Evaluating Environmental Permitting Process Duration: The Case of Clean Water Act Section 404 Permits

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Abstract

Permits are a critical tool for ensuring that infrastructure projects provide the benefits they promise without harming nearby people or the environment. However, the environmental permitting process is complex, often resulting in long review times and increased administrative costs. Identifying ways to hasten permitting processes without compromising environmental rigor is important for enabling efficient and effective infrastructure regulation. This paper evaluates the relationship between permitting duration and characteristics of the projects, applicant organizations, and regulatory regime, using a novel dataset of US Clean Water Act permits. Longer review time was associated with projects proposed by a business (rather than state or federal agencies); using an engineering consultant; requiring some combination of environmental impact analysis, historic preservation, and/or endangered species review; and located in Arizona. Project type, agency workload, and socioeconomic characteristics did not correlate with review time.

Keywords: Infrastructure permitting, infrastructure planning, environmental permitting, regulatory efficiency, water quality

1. Introduction

In the coming years, governments around the world will invest trillions of dollars in new and retrofitted public infrastructure, with an estimated 15-year need ranging from $57 trillion (Dobbs et al. 2013) to $90 trillion (The New Climate Economy 2016). Numerous dams, highways, water pipelines, and bridges are scheduled for replacement. Many more need to be upgraded, retrofitted, or expanded to accommodate growing populations, incorporate new efficient technologies, ensure higher levels of public safety, and adapt to changing sea levels or precipitation patterns.

To build or operate these projects, the developer must obtain permits or authorizations from a variety of regulatory agencies to ensure that the project avoids, minimizes, or compensates potential harm to people and the environment. A widely used regulatory tool, permitting is essentially a balancing process, between on one hand allowing landowners to use their property as they see fit, and on the other hand ensuring that public goods like clean air, biodiversity, and cultural resources are protected; as a US Fish & Wildlife Service Manual writes, "Permits provide a means to balance use and conservation" (US Fish & Wildlife Service 2002). Permitting should allow agencies to identify unacceptable environmental impacts, suggest superior approaches, and identify required mitigation activities, although evidence of permitting's actual environmental impacts is mixed (Honkasalo, Rodhe, and Dalhammar 2005; Pettersson et al. 2010; Allen and Feddema 1996; Cole and Shafer 2002; Palmer and Hondula 2014; Similä 2002).

Scholars and practitioners often raise concerns about permitting processes for being bureaucratic and complex (Davidson 1982; Davies et al. 2001; Decker 2003; Hayes 2015; Howard 2015; Kosnik 2006; Rabe 1995). Many projects require multiple interrelated approvals to protect endangered species and historic resources, maintain air and water quality, and ensure compliance with land use and zoning ordinances; these permits come from multiple agencies at local, state, and federal levels. The uncertainty and complexity of the environmental permitting process often lengthens review times, which increases administrative costs and delays potential benefits to come from the project (Bendor 2009; Decker 2003; Howard 2015; Kosnik 2006; Sunding and Zilberman 2002; Pettersson et al. 2010). Identifying ways to lessen the environmental permitting process's time (and associated resource costs) *without reducing environmental protections* is important for enabling governments to build needed infrastructure efficiently and effectively.

A first step in evaluating permit process efficiency is identifying which factors have the largest impact on permitting duration. While time is only one dimension of efficiency (Ostroff and Schmitt 1993), it is a prominent one, as a longer review time increases the permitting agency staff needed to review projects, agency resources being spent on that review, and costs to the applicant from retaining consultants, missed construction windows, and potential revenue from the project (Ulibarri, Cain, and Ajami 2017). Existing empirical analyses that exist suggest that permitting duration is driven by a mix of project, applicant, and agency characteristics, as well as the broader political context (Ando 1999; Decker 2003; Kosnik 2006; Sunding and Zilberman 2002; Ulibarri 2018). For instance, projects in more conservative states tend to receive permits faster, as do applicants with good compliance records (Decker 2003). However, these studies have tended to focus on a single type of permit (e.g., wetland protection (Sunding and Zilberman 2002)) or project (e.g., hydropower dams (Kosnik 2006; Ulibarri 2018)), yet needed infrastructure includes diverse project types and often require multiple permits. Capturing the full complexity of permitting requires analyzing a range of project types and observing the interrelation of multiple permitting processes.

To identify which factors affect permit process time in this more complex context, this study uses data on Clean Water Act §404 permits issued by the US Army Corps of Engineers (USACE). The dependent variable, review time, is measured as overall time from when an application was submitted to the permit decision; mechanisms tested include project characteristics, applicant type, and interactions with other permits required for the project. We model the relationship between duration and the hypothesized mechanisms using a Cox proportional hazards model (Cox 1972). This analysis provides empirical evidence of which factors are most strongly associated with permitting process duration across a variety of permit and project types, offering critical information for regulatory agencies to redesign their permitting approach.

In what follows, we first introduce the case background, including justification for why we study the Clean Water Act process, and then review the permitting literature to propose a series of hypothesis about factors likely to affect review time. We next introduce our data collection approach—assembling a dataset from publicly available repositories, public notices, and census data—and empirical strategy—Cox proportional hazards modeling. After presenting our results and discussing what they mean for our hypotheses, we conclude with a short discussion and questions to address in future research.

2. Case background

Under §404(b)(1) of the Clean Water Act, any activity that will discharge sediment, dredge, or fill material into wetlands or "waters of the United States" requires a permit to ensure that the waterbody or wetland will not be significantly degraded (US EPA 2016). Discharges are prohibited if they violate water quality standards or other relevant federal regulations and/or if practicable, less-damaging alternatives exist. The permits are issued by the USACE.

The §404 permitting process applies to a range of project and applicant types. Activities commonly regulated under §404 include "fill for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports) and mining projects" (US EPA 2016). These activities are associated with many types of permit applicants, including businesses (e.g., a marina dredging to maintain access to a pier or a developer leveling ground for a housing project) and public agencies (e.g., a transportation authority building a new bridge).

While the §404 permit is a "single" permit, it encompasses several other authorizations in the timeline of review, thereby capturing the complexity of a fragmented, multi-permit process. First, with very few exceptions, USACE[1] will not issue a permit until the applicant has also received a Clean Water Act §401 Water Quality Certification (WQC), issued by the state water or environmental protection agency. Second, for projects that might affect protected species or their habitat, USACE consults with either the US Fish and Wildlife Service or the National Marine Fisheries Service under Endangered Species Act (ESA) §7 and/or the Magnuson-Stevens Fishery Conservation and Management Act requirements for Essential Fish Habitat (EFH). Third, under the National Historic Preservation Act (NHPA) §106, USACE must account for potential impacts to historical and cultural resources, sometimes requiring concurrence from the State Historic Preservation Officer. Finally, projects located near the coast require compliance under the Coastal Zone Management Act (CZMA). As a federal agency, USACE is only required to comply with relevant federal statutes. While not included as part of the §404 permit timeline, many projects face additional permits required by state and local jurisdictions. Thus, studying the §404 permitting

[1] These descriptions presume that USACE is the lead federal agency, as it is in the majority of 404 permits analyzed. If another federal agency is the lead agency, it is their responsibility to conduct the required consultations.

process captures interaction with many other required authorizations that vary with a project's type and potential impacts.

In a permit application, the applicant includes a project description and proposed mitigation plan, as well as preliminary assessments of the project's environmental impacts and whether any other authorizations are necessary. The USACE then reviews the application for completeness, requesting additional information if necessary. Once the application is deemed complete, a public notice is issued within 15 days; the notice opens a (usually) 30-day public comment period. After the commenting period, the USACE reviews comments, allows the applicant to respond, begins necessary consultation with other federal agencies, and (if needed) requests additional information from the applicant. The USACE also conducts an environmental impact assessment under the National Environmental Policy Act, preparing an Environmental Assessment (EA) and, for projects likely to have significant impacts, a draft and final Environmental Impact Statement (EIS). Finally, after reviewing all materials and comments, the USACE decides whether to issue or deny the permit.

3. Hypotheses

The literature raises many potential factors that may affect the timeline of a permit review. Drawing on a systematic review and practitioner interviews, Ulibarri et al. (2017) presents a comprehensive overview of these factors. Here, we discuss the hypotheses addressed in this analysis: characteristics of (1) the project, (2) the regulatory regime, (3) the applicant organization, (4) the permitting agency, and (5) the socioeconomic setting.

