment on project 1. Similarly, if the sequence of projects is $(2,1)$, then the total time until all payments are received is $T_2+T_1+\tau_1$, assuming that $\tau_2 \leq T_1+\tau_1$.

As before, suppose that only project 1 is subject to the QuickPay reform. If the government reduces the payment delay τ_1, so that $\tau_1 \leq \tau_2$, then it is optimal for the contractor to use sequence $(2,1)$ to minimize the time until all payments are received. From the perspective of the government, the completion time of Project 1 before the QuickPay reform is T_1, and after the reform goes into effect, the completion time is T_2+T_1. Therefore, the completion time of Project 1 will increase.

In Figure 1, this theory describes the path from the node *Payment delay* to *Financing constraint* to *Project sequence*. *Payment delay* positively influences *Financing constraint* (meaning that need for financing increases). As the need for financing increases, the projects with longer payment delays are placed earlier in the sequence so that the total time until all payments are received is minimized. This is indicated by a minus sign on the link between *Financing constraint* and *Project sequence*. Thus, we obtain predictions opposite from those in Hypothesis 3.

Hypothesis 4. *The treated projects held by contractors that also hold untreated projects are delayed.*

4.4. Congestion

The main idea of this theory is that faster payments will incentivize the contractor to increase capacity and accept more projects. Barrot and Nanda (2020) showed that paying suppliers faster encourages investments and employment by these suppliers. Faster payments also reduce the administrative burden on the current employees to track and chase late payers. Therefore, QuickPay reform allows firms to increase their capacity to take on additional work (for example, by hiring more workers or using freed-up time more productively). However, congestion due to more projects can delay the completion of each project, even if the contractor's expected profit increases. In Figure 1, this corresponds to the path from *Payment delay*, which negatively influences the contractor's $PV[Payments]$, which positively influences *Work*, which increases *Congestion*, which increases the *Actual time*, which increases the *Project delay*.

Consider the following simple (M/M/1) queueing model. The contractor decides at which rate, λ, to accept projects and how to set capacity, given by rate μ. Each project generates the (optimal) expected value $P = V^*(\tau)$, which decreases in the payment delay, τ. We assume that the cost of capacity is $c\mu^2/2$. There is a cost H per unit of time the project lasts, which represents hourly wages and holding costs of materials. The expected completion time of projects under the M/M/1 assumption is $W(\lambda,\mu) = \frac{1}{\mu-\lambda}$. Thus, the contractor solves the following optimization problem:

$$\max_{\lambda,\mu} P\lambda - HW(\lambda,\mu) - c\mu^2/2, \tag{5}$$

Proposition 3 presents the optimal solution of problem (5) and the comparative statics that help us formulate hypotheses.

PROPOSITION 3. *The optimal solution of problem* (5) *is* $\lambda^* = P/c - \sqrt{H/P}$, $\mu^* = P/c$. *The optimal acceptance rate* λ^*, *the capacity* μ^*, *and the corresponding expected completion time* $W(\lambda^*,\mu^*)$ *increase in the expected value of the project* P.

Three predictions from Proposition 3 can be tested. First, when QuickPay reduces payment delay, increasing project value, the contractors should increase capacity. This is confirmed by Barrot and Nanda (2020). Second, contractors accept more work, as stated in the following hypothesis.

HYPOTHESIS 5. *After the delays on payments decrease, contractors accept more work.*

Third, while taking more projects increases the contractor's profit, it has an adverse consequence on the project completion time because more projects increase congestion and $W(\lambda^*,\mu^*)$ increases, as stated in the following hypothesis.

HYPOTHESIS 6. *Reducing payment delays will increase project delays, due to congestion.*

4.5. Aggressive bidding

The main idea of this theory is that faster payments make projects more valuable to contractors, who bid more aggressively, resulting in project delays. The link between payment timing and contractor bidding behavior is evident in several industry studies. Rabbet (2020) reports that 72% of contractors considered a reputation of slow payments in deciding how to bid on a project. Contractors said they would provide a 3.7% discount (on average) for payments made within 30 days, and 63% reported not bidding on a project due to payment concerns.

In Figure 1, this theory argues that *Payment delay* (and the resulting decrease in $PV[Payments]$) leads to an increase in the *Number of bidders*. An increase in $PV[Payments]$ and the *Number of bidders* both contribute to increasing *Aggressive bids*, which reduces *Promised time* and in turn increases *Project delay*. In contrast with previous theories, once bids are awarded, the actual completion time is not affected. Thus, project delays reflect aggressive initial bids rather than a true delay in project completion. The first testable aspect of this theory is the connection between payment delays and the number of bidders.

Hypothesis 7. *Reducing payment delays will increase the number of bidders per project.*

Aggressive bidding manifests in multiple metrics, including initial project budget and completion time, which is captured in the following two hypotheses.

Hypothesis 8a. *Reducing payment delays decreases the initial promised project budgets.*

Hypothesis 8b. *Reducing payment delays decreases the initial promised project durations.*

Because aggressive bidding is the driving force of this theory, we expect the predicted project delay to be present in competitively awarded projects only.

Hypothesis 9. *Reducing payment delays increases project delays for competitively awarded projects.*

4.6. Project stage

Our theories so far have focused on a one-period setting where a project receives only one payment and makes one initial investment. In practice, projects are often structured in stages, each associated with its own costs and payments. The start time of a new stage is linked to the finish time of the previous ones. In this subsection, we extend our earlier theories to a multi-period setting by recognizing the effect of the project stage.

Of all the mechanisms discussed so far, strategic complementarity (§4.1) is most likely to exhibit a stage-dependent effect. Intuitively, when a stage is completed faster, this expedites the payment for that stage and payments for the stages that follow. Therefore, the more stages of the project that remain, or equivalently, the earlier the current stage is, the greater the incentive to finish the current stage faster. In other words, the force of strategic complementarity is stronger for projects in early stages and weaker for projects in later stages. If other forces that affect the project completion time are not affected by the stage, we would expect that later-stage projects are subject to those other forces more, relatively speaking.[15] At this point, we do not know if the net effect of faster payments (based on other theories) is to accelerate or delay projects. Therefore, we present the following hypothesis.

[15] A slightly more formal explanation is as follows. Suppose that $\delta(s)$ is the change in project completion time due to QuickPay for a project in stage s. We decompose this change into two components $\delta(s) = \delta_1(s) + \delta_2(s)$, where $\delta_1(s)$ is the change due to the strategic complementarity force, and $\delta_2(s)$ is the change due to other forces. If stage does not affect $\delta_2(s)$ significantly, then by measuring the differential effect of stage on $\delta(s)$ we measure the differential effect of stage on $\delta_1(s)$. The prediction about $\delta_1(s)$ is that QuickPay should affect early-stage projects more, and these projects should be completed faster relative to the late-stage projects.

Hypothesis 10. *If reducing payment delay accelerates projects, then early stage projects will be accelerated more relative to late stage projects. If reducing payment delay delays projects, then early-stage projects will be delayed less relative to late-stage projects.*

Having presented several theories and hypotheses about how payment delays affect project delays, we now empirically test our hypotheses.

5. Data

5.1. Sample description

To construct our sample, we use USAspending.gov, which provides data on projects awarded by the U.S. federal government. The USAspending database does not contain information on when contractors submit their invoices and when they receive payments. However, using proprietary payment data from the Department of Defense, Barrot and Nanda (2020) verified that the QuickPay reform was implemented as stated on small business projects under fixed-priced contracts.[16] The payment duration sharply declined for such projects awarded by the Department of Defense after April 2011 but remained unchanged for similar large business projects. Barrot and Nanda (2020) also provide the four-digit North American Industry Classification System (NAICS) codes of the industries that were most affected.[17]

Given the above information, in our analysis, we use projects with fixed-price contracts awarded by the Department of Defense in industries with the four-digit NAICS codes listed in Barrot and Nanda (2020).

A public announcement about the reform was made in September 2011.[18] However, Department of Defense implemented the reform a few months prior, leading to an unanticipated decline in the timing of payment for eligible projects.[19] Specifically, the department started accelerating payments to small businesses on April 27, 2011.

In July 2012, the QuickPay reform was also extended to large business contractors. The goal of this amendment was to expedite payments to small subcontractors hired by large firms. Since *all* federal contractors were receiving accelerated payments effective July 2012, we do not have a comparable control group for identification after this date.[20] We, therefore, choose the five quarters before and the five quarters after the quarter in which QuickPay was implemented by the Department of Defense. See Figure 2 for an illustration.

[16] Projects with variable payment contracts, however, were found to not experience faster payments (see Figure 1 in Barrot and Nanda (2020)).

[17] See Figure 1 (pp. 3150) and Table IA.III (of the internet appendix) in Barrot and Nanda (2020) for further details.

[18] See Memorandum M-II-32 of the Office of Management and Budget

[19] See Memorandum 2011-O0007 of the Office of the Under Secretary of Defense, 2011 and Barrot and Nanda (2020).

[20] See `https://obamawhitehouse.archives.gov/sites/default/files/omb/memoranda/2012/m-12-16.pdf`

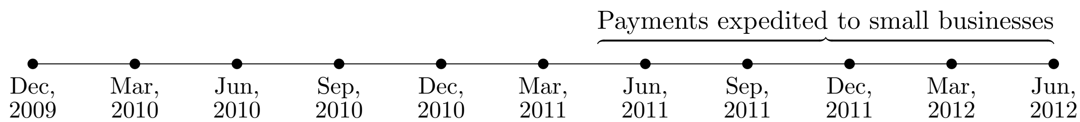


Figure 2 Treatment period.

Note: This figure shows the time periods in which payments were expedited to small contractors under the QuickPay reform.

Our final sample contains 243,371 projects with 1,608 task codes across 82 six-digit NAICS codes.[21] Appendix D provides more details on the sample selection process. We observe 276 variables defining various project characteristics. Table A.1 contains an example of the data. We extract the following information from this database.

Project characteristics: We observe whether a project is deemed a small business project, thus qualifying for expedited payments under the QuickPay reform, from the field "contracting officer's determination of business size." The entry is either "Small Business" or "Other Than Small Business". Henceforth, we refer to the latter as "large business" for expository simplicity. We obtain information on each project's initial budget, start date, initial end date, and task code. We also obtain the NAICS code of the industry that applies to a given project.

Acquisition details: Data on award details of each project includes the type of pricing of the project, the extent of competition during its solicitation stage, whether the project contractor receives financial aid from the government, as well as the government agency overseeing the project.

Modification details: We observe a time-stamped record of every modification made to a project since its inception. According to federal acquisition regulations, contracting officers must record all adjustments to a project's schedule or budget. See Table A.2 for an example.

5.2. Variable definitions and sample statistics

Our theoretical models in §4 mostly normalize a project's start time to zero and compare the actual and promised completion times. In the empirical analysis, we use time-stamped observations on project schedule adjustments and define a real-time delay metric. Specifically, our dependent variable is the percentage change in a project's projected duration over a given year-quarter. For a project i in year-quarter t, it is

$$\textit{Percent Delay Rate}_{i,t} = 100 \times \frac{(\textit{Projected duration}_{i,t} - \textit{Projected duration}_{i,t-1})}{\textit{Projected duration}_{i,t-1}}, \tag{6}$$

where $\textit{Projected duration}_{i,t} = \textit{Proposed end date}_{i,t} - \textit{Start date}_i$ denotes the projected duration of project i at the end of quarter t. $\textit{Start date}_i$ is recorded at the beginning of every project i, and $\textit{Proposed end date}_{i,t}$ is the most recently reported end date of the project i as of quarter t.

[21] Barrot and Nanda (2020) report top 20 *four-digit* NAICS codes that correspond to 82 *six-digit* NAICS codes in our sample.

Thus, *Percent Delay Rate*$_{i,t}$ measures the rate of project delay per quarter. This variable can be positive or negative, with negative delay rates indicating that the project is expected to be ahead of schedule relative to the forecast in the previous quarter.[22]

We also considered other variables, such as the total realized delay at project completion or cumulative delay on a project. These variables, however, have serious limitations in terms of measurement and identification. In contrast, our metric of delay rates has the fewest drawbacks and allows us to identify the causal effect without issues like endogeneity, censoring, serial correlation, or violation of parallel trends (that are manifest while using other variables). In Appendix E, we explain the relative advantages and disadvantages of different dependent variables in detail.

Using the delay rate as the dependent variable has several benefits. First, it generates multiple observations for the treated and control projects over time, which facilitates clear identification of the effect of QuickPay using the difference-in-differences approach and allows us to validate the parallel trends assumption. Second, it allows us to include projects that are still ongoing at the end of the sample window, as it does not rely on the actual completion time. This avoids truncating our sample to projects that end by June 2012 (see Figure 2). Third, it allows us to examine the effects of change in the project stage as a project progresses over time. This offers a richer understanding of how project dynamics moderate the effect of QuickPay.

Using the delay rate also has a drawback. A change in (quarterly) delay rates after QuickPay may not translate into a change in the ultimate delay at project completion because the effect of QuickPay may diminish or even be reverted over time after the observation horizon ends. We address this concern in Appendix E by computing the last observable total delay on projects that were subject to the reform.

We use a number of variables in our analysis to control for fixed-time effects and various project characteristics. See Table A.5 for the detailed definition of these control variables. Tables A.3 and A.4 show the summary statistics for some of these variables in our sample before and after the reform.

