Supplementary Appendix for “Moral Hazard, Incentive Contracts and Risk: Evidence from Procurement”

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1 Overview

In this supplementary appendix, we provide additional information on the following:

- Data Sources
- Missing Data and Sample Selection
- Estimation of Traffic Delay Costs
- Variable Definition
- Additional evidence of moral hazard
- Connections across multiple projects
- Evidence on enforcement
- Derivation of the likelihood function

All tables are at the end of the document.

2 Data Sources

We compiled data from three sources:

1. **FieldOps Data**: Mn/DOT used a program called FieldOps to manage project data. The project engineer records project information and daily updates in this program, for the duration of work on the project. Each project has a number of database files. The project information database contains information on the location and description of the project, the identity of the contractor and project engineer; the size and duration of the project; and the number and type of days allocated. The diary database contains daily updates on how many hours the contractor worked each day, how many hours of work were initially planned, how many hours of avoidable or unavoidable delays were recorded, what the weather conditions were like, and what the current project controlling operation was. We obtained the database files directly from Mn/DOT and wrote code in unix to convert the raw data files into a file format readable by Stata.
2. **Enforcement Data:** We obtained a spreadsheet with all the liquidated damages (time penalties) paid on each contract in the data directly from Mn/DOT. We used this data to construct the enforcement variable (see below).
3. **Weather Data:** We obtained data on rainfall and snowfall during the period 1990-2010 at a number of weather monitoring stations in Minnesota from the National Climatic Data Center (http://www.ncdc.noaa.gov/). We geocoded each contract location, and merged each contract to its three closest stations. For each contract-day, we constructed the rainfall and snowfall at the closest weather station, using data from the second or third closest stations where necessary due to missing data problems.

3 Missing Data and Sample Selection

The estimation sample is a selected subset of the contracts let by Mn/Dot during the sample period (1996–2005). There are database files for 2009 projects (some of which are let outside of the sample period), but 716 of these are corrupt and/or blank. Of the remaining files, only 943 are working day contracts. For a small fraction of the working day contracts (52/943), the project information database is available but the diary data is missing. This gives us a sample of 891 working day contracts.

We next drop very short (less than 10 working days), long (over 200 working days), big contracts (over \$10M) and those let outside of the sample period, a total of 99 contracts. We then classify projects according to their primary activity (see variable description for more details), and drop projects that are not likely to require lane closure or shoulder work, and therefore may cause little negative externality. We keep contracts whose primary activity is bridge repair, construction or resurfacing. This leaves us with 537 contracts. Further cleaning (checks on the consistency of the diary data, projects where data is missing) leaves us with a sample of 466 contracts, used in the main paper.

4 Estimation of Traffic Delay Costs

We next construct measures of traffic delay costs for the roads under construction for a sub-sample of 87 of these contracts. As you'll see, determining these costs is slow work, and so we economized on the sample size. We develop an estimate of the delay cost as follows:

$$\text{Traffic Delay Cost}_t = \text{Delay}_t \times \text{Time Value}_t \times \text{Traffic}_t$$

The daily user cost is estimated as the per user delay (in hours), times the time value for the average commuter (in \$/hour), times the average daily traffic on that road. In this we follow closely the actual Mn/DOT methodology for computing user costs. Their methodology accounts also for additional wear and tear in the case where commuters are re-routed, and for the possibility of cars with multiple occupancy. By neglecting these factors, we hope to get conservative user cost estimates.

The first element that we need to calculate is the average delay due to the construction project. In practice, this depends on whether the project engineer decides to close down lanes but still leave the road open, or to close the road and detour commuters. Whenever the road is left open, commuters must slow down, and Mn/DOT generally assumes that their commuting speed over that section is cut in half. On the other hand, if rerouted, the detour is generally longer than the original route, and that also causes delays. The decision of whether to reroute or close lanes is spelled out in the project plans, and so Mn/DOT uses this information when calculating user costs. Since we do not have access to the information, we take a conservative stance, computing the minimum of these two alternatives.

