

# **The Gun-Deck Problem: Data Provenance Failures in Timber Inventory**

*A Natural Resource Management, Labor Economics, and Institutional Design Analysis*

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## **Abstract**

The U.S. Forest Inventory and Analysis (FIA) program—the nation’s primary source of forest resource data—maintains a workforce of approximately 500–600 federal and state personnel to collect measurements across 355,000 permanent inventory plots, with roughly 70% of the workforce dedicated to field operations. State agencies from Wisconsin to Washington operate parallel timber cruising programs under similarly constrained conditions. Collectively, these federal and state inventory systems underpin a commercial timber market in which institutional timberland holdings exceed \$90 billion (Mei, 2020; Hood et al., 2015) and individual transactions routinely involve stands valued at \$1 million or more. This paper argues that the institutional design of these inventory programs creates the structural preconditions for what naval tradition calls *gun-decking*: the systematic recording of data that was never properly collected. Drawing on the Shapiro–Stiglitz (1984) shirking model, Holmström’s (1979) moral hazard framework, and recent scholarship on measurement uncertainty in national forest inventories (Barnett et al., 2023; Pollard et al., 2006), we demonstrate that the combination of modest wages (GS-4 through GS-6, approximately \$17–21/hour), remote and unmonitorable working conditions, weak verification mechanisms, and a workforce structure that relies heavily on entry-level technicians produces incentive conditions that labor economics would predict to generate systematic data quality degradation—not through individual moral failure, but through institutional design failure. We further demonstrate that published error tolerances in timber cruising standards—ranging from 15% to 30% at 95% confidence depending on sale value—translate directly into financial exposure for timber purchasers and sellers, creating information asymmetries that depress market efficiency. The analysis reframes forest data quality as an equilibrium outcome of institutional design rather than a workforce discipline problem, with implications for timber markets, carbon accounting, and forest policy.

**Keywords:** forest inventory, timber cruising, data provenance, principal–agent problem, moral hazard, efficiency wages, measurement uncertainty, institutional design, gun-decking, natural resource management

**JEL Classification:** D82 (Asymmetric and Private Information; Mechanism Design), J31 (Wage Level and Structure), Q23 (Forestry), D73 (Bureaucracy; Administrative Processes), L73 (Forest Products)

## 1. Introduction

In maritime culture, the term *gun-decking* refers to the falsification of official records—specifically, the practice of recording data that was never actually collected or procedures that were never actually performed. The term’s etymology traces to the age of sail, when midshipmen assigned to compute the ship’s position from celestial observations would instead retire to the gun deck and work backwards from dead reckoning estimates, producing plausible but fabricated navigational fixes (U.S. Naval History and Heritage Command, n.d.; Merriam-Webster, 2024). The practice was not driven by malice but by structural incentives: the observations were tedious, the conditions were harsh, the supervision was minimal, and the consequences of approximation were rarely immediate.

This paper applies the gun-deck metaphor to a strikingly parallel institutional context: the collection of forest inventory and timber cruising data by field crews across the United States. The data collection systems that support timber inventory operate at multiple levels—the U.S. Forest Service’s Forest Inventory and Analysis (FIA) program at the federal level, state agency timber cruising programs in every forested state, and private sector cruising for commercial timber transactions. Despite differences in organizational structure and statutory authority, these programs share a common institutional architecture: they deploy modestly compensated field workers into remote, unmonitorable field conditions to perform complex measurement tasks whose accuracy cannot be verified at the point of collection.

The FIA program—a congressionally mandated effort to assess the status and trends of the nation’s forest resources—is the primary source of data on which timber supply projections, carbon stock estimates, biodiversity assessments, and forest management policy depend (Burrill et al., 2021; Bechtold & Patterson, 2005). The program spends approximately \$75 million annually and maintains a network of roughly 355,000 permanent plots measured on a 5–10 year rotation across all fifty states (FIA Geospatial Showcase, 2024). State programs operate in parallel: the Wisconsin Department of Natural Resources administers timber sales on state and county forests under published cruising accuracy standards (Wisconsin DNR, 2024), while Washington’s Department of Natural Resources manages 2.1 million acres of state trust lands with its own timber cruising handbook and standards (Washington DNR, 2025). These state

programs face the same labor economics constraints as the federal system, often with even more limited budgets for quality assurance.