6. QuickPay and Project delays

6.1. Treatment and control groups, and model-free analysis

Recall that our unit of analysis is a project because in federal procurement, the classification of a firm as a small business can vary across projects. Contractors are allowed to be listed under multiple industry codes (NAICS), and their categorization for a given project depends on the industry that

[22] *Projected Duration*$_{i,t}$ is equivalent to the *Estimate at Completion* (EAC(T)) metric commonly used in Earned Value Management (EVM). While we do not have access to earned and planned values typically used to calculate $EAC(T)$, we can access a field from the USAspending data called the `Period of Performance Current End Date`. This field provides periodic updates on the expected completion time for each project, which is the variable *Proposed End Date*$_{i,t}$ in our analysis.

is most relevant to it. Since a contractor may hold both small and large business projects, this means that some large business projects may be indirectly affected by QuickPay if their contractor receives faster payments on its small business projects. That is, there may be spillovers between the treated (small) and untreated (large) projects if they have a common contractor.

To prevent this spillover effect from potentially biasing our results, our control group comprises only large business projects run by contractors that do not have small business projects. Formally, we define $Treat_i = 0$ if project i is a large business project and its contractor does not hold any small business projects, and $Treat_i = 1$ if project i is a small business project.

Figure 3 shows the de-meaned trends of percentage delay rates per quarter for treated and control projects. The vertical line signifies the start of the QuickPay reform. Before QuickPay, the average (de-meaned) delay rates on treated projects move in parallel with those of the control projects.[23] After QuickPay was enacted, the gap between the treated and control projects widened.

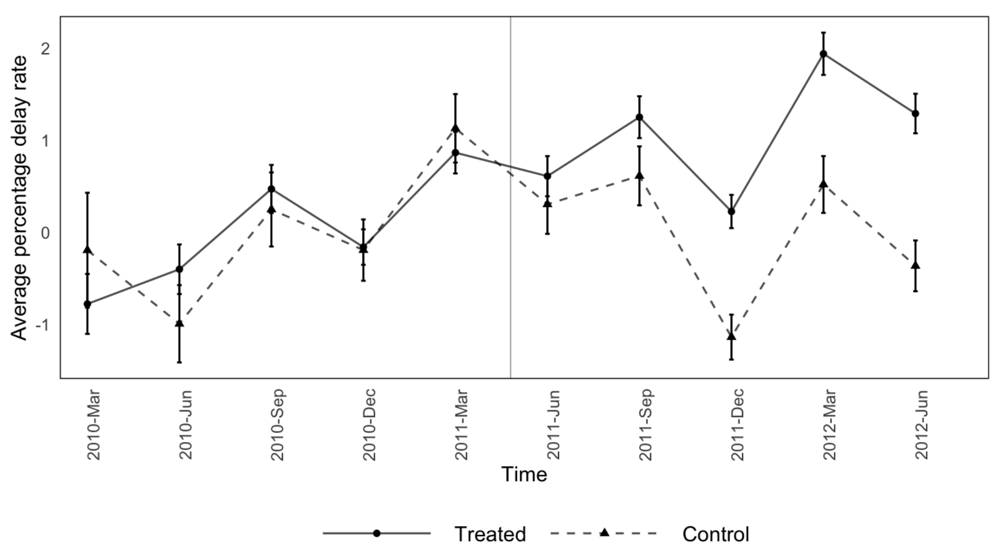


Figure 3 Trends in percentage delay rates among treated and control projects.

Note: This figure shows the percentage delay rates over time for treated and control projects, de-meaned by their average delay rate before the QuickPay reform. The vertical line marks when QuickPay was enacted (April 27, 2011).

[23] We provide further empirical evidence for the parallel trend assumption in Appendix B.2 by testing for linear time trends in project delays over the pre-treatment period.

6.2. Difference-in-Differences: Average treatment effect

We use a difference-in-differences approach to estimate the effect of faster payments under QuickPay using the following model.[24]

$$\begin{aligned} \textit{Percent Delay Rate}_{it} = &\beta_0 + \beta_1 Treat_i + \beta_2 (Treat_i \times Post_t) + \boldsymbol{\beta_3'} \boldsymbol{X_i} + \boldsymbol{\beta_4'} (\boldsymbol{X_i} \times Post_t) \\ &+ \beta_5 \ln(Stage_{it}) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}. \end{aligned} \tag{7}$$

In Eq. (7), $Post_t = 1$ for time periods after QuickPay and 0 otherwise. $\boldsymbol{X_i}$ is a vector of project controls (log of initial budget, log of initial duration, and the number of bids), $Stage_{it}$ is the stage of project i in time t, and β_t, β_{task}, and $\beta_{industry}$ are the fixed effects for the time, the project's task, and the industry, respectively. e_{it} is the error term (see Table A.5 for more details). We cluster the standard errors at the project level to account for possible serial correlation of the error term.[25]

Table 1 Effect of QuickPay on percentage delay rates

	Average treatment effect			Delay likelihood and conditional ATE					
	Percent delay rate			Log-odds (Percent delay rate >0)			E(Percent delay rate | Delay >0)		
	I	II	III	IV	V	VI	VII	VIII	IX
$Treat_i$	-1.35^{***}	-0.90^{***}	-0.91^{***}	-0.24^{***}	-0.21^{***}	-0.23^{***}	-22.85^{***}	-25.17^{***}	-25.24^{***}
	(0.11)	(0.11)	(0.11)	(0.03)	(0.03)	(0.03)	(4.28)	(4.59)	(4.64)
$Treat_i \times Post_t$	1.01^{***}	0.99^{***}	1.01^{***}	0.23^{***}	0.23^{***}	0.23^{***}	22.77^{***}	26.76^{***}	28.25^{***}
	(0.14)	(0.13)	(0.13)	(0.04)	(0.04)	(0.04)	(4.99)	(5.03)	(5.03)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Task FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Industry FE	No	No	Yes	No	No	Yes	No	No	Yes
Observations	201,738	201,738	201,738	201,867	199,508	199,470	24,045	24,045	24,045
R^2	0.18	0.21	0.21	0.24	0.30	0.30	0.39	0.46	0.46

Note. This table presents the estimated coefficients for the quarterly delay rate, delay likelihood, and conditional delay rates in a given time period before and after the QuickPay reform. Columns I-III report the results for delay rates (measured in percentage points), Columns IV-VI report the log-odds of a positive delay, and Columns VII-IX report the delay rates conditional on the delay being positive. Each specification includes a combination of fixed effects, controls for the project's stage, and a project's initial duration, initial budget, and initial bids and their interaction with $Post_t$. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***)

Table 1 (Columns I-III) presents the estimation results. The coefficient of the interaction term $Treat_i \times Post_t$ captures the effect of faster payments under QuickPay on percentage delay rates. We observe that it is positive and statistically significant (at the 1% level) across all specifications, suggesting that expediting contractor payments leads to greater project delays. The results are also nearly identical in magnitude in all three specifications.

[24] In regression (7), the term $\ln(Stage_{it})$ is singled out from other controls because, unlike other controls that are fixed features of a project, $Stage_{it}$ for project i changes over time. We log-transform this variable for better distributional fit and ease of interpretation.

[25] We also clustered the errors at the level of industry and task. The results were robust both in terms of magnitude and significance.

From the specification with most controls (column III), the quarterly delay on projects increased by 1.01 percentage points after the QuickPay reform. Relative to the average percentage delay rate of 3.88 percentage points per quarter for small business projects before QuickPay (see Table A.3), this represents an increase of 26%. Recall that the percentage delay rate is normalized by the last projected duration (see Eq. (6)). Thus, given the average initial duration of small business projects (before QuickPay) of 256.25 days (see Table A.3), this means that a small project's delay increases by an average of 2.56 days in the first quarter after QuickPay. In the following quarters, the delay will increase from the initial 2.56 days, given the longer projected duration. This treatment effect appears to have a small magnitude because it is the average of all projects, most of which report zero quarterly delays (see Table A.3). The effect conditional on positive delays is discussed in the next subsection.

This result does not support Hypothesis 1, which was based on the simplest theory that faster payment will speed up projects. However, this result is consistent with some of the subsequent hypotheses, implying that other forces, besides strategic complementarity, are active. §7 investigates these forces.

6.3. Delay likelihood and conditional average treatment effect

One must be careful when interpreting the positive average treatment effect for a variable calculated at the project-quarter level. In our sample, only 9% of quarterly percent delay rate observations are nonzero. Although projects are often delayed (29% of projects in the sample had delays), the delays don't happen every quarter.

In this subsection, we separate the effects of QuickPay on the likelihood of a delay and on the magnitude of the delay conditional on a positive delay.[26] We use the following logistic model to examine the likelihood of delays

$$\begin{aligned} Y_{it} = \beta_0 + \beta_1 Treat_i + \beta_2 (Treat_i \times Post_t) + \boldsymbol{\beta_3'} \boldsymbol{X_i} + \boldsymbol{\beta_4'} (\boldsymbol{X_i} \times Post_t) \\ + \beta_5 \ln(Stage_{it}) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}, \end{aligned} \tag{8}$$

where Y_{it} denotes the log-odds of project i experiencing a positive delay in quarter t, and all other variables are those defined in Eq. (7). To examine the expected delay rate, conditional on the positive delay, we run the model in Eq. (7) on the sub-sample of strictly positive delay observations.

Table 1 (Columns IV-IX) shows the results. Columns IV-VI report the coefficients from the logistic regression, and columns VII-IX report the results from the linear regression for expected

[26] The expected delay is $E[Delay] = E[Delay|Delay > 0]Pr[Delay > 0] + E[Delay|Delay < 0]Pr[Delay < 0]$. The ATE is $\Delta E[Delay]$. The conditional ATE is $\Delta E[Delay|Delay > 0]$, and the likelihood is $\Delta Pr[Delay > 0]$, where Δ represents the difference-in-differences of the delay metric. Therefore, the estimates of the effect of QuickPay on delay likelihood and conditional average treatment effect (Columns IV-IX) do not immediately produce the average treatment effect (ATE) in Columns I-III of Table 1.

delays conditional on them being positive. As seen in the table, QuickPay has a consistent effect on both the likelihood and the magnitude of delays. Treated projects are significantly more likely to experience a delay than control projects after QuickPay. Using the coefficient of 0.23 from Column VI, the odds of a treated project being delayed increased by approximately 0.26 relative to control projects after the reform.[27] In addition, if a project reports a delay in a quarter, then the delay reported by a treated project is 28.25 percentage points higher than a control project after the reform. Given the average initial project duration of 256 days, this is approximately 71.7 days.

6.4. Robustness checks

6.4.1. Alternative explanations. During our sample period, the U.S. government also launched other policy initiatives to help small businesses recover from the 2008 financial crisis. Notable examples include the Small Business Jobs Act of 2010 and enhancements to the SBA 8(a) in 2011. A potential concern is that what we observe is the effect of these contemporaneous policies rather than that of QuickPay. Our data includes several variables that enable us to identify projects that were unaffected by these contemporaneous policies but benefited from faster payments through QuickPay. Below, we provide a detailed description of these policies and explain the steps we took to isolate the effect of QuickPay.

Small Business Jobs Act (2010). This act was implemented on September 27, 2010—one year before the QuickPay policy. We conducted a placebo test by pretending that the treatment occurred in September 2010. Figure B.2 shows that the estimates from this placebo test are insignificant across different regression specifications, indicating that our results are not due to the Small Business Jobs Act. Furthermore, model-free analysis, presented in Figure 3, finds no discernible differences between delays of small and large projects after September 2010 and until April 2011 (when QuickPay was implemented).

In addition, some provisions of the Small Business Jobs Act (2010) were implemented through the disbursement of grants to small businesses. Therefore, to limit the influence of this act on our measurement of the effect of expedited payments due to QuickPay, we performed a robustness test on a restricted sample of contractors who did not receive any federal grants (using the variable `Receives grants`). Column I of Table 2 shows that our results are robust to this restriction.

Changes to set-aside program in 2010. Certain projects are reserved for small business contractors (known as "set-aside program"). In 2010, changes were made to this set-aside program. To verify that our results are not due to these changes, we restricted the sample to projects that did not have any "set-aside" requirements at the solicitation stage (using the variable `Type of set`

[27] The increase in odds is obtained by $exp(\beta_2) - 1$ using estimates of β_2 from Column VI of Table 1.

`aside`). These projects, therefore, could be awarded to either small or large businesses. Column II of Table 2 shows that our results remain robust.

Enhancements to SBA 8(A) program in 2011. To rule out the effects from these enhancements, we restrict the sample to projects whose contractors are not SBA 8A participants (using the variables `C8A Program participant` and `SBA certified 8a joint venture`). Column III of Table 2 shows that our results are unchanged on this restricted sample.

Changes in contractor pool. Another concern may be that our results are due to more projects being awarded to small businesses or due to changes in the composition of winning contractors after the reform. In Column IV of Table 2, we show that treated projects that had started *before* QuickPay—and therefore not subject to these dynamics—also had greater delay rates after the reform.

Finally, in Column V of Table 2, we remove projects that were subject to *any* of the preceding conditions. Once again, our results are robust.