To do this, for each contract where the location data allows us to pinpoint it on a map,

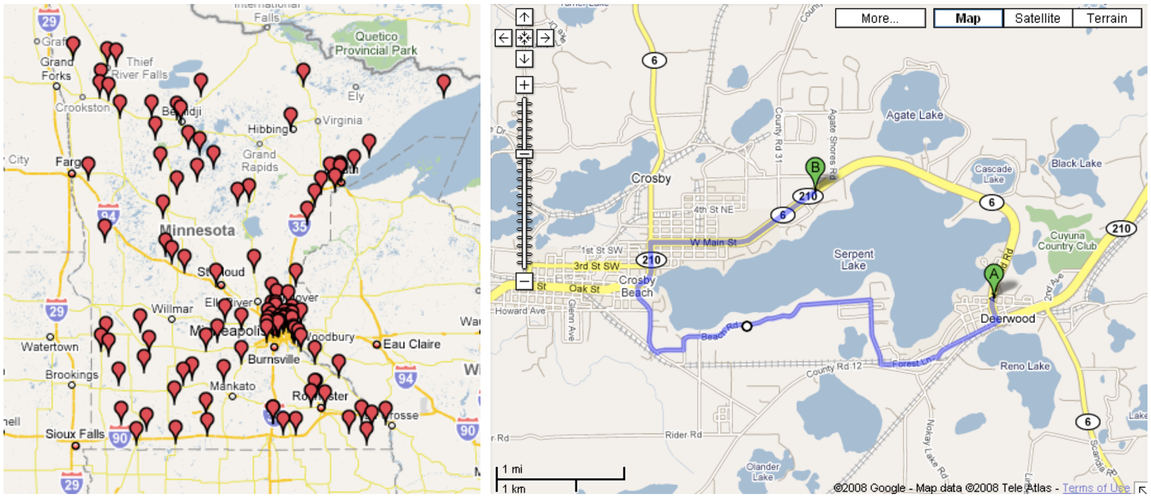

Figure 1: **Delay Calculations:** The left panel shows the locations of the highway construction projects used in the counterfactual. The right panel shows an example of a detour calculation around a section of route 6.

we use Google maps to outline the construction zone, and its length (see the left panel of Figure 1). We then use Google to calculate a travel time for that route. If the route is left open, we assume that the travel time will double, which means the delay will be equal to the original travel time. We also do our best to construct a likely detour around that section of the road, as in the right panel of Figure 1. We then use Google to estimate the time required to drive the detour, getting a delay estimate as the difference between the travel times. In practice, Mn/DOT does a less-virtual version of this exercise, actually sending personnel to drive the detour and original route at different times of day and record the data. Overall then, delays are calculated as:

$$Delay_t = \text{Min}\{Travel\ time_t, Detour\ Time_t - Travel\ time; \frac{1}{3}\}$$

The last term implies that we never allow for a delay of more than 20 minutes — this is to avoid the concern that a few outliers drive our counterfactual results. To get an estimate of the daily traffic, we use traffic volume measures from Mn/DOT at each location in the dataset.[1] For a measure of the time value, we use the rate of \$12/hour, which is the rate used in the Mn/DOT calculations.

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[1] See http://www.dot.state.mn.us/traffic/data/html/volumes.html

5 Variables Used

We summarize in Table 1 the data sources and construction of the variables that are fundamental (i.e. excluding variables that are constructed from the fundamental variables, such as work rate, backlog etc).

6 Additional Evidence on Moral Hazard

We present in this section a brief discussion of some additional evidence on moral hazard, applying the seemingly unrelated regressions (SUR) framework discussed in the main paper.

Table 2 reports three pairs of regressions, each specification adding additional fixed effects as controls. In all cases, the dependent variable in the first member of the pair is the normalized hours, and the second is the work rate. Since the set of controls in each pair is the same, running the two as a system gives the same results as equation-by-equation OLS. The main statistic of interest is the p-value on the test for the independence of the residuals across the pair of equations. In all cases the p-value is zero, so we can reject the hypothesis that the residuals are independent; moreover, the correlations are all positive. This yields the same conclusion as we reached in the main paper: contracts that require more work than expected ex-ante have higher work rates than one would have expected ex-ante, which is evidence of ex-post moral hazard and/or unobserved heterogeneity.