3.1. Project characteristics

The first set of factors expected to affect permit review time relate to characteristics of the proposed project. Specifically, we hypothesize that more complex projects are likely to require a more thorough and resource-intensive review (Kosnik 2006; Ulibarri, Cain, and Ajami 2017).

We consider several dimensions of "complexity". The first is use of new technologies, such as water reuse technologies or new approaches to environmental restoration. These technologies may lack explicit guidelines (Tong 2012), forcing agency staff to improvise in determining requirements and offering a less straightforward path to approval. They also may have more uncertain impacts, as there may be few, if any, prior examples to learn from (Ulibarri, Cain, and Ajami 2017).

The second is public versus private interest. In most private interest projects (e.g., a development project), the environment is typically pitted against economic benefits. Many public projects (e.g., transportation or environmental restoration projects) pit one environmental good against another. New infrastructure that improves water quality or reduces greenhouse gas emissions but harms endangered species, for instance, is potentially more complicated to review because there is not a straightforward value optimization and there may even be competing regulations for each resource affected.

Third, permitting a one-time action rather than ongoing operations tends to contain more uncertainties or higher stakes. For ongoing operations, §404 permits (and many others) must be reauthorized every five years; at each five-year interval, permitting agencies can revisit the project, assess known project impacts, and correct any mistakes in the previous permit. For a one-time action, the agency must infer impacts from other similar projects and has fewer opportunities to correct any mistakes (Ulibarri, Cain, and Ajami 2017). They also may condition permits on actions taken after the project (e.g., monitoring), which can cause delays.

Table 1 maps the types of project assessed in this research onto the dimensions of complexity. These categories are mutually exclusive and exhaustive of all projects in the sample.

Table 1. Project types by level of complexity

Project Type	Example	Level of complexity
Development	Housing, commercial building	Less complex: private interest, one-time action
Dredging	Marina maintenance	Less complex: public or private interest, repeat action (often)
Environment	Wetlands restoration	Most complex: novel technology, public interest, one-time action
Operations	Military use, mining	Less complex: private interest (often), repeat action
Transportation	Road, railway	More complex: public interest, one-time action
Waterway	Dam, levee	More complex: public interest, one-time action

We hypothesize that complexity matters because the agency should need more information or a greater variety of information to review applications. Scientific and technical information requirements for environmental permits tend to be high (Davies et al. 2001), as agencies need to show due diligence and make a decision grounded in best available science. The higher or more uncertain a project's environmental risks, the more information agencies may want to bolster their decision. While necessary for making an environmentally protective decision, more information can affect review time in several ways. The more information there is to review, the longer it takes the agency staff to understand the resources that may be affected and propose potential alternatives. Like most public agencies, however, permitting agencies are often short on staff and resources for their workload (Davies et al. 2001; Hammah 2015; Tong 2012), and relative to the applicant, staff may not always have the specialized expertise needed to evaluate a particular project critically (OEC and CEC 2002). Higher information requirements can also slow the review if materials are requested serially, as returned applications and requests for more information are common in many permitting processes (Tong 2012).

H1: More complex projects (environment, transportation, and waterway infrastructure) will take longer to review than less complex projects (development, dredging, or operations).

3.2. Regulatory regime

Increasing the number of resources impacted also increases the number of additional authorizations necessary. Recall that during the §404 process, many projects also undergo reviews for protected or endangered species, historic properties, and coastal zone management. Each of these consultations should add to overall time because they require coordinating with additional organization(s). Indeed, presence of endangered species has been linked to longer permit processing times in other settings (Ulibarri 2018). Additionally, because these authorizations are interdependent, each agency has to wait for other agencies to complete their analysis before they can issue a decision (Davidson 1982; OEC and CEC 2002; Rabe 1995). Thus, a delay in one permit can delay numerous others. The more permits required, the higher potential for cascading delays.

H2a: Projects that require consultations for protected species (ESA or EFH), historic properties (NHPA), and/or coastal zone management (CZMA) will take longer than those that do not.

A related source of variation in the regulatory regime is whether projects just require an Environmental Assessment (EA)—a preliminary assessment to determine whether a project's impacts are likely to be significant—or a full Environmental Impact Statement (EIS). EISs are far more detailed than EAs, and therefore should take longer to prepare. Moreover, EISs are released in both draft and final form, with opportunity for public input during both stages; public input has been shown to increase permitting process duration (Decker 2003; Dwyer, Brooks, and Marco 1999; Kosnik 2006). For these reasons, EISs should take longer to prepare and therefore lengthen permit decisions more than EAs.

H2b: Projects requiring a full EIS will take longer than those that just require an EA.

3.3. Applicant characteristics

Applicant organizations enter each new permitting process with wide discrepancies in resources, knowledge, and prior experience, which are expected to lead to differences in review duration. As noted above, many applications are returned because of applicant errors or requests for more information (Tong 2012); applicants who have prior experience with the process are less likely to make mistakes (OEC and CEC 2002). Likewise, applicants who surpass minimum required standards are more likely to have their permits approved (Kahn 2000), suggesting that applicants who know what the agencies want to see are more likely to have permits processed quickly. Indeed, some applicants may tailor their applications to the specific desires of an individual permitting staff member (Ulibarri, Cain, and Ajami 2017).

Access to knowledge about the process varies across different types of organizations. State and federal government agencies often have many similar projects within their jurisdiction: e.g., a transportation authority rebuilding a stretch of highway has likely overseen many such projects and therefore have gone through the §404 process before. Private businesses, local governments, and nonprofit organizations may not have as much repeat experience.

Additionally, the permitting process is technically demanding and can require access to specialized data (Ulibarri, Cain, and Ajami 2017). An organization that is larger, wealthier, or has more technically-trained staff is more likely to produce a complete application on the first try. Federal agencies and businesses often have the largest such capacity, followed by state agencies and local governments, and nonprofits usually have the smallest capacity.

H3a: Federal governments will have applications processed the fastest, followed by state government and business applicants. Local government and non-profit applicants will be slowest.

However, differences in applicant resources and experience may be overcome by hiring private consultants to undertake the permitting process (Ulibarri, Cain, and Ajami 2017). Many engineering consulting firms specialize in environmental permitting, and (in theory) provide applicants with the expertise and resources to move quickly through the permitting process.

H3b: Regardless of organization type, applicants who use consultants will have applications processed faster than those that do not.

3.4. Permitting agency characteristics

Permitting review time has been shown to vary across individual offices of a regulatory agency (Kosnik 2006), suggesting that characteristics of the regulatory agency itself can also affect review time. Many permitting offices have substantial staffing constraints, with high turnover in permitting staff, overloaded staff, and/or a lack of subject expertise because staff are new to the job or lack technical training (Decker 2003; Hammah 2015; Ulibarri, Cain, and Ajami 2017). While obtaining data on permitting staff numbers, educational background, or years of service is challenging, a proxy for staff constraints is the number of permit applications each office has to review (Kosnik 2006). While an office that regularly reviews more applications is likely to hire more staff, shorter term fluctuations—e.g., a month that happens to have double the usual submissions—would lead to a higher workload per staff member. We posit that the more permit applications concurrently being processed by an office while a particular project is under review, the more likely that permit decision will take longer.

H4: Applications being reviewed in offices with more concurrently-reviewed applications will take longer to review than those with fewer concurrent applications.

3.5. Socioeconomic characteristics

Finally, permitting processes include opportunities for public input, whether explicitly via public comment periods or open meetings or implicitly via the opportunity for lawsuits. Socioeconomic differences in the area around the project are likely to influence the magnitude and direction of public support for a project, which in turn affects whether public input is likely to yield critical re-evaluation of the project and extend the agency's review. Projects in higher population density areas have the potential for more direct impacts on neighboring communities and/or economic activity, are more visible, and have a higher number of people who could engage during the permitting process (Decker 2003). Likewise, areas that are wealthier are more likely to have the capital to mobilize against harmful or less desirable projects (Schaffer Boudet and Ortolano 2010; Ulibarri, Cain, and Ajami 2017). These two factors mean that people are more likely to engage in the permit review process, slowing down the permit decision (Decker 2003; Dwyer, Brooks, and Marco 1999; Kosnik 2006)—but also increasing the likelihood of a less harmful project (Enserink 2000; Ulibarri 2015)).