Table 2 Alternative explanations: Other contemporaneous policies

	Percent delay rate$_{it}$				
	Excluding contractors that receive grants	Excluding set-aside projects	Excluding 8(A) contractors	Excluding projects that started after QuickPay	Excluding all preceding projects
	I	II	III	IV	V
$Treat_i$	-0.90***	-1.18***	-0.92***	-0.82***	-0.94***
	(0.12)	(0.12)	(0.11)	(0.11)	(0.14)
$Treat_i \times Post_t$	1.13***	1.05***	0.92***	1.35***	1.31***
	(0.15)	(0.15)	(0.14)	(0.17)	(0.21)
Industry FE	Yes	Yes	Yes	Yes	Yes
Task FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Observations	175,229	139,862	189,890	134,165	80,909
R^2	0.22	0.21	0.21	0.22	0.21

Note. This table presents the estimated coefficients for the quarterly delay rate for different subsamples. Column I reports the estimated treatment effect for projects whose contractors do not receive any federal grants. Column II reports the estimates for projects that were not subject to any "set-aside" requirements. Column III reports the estimates for projects whose contractors were not 8(A) program participants, and Column IV restricts the sample to projects that started before QuickPay. Each specification includes fixed effects for the time, task, and industry, controls for the project's stage, as well as a project's initial duration, initial budget, and initial bids and their interaction with $Post_t$. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

6.4.2. Matching and Placebo tests. Because QuickPay was applied only to small business projects, one may be concerned that our results are driven by inherent differences between small and large business projects in the absence of the treatment. Although we justify the parallel trends assumption (in Figure 3 and Appendix B.2), we further validate our findings by re-running our analysis on a matched sample.

Specifically, we match the treated and control projects on the task type, industry code, awarding sub-agency, time period, initial budget, initial duration, number of offers received, and contractor's past performance.To measure past performance, we calculated the fraction of projects that were delayed before QuickPay for each contractor and included it as a matching variable. We use twelve different matching methodologies (see Ho et al. 2007), including coarsened exact matching, optimal full matching, propensity score matching, k-nearest neighbor matching ($k = 2, 3, 4$), Mahalanobis and lasso distance matching, classification tree matching, and propensity score matching with n-caliper ($n = 0.3, 0.4, 0.5$) size. Figure 4 shows that our findings are robust—the estimated treatment effect is positive and statistically significant at the 1% level across all matching methods. Further, Figure 5 shows that the treated and control projects share a common support after matching. In particular, the treated and control projects have a similar distribution with respect to the number of bids they receive, their initial duration, and their initial budget. We also conducted placebo tests by randomly assigning projects to the treatment group, and assigning a false treatment date (pre-QuickPay)—see Appendix B.1 for details. Figures B.1 and B.2 show that the results from the placebo tests are largely insignificant, suggesting that our findings are unlikely to be driven by chance.

7. Mediators of delays

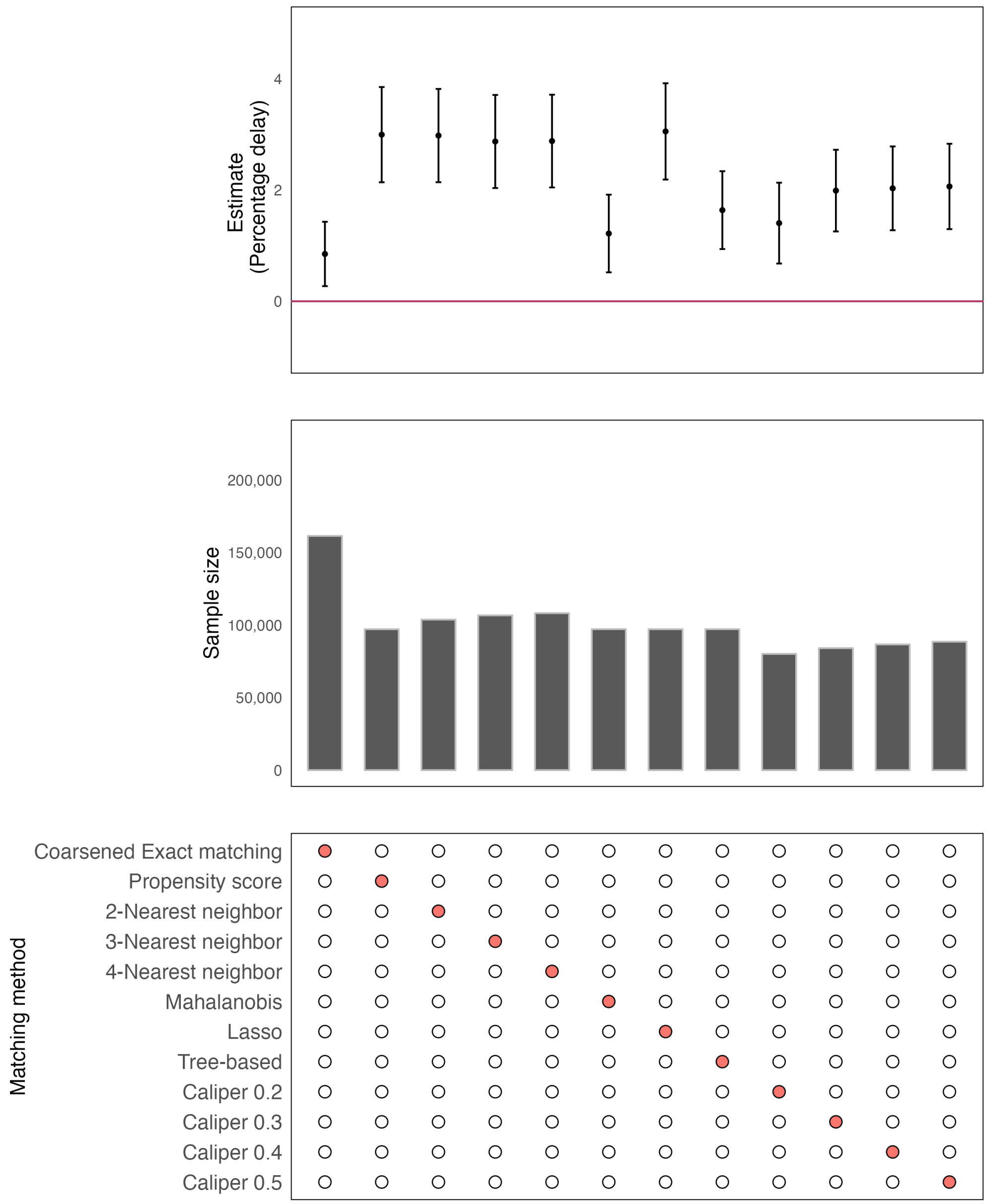
As seen in the previous section, the net effect of QuickPay is to increase the project delay rates. There are multiple mediators of the payment delays' effect on project delays, as described in §4. In this section, we investigate which theory predictions are consistent with empirical observations and quantify the significance of each mediator.

7.1. Lack of financial liquidity

Recall that according to Hypothesis 2 (§4.2), for contractors who are severely financially constrained, reducing payment delays increases project delays. We proxy for the contractor's financial constraints by the fraction of its projects that receive financial assistance from the government. In our sample, each project has a field called "contract financing", indicating whether the project received financing from the government. We argue that a contractor with a greater fraction of projects receiving contract financing (CF) is more financially constrained than those with a smaller fraction of such projects. There are two important notes regarding contract financing.

First, contractors are still financially constrained *after* receiving contract financing because, according to Federal Acquisition Regulations (FAR §32.104–32.105), contract financing is provided "only to the actual extent needed for prompt and efficient performance" and "for financing of contractor working capital, not for the expansion of contractor-owned facilities or the acquisition of fixed assets." Contractors receiving contract financing will generally have to "demonstrate actual financial need or the unavailability of private financing." In addition, contractors that receive financing "will make expenditures for contract performance during the pre-delivery period that

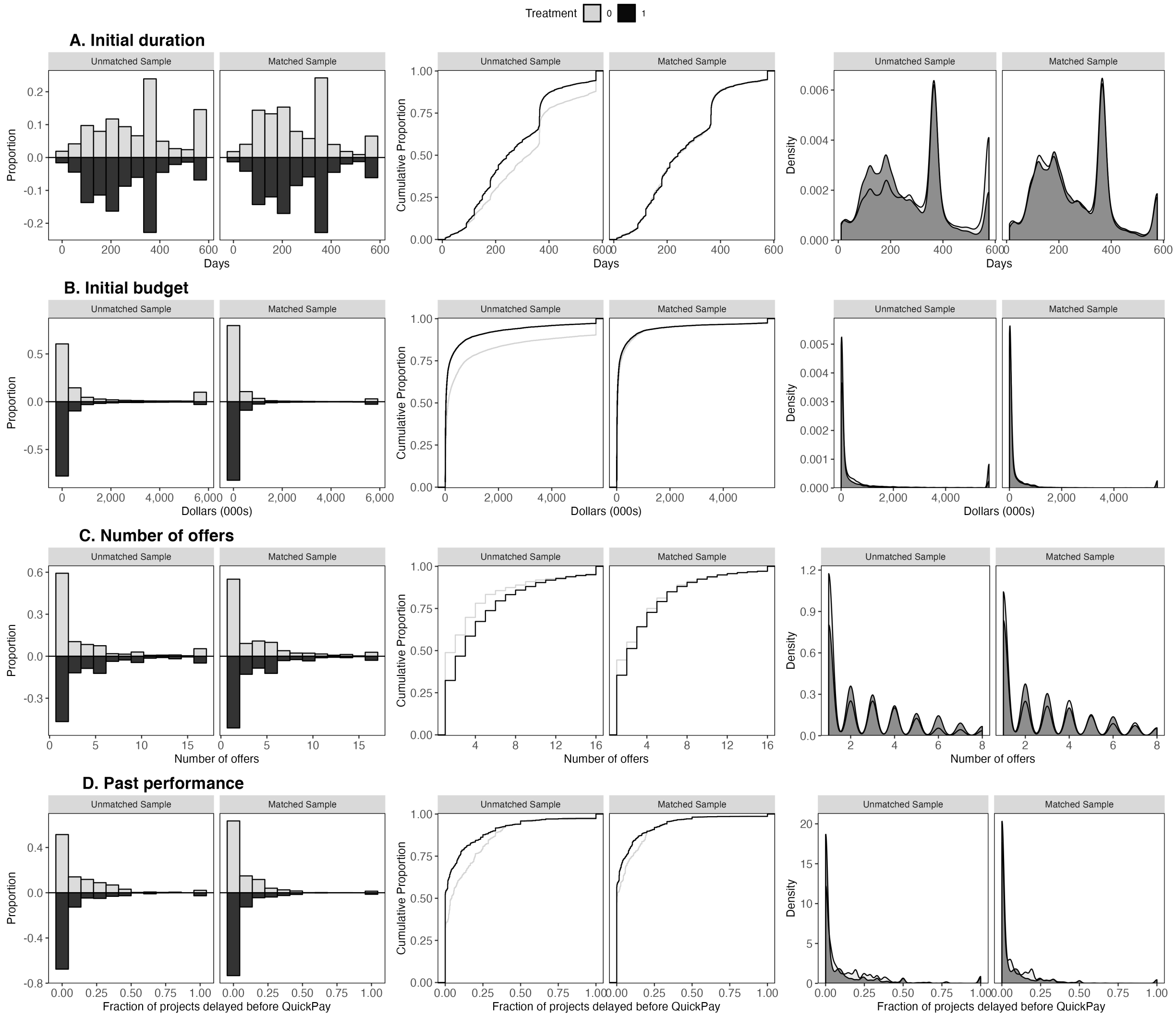
Figure 4 **Matched difference-in-differences**



Note. This figure shows our main results under different matching techniques. For instance, the first column shows the results from Coarsened Exact Matching, whereas the last column shows the results from Propensity score matching with 0.5 caliper size. The bottom panel illustrates the matching method used (shown in red colored bullets). The middle panel displays the number of observations in each matched sample. The top panel displays the estimated coefficient and 95% confidence interval corresponding to $Treat_i \times Post_t$ in Eq. 7.

have a significant impact on the contractor's working capital." See Appendix F for additional details.

Figure 5 Balance plots under coarsened exact matching



Note. This figure shows the distributional balance for treated and control projects after coarsened exact matching. The top panel displays the proportion, empirical CDF, and density plots for the initial duration, the middle panel displays these plots for the initial budget, and the bottom panel displays these plots for the number of offers received.

Second, the need for contract financing does not mean that contractors cannot carry out the project effectively. As specified in the federal procurement guidelines (FAR §32.107), if "the contractor or offeror meets the standards prescribed for responsible prospective contractors . . . , the contracting officer shall not treat the contractor's need for contract financing as a handicap for a contract award; e.g., as a responsibility factor or evaluation criterion." This regulation implies that all awarded contractors are capable and qualified to handle the project.

The following specification captures the mediating effect of a contractor's liquidity constraint on project delays.

$$\begin{aligned} Percent\ Delay\ Rate_{it} = \beta_0 + \beta_1 Treat_i + \beta_2 (Treat_i \times Post_t) + \beta_3 CFPercent_i + \\ \beta_4 (Treat_i \times CFPercent_i) + \beta_5 (CFPercent_i \times Post_t) + \\ \beta_6 (Treat_i \times Post_t \times CFPercent_i) + \beta_7 \ln(Stage_{it}) + \\ \boldsymbol{\beta_8'} \boldsymbol{X_i} + \boldsymbol{\beta_9'} (\boldsymbol{X_i} \times Post_t) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}, \end{aligned} \tag{9}$$

where

$$CFPercent_i = \frac{Num.\ of\ projects\ owned\ by\ project\ i\text{'s}\ contractor\ that\ receive\ CF}{Num.\ of\ projects\ owned\ by\ project\ i\text{'s}\ contractor} \times 100.$$

This model divides the treatment effect into two parts. The coefficient β_2 characterizes the treatment effect that is shared by all projects, and β_6 measures the additional treatment effect on projects whose contractors received financial assistance.