The thesis of this paper is that the institutional architecture of timber inventory—its wage structure, monitoring capacity, employment terms, and verification mechanisms—creates precisely the conditions under which standard labor economics models predict systematic shirking and data quality degradation. This is not an accusation against individual field technicians, who frequently perform demanding physical work in difficult and sometimes dangerous conditions. It is an analysis of institutional design. When an organization deploys modestly compensated field workers into remote, unmonitorable field conditions to perform complex measurement tasks whose accuracy cannot be verified at the point of collection, the resulting data quality problems are not moral failures of the workforce. They are engineering failures of the institution.

The contribution of this paper is fourfold. First, we formalize the forest inventory data quality problem using the principal–agent framework from contract theory, drawing specifically on the Shapiro–Stiglitz (1984) shirking model and Holmström’s (1979) analysis of moral hazard and observability. Second, we synthesize the empirical evidence on measurement uncertainty and data quality across both federal FIA and state timber cruising programs, connecting documented patterns of measurement discrepancy to the structural predictions of the theoretical models. Third, we trace the economic consequences of the data provenance gap through commercial timber transactions, demonstrating that institutionalized error tolerances translate directly into financial exposure for buyers and sellers in a market exceeding \$90 billion in institutional holdings (Mei, 2020). Fourth, we discuss the implications of the gun-deck problem for institutional reform, noting that standard principal–agent remedies face fundamental constraints in the timber inventory context and that emerging autonomous sensing technologies may offer a structural alternative worthy of further investigation.

## **2. The Institutional Architecture of Timber Data Collection**

### **2.1. Federal Inventory: The FIA Program**

The Forest Inventory and Analysis program is the longest-running continuous forest survey in the world, with roots extending back to the McSweeney–McNary Forest Research Act of 1928.

In its modern form, established by the Agricultural Research, Extension, and Education Reform Act of 1998, the program operates through four regional research stations—Northern, Southern, Pacific Northwest, and Rocky Mountain—each coordinating data collection, analysis, and reporting for its geographic area (Bechtold & Patterson, 2005). The program’s sampling design places one permanent plot for approximately every 6,000 acres of forest, using a probabilistic framework that enables unbiased estimation of forest attributes from national to county scales (FIA National Program, 2024). The program invests approximately \$75 million per year and maintains a total workforce of approximately 500–600 federal and state personnel, of whom roughly 351 are federal full-time equivalents (FIA Business Report, 2022). Approximately 70% of the workforce is dedicated to field operations, split evenly between federal and state partner employees, with the remainder in analysis, research, information management, and administration.

Field measurements are collected on a cluster of four subplots per sample location, with crews recording data on more than 300 variables per plot visit, including tree species identification, diameter at breast height (DBH), total height, crown condition, site characteristics, down woody material, and understory vegetation. A typical plot visit requires one full day of field work, with crews navigating to remote locations using GPS coordinates, aerial imagery, and previous crew directions (PNW-FIA Data Collection, 2024). The data feeds directly into national estimates of timber volume, forest carbon stocks, species distribution, and forest health—estimates that in turn inform climate policy, timber markets, biodiversity conservation, and international reporting obligations under the United Nations Food and Agriculture Organization’s Global Forest Resources Assessment (FIA National Program, 2024). This workforce of roughly 350–420 field personnel is responsible for maintaining measurements on 355,000 permanent plots across all fifty states on a 5–10 year rotation—an enormous geographic footprint relative to the number of people collecting data.

## **2.2. State Timber Cruising Programs**

State agencies operate timber cruising programs that parallel the FIA system in structure but differ critically in purpose: state cruise data directly determines the financial terms of timber sale transactions. The Wisconsin Department of Natural Resources Timber Sale Handbook (2461) establishes explicit sampling error standards tied to sale value: for sales with an estimated

appraised value up to \$10,000, the standard is  $\pm 20\%$  error with two standard deviations; for sales exceeding \$10,000, the standard tightens to  $\pm 15\%$  (Wisconsin DNR, 2024). The handbook further sets a general goal for final sale volumes to be within 20% of cruise estimates. Washington State's DNR Timber Cruising Handbook targets less than 10% sampling error for timber sales on state trust lands (Washington DNR, 2025).