H5a: Higher population density surrounding a project will be associated with longer permit review times.

H5b: Higher income areas will be associated with longer review times.

4. Methods

4.1. Data

To test how permit review time correlates with project, regulatory, organizational, and socio-economic characteristics, we assembled a dataset of applications to the USACE South Pacific Division, one of nine divisions across the US. While a national study would capture §404 process's the full variation of project, applicant, and socioeconomic characteristics, we focused on one division to obtain a complete picture of the process while streamlining data collection efforts.[2] This analysis focuses on the South Pacific Division, which spans the southwestern US and is subdivided into four districts, headquartered in Albuquerque, Los Angeles, Sacramento, and San Francisco (see Figure 1). States in the South Pacific Division encompass a range of potentially

[2] Selecting a single district enabled targeted data collection, which included Freedom of Information Act Requests to obtain documents as well as targeted searches on each district's website. Assembling the dataset for the South Pacific District took three research assistants a year; the whole country would be a monumental task.

interesting characteristics, including socioeconomics (e.g., state median incomes in the top and bottom quartiles) and regulatory characteristics (e.g., high and low receptiveness to environmental policies (Rabe 2010) and varied levels of government effectiveness (US News and McKinsey & Company 2017)), ensuring that the sample captures relevant variation without being nationwide.

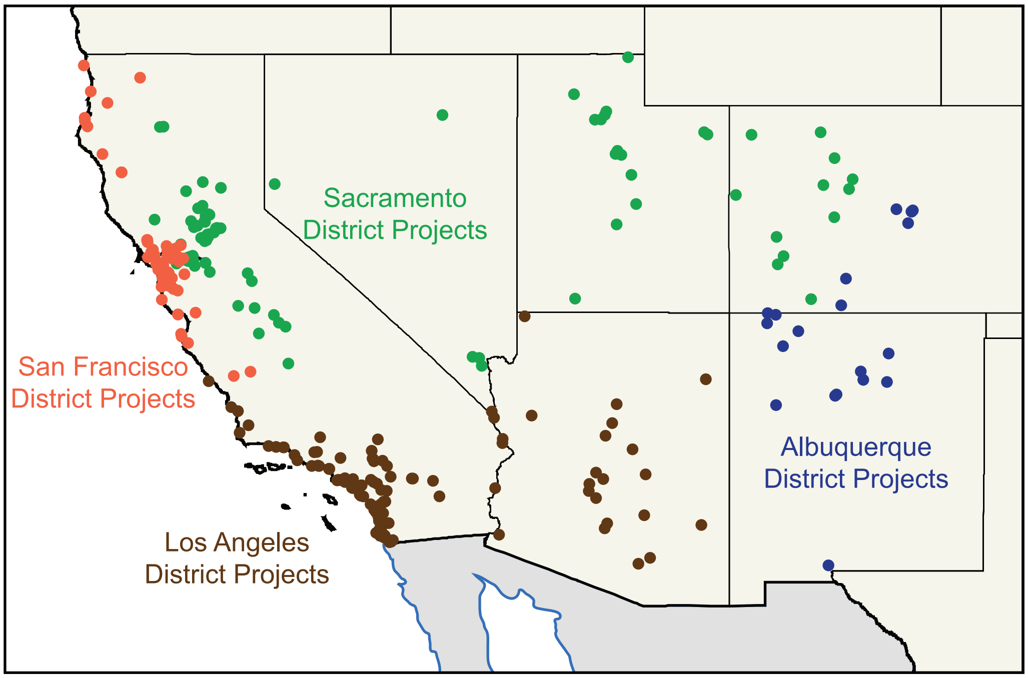

Figure 1. Project locations in the USACE South Pacific Division, colored by permitting district

This analysis focuses on standard permits, which are individual project authorizations typically required for more complicated or potentially impactful projects. Unlike the more straightforward letter of permission or nationwide permit programs (in which activities meeting certain criteria are pre-authorized under an existing permit), standard permits provide increased opportunity for public input through an open comment period. Because they are for more complicated projects, these permits provide a good case to observe a larger variation in agency familiarity and additional authorizations.

The dataset was compiled from public notices and public databases of §404 permits.

Summary lists of final and pending individual standard permits were exported from USACE's database of Other Regulated Material (ORM) for Jurisdictional Determinations and Permit Decisions[3]. The summary list documented each project's name and geographic coordinates, the applicant's name, the USACE district reviewing the application, the USACE's permit decision (issue, issue with special conditions, deny, pending), and the dates of public notice and permit decision (for completed decisions).

Application submission dates were obtained from the USACE South Pacific Division. The major outcome variable in the analysis, time-to-decision, was calculated as the time (in years) elapsed between application initiation[4] and the final permit decision.

For this analysis, we selected permits whose application was submitted to the USACE between January 1, 2013 and July 31, 2016 (n =302). Interestingly, the vast majority of the 302 projects were either issued a permit (n = 237) or still pending (n = 63); there were only two denials in the sample.[5] Figure 1 shows a map of the projects, color coded by USACE district.

Additional project details, including the project type, the applicant type, other permits required, and whether the applicant used a consultant, were coded manually from public notice documents. 285 of the 302 applications (94%) were matched with public notice files posted online. Of the 17 projects missing a public notice, 11 had never received a public notice (either because

[3] http://corpsmapu.usace.army.mil/cm_apex/f?p=340:2:0::NO (accessed October 27, 2017).

[4] Application initiation was estimated as the earliest of (1) application submission, (2) the date the application was deemed complete, and (3) the public notice date, because there were a number of cases where the complete or public notice date occurred prior to the application submission date. Based on interviews with permitting agencies and applicants, we know that many applications are returned to applicants, either as requests for more information or denied permits with an invitation to reapply (Ulibarri, Cain, and Ajami 2017). Our dataset only captures the final "submission" and is therefore undercounting the total review time. However, by using the earliest associated date as the review start, we aim to capture some of that additional time.

[5] These were issued for two adjacent and interrelated projects; the denials occurred on the same day.

they were pending or they were a rare case where the USACE did not require one). We could not locate the notices for the other 6. The 17 projects missing public notices were all in California, but distributed among the Los Angeles, Sacramento, and San Francisco districts. The cases without public notices were, on average, in census tracts with slightly higher population densities (mean = 1891 vs. 1728 people/mi^2) and slightly higher median household incomes ($74,000 vs. $68,000). Finally, the mean review duration not including pending cases was slightly longer (1.09 vs. 1.03 years).

Projects were classified into six mutually exclusive, collectively exhaustive categories: development, dredging, environment, operation, transportation, and waterway (see Table 1). Similarly, applicants were categorized into five organization types: federal government, state government, local government, non-profit, and private.

Which additional permits or authorizations were required was gleaned from the public notice. Some notices provided concrete evidence whether a project would require an authorization: "The proposed project would not adversely affect Essential Fish Habitat (EFH) as defined in the Magnuson-Stevens Fishery Conservation and Management Act." Others, however, were vague: "Based on an initial review, USACE has made a preliminary determination that the project either has no potential to cause effects to these resources or has no effect to these resources. USACE will render a final determination on the need for consultation at the close of the comment period" or "The Corps has made a preliminary determination that the proposed activity may affect Federally-listed endangered or threatened species or their critical habitat. The Corps will initiate consultation with the U.S. Fish and Wildlife Service pursuant to Section 7 of the Endangered Species Act, as appropriate." We thus used the public notice language and our knowledge of the process (e.g., a Utah project would never require Coastal Zone authorization) to determine the likelihood that each authorization was required. These were coded at one of four levels: not required (the first example above), unlikely (the second example), likely (the third example), or definitely required. To reduce the number of variables in the analysis, these were collapsed into two categories: No (not required and unlikely) and Yes (likely and definitely required). We focused on federal authorizations (NHPA, ESA, EFH, and CZMA) and whether the project required a full EIS, as these were consistent requirements across the states in the sample. State or local authorizations were excluded, as were WQCs, as only a handful of projects did not require one.

To estimate agency workload, for each project we calculated the number of applications also under review in that USACE district during the project's review period.[6] The workload also serves as a district proxy, as there was no overlap in workload range between districts.