Table 3 reports the estimates. The coefficient of interest is the interaction term $Treat_i \times Post_t \times CFPercent_i$, whose estimate is positive and statistically significant in all specifications. Column III shows that projects had an additional 0.01 percentage points of delay after QuickPay for each percentage point increase in the fraction of financially assisted projects held by the contractor. In our sample, variable $CFPercent_i$ has the following statistics: mean 11.5, 1st quartile 0, median 0.39, 3rd quartile 6.67, and standard deviation 23.56. Thus, if a small project's $CFPercent_i$ increases from the 1st quartile value of zero to the mean of 11.4, the additional delay caused by the contractor's financial constraints is 0.114 ($= 0.01 \times 11.4$) percentage points.

This is approximately one-sixth higher than a project held by contractors that do not receive financing on any of their projects, whose delay rate is 0.82 percentage points (coefficient of $Treat_i \times Post_t$ in column III). Furthermore, compared with the baseline effect of 1.01 percentage points (see Table 1), this average additional delay of 0.114 percentage points would account for more than 10% of the net effect of QuickPay. These findings support our Hypothesis 2: if contractors face financial liquidity constraints, then faster payments increase project delays.

7.2. Project sequence

From §4.3, contractors that hold both large and small business projects can change their sequence in response to QuickPay, affecting the completion time. We test the prediction by looking at how the treatment effect on small business projects is mediated by the existence of large business projects at the same contractor.[28] Define $PortfolioTreat_i = 1$ if project i is a small project whose

[28] These large business projects are not part of our control group. As described in §6, our control group only constitutes large business projects whose contractors do not hold any small business projects. Therefore, there are no spillovers between treated and control projects in our estimations.

Table 3 Financial liquidity and the QuickPay reform

	Percent delay rate		
	I	II	III
$Treat_i$	-1.37^{***}	-0.97^{***}	-0.95^{***}
	(0.11)	(0.12)	(0.12)
$CFPercent_i$	0.04^{***}	-0.003	-0.004
	(0.003)	(0.003)	(0.003)
$Treat_i \times Post_t$	0.70^{***}	0.78^{***}	0.82^{***}
	(0.15)	(0.14)	(0.14)
$Post_t \times CFPercent_i$	-0.02^{***}	-0.01^{**}	-0.01^{**}
	(0.004)	(0.004)	(0.004)
$Treat_i \times CFPercent_i$	0.01^{*}	0.004	0.002
	(0.004)	(0.004)	(0.004)
$Treat_i \times Post_t \times CFPercent_i$	0.02^{***}	0.01^{**}	0.01^{**}
	(0.005)	(0.005)	(0.005)
Controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Task FE	No	Yes	Yes
Industry FE	No	No	Yes
Observations	201,738	201,738	201,738
R^2	0.18	0.21	0.22

Note. This table presents the estimated coefficients for the delay rate (measured in percentage points) in a given time period before and after the QuickPay reform. Each specification includes a combination of fixed effects, controls for the project's stage, and a project's initial duration, initial budget, and initial bids and their interaction with $Post_t$. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

contractor holds at least one large project over the observation horizon and is zero otherwise. We run the following regression.

$$\begin{aligned} Percent\ Delay\ Rate_{it} = \beta_0 &+ \beta_1 Treat_i + \beta_2 (Treat_i \times Post_t) + \beta_3 PortfolioTreat_i \\ &+ \beta_4 (PortfolioTreat_i \times Post_t) + \beta_5 \ln(Stage_{it}) \\ &+ \boldsymbol{\beta_6'} \boldsymbol{X_i} + \boldsymbol{\beta_7'} (\boldsymbol{X_i} \times Post_t) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}, \end{aligned} \tag{10}$$

Coefficient β_2 captures the treatment effect shared by all small business projects, and β_4 measures the change in treatment effect caused by large business projects at the same contractor. Project sequence theory predicts β_4 to be nonzero and may be negative (Hypothesis 3) or positive (Hypothesis 4).

Table 4 shows that the estimate for β_4, i.e., coefficient of the interaction term $PortfolioTreat_i \times Post_t$, is negative across all specifications. Thus, small business projects that have large business projects in the same portfolio are delayed less compared to small business projects without large business projects. This result supports Hypothesis 3, indicating that the contractor with both project types may re-sequence small and large business projects to work on small business projects

Table 4 Effect of QuickPay via projects sequencing

	Percent delay rate		
	I	II	III
$Treat_i$	-0.54^{***}	-0.68^{***}	-0.71^{***}
	(0.11)	(0.12)	(0.12)
$PortfolioTreat_i$	-2.41^{***}	-0.72^{***}	-0.64^{***}
	(0.10)	(0.10)	(0.10)
$Treat_i \times Post_t$	1.09^{***}	1.11^{***}	1.13^{***}
	(0.15)	(0.15)	(0.15)
$PortfolioTreat_i \times Post_t$	-0.33^{**}	-0.38^{***}	-0.38^{***}
	(0.14)	(0.14)	(0.14)
Controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Task FE	No	Yes	Yes
Industry FE	No	No	Yes
Observations	201,738	201,738	201,738
R^2	0.18	0.21	0.21

Note. This table presents the estimated coefficients for the delay rate (measured in percentage points) for small business projects, with and without a large business project in the same portfolio, before and after the QuickPay reform. Each specification includes time fixed effects and controls for the project's initial characteristics (such as duration, budget, and number of bids) and their interaction with $Post_t$. Columns II and III also include fixed effects for project task and industry, respectively. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

first, reducing their delay. In particular, the delay rates for such projects decrease by 0.38 percentage points. This is about one-third less than the delay rate of projects whose contractors hold exclusively small business projects—the delay for such projects increases by 1.13 percentage points (see coefficient for $Treat_i \times Post_t$ in column III). Furthermore, if we compare the coefficient of $PortfolioTreat_i \times Post_t$ with the baseline treatment effect of 1.01 percentage point in Table 1, the decrease in delay would account for about 40% of the net effect of QuickPay.

7.3. Congestion

The theory in §4.4 posits that contractors receiving faster payments under QuickPay accept more work (Hypothesis 5), which then creates congestion and increases project delays (Hypothesis 6). Because Hypothesis 5 is on the contractor level, in contrast to our main model, here we run regressions on contractors instead of projects. For this analysis, we define $ContractorTreat_k = 0$ if contractor k has only large business projects and is thus unaffected by QuickPay. We set $ContractorTreat_k = 1$ if contractor k has only small business projects. These contractors should benefit more from QuickPay than those that have both small and large business projects. Thus, using these contractors as the treatment group should provide the strongest effect of QuickPay on increasing workload.[29] We measure a contractor's workload using three metrics: (1) number of projects, (2) number of tasks, and (3) total budget across projects in a given year-quarter. Table 5 shows the results.

Table 5 Congestion and QuickPay reform

	Number of projects per contractor		Total initial budget per contractor (000,000's)		Number of tasks per contractor	
	I	II	III	IV	V	VI
Constant	5.03***		4.73***		1.73***	
	(0.38)		(0.52)		(0.04)	
$ContractorTreat_k$	−2.03***	−2.03***	−3.30***	−3.30***	−0.23***	−0.23***
	(0.39)	(0.39)	(0.53)	(0.53)	(0.04)	(0.04)
$Post_t$	0.94**		2.46***		0.17***	
	(0.41)		(0.29)		(0.02)	
$ContractorTreat_k \times Post_t$	−0.58	−0.58	−1.47***	−1.48***	−0.04	−0.04
	(0.41)	(0.41)	(0.29)	(0.29)	(0.03)	(0.03)
Time FE	No	Yes	No	Yes	No	Yes
Observations	84,391	84,391	84,391	84,391	84,391	84,391
R^2	0.005	0.01	0.01	0.02	0.01	0.01

Note. This table presents the estimated coefficients for the number of projects, total budget, and number of tasks per contractor before and after the QuickPay reform. The standard errors (reported in parentheses) are robust and clustered at the contractor level. Significance levels: 10% (*), 5% (**), and 1% (***).

As seen in the table, there is no significant increase in the number of projects, the total initial budget, or the number of tasks performed by treated contractors after QuickPay. In fact, the total initial budget decreases (see columns III and IV). These results indicate that contractors did not use the increased resources after QuickPay to expand the scale or scope of their projects. Because the workload did not increase, the congestion theory cannot explain the changes in project delay rate after the QuickPay.

7.4. Aggressive bidding

The theory in §4.5 postulates that the QuickPay reform makes small business projects more attractive, which leads to more aggressive bids from the competing contractors (Hypotheses 7 through 8b). These aggressive bids could then result in project delays (Hypothesis 9). We test this theory by first testing the predicted aggressive bidding behavior caused by QuickPay.

Because the bidding theory applies only to projects that are competitively awarded, we restrict our attention to the subsample of such projects.[30] We examine the effect of QuickPay on the number

[29] In a robustness check, we also analyze the full sample by defining $ContractorTreat_k$ as an indicator that equals 1 if contractor k receives both small business and non-small business projects. The results are qualitatively similar to those reported in Table 5 with this specification.

[30] From Tables A.3 and A.4, competitively awarded projects constitute about 80% of our full sample.

of bids, initial budget, and initial duration.[31] In this analysis, each observation corresponds to a project and not a project-quarter. We run the following regression:

$$Y_i = \beta_0 + \beta_1 Treat_i + \beta_2 (Treat_i \times SA_i) + \tau_i + \beta_{task} + e_i. \tag{11}$$

In Eq. (11), Y_i denotes metrics of aggressive bidding (number of bids, initial duration, and budget) for project i, $Treat_i$ is an indicator that equals 1 if project i is a small business project, SA_i is an indicator that equals 1 if project i starts after QuickPay, and τ_i captures the time fixed effects on the starting time of project i. Coefficient β_2 captures the effect of QuickPay on bidding behavior.

Table 6 QuickPay and bids on competitively-awarded projects

	Number of bids	Initial duration (days)	Initial budget (000s)
	I	II	III
$Treat_i$	0.76^{***}	-11.25^{***}	-86.23^{***}
	(0.03)	(0.83)	(6.13)
$Treat_i \times SA_i$	0.08^{**}	-3.26^{***}	-27.82^{***}
	(0.04)	(1.12)	(8.43)
Task FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Observations	124,049	166,778	170,536
R^2	0.18	0.24	0.23

Note. This table reports the estimated coefficients for the winning bids of competitively awarded treated projects after the QuickPay reform. Column I presents the estimates for the number of bids received, Column II shows the effect on initial duration, and Column III shows the effect on the initial budget. All specifications control for time and task characteristics. The standard errors are reported in parentheses. Significance levels: 10% (*), 5% (**), and 1% (***).

Our estimates, shown in Table 6, support Hypotheses 7, 8a, and 8b. Column I shows that, on average, winning small business projects started after QuickPay received 0.08 more bids, which is a 1.7% increase from the sample average of 4.58 bids (Table A.3). QuickPay also decreases the initial duration of winning small business projects by 3.26 days (Column II), which is a 1.3% decrease from the pre-QuickPay sample average of 256.25 days. QuickPay decreases the initial budget of the winning small business projects by $27,820 (Column III), which is a 5.2% decrease from a sample average of $534,940 (Table A.3). These findings suggest that projects eligible for QuickPay were sought-after, and the winning bids were more aggressive.

We now test Hypothesis 9 and quantify how QuickPay affects project delays due to competition. Intuitively, if a competitively awarded small business project starts before QuickPay, it is not subject to aggressive bidding and competitive forces but is still influenced by other forces due to

[31] We can only observe the initial budget and initial duration for projects whose bids were accepted at the solicitation stage.

QuickPay. Only small business projects awarded after QuickPay are affected by aggressive bidding. Thus, we shall test Hypothesis 9 by estimating the additional delay rate of small business projects that start after QuickPay. Formally, we run the following regression.[32]

$$\begin{aligned} Percent\ Delay\ Rate_{it} = \beta_0 + \beta_1 Treat_i + \beta_2(Treat_i \times Post_t) + \beta_3 SA_i + \beta_4(Treat_i \times Post_t \times SA_i) \\ + \beta_5 \ln(Stage_{it}) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}. \end{aligned} \tag{12}$$

The variable SA_i is defined earlier in this section, and other variables are defined in Eq. (7). Coefficient β_2 in this specification captures the baseline treatment effect shared by all small business projects. The additional treatment effect caused by aggressive bidding is measured by β_4, i.e., the coefficient of $Treat_i \times Post_t \times SA_i$. Hypothesis 9 predicts that β_4 is positive.

Table 7 Effect of QuickPay through aggressive bidding

	Percent delay rate		
	I	II	III
$Treat_i$	-1.94^{***}	-0.50^{***}	-0.51^{***}
	(0.12)	(0.12)	(0.12)
SA_i	1.45^{***}	1.52^{***}	1.48^{***}
	(0.18)	(0.18)	(0.18)
$Treat_i \times Post_t$	0.30^{*}	0.16	0.16
	(0.18)	(0.17)	(0.17)
$Treat_i \times Post_t \times SA_i$	0.58^{***}	0.76^{***}	0.76^{***}
	(0.19)	(0.19)	(0.19)
Controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Task FE	No	Yes	Yes
Industry FE	No	No	Yes
Observations	184,885	184,885	184,885
R^2	0.06	0.12	0.13

Note. This table presents the estimated coefficients for the delay rate (measured in percentage points) of competitively-awarded projects in a given time period before and after the QuickPay reform. Each specification controls for the project's stage in a given time period. Column I includes fixed effects for time, and columns II-III also include fixed effects for task and industry, respectively. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

Table 7 shows the results: competitively-awarded small business projects that started after QuickPay are delayed more than those that started before. Aggressive bidding increases the project delay by approximately 0.76 percentage points per quarter.[33]

[32] We do not include controls for initial bids in this regression as they are the mediators. Including these variables would lead to over-control bias described in Cinelli et al. (2024) and Angrist and Pischke (2009).