Table 3 reports the same sets of regressions, but changing the second dependent variable in each pair to the ratio of days worked to days charged. This is essentially a test for adaptation on the extensive margin: when a contract requires extra work, do contractors work more days? Again we find a significant and positive correlation between the residuals in all cases.

7 Connections across multiple projects

An interesting question — not explored in the main paper — is whether there is evidence that shocks on one contract controlled by a contractor lead to adaptation on other projects (i.e. can firms with multiple projects risk share across contracts)? We find little evidence of this. Our testing approach is to construct a measure of the shock on each project as in the main paper (i.e. as a residual from a first stage regression), and then, for each contract,

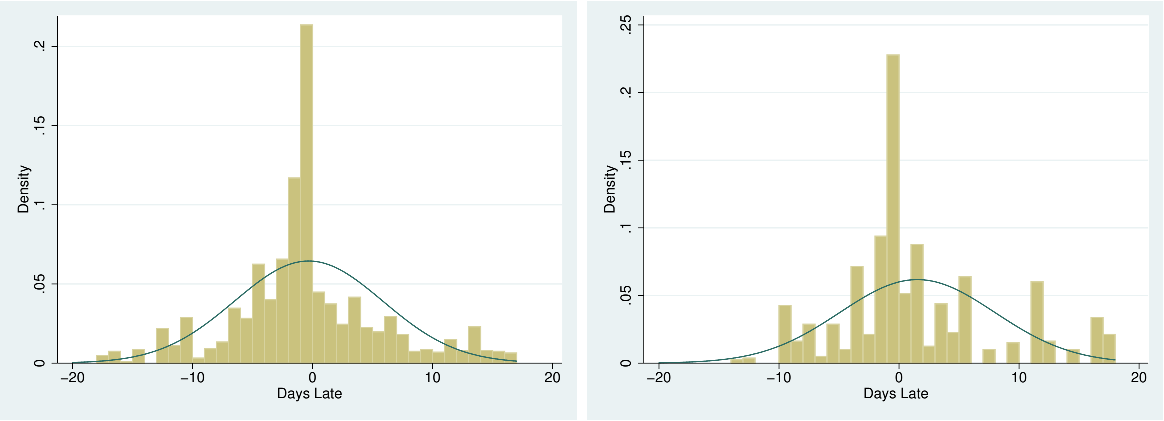

Figure 2: Distribution of days late by contractors working on a single project (left) and multiple projects (right)

construct the residual on overlapping projects as the weighted average residual from projects the firm is contemporaneously working on (where the weights are the number of overlapping days). As shown in Table 4, we find no evidence of statistically significant linkages on either the intensive or extensive margins: when other contracts experience negative shocks (positive overlapping residuals), there is a modest positive effect on the work rate and ratio of days worked to charged.

Similarly, one might have thought that the atom in days taken was purely an artifact of contractors with multiple projects shifting work between them, rather than a change in work rate (although the evidence in the main paper suggests this cannot be the case). In Figure 2 we show that there is an atom of on-time completions both for contractors working on a single project and those working on multiple projects, which is further evidence against this hypothesis.

8 Evidence on Enforcement

In the main paper, we argued that there was little evidence that the project engineer "colluded" with the contractors, awarding them unavoidable delays so that they could finish on time. We provide some evidence of this in columns 1 and 2 of Table 5. When we regress the normalized unavoidable delay days on covariates, we find that there are very few statistically significant observable predictors — and if anything, project engineers seem less likely to grant delays when the planned pace of the project is fast, or contractors are working on multiple projects at once (though this is interpreting a partial correlation as causal). Once we add in firm and project engineer fixed effects, we find that the firm fixed effects are not jointly significant, although the project engineer fixed effects are. So it appears there is some heterogeneity in how the rules are enforced across project engineers, but no evidence that some contractors are good at convincing project engineers to give them unearned delays.