For socioeconomic covariates, the American Community Survey (ACS) data on population and income by census tract were assigned to each application according to the project's geographical coordinates. This was done by spatially joining projects to census tracts whose boundaries were defined in 2014 (US Census Bureau 2014). Projects in the sample were assigned to 249 census tracts across seven states. Socioeconomic covariates in the analysis are the 5-year (2011 to 2015) population density and median household income, both logged for the statistical analysis.[7]

We lastly included dummy variables for the state where each project is located, as each state has a unique regulatory environment, state-level permitting requirements, and other

[6] While a more complete measure of staff workload would be to normalize application numbers over staff size, data on staff size is not available. However, our workload measure is dynamic (every application has a different number of applications subsequently under review in that office), so it captures short-term fluctuations (a month with substantially more or less applications submitted) that would be unlikely to lead to changes in staff size.
[7] Other socioeconomic variables, including education (% bachelor's degree), race (% white), and income inequality (GINI index), were considered, but were not found to significant in any model formulation.

unobservable characteristics that are likely to affect overall review time. Because Nevada and Texas each had small observation counts, we joined Nevada and Utah (NV-UT) and New Mexico and Texas (NM-TX) into single variables.

Tables 2 and 3 provide descriptive statistics on all explanatory variables. For the categorical variables, Table 2 provides the distribution of all applications by level, as well as the count of applications in that level that received a permit.

Table 2. Descriptive statistics of categorical variables

			Applications		Applications w/ Decision
Hypothesis	Variable		*n*	%	*n*
H1	Project type	Development	80	28	50
		Dredging	43	15	42
		Environment	32	11	25
		Operation	24	8	19
		Transportation	46	16	41
		Waterway	60	21	50
H2a	NHPA	No	197	69	170
		Yes	88	31	57
	ESA	No	116	41	105
		Yes	169	59	122
	EFH	No	203	71	156
		Yes	82	29	71
	CZMA	No	200	70	150
		Yes	85	30	77
H2b	EIS	No	169	59	145
		Yes	116	41	82
H3a	Applicant type	Business	121	42	82
		Non-profit	10	4	9
		Local	103	36	87
		State	27	9	26
		Federal	24	8	23
H3b	Consultant use	No	159	56	133
		Yes	126	44	94
[Control]	State	AZ	30	11	27
		CA	201	71	148
		CO	19	7	18
		NM	13	5	13
		NV	5	2	5
		TX	2	1	2
		UT	15	5	14

Descriptive statistics for continuous covariates are in table 3. Between 2011 and 2015, mean density around project locations was 1728 people/mi^2 (compared to an average of 99 people/mi^2 in the continental US), indicating that these projects were built in more urbanized settings. Households living around the project locations on average had higher incomes (sample median of $62,100 versus national median household income $53,718) during the same time period (Proctor, Semega, and Kollar 2016), likely reflecting the fact that the majority of these projects were in California.

Table 3. Descriptive statistics of continuous variables

Hypothesis	Variable	n	Mean	SD	Min	Max
[DV]	Review duration (days)	285	426	379	15	1676
H4	Agency workload	285	34.2	16.5	2.8	70.0
H5a	Population density (/mi^2)	284	1728	3293	0.2	23730
H5b	Median household income (US$)	277	68240	29264	14290	171400

A challenge in the dataset is right-censoring of projects still under review. Applications with permits issued (n = 227) spent on average 297 days under review. For applications with pending decisions (n = 58), the durations right censored on October 1, 2017 averaged 931 days under review, more than triple the former. This strongly indicates that censoring did not happen at random, but that harder-to-permit projects were more likely to remain under review. Fortunately, as discussed below, survival analysis accounts explicitly for censored data in the model.

4.2. Empirical Approach

Our research objective was to determine what characteristics predict whether a permit application received a decision from USACE, conditional on having remained under review until that time. Like many other studies of regulatory process duration (Ando 1999; Decker 2003; Kosnik 2006; Ulibarri 2018), we use a Cox proportional hazards model (Cox 1972) to model the relationship between decision duration and the explanatory variables. Because time can only take positive values, it does not approximate a normal distribution and is therefore inappropriate for a standard OLS regression. Additionally, there were many pending applications in the dataset; using their right-censored duration as the final duration would undercount the total time it will ultimately take them to receive a decision. A hazard model can accommodate data with these characteristics.

Unlike a regular OLS model, which would estimate changes in actual review duration, a hazards model estimates the likelihood that an application with particular characteristics receives a permit decision after being under review until a time particular time. We first construct a discrete hazard function

$$\hat{h}(t_j) = \frac{d_j}{r_i} \qquad (1)$$

which estimates the likelihood that an application receives a decision between time t_j and t_{j+1}, conditional on being under review immediately before time t_j . Here, t_j are uncensored durations ordered from the smallest to largest, d_j is the number of applications for which decisions were made between t_j and t_{j+1}, and r_j is the number of cases present just prior to t_j.

The hazards model addresses censored data by adjusting the number of cases considered for each time period. During the period between t_j and t_{j+1}, both the events (decisions issued) and cases (pending applications) right-censored during or after the period are included. Therefore, censored data are not omitted, but accounted for as the denominator of the estimated hazards.

Proportional hazard models associate an estimated baseline hazard with mean-centered explanatory variables in the following form:

$$h(t_j \mid \mathbf{X}_i) = h_0(t_j) e^{(\mathbf{X}_i - \bar{\mathbf{X}})\boldsymbol{\beta} + \boldsymbol{\varepsilon}} \qquad (2)$$

Here, $h_0(t_j)$ represents the baseline hazard, the average risk[8] that a permit decision is issued after t years. **X** is the matrix of explanatory variables—project type, regulatory characteristics, applicant type, agency workload, socioeconomic characteristics, and state—with i indexing a subpopulation; β are the parameters to be estimated and ε is the error term. The explanatory variables affect the baseline hazard multiplicatively, so a positive coefficient indicates that the hazard increases (thereby decreasing the review duration) if the corresponding covariate increases; a negative coefficient increases the review duration.

The analysis was conducted in the R environment using the *coxph* (Therneau and Lumley 2017) and *eha* (Broström 2017) packages. To assess the impact of model specification on our results, we also tested a series of parametric proportional hazard models and accelerated failure time models, which are presented in the Supplementary Material.

5. Results

Figure 2 displays the baseline hazard and survival functions for the §404 permits. As baseline functions, they indicate the process for an average application, with all covariates at their means. The cumulative hazard (left panel) shows $H_0(t_j)$, the cumulative likelihood of receiving a permit after t years, conditional on having survived until time t. The right panel, the Kaplan-Meier survival function $\hat{S}_0(t_j)$, is the maximum likelihood estimate of the probability after t years that the average application leaves the review phase and receives a permit; it is equivalent to the natural exponential of $-H(t)$.

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[8] The risk when all explanatory variables equal zero.