[33] An alternative explanation of Table 7 might be that QuickPay attracted more small businesses, including inexperienced small businesses, to bid more aggressively. Thus, these inexperienced small businesses are more likely to win

7.5. Role of project stage

The discussion in §4.6 also considers a dynamic setting and predicts that the strategic complementarity force weakens as a project progresses. Thus, for late-stage projects, the incentive to accelerate due to strategic complementarity is weaker, and other forces that delay projects are manifested more, leading to Hypothesis 10. We examine how the project stage moderates the treatment effect of QuickPay by running the following regression:

$$\begin{aligned} Percent\ Delay\ Rate_{it} = \beta_0 + \beta_1 Treat_i + \beta_2(Treat_i \times Post_t) + \beta_3 \ln(Stage_{it}) + \beta_4(Treat_i \times \ln(Stage_{it})) \\ + \beta_5(Post_t \times \ln(Stage_{it})) + \beta_6(Treat_i \times Post_t \times \ln(Stage_{it})) \\ + \boldsymbol{\beta_7'} \boldsymbol{X_i} + \boldsymbol{\beta_8'}(\boldsymbol{X_i} \times Post_t) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}. \qquad (13) \end{aligned}$$

Here $Stage_{it}$ is the ratio between the time elapsed and the projected life of project i at time t (see Table A.5 for the variable definition, and Tables A.3 and A.4 for summary statistics). The coefficient of interest is β_6, which describes how the treatment effect changes with respect to a project's stage.

Table 8 reports the estimates. The effect of the project stage is positive and statistically significant across specifications. Specifically, a 1% increase in the project's stage increases the treatment effect by approximately 0.0063 percentage points (1% of coefficient for $Treat_i \times Post_t \times \ln(Stage_{it})$ in column III) under QuickPay. Thus, the further along a small project, the more delay QuickPay causes. Since the net effect of QuickPay is to delay projects, Table 8 shows that early-stage projects are delayed less relative to late-stage projects, consistent with the latter part of Hypothesis 10.

8. Discussion and Conclusion

Long payment delays to contractors are both common and contentious in practice. Yet, there is limited research on how payment delays affect project completion times. In this paper, we develop several theories to explain the link between payment and project delays and use them to formulate testable hypotheses. We then empirically test these hypotheses on the U.S. government's project data by taking advantage of an exogenous shock introduced by the QuickPay reform: a policy that expedited payments to certain federal contractors.

One of our theories relies on a simple prediction that faster payments make projects more valuable and motivate contractors to complete the projects sooner. Surprisingly, we find that faster payments instead led to greater project delays.

the projects, subsequently changing the contractor pool after QuickPay. If inexperienced contractors are more likely to delay projects, the increase in delay rate after QuickPay in Table 7 could be partially caused by the change in the contractor pool. While we did find empirical evidence that inexperienced contractors have greater delays as a baseline, we did not find evidence of an increase in the proportion of inexperienced contractors after QuickPay. Thus, the data does not support this alternative mechanism.

Table 8 Mediating effect of project stage

	Percent Delay Rate		
	I	II	III
$Treat_i$	-1.73^{***}	-1.34^{***}	-1.37^{***}
	(0.21)	(0.21)	(0.20)
$\ln(Stage_{it})$	2.45^{***}	2.53^{***}	2.53^{***}
	(0.07)	(0.07)	(0.07)
$Treat_i \times Post_t$	1.82^{***}	1.85^{***}	1.90^{***}
	(0.26)	(0.25)	(0.25)
$Treat_i \times \ln(Stage_{it})$	-0.23^{**}	-0.27^{***}	-0.29^{***}
	(0.09)	(0.09)	(0.09)
$Post_t \times \ln(Stage_{it})$	0.49^{***}	0.23^{**}	0.22^{**}
	(0.09)	(0.09)	(0.09)
$Treat_i \times Post_t \times \ln(Stage_{it})$	0.56^{***}	0.62^{***}	0.63^{***}
	(0.11)	(0.11)	(0.11)
Controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Task FE	Yes	Yes	Yes
Industry FE	No	Yes	Yes
Observations	201,738	201,738	201,738
R^2	0.18	0.21	0.22

Note. This table presents the estimated coefficients for the delay rate (measured in percentage points) in a given time period before and after the QuickPay reform. Each specification includes a combination of fixed effects, controls for a project's initial duration, initial budget, and initial bids and their interaction with $Post_t$. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

This counterintuitive result can be explained by some of our other theories. One theory is that of financial liquidity constraints. We find that contractors facing liquidity constraints had greater project delays after the reform. This indicates that faster payments could have alleviated time pressure on financially constrained contractors, allowing them to complete projects at a slower pace while still meeting their financial obligations.

Another theory is that of competition among contractors. We find that after QuickPay, the winning bids on projects subject to faster payments were more aggressive. This made the delays (relative to these aggressive bids) seem longer. However, delays were not just in appearance. Even projects that were not subject to aggressive bidding were delayed.

We found evidence that contractors accelerated some projects. For example, we tested whether QuickPay induced contractors to prioritize projects. We find that small projects with co-existing large projects were delayed less. This suggests that contractors who manage treated and untreated projects accelerate treated projects, possibly at the expense of untreated projects.

We examined the effect of QuickPay on projects at different stages of completion. Although QuickPay delayed projects at all stages, early-stage projects experienced shorter delays than late-stage projects. This is consistent with the theory that there is a greater benefit to accelerating early-stage projects due to the higher payment value remaining for the contractors.

Finally, we ruled out congestion as an explanation for delays because we found no significant evidence that contractors accepted more work after the reform.

Longer delays for treated projects after QuickPay are undesirable, but there are other consequences of QuickPay that can be beneficial. The project management literature describes the "iron triangle" of time, cost, and quality. We cannot measure project quality, but we did not find evidence of increased cost overruns on treated projects after the reform.[34]

Our work contributes to the understanding of nuanced tradeoffs faced by policymakers. In recent years, a number of policies have been implemented globally to expedite payments to small businesses. These initiatives aim to improve the financial stability of small firms, generate employment opportunities, and stimulate economic growth. While these policies seem to achieve their intended objectives (e.g., see Barrot and Nanda 2020), our research reveals that accelerating payments can affect operational performance, causing longer delays as an unintended consequence. The costs of these unintended consequences can take many forms. Delaying the use of the product or service reduces its value to the principal. Even if the delay is imaginary, attributed purely to ambitious initial timelines, it exacerbates information asymmetry for the principal, making it difficult to select the most suitable bidder, efficiently allocate scarce resources, and plan further steps that rely on the product and service being available.

To mitigate the negative effect of expedited payments on project delays, the government can incentivize contractors to complete projects on time. In an unreported analysis, we found some evidence that small projects receiving performance incentives had fewer delays than those without such incentives. This approach can help the government support contractors while controlling project delays.

Although we study the effect of shorter payment delays on public project delays, we expect our findings to be applicable in more general settings. Longer payment terms are prevalent in supply chains (e.g., trade credit). However, empirically studying general contract settings is difficult because of the endogeneity problem. To the best of our knowledge, ours is the first paper to use the exogenous shock to payment terms to study the relationship between the timing of payments and project delays.

[34] We examined the impact of QuickPay on cost overruns using three metrics: (i) quarterly change in projected costs, (ii) percentage overrun relative to the preceding quarter's budget, and (iii) percentage overrun relative to the initial budget. We did not find a significant effect of the reform on any of these metrics, indicating that the policy did not lead to higher costs for the treated projects. We do not report these results due to space constraints.

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Appendices for "QuickPay and Project Delays"

Appendix A: Data and Summary statistics

Table A.1 Example of project data (Source: USAspending.gov)

Project characteristics	
Contract award unique key	CONT_AWD_0002_9700_W912DW10D1017_9700
Initial budget	$4,416,471.26
Start date	2011-05-13
First-reported end date	2011-11-30
Actual end date	2012-02-29
Project description	Construction along road infrastructure project of primary power, telecomm distro systems, and coordination with commercial utilities
Task code and description	Y199 – Construct/Misc Bldgs
Contracting officer's determination of business size	Small Business
NAICS code	236220 – Commercial and Institutional Building Construction
Acquisition details	
Awarding agency	Department of Defense
Type of pricing	Firm Fixed Price
Extent competed	Full and open competition after exclusion of sources
Number of offers received	4
Contract financing code and type	A – FAR 52.232-16 Progress payments
Receives grants	False

Table A.2 Example of modifications made to the project described in Table A.1.

Proposed end date	Description
2011-11-30	Construction along road infrastructure project of primary power, telecomm distro systems, and coordination with commercial utilities
2011-12-18	Remove tree at 8th & Pendleton
2012-02-29	Water line rework and tree removal

Table A.3 Summary statistics for time period 2009-2011 (pre-treatment period in Fig. 2)

	Small business projects					Large business projects				
	Mean	Std. dev	5%	95%	Obs.	Mean	Std. dev	5%	95%	Obs.
Percentage delay rate	3.88	25.08	0.00	14.07	45,944	5.69	30.93	0.00	33.59	35,894
Initial duration (in days)	256.25	155.34	76.00	489.00	45,944	282.14	163.94	80.00	568.00	35,894
Initial budget (000s)	534.94	2,338.67	3.31	2,535.99	45,944	1,440.09	5,164.52	3.71	7,492.45	35,894
Number of offers	4.58	6.59	1.00	15.00	45,944	3.96	9.30	1.00	13.00	35,894
Project stage	0.33	0.23	0.02	0.75	45,944	0.34	0.24	0.02	0.75	35,894
Positive delay (indicator)	0.06	0.24	0.00	1.00	45,944	0.08	0.28	0.00	1.00	35,894
Negative delay (indicator)	0.01	0.09	0.00	0.00	45,944	0.01	0.09	0.00	0.00	35,894
Competitively awarded (indicator)	0.87	0.33	0.00	1.00	45,944	0.81	0.39	0.00	1.00	35,894
Contract financing (indicator)	0.13	0.33	0.00	1.00	45,944	0.14	0.34	0.00	1.00	35,894
	Count					Count				
Number of task codes	786					707				
Number of NAICS codes	64					65				

Table A.4 Summary statistics for period 2011-2012 (treatment period in Fig. 2)

	Small business projects					Large business projects				
	Mean	Std. dev	5%	95%	Obs.	Mean	Std. dev	5%	95%	Obs.
Percentage delay rate	4.36	23.32	0.00	27.22	67,523	4.54	24.02	0.00	29.59	60,748
Initial duration (in days)	293.29	179.56	87.00	606.00	67,523	337.92	199.09	90.00	733.00	60,748
Initial budget (000s)	750.96	2,911.52	3.51	3,886.88	67,523	1,824.54	6,141.86	3.72	10,306.48	60,748
Number of offers	4.62	5.60	1.00	15.00	67,523	3.67	7.12	1.00	12.00	60,748
Project stage	0.41	0.26	0.03	0.85	67,523	0.43	0.26	0.03	0.85	60,748
Positive delay (indicator)	0.09	0.28	0.00	1.00	67,523	0.10	0.29	0.00	1.00	60,748
Negative delay (indicator)	0.01	0.08	0.00	0.00	67,523	0.01	0.10	0.00	0.00	60,748
Competitively awarded (indicator)	0.87	0.34	0.00	1.00	67,523	0.72	0.45	0.00	1.00	60,748
Contract financing (indicator)	0.13	0.33	0.00	1.00	67,523	0.14	0.35	0.00	1.00	60,748
	Count					Count				
Number of task codes	947					900				
Number of NAICS codes	62					64				

Table A.5 Variable definitions

Variable name	Definition
Task code	This variable characterizes the work that a given project entails, and is considerably granular. For example, the construction of recreational buildings and the construction of office buildings are two distinct task categories in our sample.
Ln(1+Initial budget)	This variable controls for systematic differences in the scale of projects that may affect delays. A project with a budget of $1 million, for example, is likely to be more complex than a project worth $100,000 even if the two fall under the same task category (such as building construction). We measure this variable through the project's anticipated budget when it was launched, and log-transform it to reduce the skew.
Ln(1+Initial duration)	We control for the estimated duration (in days) of a project when it was proposed initially. To construct this variable, we subtract the project's start date from its first-reported end date. We log-transform this variable to reduce its skew.
Number of offers	We account for the number of competitive offers that were received on a given project. Projects that receive few offers may involve more niche and specialized work than those receiving hundreds of offers.
Time	We include year-quarter fixed effects to account for any systematic variation that may occur in a given time period between the treated and the control projects. That is, we include an indicator for all (but one) quarters in our sample.
Project stage	We define the stage of a project-quarter as the time elapsed since the project's initiation relative to its total projected duration. Formally, for a project i in quarter t, we construct the variable $Stage_{it} = (t-1-StartDate_i)/Duration_{i,t-1}$.
Competition	We determine whether a project was awarded competitively. The majority of the projects in our sample are subject to full and open competition. There are exceptions due to reasons that include sole source, national security concerns, and patents held by the contractor.
NAICS code	We account for industry-specific differences between treated and control projects by including the six-digit NAICS code for the project as a control variable.
Contract financing	We proxy for a contractor's financial constraints by ascertaining whether the contractor received financial assistance from the federal government to carry out its projects. For this purpose, we use the variable "receives contract financing" in the USAspending database.