We also claimed that the enforcement probability appears to be unrelated to any of the contract characteristics, and therefore can be modeled as a (latent) constant parameter p (whose realization, the enforcement decision, is known to the contractor). Evidence in favor of this is presented in columns 3 and 4 of the same table. The only characteristic that is significantly correlated with the enforcement outcome is the overlap with other projects (in the column 4 specification), and given the number of regressors, it is not that surprising that one of them turns up as significant. It therefore appears that enforcement is reasonably modeled as being random, at least ex-ante.

9 Derivation of the likelihood function

Recall that the marginal benefit of delay function takes the form (dropping t subscripts):

$$-c'(d) = \alpha d + d^T \left(\widetilde{x}\gamma + \delta\theta + \varepsilon\right)$$

where ε is latent and distributed $N(0, \sigma^2)$; and θ is estimated in a first stage. Recall also the additional penalties from waiting another day and the penalties saved by completing a day earlier:

$$\begin{aligned}\Delta^+(d) &= 1(\text{enforced})1(d+1 > d^T)(d+1-\max\{d, d^T\})c_D \\ \Delta^-(d) &= 1(\text{enforced})1(d > d^T)(d-\max\{d-1, d^T\})c_D\end{aligned}$$

We use the following necessary conditions:

$$c(d) < c(d+1) + \Delta^+(d) \text{ and } c(d) < c(d-1) - \Delta^-(d)$$

Now we have that

$$c(d) - c(d-1) = -\int_{d-1}^{d} \alpha s + d^T \left(\widetilde{x}\gamma + \delta\theta + \varepsilon\right) ds = -\alpha d + \frac{\alpha}{2} - d^T \left(\widetilde{x}\gamma + \delta\theta + \varepsilon\right)$$

$$c(d+1) - c(d) = -\int_{d}^{d+1} \alpha s + d^T \left(\widetilde{x}\gamma + \delta\theta + \varepsilon\right) ds = -\alpha d - \frac{\alpha}{2} - d^T \left(\widetilde{x}\gamma + \delta\theta + \varepsilon\right)$$

This implies the following bounds on ε:

$$\frac{1}{d^T}\left(\Delta^-(d) + \frac{\alpha}{2} - \alpha d\right) - x\gamma - \delta\theta < \varepsilon < \frac{1}{d^T}\left(\Delta^+(d) - \frac{\alpha}{2} - \alpha d\right) - x\gamma - \delta\theta$$

And then dividing through by sigma, we get the likelihood contribution of each datapoint:

$$\ell = \Phi\left(\frac{1}{d^T\sigma}\left(\Delta^+(d) - \frac{\alpha}{2} - \alpha d\right) - \frac{1}{\sigma}(x\gamma - \delta\theta)\right) - \Phi\left(\frac{1}{d^T\sigma}\left(\Delta^-(d) + \frac{\alpha}{2} - \alpha d\right) - \frac{1}{\sigma}(x\gamma - \delta\theta)\right)$$

where Φ denotes the standard normal cdf.

We now comment briefly on the implementation of the EM algorithm here. Given the parameter estimates, we must derive a posterior distribution over the enforcement realizations. This will be different for contracts that finished late, "early" and on-time. If late — defined here as $d > d^T$ — whether they were enforced is observable, and so the posterior is an indicator at the observed value. If "early" — defined here as $d \leq d^T - 1$ — there is no new information from observing the completion time, and the posterior puts weight on 1 equal to the prior probability p (a parameter estimated during the maximization step). If $d \in (d^T - 1, d^T]$, then define l_1 as the likelihood contribution when the Δ terms are evaluated under enforcement and l_2 as that when they are zero. Then the posterior on 1 is given by $pl_1/(pl_1 + (1-p)l_2)$.

In the maximization step, we maximize the expected log likelihood given the current posterior. Because we assume p independent of all other parameters, the likelihood maximizing guess is the mean posterior. All other parameters are maximized jointly using the above likelihood function.