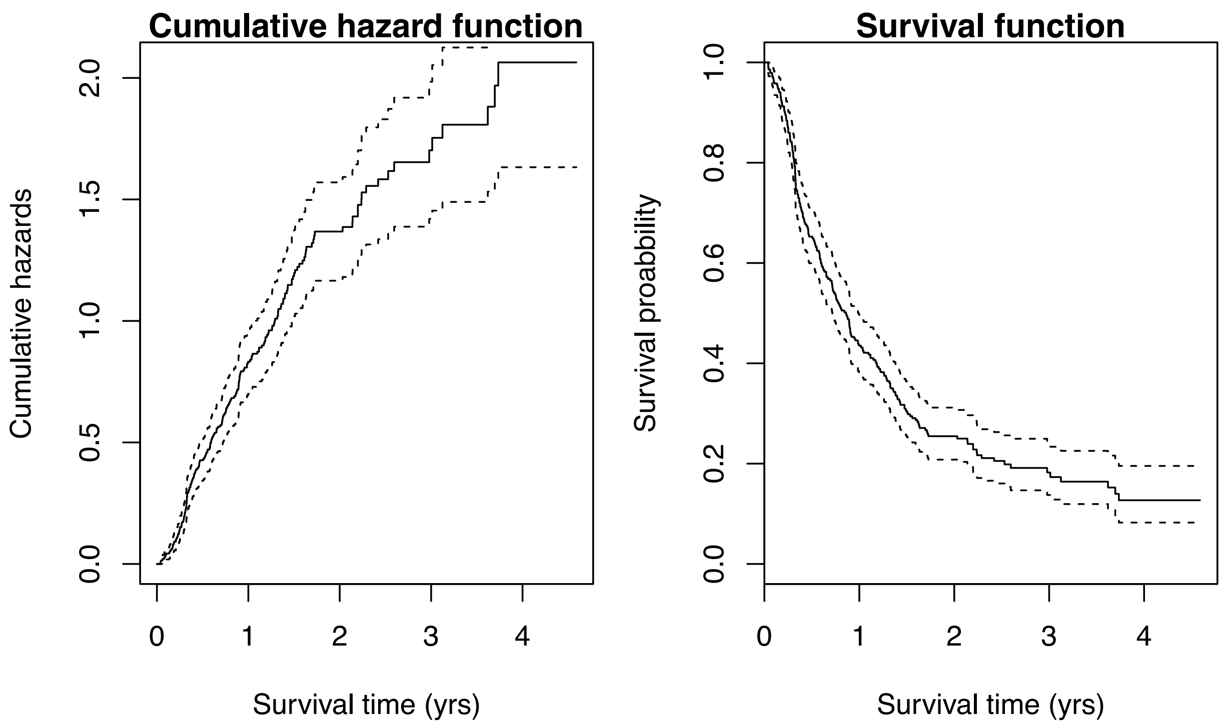

Figure 2. Estimated $H_0(t_j)$ *and* $\widehat{S_0}(t_j)$

The mean review duration of the 285 applications in the sample was 426 days (about 1.2 years). The steep initial slope in the survival curve (figure 2) indicates that many projects receive permits quickly (at or before this mean time). However, the slope decreases between one and two years, indicating that applications still under review at two years are increasingly more likely to remain under review rather than receive a permit for each additional time step.

The compiled data were fitted using Cox proportional hazard models (Therneau and Lumley 2017). Table 4 summarizes model results under three different specifications. In interpreting these results, the parameters have an additive effect on the natural log of the expected likelihood an application will exit review (receive a decision). Further, we can exponentiate each parameter (exp(β)) to estimate the multiplicative relationship to expected review time. Thus, a positive coefficient indicates a higher likelihood that a permit is issued for any time t (i.e., a shorter average review time) and a negative coefficient indicates a lower likelihood.

Table 4. Estimation results of cox proportional hazard models

		Model 1 Full model	Model 2 Reliable variables	Model 3 Lowest AIC	Model 4 Preferred
Project	Development[a]	0	0		0
	Dredging	0.78 (0.31)*	0.91 (0.26)***		0.81 (0.26)**
	Environment	0.13 (0.31)	0.34 (0.27)		0.17 (0.28)
	Operation	-0.03 (0.30)	0.08 (0.29)		0.01 (0.28)
	Transport	0.39 (0.28)	0.51 (0.27)		0.39 (0.28)
	Waterway	0.39 (0.25)	0.43 (0.25)		0.39 (0.25)
NHPA	Yes	-0.29 (0.20)	-0.53 (0.18)**	-0.39 (0.18)*	-0.32 (0.19)
ESA	Yes	-0.43 (0.18)*	-0.33 (0.17)	-0.27 (0.16)	-0.34 (0.17)*
EFH	Yes	0.00 (0.23)			
CZMA	Yes	0.31 (0.23)		0.37 (0.18)*	
EIS	Yes	-0.71 (0.22)**		-0.83 (0.19)***	-0.84 (0.20)***
Applicant	Business[a]	0	0	0	0
	Federal	0.83 (0.31)**	0.91 (0.28)**	1.19 (0.26)***	0.95 (0.28)**
	Local	0.29 (0.21)	0.32 (0.21)	0.51 (0.16)**	0.31 (0.21)
	Non-profit	0.49 (0.38)	0.52 (0.38)	0.78 (0.36)*	0.54 (0.38)
	State	0.73 (0.32)*	0.72 (0.31)*	1.03 (0.25)***	0.81 (0.31)**
Consultant	Yes	-0.33 (0.16)*	-0.24 (0.15)	-0.31 (0.15)*	-0.29 (0.15)
District Workload		0.00 (0.01)			
ln(Population density + 1)		-0.01 (0.04)			
ln(Median HH income)		0.01 (0.19)			
State	CA[a]	0	0	0	0
	AZ	-1.19 (0.26)***	-1.19 (0.24)***	-1.20 (0.25)***	-1.11 (0.24)***
	CO	0.95 (0.37)*	0.32 (0.32)	1.06 (0.36)**	1.06 (0.37)**
	NM+TX	1.17 (0.50)*	0.60 (0.34)	1.26 (0.36)**	1.26 (0.37)**
	UT+NV	0.24 (0.36)	-0.11 (0.33)	0.42 (0.35)	0.39 (0.35)
n (events)		277 (220)	285 (227)	285 (227)	285 (227)
Log-likelihood		-1010.2	-1058.3	-1051.7	-1048.5
AIC		2064	2149	2129	2131

Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. [a] Reference category.

Model 1 is the baseline model and includes all 12 covariates.

Model 2 draws on a sensitivity analysis inspired by Leamer (1983). Cox proportional hazard models of application durations were estimated on all possible unique combinations of explanatory variables. Instead of creating a limited number of scenarios of variable selection subject to researcher perspectives and prior information, 2^{12}, or 4096 total, models were estimated. The distributions of coefficient estimates were acquired from all possible models. For each coefficient, the interval between the 2.5th and the 97.5th percentile of estimates was formed and contrasted with zero (see Supplementary Material for full results). Effects corresponding to coefficients whose 95% interval extends to both sides of zero are not consistently different from zero and should be fragile to model specifications. Out of all possible coefficients from the 12 tested variables, five variables had 95% intervals containing zeros, suggesting their fragility to variable selection. The remaining seven variables—state, project category, applicant type, consultant use, NHPA, ESA, and CZM—had one or more coefficients estimated consistently on one side of zero for at least 95% of all possible model specifications. Therefore, their estimates were much more reliable in most model estimation. Model 2 includes only these reliable variables.

Model 3 presents the model that has the lowest Akaike's Information Criterion (AIC) of the 4096 tested models, suggesting that these parameters provide the best fit for the data.

Finally, Model 4 retains the variables that were significant in at least two model specifications.

All four models produced very similar parameter estimates in both magnitude and direction, despite minor differences in significance levels. In the following discussion, we use parameters from Model 4 unless otherwise noted. Supplementary Material presents additional parametric and accelerated failure time model specifications.

Review time was partially associated with project type. In particular, dredging projects were 125% more likely ($exp(0.81) - 1 = 1.25$) to receive a decision for any time than a development project ($p = 0.002$). (Note that while this may seem like a large percentage, the baseline hazard is quite low—less than 0.02 for the first four years. A 1000% increase only raises the probability to 0.2.) Environmental, transportation, and waterway infrastructure projects were consistently more likely to receive permit decisions for any given time than development projects, but these results were not significant. Parameters for operations projects were not reliable across different model specifications.

Turning to regulatory regime, projects requiring ESA or NHPA authorizations were consistently less likely to receive a decision (by 29% and 27%, respectively), but their coefficients were not always statistically significant. Interestingly, projects requiring CZMA authorization were faster than those *not* required, though not significantly. Projects that were required to complete Environmental Impact Statements were 57% less likely to receive a decision ($exp(-0.84) - 1 = -0.57$) than those just undergoing an EA ($p < 0.001$), but this was not a reliable result in the sensitivity analysis.

Applications made by businesses experienced significantly slower reviewing durations compared to state and federal governments. On average, a state agency was 124% more likely to receive a decision compared to a private business ($p = 0.01$) and a federal agency was 158% more likely ($p < 0.001$). Local governments and non-profits both had consistently positive coefficients (indicating faster reviews that businesses), but these were not significantly different than zero.

Projects using a consultant were 25% less likely to receive a decision for any given time compared to projects that did not, but this result was not consistently significant.

The number of applications concurrently under review in a district was not associated with the likelihood of an individual permit being issued. Likewise, neither population density nor median household income was found to be associated with permit review time.