The USFS Timber Cruising Handbook (FSH 2409.12) establishes its own tiered error standards for timber sale appraisals, with acceptable sampling error varying by estimated sale value and whether the sale is scaled or sold lump sum. For sales in the \$20,000–\$45,000 range, the acceptable sampling error at the sale-as-a-whole level can reach 30% at 95% confidence for scaled sales; for individual strata within a sale, the allowed error extends to 50% (USFS, 2009). These are not aberrations—they are the published standards. The system is designed to tolerate significant uncertainty, and every downstream user of the data inherits that uncertainty.

Colorado's experience with the FIA program offers a suggestive institutional precedent. Colorado was the first state in the Rocky Mountain Region where leadership of the FIA process was assumed by a state agency, with the Colorado State Forest Service conducting fieldwork under USDA Forest Service funding (Colorado State Forest Service, 2024). This model of institutional flexibility—separating data collection operations from the centralized federal apparatus—demonstrates that the boundary between federal and state timber inventory is more porous than the organizational charts suggest, and that data quality challenges at one level propagate through the entire system.

### **2.3. The Labor Economics of Seasonal Field Work**

The workforce that collects timber inventory data—whether for FIA plots, state timber sales, or commercial transactions—operates under employment conditions that labor economists would recognize as structurally challenging for data integrity. Entry-level FIA Forestry Technician positions (0462 series) are classified at GS-4 and GS-5 on the federal General Schedule pay scale, with experienced technicians and crew leads reaching GS-7 to GS-9 (FIA Business Report, 2022). Under the 2025 General Schedule with Rest of U.S. locality pay, a GS-4, Step 1 position earns approximately \$17.07 per hour; a GS-6, Step 1 earns approximately \$21.29 per hour (Office of Personnel Management, 2025). While these wages exceed the federal minimum, they

remain modest given the substantial physical demands, technical complexity, and geographic isolation of forest inventory work—and in many labor markets they compete directly with less demanding positions in retail, logistics, and food service.

The workforce challenges extend well beyond compensation. A 2022 Government Accountability Office report on federal wildland firefighter recruitment and retention—a closely related workforce sharing many of the same structural characteristics—identified low pay as the most commonly cited barrier, with officials and all sixteen nonfederal stakeholders interviewed confirming that entry-level wages were inadequate given the demands and conditions of the work (GAO, 2022). The same structural dynamics affect timber inventory field crews: geographic postings that require extensive travel and camping, physically demanding work in all weather conditions across rugged terrain, and—particularly for entry-level and temporary positions—limited benefits and constrained career advancement pathways. State agency positions often face even tighter compensation constraints, as state forestry budgets lack the federal General Schedule floor.

#### **2.4. The Monitoring Problem**

The defining characteristic of timber inventory field work, from a labor economics perspective, is its *unmonitorability*. Field crews operate in remote, forested environments—often hours from the nearest paved road—where direct supervision is structurally impossible. The measurement tasks themselves involve subjective judgments (species identification, decay class assessment, crown condition evaluation) alongside objective measurements (DBH, height) that require proper technique to execute accurately. A crew that approximates a diameter measurement, estimates a height rather than measuring it with a clinometer or laser rangefinder, or records a species identification without fully verifying it through bark, twig, and leaf characteristics produces data that is indistinguishable from carefully collected data at the point of submission.

The FIA program's quality assurance (QA) framework acknowledges this challenge and attempts to address it through a system of blind check plots, in which QA crews remeasure a sample of plots previously measured by production crews (Pollard et al., 2006). The 2006 National Data Quality Assessment Report, covering QA data collected between 2000 and 2003, found that while repeatability was within Measurement Quality Objective (MQO) standards for

many variables, there were significant instances of noncompliance—both cases where all regions fell below standards and cases where specific regions diverged substantially from others (Pollard et al., 2006). More recently, Barnett et al. (2023), analyzing paired QA and operational data from 2,790 plots and 51,740 trees across the Northern Region, found that measurement discrepancies were generally small for objective variables like DBH but substantially higher for variables requiring judgment, including tree class, decay class, and cause of mortality.