Table 1: Sources and Definitions of Variables used in the Analysis

Variable	Unit	Sample	Source	Definition
Contract Value	$	All	Project Information	Winning bid on this project. Amount due to contractor on successful completion.
Engineer Days	Days	All	Diary Data	Design engineer's estimate of the project length, in working days (i.e. excluding weekends and holidays). Specifies the number of days the prime contractor is allowed to take to complete the project.
Days charged	Days	All	Diary Data	Working days charged by the project engineer during the course of the project.
Days worked	Days	All	Diary Data	Number of days on which the hours worked was positive.
Engineer's hours estimate	Hours	All	Diary Data	Sum of all the working hours in the plan submitted by the prime contractor to the project engineer. Imputed where missing.
Hours worked	Hours	All	Diary Data	Sum of all the hours worked recorded by the project engineer throughout the course of the contract.
Avoidable delays	Hours	All	Diary Data	Sum of all the hours of avoidable delay recorded by the project engineer throughout the course of the contract.
Unavoidable delays	Hours	All	Diary Data	Sum of all the hours of unavoidable delay recorded by the project engineer throughout the course of the contract.

Unavoidable delay days	Days	All	Diary Data	Sum of all the working days on which the contractor was not charged a day and the hours of unavoidable delays was positive.
Contract late?	Binary	All	Diary Data	Binary variable indicating if the number of working days taken exceeded the project target, as measured by the project engineer.
Enforced	Binary	Late contracts only	Mn/DOT Spreadsheet	Binary variable indicating if the liquidated damages paid was positive
Types of Work	Categorical	All	Project Information	Types of work required during the project, based on the project description in the bid summary. Constructed via keyword matching in the project description.
Daily traffic	Vehicles	Delay Subsample	Traffic Volumes	Average annual daily traffic (AADT) near the contract location.
Daily rainfall	Inches	All	Weather Data	Rainfall at the closest weather station to the contract (by distance).
Daily snowfall	Inches	All	Weather Data	Snowfall at the closest weather station to the contract (by distance).

Table 2: Ex-post moral hazard: correlation tests

	(1)		(2)		(3)	
Time penalty	-0.017	0.002	-0.005	0.002	-0.022	-0.000
	(0.014)	(0.006)	(0.014)	(0.007)	(0.014)	(0.007)
Engineer work rate	-0.173	0.255***	-0.190*	0.226***	-0.301**	0.209***
	(0.107)	(0.047)	(0.114)	(0.054)	(0.117)	(0.058)
Contract value ($ K/day)	0.086***	0.010**	0.089***	0.010**	0.097***	0.007
	(0.009)	(0.004)	(0.010)	(0.005)	(0.009)	(0.005)
Historical daily rainfall	0.002	0.005	0.011	0.003	0.057**	-0.009
	(0.023)	(0.010)	(0.024)	(0.011)	(0.025)	(0.012)
Historical chance of snow	0.036	-0.008	0.031	-0.001	-0.002	0.007
	(0.042)	(0.018)	(0.040)	(0.019)	(0.036)	(0.018)
Firm capacity > $3M	0.017	0.250				
	(0.379)	(0.167)				
In-state contractor	-0.526	0.291				
	(0.589)	(0.260)				
Firm backlog / firm capacity	0.126	-0.033	-0.292	0.133	-0.622	0.408
	(0.561)	(0.248)	(0.662)	(0.314)	(0.629)	(0.312)
Overlap with other projects	-0.297	0.307*	0.290	0.375*	0.278	0.075
	(0.415)	(0.183)	(0.475)	(0.226)	(0.467)	(0.232)
District/Work/Year FE	yes	yes	yes	yes	yes	yes
Firm FE	no	no	yes	yes	yes	yes
Project Engineer FE	no	no	no	no	yes	yes
Test: independent residuals	0.00		0.00		0.00	
R^2	0.40	0.29	0.53	0.34	0.68	0.54
N	466		400		358	