Finally, the state where a project is located is correlated with review time. Compared to a project in California, the average project in Arizona is 67% less likely to receive a permit decision for any time ($p < 0.001$). Projects in Colorado were 189% more likely to receive decisions quickly than California projects ($p = 0.004$); New Mexico/Texas projects are 252% more likely to receive a decision (p = 0.001). Projects in Utah and Nevada were not significantly different from California.

6. Discussion

Our first hypothesis (H1) was that more complex projects (environmental restoration, transportation, and water infrastructure projects) would take longer to review than development, dredging, or operations projects. This hypothesis was not supported, as decisions on development (one of the least complex projects) were consistently found to take longer than dredging, environment, transportation, and water infrastructure projects. However, only dredging projects reached decisions significantly faster than development projects, which suggests that different categories of projects do not inherently face differing review times—a ongoing operations project is not always more or less time consuming to review than a transportation project simply because it is an ongoing operations project.[9] There may be other dimensions along which projects vary, but which we cannot estimate with this dataset. For instance, other studies have found that project size is associated with longer reviews—in the specific context of permitting hydropower dams (Kosnik 2006; Ulibarri 2018)—but "project size" no longer translates when comparing across project types.

H2a, which predicted that additional federal authorizations would increase review time, was partially supported. The coefficients for projects requiring ESA and NHPA consultation were negative (slower on average than those not requiring consultation), but were not consistently significant. However, that neither EFH nor CZMA authorizations slowed down the process

[9] We also conducted analyses with dummy variables for the two components of "complexity" (Table 1): Ongoing operations vs. one time permits, and projects with broader public interest (a transportation project) vs. a private interest (dredging for a yacht club). Neither variable was found to be significant or to contribute to model fit in any model specification.

suggests that additional authorizations alone does not necessarily slow down review time, but instead depends on type and timing of each review.

Additionally, the extent of environmental review (H2b) was found to be significantly associated with differences in review time, supporting our expectation. Projects requiring a full EIS were 57% less likely to receive a decision for any time than those just requiring an EA.

Turning to H3a, different types of applicants were found to have different likelihoods of moving through the process quickly. Specifically, when applicants were federal or state agencies, decisions were made significantly faster compared to businesses, so the divide in speed was between large public agencies on one hand and businesses on the other. Our hypothesis was based on differential access to knowledge about the permitting process and/or financial and staff resources, which businesses often have, yet they were on average slowest through the process. An alternative hypothesis would be that there may be a shared understanding or higher levels of trust between public sector employees. There are several different ways this could lead to faster reviews. First, the applicant could find it easier to get information about the process if the permitting agency is more forthcoming for likeminded organizations. Second, the permitting staff could undertake a quicker review because they trust that other government employees will be accurate in how they represent the project.

An additional consideration in interpreting this finding is that each organization type—particularly businesses—encompasses a range of capacities and expertise. Our data do not distinguish between a small family-owned business and a multinational (or at least multi-state) corporation, yet they are likely to have drastically different levels of knowledge and expertise.

The null finding on project type, paired with the public-versus-private distinction for applicant type, raises an interesting question about the role of public versus private interests in permitting processes. On one hand, we see an unconscious preference for public agencies, which are likely to be shepherding a public-interest project (like transportation or environmental restoration) through the process. On the other hand, we don't see a time distinction between private-interest projects (development, mining) and public-interest projects (transportation or environmental restoration)[10]. This suggests that the primary driving factor is the applicants, not the projects they are proposing.

While the theoretical framework suggested that use of a consultant would speed applications through the process regardless of applicant type (H3b), our results suggest otherwise. On average, projects using a consultant were 25% less likely to receive a permit decision at any time than those that did not (though the result is not consistently significant), which suggests that consultants are being retained for more complicated projects. These projects may have moved through the process more quickly than they would have without a consultant, but it is impossible to tell from these data.

The expectation that higher staff workloads would slow down the process (H4) was also not supported. This suggests that offices adapt to their workload, having the appropriate staffing and process to handle the different number of applications that pass through their district.

Socioeconomic characteristics (H5)—population density and income—were not found to be significantly associated with review time, a finding that contradicts much of the literature. This is particularly interesting because the hypothesized mechanism for socioeconomic characteristics to matter is through public participation, and we focused on standard permits, which have

[10] We conducted an analysis with a dummy variable for private projects (developments, mining, yacht club dredging) versus public projects (transportation, environmental restoration, drinking water infrastructure), and it was not significant.

substantially higher opportunities for public engagement. If socioeconomic differences are not associated with differences in review time in these cases, they're even less likely to matter in a letter of permission or nationwide permit. However, these results should not be considered definitive, as our time period does not include any actions like lawsuits or complaints that occurred after a permit was issued, and demographic differences could definitely play a role in what groups mobilize in these instances.

Finally, while this was not one of our hypotheses, the state where a project is located is correlated with review time. Specifically, projects in Arizona were relatively slow, and projects in Colorado and New Mexico were relatively fast. This effect is separate from other factors along which the states differ. While we would expect to see differences across individual offices in the Division (Kosnik 2006), the district workload—closely correlated with the district—was not significant, and most states in the sample are covered by more than one district, so district differences are unlikely to be driving this result. Similarly, the large metropolitan areas in California, Arizona, and Colorado give these states higher population densities, but population density was insignificant in our models. Moreover, while California has the most state-level environmental and health protections in the country, New Mexico (faster decisions) and Arizona (slower decisions) are tied for the second most environmental and health protections of southwestern states (Rabe 2010), suggesting that difference across states are not due to varying regulatory settings.

While we selected the §404 process because it captured a complex process with multiple interacting permits and a variety of project and applicant types, this decision comes with methodological limitations – namely, that there is unobserved variation underlying the observed differences in duration. We did not account for any local or state level authorizations, as these would be hard to find the data and challenging to compare in a meaningful way, instead opting for state fixed effects. Likewise, comparing different types of applicants and projects is challenging to do in a meaningful way. As we note above, not all businesses are created equal, nor are all dredging projects. Nevertheless, by estimating the average association of each of these very messy constructs, we can continue to build knowledge about the widespread and understudied practice of permitting.

A final implication of this work is how rarely projects were simply refused a permit: there were only two denials (both with an invitation to re-apply) in our entire dataset. This holds true even in the set of applications submitted since 2010 (over 600 projects). This is surprising, as one would assume that of the hundreds of projects proposed for federal review, some would be so harmful to the environment or neighboring communities that they should not be built (even with substantial off-site mitigation or compensation). Exploring reasons for the lack of denials could yield valuable insights into the effectiveness of permitting processes. Does the existence of permitting dissuade harmful projects from being proposed in the first place? Does agency review help improve these projects such that they are ultimately more environmentally appropriate and can be permitted? Or will any proposed project ultimately be approved, whether it indeed changed to be less harmful?

7. Conclusion

This research aimed to identify factors associated with longer or shorter permit review times, using the case of CWA Section 404 permits. Compared to the available literature on permitting, this study provided a number of contradictory and sometimes counterintuitive results. Longer review time was associated with projects proposed by a business (rather than state or federal agencies), using an engineering consultant, located in Arizona, and requiring some combination of EIS, historic preservation, and/or endangered species review. However, other factors that the literature holds to drive permitting duration, including project type, agency workload, and socioeconomic characteristics, did not correlate with permitting review time.

However, rather than viewing our results as a definitive primer on permitting process duration, we contend that this is a call to arms for scholars of planning, administration, and regulation to think critically about this ubiquitous policy tool. Studies of permitting *processes*—as opposed to legal studies on the details of a specific permit statute (Connolly 2006; Davidson 1982; Troxler 2013) or technical studies on the effects of permitting on air or water quality (Honkasalo, Rodhe, and Dalhammar 2005; Palmer and Hondula 2014; Pettersson et al. 2010)—are limited. We need more research, investigating the process for multiple permit types—clean air, zoning, building codes—and multiple project types. This study also only considered federal level review, but many permits happen at local, regional, or state jurisdictions, where there may be very different staffing and information constraints, interactions with other agencies, or pressures from interest groups or nearby communities. It also focused on the US, which has extensive opportunities for public input compared to other national settings (Dwyer, Brooks, and Marco 1999). Moreover, this study only considered factors that affect agency review. Interviews from our prior work suggested that many challenges arise while applicants are preparing their application for submission (Ulibarri, Cain, and Ajami 2017), indicating the need for studies of the pre-application process. Finally, while this study focused on process efficiency, effectiveness and equity are also fundamental features of a good process. While making the permitting process faster may be beneficial from a staff time and monetary resources perspective, the effects of any efficiency gain should be weighed carefully against potential impacts on the environment or surrounding communities if the permits themselves are no longer as effective.