State timber cruising programs face analogous monitoring challenges, often with fewer resources for quality control. The USFS Timber Cruising Handbook (FSH 2409.12, Chapter 60) establishes check cruising procedures requiring verification of a minimum number of trees per sale, with Regional supplements specifying additional requirements (USFS, 2019). Wisconsin’s handbook requires that cruising be performed by “qualified resource professionals and technicians fully trained in the collection and coding of recon data” (Wisconsin DNR, 2024)—but the qualification is a procedural requirement, not a monitoring mechanism. Crucially, the blind check system has inherent limitations: QA crews can only remeasure a fraction of total plots; the elapsed time between production measurement and QA remeasurement introduces natural variation that confounds detection of fabrication; and the system is designed to detect random measurement error, not the systematic approximation that the gun-deck metaphor describes.

### **3. A Principal–Agent Analysis of Timber Data Collection**

#### **3.1. Formalizing the Problem**

The timber inventory data collection system maps directly onto the principal–agent framework that has been central to contract theory since the foundational work of Mirrlees (1975, 1976), Holmström (1979), and Grossman and Hart (1983). The principal—the inventory program, representing the public interest in accurate forest resource data or the commercial interest in accurate transaction data—contracts with agents—field technicians—to perform measurement tasks. The principal’s objective is high-quality data; the agent’s objective includes compensation, working conditions, and effort minimization. The fundamental problem is that the principal cannot directly observe the agent’s effort. The agent’s action (careful versus approximated

measurement) is *hidden*—it cannot be observed by the principal and cannot be contractually specified in a manner enforceable by a court (Hart & Holmström, 1987).

In the taxonomy of Hart and Holmström (1987), this is a *hidden action* problem—the canonical moral hazard setting. The agent becomes privately informed after the contract is established: the field technician knows whether they carefully wrapped a diameter tape around each tree at exactly 4.5 feet above ground, properly calibrated their instruments, and correctly identified species through systematic examination of bark, twig, and leaf characteristics—or whether they approximated, estimated, or extrapolated. The output (recorded data) is a noisy signal of the input (measurement effort), because natural variability in forest conditions, instrument precision, and subjective judgment introduce irreducible variation that masks the distinction between careful and careless measurement.

### **3.2. The Shapiro–Stiglitz Shirking Model Applied**

The Shapiro–Stiglitz (1984) model provides a particularly illuminating framework for the timber inventory context. In their formulation, workers choose between two levels of effort—working (exerting costly effort  $\bar{e}$ ) or shirking (exerting zero effort)—and firms cannot directly observe effort but can detect shirking with some probability  $q$  per unit time, with detected shirking resulting in termination. The model demonstrates that in equilibrium, firms must pay a wage above the market-clearing level—an *efficiency wage*—to make the expected cost of shirking (job loss) exceed its expected benefit (reduced effort). The no-shirking condition (NSC) specifies the minimum wage at which workers will choose not to shirk, given the detection probability, the exogenous job separation rate, the cost of effort, and the value of the outside option.

Applied to the timber inventory field crew context—whether federal FIA, state DNR, or commercial cruising contractor—the Shapiro–Stiglitz framework reveals a near-perfect alignment of conditions favoring shirking. The detection probability  $q$  is extremely low: blind check plots represent a small fraction of total measurements, with substantial temporal lag between measurement and verification. The cost of effort  $\bar{e}$  is high: careful forest mensuration in steep, brushy, remote terrain under variable weather conditions is physically demanding and time-consuming. The wage  $w$  is modest relative to the demands of the work: entry-level GS-4 and GS-5 positions provide limited premium over the reservation wage given the physical

difficulty and geographic isolation involved. And the outside option—the expected utility of alternative employment—is competitive, particularly for entry-level and temporary positions, given the limited benefits and constrained career advancement associated with lower-grade federal field work.

In the language of the Shapiro–Stiglitz model, timber inventory programs pay wages that may fall below the no-shirking condition for their most demanding field positions. The program’s implicit strategy for eliciting effort relies substantially on the intrinsic motivation and professional integrity of its workforce—a strategy that efficiency wage theory would predict to be fragile, particularly under conditions of high turnover at entry levels, minimal training investment relative to task complexity, and the geographic isolation that characterizes field operations.