Each pair of columns gives results from seemingly unrelated regressions, where the dependent variable in the first of the pair is the total hours taken, normalized by the engineer's days; and the second is the work rate (total hours worked divided by total days worked). In (2) the estimation sample consists only of contracts where each contractor participated in at least 3 contracts in the sample; additionally in column (3) each project engineer has managed at least two contracts. Significance levels are denoted by asterisks (* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$). Capacity is measured as the firm's maximum backlog over the sample period. Overlap is the fraction of planned days that overlap with planned construction on other projects the firm is contracted for. Test: independent residuals reports p-values from a Breusch-Pagan test of the independence of the residuals in the pairs of equations.

Table 3: Ex-post moral hazard: extensive margin

	(1)		(2)		(3)	
Time penalty	-0.017	0.002*	-0.005	0.002*	-0.022	0.001
	(0.014)	(0.001)	(0.014)	(0.001)	(0.014)	(0.001)
Engineer work rate	-0.173	-0.024***	-0.190*	-0.020**	-0.301**	-0.016
	(0.107)	(0.009)	(0.114)	(0.010)	(0.117)	(0.010)
Contract value ($ K/day)	0.086***	0.004***	0.089***	0.004***	0.097***	0.004***
	(0.009)	(0.001)	(0.010)	(0.001)	(0.009)	(0.001)
Historical daily rainfall	0.002	0.001	0.011	0.003	0.057**	0.004*
	(0.023)	(0.002)	(0.024)	(0.002)	(0.025)	(0.002)
Historical chance of snow	0.036	-0.002	0.031	-0.002	-0.002	-0.003
	(0.042)	(0.003)	(0.040)	(0.003)	(0.036)	(0.003)
Firm capacity > $3M	0.017	-0.033				
	(0.379)	(0.032)				
In-state contractor	-0.526	-0.049				
	(0.589)	(0.049)				
Firm backlog / firm capacity	0.126	0.097**	-0.292	0.051	-0.622	0.039
	(0.561)	(0.047)	(0.662)	(0.055)	(0.629)	(0.054)
Overlap with other projects	-0.297	-0.063*	0.290	-0.037	0.278	-0.044
	(0.415)	(0.035)	(0.475)	(0.040)	(0.467)	(0.040)
District/Work/Year FE	yes	yes	yes	yes	yes	yes
Firm FE	no	no	yes	yes	yes	yes
Project Engineer FE	no	no	no	no	yes	yes
Test: independent residuals	0.00		0.00		0.00	
R^2	0.40	0.23	0.53	0.36	0.68	0.55
N	466		400		358	

Each pair of columns gives results from seemingly unrelated regressions, where the dependent variable in the first of the pair is the total hours taken, normalized by the engineer's days; and the second is the ratio of days worked to days charged. In (2) the estimation sample consists only of contracts where each contractor participated in at least 3 contracts in the sample; additionally in column (3) each project engineer has managed at least two contracts. Significance levels are denoted by asterisks (* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$). Capacity is measured as the firm's maximum backlog over the sample period. Overlap is the fraction of planned days that overlap with planned construction on other projects the firm is contracted for. Test: independent residuals reports p-values from a Breusch-Pagan test of the independence of the residuals in the pairs of equations.