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Evaluating Environmental Permitting Process Duration: The Case of Clean Water Act Section 404 Permits

Supplemental Material

Appendix A: Parametric Model Results

The Cox proportional hazard model uses hazard atoms to estimate cumulative hazard function without any assumptions about the distribution of survival times. Parametric proportional hazard models assume specific forms of the baseline hazards $h_0(t_i)$ and specify distributions of the error term. In Table A1, a variety parametric proportional hazard models following different distributions are presented to further assess sensitivity to model specification and the reliability of survival analysis.

Coefficients estimated were consistent across all popular distributions, including the exponential distribution (Exp), the Weibull distribution (Weibull), the extreme value distribution (EV), the log-logistic distribution (LnLogit), and the lognormal distribution (LN). For comparison, we present the standard Cox model presented in the results in the first column. This analysis suggests that the best-fit covariate selection specified in the preferred Cox model is not sensitive to distributional assumptions in parametric proportional hazard models using the data analyzed in this study.

A second parametric approach is accelerated failure time (AFT) models, which associate the survival function with explanatory variables:

$$\hat{S}(t_j | \mathbf{X}_i) = \widehat{S_0}(t_j e^{(\mathbf{X}_i - \bar{\mathbf{X}})\boldsymbol{\beta} + \boldsymbol{\varepsilon}}) \quad (A.1)$$

As with Cox, a positive estimate suggests a shorter survival time—thus a faster review process—as the covariate increases. The AFT model assumes that the ratio of survival times between

Table A1. Estimation results of parametric proportional hazard models.

		Cox	Exp	Weibull	EV	LnLogit	LN
Intercept						1.13*	2.90*
Project	Development[a]	0.00	0.00	0.00	0.00	0.40	0.40
	Dredging	0.81**	0.74**	0.88**	0.91**	0.10**	0.10**
	Environment	0.17	0.14	0.14	0.10	0.13	0.13
	Operation	0.01	0.04	-0.02	-0.05	0.10	0.10
	Transport	0.39	0.28	0.36	0.29	0.10	0.10
	Waterway	0.39	0.30	0.41	0.38	0.16	0.16
NHPA	Yes	-0.32	-0.28	-0.36	-0.38	0.41	0.41
ESA	Yes	-0.34*	-0.32	-0.37*	-0.40*	0.73*	0.73*
EIS	Yes	-0.84***	-0.75***	-0.93***	-1.01***	0.46***	0.46***
Applicant	Business[a]	0.00	0.00	0.00	0.00	0.57	0.57
	Federal	0.95**	0.84**	1.06***	1.08***	0.04***	0.04***
	Local	0.31	0.30	0.35	0.39	0.30	0.30
	Non-profit	0.54	0.49	0.63	0.68	0.04	0.04
	State	0.81**	0.74*	0.91**	1.00**	0.05*	0.05**
Consultant	Yes	-0.29	-0.24	-0.27	-0.23	0.47*	0.47
State	CA[a]	0.00	0.00	0.00	0.00	0.06	0.06
	AZ	-1.11***	-0.86***	-1.17***	-1.10***	0.86***	0.86***
	CO	1.06**	0.94**	1.12**	1.18**	0.03**	0.03**
	NM+TX	1.26**	1.02**	1.29***	1.31***	0.02**	0.02**
	UT+NV	0.39	0.53	0.51	0.67	0.04	0.04
ln(scale)				5.52***	5.82***	5.97***	7.79***
ln(shape)				0.32***	0.01	0.58***	-0.38
Log-likelihood		-1049	-1570	-1555	-1572	-1548	-1548
AIC		2131	3174	3144	3177	3130	3129

Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. $N = 285$; events = 227.

different subpopulation defined by certain covariate values be constant over time. Unlike proportional hazard models, AFT models allow the ratio of hazards between subpopulations to differ in the beginning of the study period and converge over time.

As shown in Table A2, several popular distributions for accelerated failure time models, including exponential, Weibull, extreme value, log-logistic, and log-normal, appeared very similar in terms of estimate sign, magnitude, and significance, with the exception being slightly longer review times for operations projects under the Weibull and extreme value models. These results were also consistent with the Cox model.

Table A2. Estimation results of parametric accelerated failure time models.

		Cox	Exp	Weibull	EV	LnLogit	LN
Project	Development[a]	0.00	0.00	0.00	0.00	0.00	0.00
	Dredging	0.81**	0.74**	0.64**	0.62**	0.74***	0.77***
	Environment	0.17	0.14	0.10	0.07	0.17	0.22
	Operation	0.01	0.04	-0.02	-0.02	0.05	0.08
	Transport	0.39	0.28	0.26	0.24	0.33	0.27
	Waterway	0.39	0.30	0.30	0.35	0.28	0.32
NHPA	Yes	-0.32	-0.28	-0.26	-0.27	-0.12	-0.08
ESA	Yes	-0.34*	-0.32	-0.27*	-0.24	-0.37**	-0.34*
EIS	Yes	-0.84***	-0.75***	-0.68***	-0.74***	-0.57***	-0.57***
Applicant	Business[a]	0.00	0.00	0.00	0.00	0.00	0.00
	Federal	0.95**	0.84**	0.77***	0.68**	0.84***	0.86***
	Local	0.31	0.30	0.25	0.24	0.25	0.28
	Non-profit	0.54	0.49	0.46	0.54*	0.33	0.29
	State	0.81**	0.74*	0.66**	0.67**	0.63**	0.71**
Consultant	Yes	-0.29	-0.24	-0.20	-0.16	-0.25*	-0.25*
State	CA[a]	0.00	0.00	0.00	0.00	0.00	0.00
	AZ	-1.11***	-0.86***	-0.85***	-0.92***	-0.73***	-0.73**
	CO	1.06**	0.94**	0.81**	0.70**	0.84**	0.81*
	NM+TX	1.26**	1.02**	0.94***	0.96***	0.80**	0.76*
	UT+NV	0.39	0.53	0.37	0.22	0.62*	0.64*
ln(scale)				5.52***	5.89***	5.29***	5.33***
ln(shape)				0.32***	-0.01	0.69***	0.07
Log-likelihood		-1049	-1570	-1555	-1565	-1554	-1562
AIC		2131	3174	3144	3163	3141	3158

Note: * $p < 0.05$; ** $p < 0.01$; ***$p < 0.001$. $N = 285$; events = 227.

In conclusion, results under various parametric assumptions of the functional form—on either the hazard in proportional hazard models or the survival function in accelerated failure time models—do not alter the interpretation of our preferred Cox model. Moreover, the preferred Cox model has substantially better model fit (lower AIC and higher log-likelihood) than any of the alternative functional forms tested.

9. Appendix B: Parameter Sensitivity Analysis

Figure B1 presents distributions of all potential coefficients across all possible Cox proportional model specifications. 2^{12} different models were estimated, for all combinations of the 12 variables. Black vertical lines represent the 2.5^{th} and 97.5^{th} percentiles, and the thick red vertical lines mark zero. Coefficients with zeros outside of their 95% interval had reliable signs, while others were fragile to model specification.