Appendix B: Robustness checks

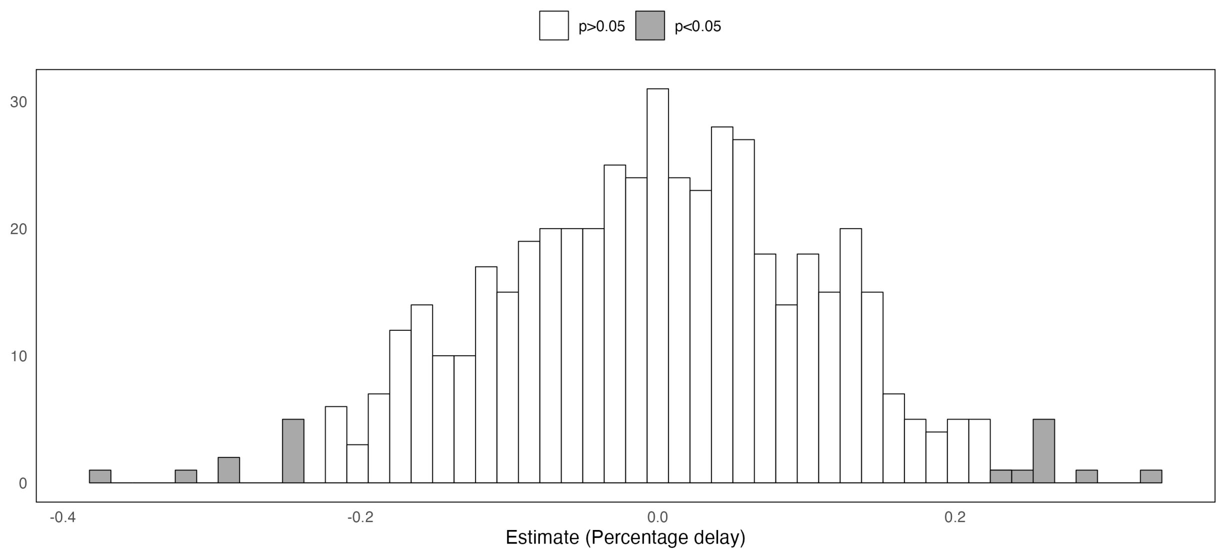
B.1. Placebo tests

To ensure that our results are indeed due to QuickPay and not an artifact of spurious correlations in the data, we conducted two placebo tests. The first one is with respect to the treatment group, and the second one is with respect to the treatment timing.

Treatment group: In the first placebo test, we randomly assign projects into treatment and control groups instead of using the true treated group of small business projects. In this placebo test, the treatment time is still the actual time when QuickPay was enacted i.e., April 2011.

We generate 500 samples for the "false treatment group" and then re-estimate the specification in Eq. (7) for each sample. Figure B.1 shows the results – the estimated coefficients are statistically insignificant in more than 95% of the placebo runs, bolstering confidence that our results are not due to systematic differences between the treatment and control groups.

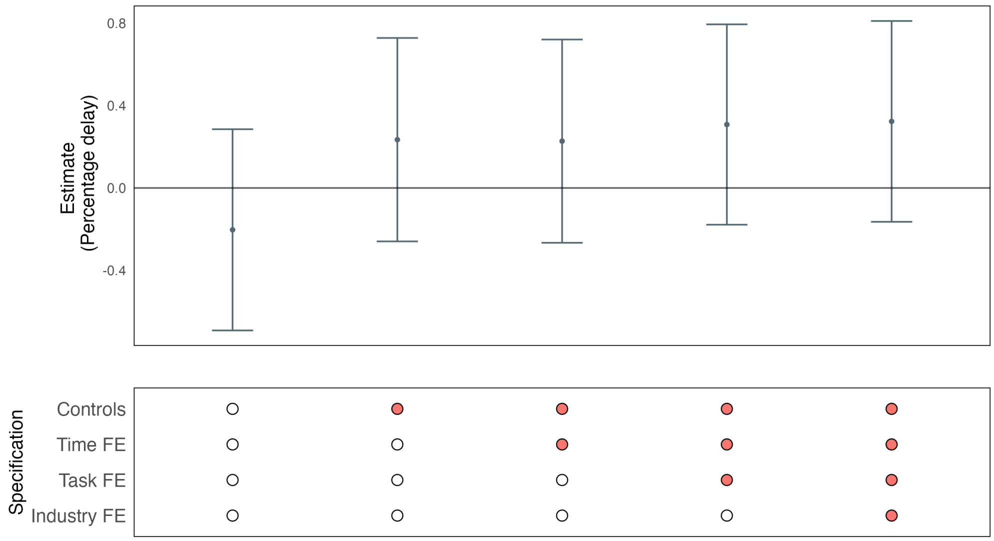
Figure B.1 Placebo test – Treatment group



Treatment timing: We pretend that the treatment occurred in September 2010, two quarters before the actual QuickPay enactment, which happened in April 2011. We then run a difference-in-differences model on the time periods between March 2010 and March 2011. The time periods after March 2011 are not included in this analysis as they will reflect the true impact of the QuickPay policy. The treatment *group* is still small business projects.

If our identification strategy is valid, we should not see a significant treatment effect in this placebo test. Figure B.2 confirms this is true for all regression specifications (including and excluding project controls and fixed effects).

Figure B.2 Placebo test – Treatment timing



B.2. Parallel trends test

The assumption of parallel trends is critical to the validity of a difference-in-differences analysis. In particular, our identifying assumption is that in the absence of QuickPay, the delay rates on treated and control projects would have been parallel over time. We follow the approach in Cui et al. (2020) to assess the validity of this assumption. We test for linear time trends of pre-treatment delay rates (i.e., delay rates before QuickPay) by specifying the following regressions. For the linear regression model, we run

$$\begin{aligned}\text{Percent Delay Rate}_{it} &= \beta_0 + \beta_1 Treat_i + \beta_2 QtrNum + \beta_3 (Treat_i \times QtrNum) + \boldsymbol{\beta_4'} \boldsymbol{X_i} + \boldsymbol{\beta_5'}(\boldsymbol{X_i} \times QtrNum) \\ &+ \beta_6 ln(Stage_{it}) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}, \end{aligned} \tag{14}$$

For the logistic regression, we run

$$\begin{aligned}\text{Y}_{it} &= \beta_0 + \beta_1 Treat_i + \beta_2 QtrNum + \beta_3 (Treat_i \times QtrNum) + \boldsymbol{\beta_4'} \boldsymbol{X_i} + \boldsymbol{\beta_5'}(\boldsymbol{X_i} \times QtrNum) \\ &+ \beta_6 ln(Stage_{it}) + \beta_t + \beta_{task} + \beta_{industry} + e_{it}, \end{aligned} \tag{15}$$

where $QtrNum$ denotes the number of quarters since the beginning of the time horizon and until the launch of QuickPay in April 2011, and other variables are the same as defined in previous sections. The coefficient of interest in these regressions is β_3, which measures the time variation in delay rates between treated and control observations before QuickPay was enacted. Table B.1 reports the results – the estimated coefficient is close to, and not statistically distinguishable from, zero in nearly all specifications, suggesting that the delay rates for treated and control projects evolved in parallel before the QuickPay policy.

B.3. Alternative delay metrics

The main analysis used the percentage delay rate per quarter as the metric of delays (see definition in Eq. (6)). We also performed the analysis with three alternative delay metrics: (i) days of delay per quarter, (ii) days of delay over half a year, and (iii) delay rate per quarter relative to the project's initial duration (following Calvo et al. 2019 and Dhingra et al. 2024).

Table B.1 Percentage delay rates before QuickPay

	Percent delay rate			Log odds (Delay rate> 0)		
	I	II	III	IV	V	VI
$Treat_i$	-0.65	-0.44	-0.52	-0.14	-0.10	-0.12
	(0.41)	(0.41)	(0.41)	(0.12)	(0.13)	(0.13)
$Treat_i \times QtrNum$	-0.17*	-0.03	-0.03	-0.02	-0.01	-0.01
	(0.09)	(0.09)	(0.09)	(0.02)	(0.03)	(0.03)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Task FE	No	Yes	Yes	No	Yes	Yes
Industry FE	No	No	Yes	No	No	Yes
R^2/Pseudo R^2	0.20	0.26	0.27	0.26	0.34	0.35
Observations	77,984	77,984	77,984	78,035	74,512	74,454

Note. This table measures the linear time trend between treated and control projects before QuickPay. Each specification controls for the project's initial characteristics (such as duration, budget, and number of offers) and their interaction with $QtrNum$, as well as the project stage. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

B.3.1. Days of delay and varying period length. In this definition, we use days of delay as the dependent variable but still consider delays on a quarterly basis. Formally, we define

$$Days\ of\ Delay_{i,t} = Projected\ duration_{i,t} - Projected\ duration_{i,t-1}.$$

Column I in Table B.2 shows that the treatment effect is significant at the 1% level. On average, QuickPay causes a project to be delayed by an additional 1.74 days per quarter, which is on par with the result using percentage delays.

Next, we increase the length of the period (t) over which delay is calculated to six months. Column II of Table B.2 shows that the treatment effect on delays over half a year is twice that of quarterly ones, indicating that QuickPay has a persistent effect over time.

B.3.2. Delay relative to the project's initial duration. We measure how QuickPay affects the quarterly delay rate relative to initial project durations rather than the last projected duration in Eq. (6). For project i in time period t, we define

$$Delay/Initial = \frac{Days\ of\ Delay_{it}}{Initial\ Duration_i} \times 100.$$

Table B.2, Column III displays the results. After the QuickPay reform, the quarterly delay on treated projects increased by 1.23 percentage points relative to their initial duration. The effect is statistically significant at the 1% level.

B.4. Contractors with only one type of project

In our main analysis, the treatment group included all small business projects of a contractor, while the control group comprised only those large business projects whose contractors did not hold small business projects. This design eliminated potential spillovers between treated and control projects, ensuring compliance with the Stable Unit Treatment Value Assumption (SUTVA), which requires that the treatment effect for any unit depends only on its own treatment status.

To further validate the robustness of our results to SUTVA, in this section, we also exclude treated (small) projects of contractors who hold large business projects. The resulting sample consists of only those contractors who hold exclusively small or large business projects. We re-ran the baseline regression model in Eq. (7) on this restricted sample. Column IV of Table B.2 shows that our estimates are robust to this specification—the treatment effect remains positive and statistically significant at the 1% level.

Table B.2 Robustness tests

	Days of delay		Delay/	Percent Delay Rate
	Quarterly	Semi-annual	Initial	(SUTVA)
	I	II	III	IV
$Treat_i$	-1.84^{***}	-3.77^{***}	-1.17^{***}	-0.88^{***}
	(0.18)	(0.55)	(0.14)	(0.14)
$Treat_i \times Post_t$	1.74^{***}	3.87^{***}	1.23^{***}	1.34^{***}
	(0.24)	(0.74)	(0.17)	(0.18)
Controls	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Task FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	201,867	84,737	200,789	157,166
R^2	0.18	0.22	0.22	0.21

Notes: This table reports the estimated coefficients from various robustness tests. Columns I and II consider the days of delay on a project over a one-quarter and six-month period, respectively. Column III considers the delay rate relative to a project's initial duration as the dependent variable. Finally, column IV reports the estimates when the sample is restricted to contractors who hold exclusively treated or exclusively untreated projects. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

B.5. All defense projects with fixed price contracts

Since we do not have access to data on invoice approval and receipts for each project (as it is proprietary information), our main sample relied on the four-digit NAICS codes provided in Barrot and Nanda (2020), who verified that the QuickPay reform was implemented using proprietary data from one of the payment systems of Department of Defense called MOCAS.

In this section, we re-run our analysis on an extended sample where we consider *all* fixed price contracts awarded by the Department of Defense between 2009-2012 (i.e., we do not exclude any NAICS code from the sample). Table B.3 shows that our results are robust to this extension—the treatment effect is positive and statistically significant across specifications. However, we cannot confirm whether payments were expedited for all defense projects held by small businesses in this sample, as some projects may have payment systems other than MOCAS (which Barrot and Nanda 2020 verified).

B.6. All defense projects projects with cost contracts

In our main analysis, we restricted our attention to fixed price contracts because Barrot and Nanda (2020) verified that projects with such contracts indeed experienced faster payments once QuickPay was launched. Projects with other contract types, e.g., variable payment contracts, did not receive faster payments.