Table 4: Ex-post moral hazard: multiple projects

	Work rate			Days worked / days charged		
Residual	0.095***	0.255***	0.293***	0.032***	0.029***	0.028***
	(0.027)	(0.048)	(0.072)	(0.005)	(0.006)	(0.008)
Residual on overlapping projects	0.009	0.014	0.032	0.001	-0.002	0.004
	(0.034)	(0.070)	(0.128)	(0.006)	(0.008)	(0.014)
Time penalty	-0.005	0.013	-0.011	0.002	0.002	-0.001
	(0.008)	(0.013)	(0.017)	(0.001)	(0.002)	(0.002)
Engineer work rate	0.267***	0.201**	0.245*	-0.020*	-0.016	-0.007
	(0.060)	(0.102)	(0.145)	(0.011)	(0.012)	(0.016)
Contract value ($ K/day)	0.015***	0.030***	0.030**	0.003***	0.003***	0.004***
	(0.005)	(0.009)	(0.012)	(0.001)	(0.001)	(0.001)
Historical daily rainfall	-0.001	0.017	0.014	0.003	0.004	0.003
	(0.013)	(0.023)	(0.036)	(0.002)	(0.003)	(0.004)
Historical chance of snow	-0.030	-0.054	-0.121*	-0.001	-0.001	-0.007
	(0.021)	(0.037)	(0.064)	(0.004)	(0.004)	(0.007)
Firm capacity > $3M	0.297			0.012		
	(0.249)			(0.045)		
In-state contractor	0.317			-0.050		
	(0.443)			(0.080)		
Firm backlog / firm capacity	-0.173	0.801	1.232	0.094	0.079	0.065
	(0.322)	(0.561)	(0.758)	(0.058)	(0.066)	(0.085)
Overlap with other projects	0.600**	0.219	-0.150	-0.117***	-0.070	-0.070
	(0.240)	(0.436)	(0.596)	(0.044)	(0.051)	(0.067)
District/Work/Year FE	yes	yes	yes			
Firm FE	no	yes	yes			
Project Engineer FE	no	no	yes			
R^2	0.38	0.50	0.65	0.43	0.49	0.68
N	274	274	248	274	274	248

The dependent variable in the first three columns is work rate; in the next three it is the ratio of days worked to days charged. The estimation sample includes only overlapping contracts. All results are from OLS regressions, and standard errors are robust. Significance levels are denoted by asterisks (* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$). Capacity is measured as the firm's maximum backlog over the sample period. Overlap is the fraction of planned days that overlap with planned construction on other projects the firm is contracted for. Residual refers to the residual from a regression of hours worked divided by engineer's days on the same set of covariates (i.e. those corresponding to that column); the residual on overlapping projects is the weighted average residual from projects the firm is contemporaneously working on, weighted by the overlapping days.

Table 5: Contract monitoring and enforcement

	Unavoidable delay fraction		Penalty applied	
Time penalty	0.000	-0.000	0.006	-0.003
	(0.001)	(0.001)	(0.004)	(0.005)
Engineer work rate	-0.038***	-0.045***	-0.007	-0.017
	(0.008)	(0.013)	(0.027)	(0.030)
Contract value (\$K/day)	0.001	0.001	-0.003	-0.002
	(0.001)	(0.001)	(0.003)	(0.003)
Historical daily rainfall	0.002	0.007**	0.002	0.001
	(0.002)	(0.003)	(0.005)	(0.005)
Historical chance of snow	0.002	-0.002	-0.004	0.000
	(0.001)	(0.003)	(0.004)	(0.007)
Firm capacity $>$ \$3M	0.014		-0.020	0.042
	(0.034)		(0.102)	(0.114)
In-state contractor	0.044		0.021	0.164
	(0.033)		(0.164)	(0.199)
Firm backlog / firm capacity	0.043	0.016	0.065	0.066
	(0.037)	(0.063)	(0.141)	(0.153)
Overlap with other projects	-0.081**	-0.058	0.101	0.219**
	(0.034)	(0.054)	(0.099)	(0.101)
District/Work/Year FE	yes	yes	no	yes
Firm/Engineer FE	no	yes	no	no
Wald Test: Firm FE (p-value)	-	0.22	-	-
Wald Test: Engineer FE (p-value)	-	0.00	-	-
R^2	0.15	0.47	0.03	0.33
N	466	358	153	153

In the first two columns, the dependent variable is the number of days on which the project engineer awarded an unavoidable delay divided by the engineer's days. In the last two columns, an observation is a late contract, and the dependent varible is whether the late penalty was enforced. All regressions are by OLS with robust standard errors. Significance levels are denoted by asterisks (* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$). Capacity is measured as the firm's maximum backlog over the sample period. Overlap is the fraction of planned days that overlap with planned construction on other projects the firm is contracted for.