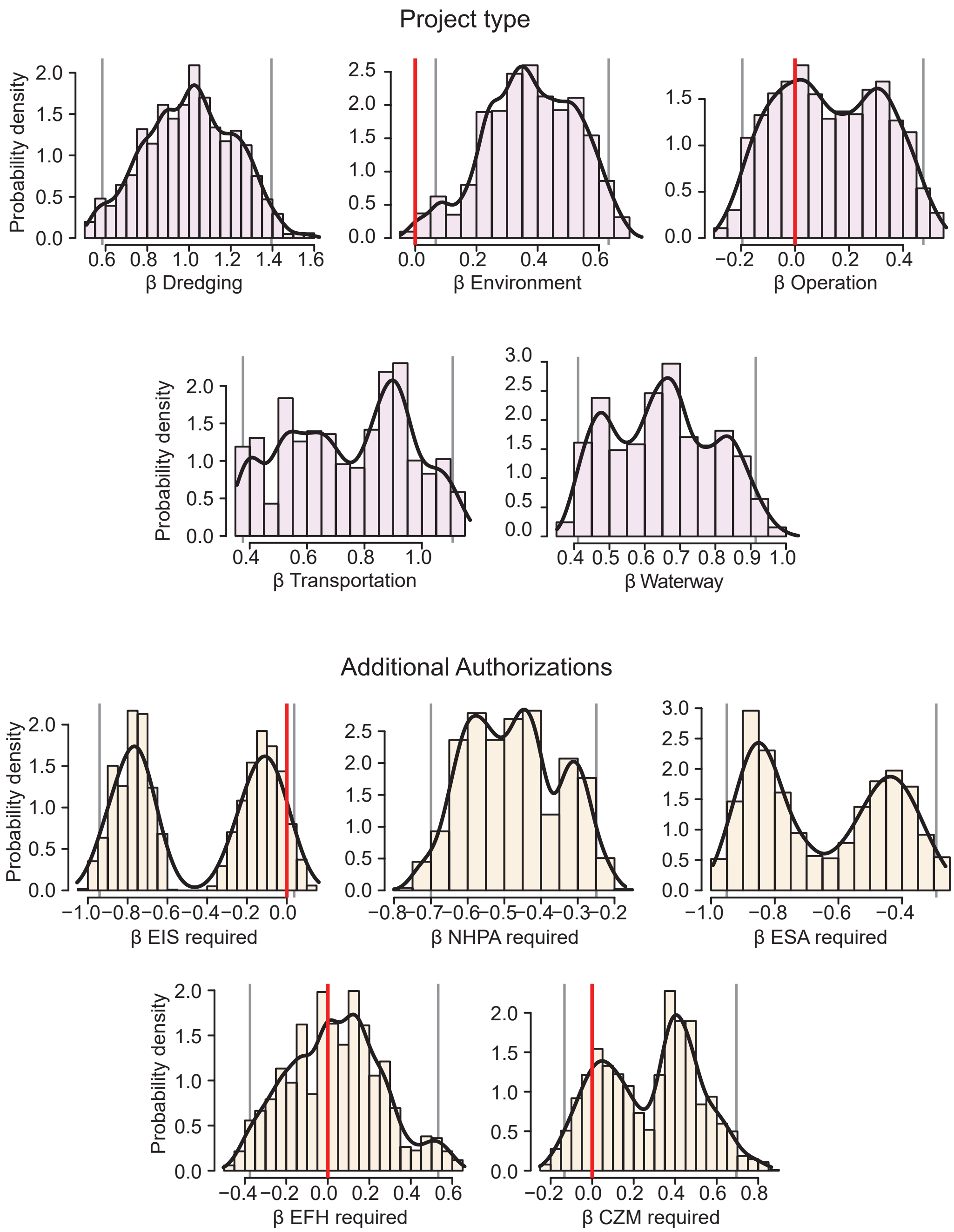

Figure B1(a). Distribution of coefficient estimates across all possible Cox proportional hazard models. Black vertical lines show 2.5th to 97.5th percentile interval; thick red vertical lines show zeros.

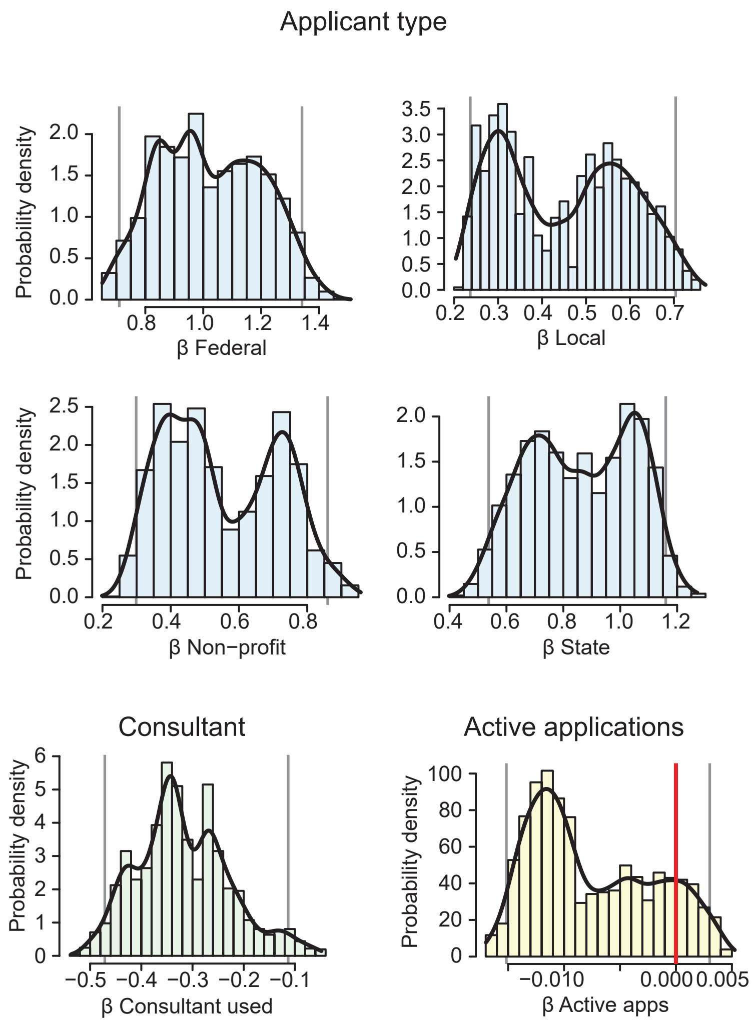

Figure B1(b). Distribution of coefficient estimates across all possible Cox proportional hazard models. Black vertical lines show 2.5th to 97.5th percentile interval; thick red vertical lines show zeros.

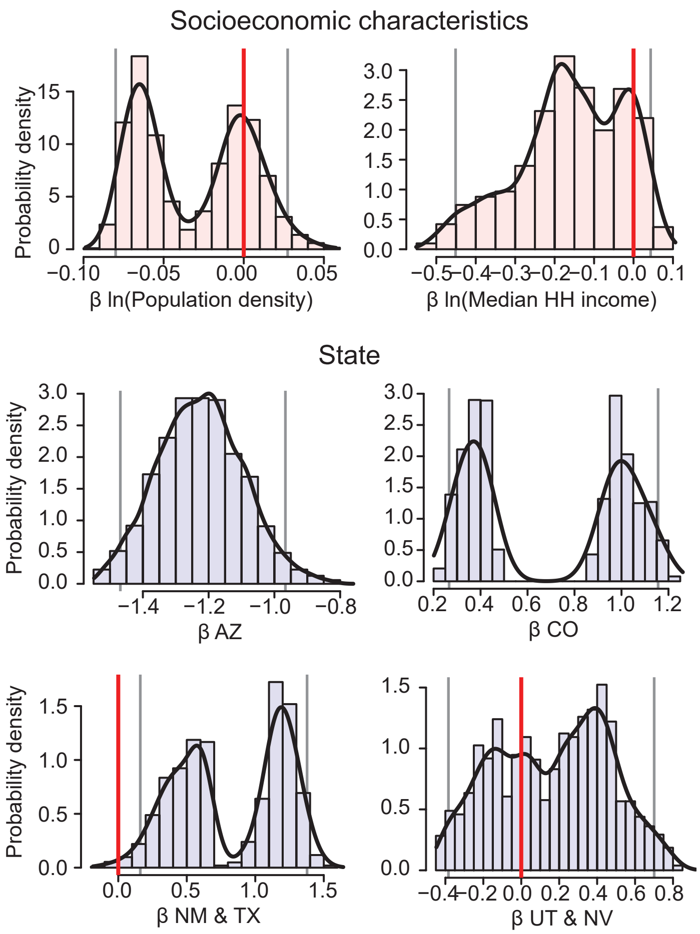

Figure B1(c). Distribution of coefficient estimates across all possible Cox proportional hazard models. Black vertical lines show 2.5th to 97.5th percentile interval; thick red vertical lines show zeros.