Table B.3 Extended sample – All defense projects with Fixed Price Contracts

	Percent delay rate$_{it}$			
	I	II	III	IV
Constant	0.40***			
	(0.03)			
$Treat_i$	-0.62***	-0.62***	-0.37***	-0.39***
	(0.02)	(0.02)	(0.02)	(0.03)
$Post_t$	-0.10**			
	(0.04)			
$Treat_i \times Post_t$	0.30***	0.31***	0.31***	0.32***
	(0.03)	(0.03)	(0.03)	(0.03)
Controls	Yes	Yes	Yes	Yes
Time FE	No	Yes	Yes	Yes
Task FE	No	No	Yes	Yes
Industry FE	No	No	No	Yes
Observations	1,191,596	1,191,596	1,191,596	1,189,571
R^2	0.08	0.08	0.11	0.12

Note. Each specification includes a combination of fixed effects and controls for a project's initial duration, budget, and bids. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

In this section, we replicate our analysis on the sample of cost-plus contracts that were already receiving faster payments before QuickPay and, therefore, were not affected by the policy. As expected, we do not find any effect on delays of small projects in this sample—Table B.4 shows that the estimate of $Treat_i \times Post_t$ is statistically insignificant across all specifications.

Table B.4 Extended sample – All defense projects with Cost Contracts

	Percent delay rate$_{it}$			
	I	II	III	IV
Constant	2.79***			
	(0.17)			
$Treat_i$	0.30**	0.31***	-0.04	-0.21*
	(0.12)	(0.12)	(0.12)	(0.13)
$Post_t$	-1.66***			
	(0.20)			
$Treat_i \times Post_t$	0.05	0.03	0.11	0.09
	(0.15)	(0.15)	(0.15)	(0.15)
Controls	Yes	Yes	Yes	Yes
Time FE	No	Yes	Yes	Yes
Task FE	No	No	Yes	Yes
Industry FE	No	No	No	Yes
Observations	86,851	86,851	86,851	86,851
R^2	0.11	0.11	0.13	0.14

Note. Each specification includes a combination of fixed effects and controls for a project's initial duration, budget, and bids. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

B.7. Excluding projects with scope changes

In the USAspending data, every change to a project's deadline is assigned an "action type code," which describes the broad reason for the change. Some of these codes reflect additional work assigned by the government beyond the scope of the initial project agreement. Examples include `G: Exercise an Option`, `A: Additional Work (New Agreement, Justification Required)`, `D: Change Order`, and `L: Definitize Change Order`. Other action types are purely administrative (e.g., `M: Other Administrative Action` and `W: Entity Address Change`) or represent agreements for work within the original project scope (e.g., `B: Supplemental Agreement for Work Within Scope`). Additionally, certain action types describe the project's status and are also necessary for calculating delay rates accurately, such as `Legal Contract Cancellation` or `Terminate for Cause`.

In our main analysis, we include all action types when calculating delay rates. This is because, in general, scope changes and additional work are common reasons for project delays. Our estimates thus capture the full extent of delays, including those prompted by scope changes. Moreover, a project's deadline may be extended for multiple reasons in a given time interval, with each reason associated with a different action type.

As such, in our sample, a vast majority of the projects are delayed due to action types M and B described above—neither of which correspond to scope changes. We test the robustness of our findings to different action types by excluding projects that underwent modifications due to changes in scope (i.e., action types G, A, D, and L) or for reasons other than "administrative action." Table B.5 shows our results are robust to this restriction. Columns I-III consider projects that do not experience any additional work being assigned during their course. Columns IV-VI consider projects that had no modification other than action type M. As seen in the table, the estimated treatment effect remains positive and statistically significant across all specifications.

B.8. Other robustness tests

In this section, we describe a few more robustness tests that validate our findings.

B.8.1. Are agencies changing the way projects are being awarded? Our theory in §4.5 posits that the nature of competition can change after QuickPay in that contractors may bid more aggressively. One may question whether the contract award process has also changed after QuickPay, i.e., are federal agencies strategically altering their decisions regarding which contracts are awarded to which type of contractor? Intuitively, the answer to this question should be "No" because the QuickPay objectives did not mention changes to the award process. The assumption that the awarding process does not change in response to the policy restricting payment terms is consistent with other papers in the literature (e.g., Barrot and Nanda (2020), Chen et al. (2016), Barrot (2016))

But to rigorously test this conjecture, we would need to know (i) the set of potential projects that an agency is considering offering, (ii) the set of projects that are actually offered (i.e., projects for which RFPs are issued), (iii) bids and proposals received on these projects, and (iv) projects selected from the proposals received. We will then need to compare the changes in these four steps for an agency office before and after

Table B.5 Excluding projects with certain action types

	Percent delay rate$_{it}$					
	Exclude projects with action types D, A, L, and G			Exclude projects with any action type other than M		
	I	II	III	IV	V	VI
$Treat_i$	-0.98***	-1.04***	-1.00***	-0.58***	-0.63***	-0.63***
	(0.11)	(0.11)	(0.11)	(0.09)	(0.09)	(0.09)
$Treat_i \times Post_t$	0.64***	0.67***	0.70***	0.30***	0.33***	0.36***
	(0.14)	(0.14)	(0.14)	(0.12)	(0.12)	(0.12)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Task FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	Yes	Yes	No	Yes	Yes
Subagency FE	No	No	Yes	No	No	Yes
Observations	165,091	165,091	165,091	130,707	130,707	130,707
R^2	0.22	0.22	0.23	0.17	0.17	0.18

The sample is restricted to projects with only some action types. Controls include project stage, initial duration, initial budget, and number of bids. Initial duration, initial budget, and number of bids are also interacted with Post are also included as controls. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

QuickPay. Unfortunately, we do not have access to this level of detail on the project selection process that is at play at the agency level. The USAspending data only reports the post-award outcomes for the projects, thus making it infeasible to test this hypothesis without additional proprietary data.

To further assess the validity of our findings against these concerns, recall that we had run our results on the sub-sample of projects that had started before QuickPay (see Table 2, Column IV). These projects would not be subject to any changes in the nature of competition or the nature of the contract awarding process spurred by the QuickPay reform. Table 2 shows that our results were robust to this restriction—the estimated treatment effect remains positive and statistically significant at the 1% level.

B.8.2. Why are some controls allowed to vary after QuickPay (Post×X) but not others? In our main analysis, we interacted several control variables (initial duration, budget, and offers) with $Post_t$ but did not interact $Stage_{it}$ with $Post_t$. The variables 'initial duration' , 'initial budget', and 'number of offers' are fixed for a project and do not vary over time. We had included their interaction with the Post dummy to prevent our estimation results from being biased if the treated and control projects vary in their performance over time due to underlying heterogeneity in the distribution of their initial budget, duration, and number of offers received. This is consistent with the approach used in the literature on payment timing under trade credit—see, for example, Barrot (2016).[35]

In Table B.6, we show that our main results are still positive and statistically significant at the 1% level when we omit the $Post \times X$ controls from our regression models (see Columns VII-IX).

[35] We did not include the interaction of fixed effects with the Post variable to avoid over-fitting since we have around 80 industry codes, and more than 1,000 task categories in the sample.

We did not consider the interaction of the control variable $Stage_{it}$ with $Post_t$ because it is not an initial project characteristic that agencies can tweak. Our goal was to capture the effects of different initial characteristics on different trends after QuickPay (irrespective of the project's treatment status). To check robustness, we repeated baseline analysis to include the interaction, and our results do not change—Columns IV-VI of Table B.6 show that the estimated treatment effect remains unchanged with this addition.

Table B.6 Difference-in-differences with and without Stage interaction

	Percent delay rate$_{it}$								
	Excluding $Stage \times Post_t$ (Baseline model)			Including $Stage \times Post_t$			Excluding $X \times Post_t$		
	I	II	III	IV	V	VI	VII	VIII	IX
$Treat_i$	-1.35***	-0.90***	-0.91***	-1.38***	-0.92***	-0.93***	-1.27***	-0.88***	-0.88***
	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.10)	(0.10)	(0.10)
$Treat_i \times Post_t$	1.01***	0.99***	1.01***	1.05***	1.02***	1.04***	0.88***	0.95***	0.97***
	(0.14)	(0.13)	(0.13)	(0.14)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Task FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Industry FE	No	No	Yes	No	No	Yes	No	No	Yes
Pseudo R^2	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Observations	201,738	201,738	201,738	201,738	201,738	201,738	201,738	201,738	201,738
R^2	0.18	0.21	0.21	0.18	0.21	0.21	0.17	0.21	0.21

Note. This table presents the estimated coefficients for the quarterly delay rate for different subsamples. Each specification includes controls for the project's stage, as well as a project's initial duration, initial budget, and initial bids and their interaction with $Post_t$. The standard errors (reported in parentheses) are robust and clustered at the project level. Significance levels: 10% (*), 5% (**), and 1% (***).

Appendix C: Technical statements and Proofs

LEMMA 1. *Function $V(T,\tau)$ given in equation (1) is supermodular.*

Proof of Lemma 1 The cross-partial second derivative $\frac{\partial^2 V(T,\tau)}{\partial T \partial \tau} = e^{-r(T+\tau)} P r^2 > 0$. ■

Proof of Proposition 2. From the hypothesis of this proposition, for some τ_1, $W_{1,2} \geq W_{2,1}$. Using the definition (4) and moving all terms that are affected by τ_1 to the left-hand-side of the inequality, and other terms to the right-hand-side, we obtain:

$$V_1(1 - e^{-rT_2}) + e^{-rT_1} V_2 \geq V_2. \tag{16}$$

From Proposition 1, optimal T_1 increases in τ_1. Using the envelope theorem, V_1 decreases in τ_1. Observe that $1 - e^{-rT_2} \geq 0$. These three statements together mean that as τ_1 decreases, (16) continues to hold and, thus $W_{1,2} \geq W_{2,1}$. ■

Proof of Proposition 3 From the first-order conditions for problem (5), $\mu^* = P/c$, $\mu^* - \lambda^* = \sqrt{H/P}$, $W(\lambda^*, \mu^*) = \sqrt{P/H}$ and $\lambda^* = P/c - \sqrt{H/P}$. The comparative statics with respect to P follow immediately from these expressions. ■

Appendix D: Sample construction

Federal agency: We consider projects awarded by the Department of Defense (DoD), which is the government's largest agency and awards more than half of all federal projects. The QuickPay reform was publicly announced in September 2011. However, the DoD started accelerating payments to eligible contractors several months in advance (in April 2011) leading to a large and unanticipated decline in payment delays. This ensures our sample is not subject to anticipatory effects by contractors. Barrot and Nanda (2020) verified the implementation of QuickPay by the DoD using proprietary payment data from the agency.

Time period: We collect data on projects awarded between 2010 and 2012. This time period ensures our sample is centered around the date when QuickPay was implemented by DoD (i.e., April 2011). We further restrict the sample to time periods before July 2012 as QuickPay was extended to both small and large business projects on this date, i.e., *all* federal contractors started receiving faster payments (so we do not have a control group after this time).

Contract pricing: We restrict our sample to contracts awarded under the "Firm Fixed Price" scheme. This is the most common type of contract pricing used in federal procurement projects, and agency officers are encouraged to use this pricing type as much as possible. In 2010-2012, for example, 91.5% of the projects were awarded under the firm fixed price scheme.[36] Other pricing schemes, such as cost-plus contracts, were already receiving payments within 15 days even before QuickPay and, therefore, were not affected by this policy.

NAICS codes: We use the four-digit North American Industry Classification System (NAICS) codes of the industries that were most affected as listed in Barrot and Nanda (2020) (Table IA.III). The USAspending database does not contain information on when contractors submit their invoices and when they receive payments. However, using proprietary payment data from the Department of Defense, Barrot and Nanda (2020) verified that the reform was implemented as stated. Barrot and Nanda (2020) report top 20 *four-digit* NAICS codes that correspond to 82 *six-digit* NAICS codes in our sample.[37]

Exclude small disadvantaged business projects: We exclude projects awarded to small disadvantaged businesses (around 5% of the sample) because these contractors were already receiving payments within 15 days of invoice receipt before QuickPay and, therefore, were not affected by the reform.

Exclude projects with bundled contracts: We exclude projects that were categorized as a bundled contract (less than 1% of the sample). In federal procurement, bundled contracts consolidate requirements for some products and services that were previously performed under smaller contracts into one large contract. These projects are, therefore, by design, unsuitable to be awarded to small businesses (see FAR §7.107-3) and would not serve as a comparable control group for our study.

[36] Other types of fixed price schemes were used on approximately 4% of the projects. Our results are robust to the inclusion of these contract types.

[37] See Figure 1 (pp. 3150) and Table IA.III (of the internet appendix) in Barrot and Nanda (2020) for further details.

Appendix E: Alternative dependent variables

Before conducting the study, we contemplated using various variables, including the final delay on the project. After careful consideration, we chose the quarterly percentage delay rates as the dependent variable because this allows us to estimate the causal effect of QuickPay and has fewer drawbacks than the alternatives. The table below summarizes the advantages and disadvantages of various variables. The discussion that follows provides details. We also conducted a robustness test to examine project-level delays (detailed below).

Dependent variable	**Advantages**	**Disadvantages**
Quarterly delay rates $= \frac{T_{i,t}-T_{i,t-1}}{T_{i,t-1}-IT_i}$ (Our primary approach)	• Robust DiD identification strategy • Parallel trends can be validated • No endogeneity or censoring • Metric can capture the time-varying effect of QuickPay • No serial correlation by construction	• May not represent the actual delay on the project
Semi-annual delay rates $= \frac{T_{i,t}-T_{i,t-2}}{T_{i,t-2}-IT_i}$ (Our secondary approach)	• Robust DiD identification strategy. • Parallel trends can be validated • No endogeneity or censoring • Metric can capture the time-varying effect of QuickPay • No serial correlation by construction • Can measure the effect of policy over multiple quarters (e.g., the positive effect would indicate no reversal in quarterly rates)	• May not represent the actual delay on the project • Fewer observations than quarterly delay rates
Total realized delay $= FT_i - IT_i$	• Intuitive	• Final completion time is not known for projects in progress • Identifying the assumptions of DiD is impossible as the parallel trends cannot be tested • Final completion time is endogenous • Initial completion time can be inaccurate • Metric cannot capture the time-varying effect of QuickPay
Cumulative delay at time $t = T_{i,t} - IT_i$	• Intuitive	• Parallel trends are violated • Serially correlated by construction
Alternate treatment variable	**Advantages**	**Disadvantages**
Fraction of time under QuickPay	• Intuitive	• Initial completion time can be inaccurate • Final completion time is endogenous

Notation. $T_{i,t}$ = projected completion time for project i at time t. IT_i = initial projected completion time for project i. FT_i = final completion time for project i.

I. Alternative dependent variables. We considered three alternative dependent variables: 1) Semi-annual delay rates, 2) Total realized delay on a project, and 3) Cumulative delay rate on a project. The first variable is included in our analyses (Appendix B.3.1.). For the other two variables, we describe their advantages and disadvantages below and explain how our primary dependent variable (quarterly delay rate) avoids these disadvantages.

1. **Total realized delay on a project**. Total realized delay is the difference between the final completion time of a project (FT_i) and its initial projected completion time (IT_i).

   Advantages: This variable is intuitive and captures the actual delay on a project.

   Disadvantage 1: This variable can be censored because the final completion time is not known for projects in progress.

   How our variable overcomes this issue: In contrast, there is no censoring in our dependent variable of quarterly delay rates because projected completion times are observed every quarter for all projects.

   Disadvantage 2: The identification strategy for causality with this metric is unclear because this definition generates only one observation for each project (as opposed to an observation for each project-quarter). When the observations are on the project-quarter level, it is clear which observations are pre- and which ones are post-QuickPay. However, this is less clear at the project level because a project may straddle the QuickPay implementation.

   Suppose we use initially-projected durations to define projects for pre- and post-QuickPay periods. That is, we set $Post_i = 1$ if project i is initially slated to end after QuickPay and $Post_i = 0$ otherwise. This is likely to undercount projects that were exposed to QuickPay because some projects will be delayed and eventually finish after the reform. This leads to a biased estimate of the treatment effect.

   Suppose we use the realized completion time instead. This is also problematic because the realization of the dependent variable determines the value of the independent variable $Post_i$, leading to reverse causality.

   One way to avoid these issues, caused by projects that straddle QuickPay, is to consider projects that start and end before QuickPay as $Post_i = 0$ and projects that start and end after QuickPay as $Post_i = 1$. This assuages some issues with endogeneity but severely restricts the sample (as all projects straddling QuickPay implementation time are removed). Nevertheless, we performed this analysis, and our results were robust.

   How our variable overcomes this issue: With our dependent variable, $Post_t$ is defined at the quarter-level. The definition of $Post_t$ is unambiguous and is independent of the components of the dependent variable: simply, quarters after QuickPay implementation have $Post_t = 1$, and $Post_t = 0$ otherwise.

   Disadvantage 3: The parallel trends assumption necessary for the canonical difference-in-differences approach cannot be validated because this metric will only give one observation for treated and control projects pre-QuickPay.

How our variable overcomes this issue: We have multiple observations pre-QuickPay that allow us to assess parallel trends between treated and control projects.

2. **Cumulative delay rates.** Cumulative delay rate is the difference between the projected completion time of the project in quarter t ($T_{i,t}$) and the initial projected completion time (IT_i).

Advantages: The variable is intuitive and can capture the cumulative delays that a project has experienced up to time t.

Disadvantage 1: The parallel trends assumption is violated—see Figure E.1. This is intuitive because the cumulative delay rate is roughly the average quarterly delay rate multiplied by the number of quarters. For parallel trends to hold, the treated and control groups should have *identical* quarterly delay rate pre-treatment, and we know from our data that this is not true. As shown in the summary statistics of our original submission, the treated group has a significantly lower baseline quarterly delay rate than the control group.

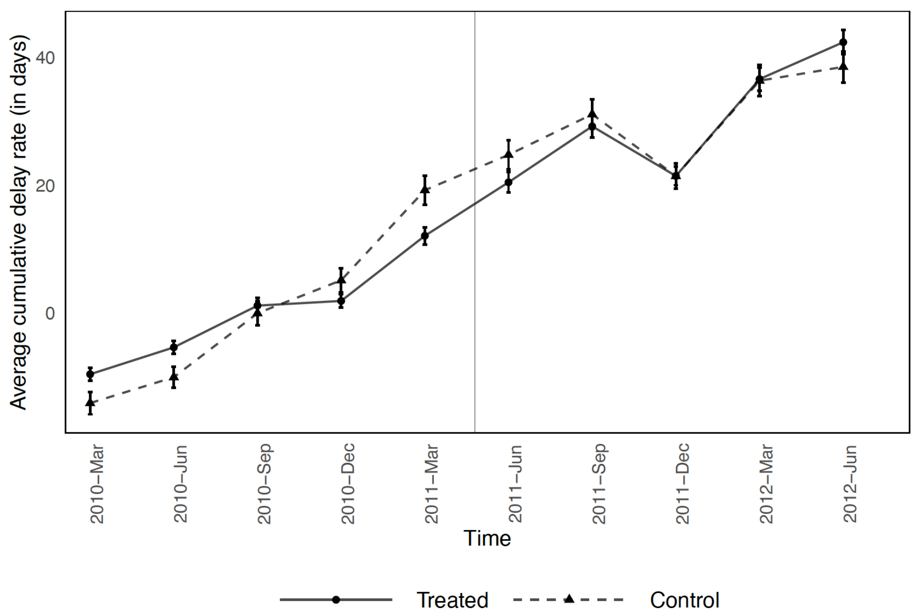


Figure E.1 **Time trends with cumulative delay rate**

How our variable overcomes these issues: We show that the delay rates for treated and control projects follow parallel trends before the reform (see, for example, Figure 3).

Disadvantage 2: This variable is likely serially correlated. This is because the expected completion time for project i at time t is $T_{i,t} = IT_i + \sum_{\tau=0}^{t} \delta_{i,\tau}$ where $\delta_{i,\tau}$ is the delay occurring in quarter τ and IT_i is the initial estimate of the completion time. Even if the delays $\{\delta_{i,\tau}\}$ are independent, the expected completion times $\{T_{i,t}\}$ are correlated. As shown in Bertrand et al. (2004), serial correlation of the dependent variable is a critical factor that leads to underestimation of standard errors in difference-in-differences studies.

How our variable overcomes these issues: We correct for serial correlation in two ways. First, our current measure of quarterly delay rates is a first-differenced variable that only accounts for changes in project duration since the previous time period. This is analogous to studies on financial time series that consider changes in asset prices (i.e., returns) rather than price levels as a dependent variable. The changes in asset prices are independent, but price levels are correlated. Second, we cluster the standard errors at the project level (i.e., at the level where treatment is applied as suggested in Bertrand et al. 2004 and Abadie et al. 2023).

II. Alternative treatment variable. Referee 3 suggested that we could define the treatment variable as the "proportion of the project period occurring after the QuickPay." This raises similar concerns as mentioned in Point 1 (Disadvantage 2) above. Project duration changes over time, and the proportion of the project after QuickPay is directly affected by the project delay, causing reverse causality. Our current metric is immune from these concerns.

III. Robustness test. To further assuage concerns, we conducted a robustness test to examine project-level delays. Specifically, we define the dependent variable to be the overall delays on the project: $Delay_i = \text{\textit{Last Reported End Date}}_i - \text{\textit{Initial End Date}}_i$.[38] This variable is similar to the ones proposed above. It differs from the cumulative delay rate in providing just one observation per project. It differs from the total realized delay on a project by using the reported end date instead of the realized end date. This variable is not censored or serially correlated. However, it is still subject to other disadvantages discussed above.

Similar to the total realized delay, this definition requires $Post$ to be defined at the project level. We define the indicator $Post_i$ as 1 if project i has the initial completion date after QuickPay. The treated projects are still those that are held by small business contractors, i.e., $Treat_i$ remains unchanged. We run the following regression:

$$Delay_i = \beta_0 + \beta_1 Treat_i + \beta_2 Post_i + \beta_3 (Treat_i \times Post_i) + e_i.$$

Table E.1 shows the results—the treatment effect is still positive and statistically significant, with projects receiving faster payments reporting substantially higher delays after the reform. Projects receiving faster payments under QuickPay were delayed by an additional 7-9 days after the reform relative to comparable control projects. The log-odds of a treated project reporting a positive delay increased by 0.15-0.27 after the reform, and the conditional delay increased by 20-25 days.

While these results point to an effect of QuickPay on overall project delays, they may be subject to biases if projects are eventually exposed to the reform (as discussed earlier). This means that certain projects will falsely be in the control group. Accordingly, we posit that our estimates in Table E.1 provide a lower bound on the causal effect of QuickPay on project delays.

[38] Recall that QuickPay extended to *all* projects in July 2012. We, therefore, consider the last reported completion dates for projects on or before July 2012.

Table E.1 Effect of QuickPay on overall project delays

	Average treatment effect			Delay likelihood and conditional ATE					
	Delay days			Log-odds (Delay days >0)			E(Delay days | Delay >0)		
	I	II	III	IV	V	VI	VII	VIII	IX
$Treat_i$	-11.16***	-6.80***	-7.27***	-0.57***	-0.22***	-0.27***	-21.42***	-12.25**	-10.11**
	(0.79)	(1.59)	(1.43)	(0.04)	(0.04)	(0.03)	(3.86)	(4.29)	(4.19)
$Post_i$	11.73*	10.30*	10.06*	0.47***	0.50***	0.49***	0.47	1.84	1.17
	(6.55)	(5.42)	(5.37)	(0.14)	(0.15)	(0.15)	(20.76)	(16.30)	(16.08)
$Treat_i \times Post_i$	9.36***	7.48***	7.65***	0.27***	0.14**	0.15***	25.03***	20.78***	21.53***
	(1.13)	(1.60)	(1.52)	(0.06)	(0.07)	(0.06)	(5.15)	(5.08)	(5.06)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Start Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Task FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Industry FE	No	No	Yes	No	No	Yes	No	No	Yes
Observations	195,138	195,138	195,138	195,129	192,106	191,974	20,300	20,300	20,300
R^2/Pseudo R^2	0.00544	0.01239	0.01284	0.06213	0.17811	0.18601	0.00975	0.02328	0.02393

Note. Each specification includes a combination of fixed effects, controls for a project's initial duration, initial budget, and initial bids. The standard errors (reported in parentheses) are robust and clustered by the quarter in which projects started. Significance levels: 10% (*), 5% (**), and 1% (***).

Appendix F: Contract Financing

Why is contract financing a good proxy? Because many contractors in our sample are small, privately-owned businesses, data that directly measures their financial health is unavailable. The use of contract financing for projects, on the other hand, is a good proxy for the contractor's liquidity constraints. This is because according to Federal Acquisition Regulations (FAR 32.104–32.105), contract financing is provided "only to the actual extent needed for prompt and efficient performance," "for financing of contractor working capital, not for the expansion of contractor-owned facilities or the acquisition of fixed assets." Contractors receiving contract financing generally "will not be able to bill for the first delivery of products for a substantial time after work must begin (normally 4 months or more for small business concerns, and 6 months or more for others), and will make expenditures for contract performance during the pre-delivery period that have a significant impact on the contractor's working capital," or "demonstrate actual financial need or the unavailability of private financing." Thus, contractors are still financially constrained *after* receiving contract financing.

Who can apply for contract financing? According to Federal Acquisition Regulations, any firm can apply for contract financing, and the contracting officer decides whether to extend it. In particular, the contracting officer must consider the following order of preference when contract financing is requested (FAR 32.106): (a) Private financing without Government guarantee, (b) Customary contract financing other than loan guarantees and certain advance payments, (c) Loan guarantees, (d) Unusual contract financing, and (e) Advance payments. This regulation means that contractors who receive contract financing from the government are likely to have low accessibility to private financing. Government financing is likely the last resort for their effort in financing the project. Table A.3 shows that the proportion of projects receiving contract financing is similar across small and large businesses, and there is also no notable change after QuickPay.

What are the relative pros and cons of entering into the arrangement? The upside of obtaining contract financing is the financial liquidity and capability to carry out the project. In return, when granted, the project will have "(1) a bid or negotiated price that will be lower than such price would have been in the absence of the contract financing, or (2) contract terms and conditions, other than price, that are more beneficial to the Government than they would have been in the absence of the contract financing" (FAR 32.005). It is important to note that while such negotiations might affect the contractor's initial bid for project completion, this is a baseline effect that would be common to all projects before and after QuickPay. We are interested in the *change* in project delay rate after QuickPay started. Thus, the influence of contract financing on a project's initial characteristic *levels* would not interfere with the difference-in-differences analysis.

Furthermore, unless contract financing is in the form of advance payments, "the contract shall not provide for any other type of specific charges, such as interest, for contract financing" (FAR 32.005). Thus, a possible downside of using contract financing is that the payback is in a case-by-case, non-standard form that can depend heavily on negotiations with the contracting officer. This may discourage contractors from requesting contract financing. Thus, those who applied and obtained it are highly likely severely financially constrained, with little or no access to private financing.