### **3.3. Calibrating the No-Shirking Condition**

To move from qualitative prediction to quantitative assessment, we calibrate the Shapiro–Stiglitz no-shirking condition (NSC) using federal wage data. The NSC specifies the minimum wage  $w^*$  at which a worker will choose not to shirk:  $w^* = \dot{w} + \bar{e} + (\bar{e}/q)(r + b)$ , where  $\dot{w}$  is the outside option (reservation wage),  $\bar{e}$  is the disutility of effort,  $q$  is the per-period probability of detecting shirking,  $r$  is the discount rate, and  $b$  is the exogenous separation rate. Two simplifying assumptions should be stated explicitly. First, we assume risk-neutrality and linear utility in income, which allows us to proxy the utility cost of effort  $\bar{e}$  as a dollar amount (a percentage of the hourly wage). This is a standard simplification in applied efficiency wage models but means that the calibrated NSC wages should be interpreted as approximations rather than exact thresholds. Second, the binary effort structure of the Shapiro–Stiglitz model—workers either exert full effort or shirk entirely—overstates the implied wage gap because it treats partial effort as equivalent to zero effort. The NSC wages computed below are therefore upper bounds for what is in practice a continuous effort allocation problem, as discussed in Section 3.4. Despite this, the calibration is informative: if actual wages fall below even an upper-bound NSC, the model’s prediction of shirking as an equilibrium outcome is robust to relaxation of the binary assumption.

A critical modeling choice concerns the exogenous separation rate  $b$ . In the Shapiro–Stiglitz model,  $b$  represents the rate at which workers involuntarily lose their jobs for reasons unrelated to shirking—it captures the background risk of job loss that, combined with the efficiency wage premium, makes workers fear termination. For permanent employees, annual separation rates of 0.25–0.30 are conventional estimates. However, many FIA field technicians hold seasonal appointments that end every October regardless of performance. For these workers, the annual separation rate is effectively 1.0—they are all separated—which fundamentally undermines the efficiency wage mechanism: the threat of firing has no bite if the job ends in three months anyway.

We address this by reframing the model in within-season terms, using monthly periods. The relevant  $b$  is not the end-of-term separation but the within-season rate of involuntary separation for non-shirking reasons: injury, budget-driven layoffs, reassignment, or other exogenous disruptions. We estimate this at  $b = 0.01$ – $0.03$  per month, reflecting the relative stability of seasonal appointments once the field season begins. The discount rate  $r = 0.005$  per month corresponds to approximately 6% annually. The detection probability  $q$  is calibrated at 0.005–0.020 per month, reflecting the FIA blind check system in which QA crews remeasure a small fraction of plots with substantial temporal lag. The outside option  $\hat{w}$  is set at \$15 per hour, representing comparable entry-level employment in retail, logistics, or food service—sectors that compete directly with seasonal federal field positions. The effort cost  $\bar{e}$  is parameterized at 15%, 25%, and 40% of the GS-4 hourly wage (\$17.07), spanning the range from routine measurement tasks to physically demanding work in adverse terrain and weather conditions.

Table 1 presents the calibrated NSC wage  $w^*$  across the parameter space of detection probability  $q$  and effort cost  $\bar{e}$ , with the within-season separation rate fixed at  $b = 0.02$  per month.

**Table 1. No-Shirking Condition Wage  $w^*$  (\$/hour) by Detection Probability and Effort Cost**

Parameters:  $\hat{w} = \$15/\text{hr}$  (outside option),  $b = 0.02/\text{month}$  (within-season separation),  $r = 0.005/\text{month}$  (discount rate). Effort cost  $\bar{e}$  expressed as percentage of GS-4, Step 1 wage (\$17.07/hr). Actual wages: GS-4 = \$17.07/hr; GS-5  $\approx$  \$19.10/hr; GS-6 = \$21.29/hr.

$\bar{e}$ (% of wage)	$q = 0.005$	$q = 0.010$	$q = 0.020$
\$2.56 (15%)	\$30.36	\$23.96	\$20.76
\$4.27 (25%)	\$40.62	\$29.95	\$24.61
\$6.83 (40%)	\$55.98	\$38.91	\$30.37

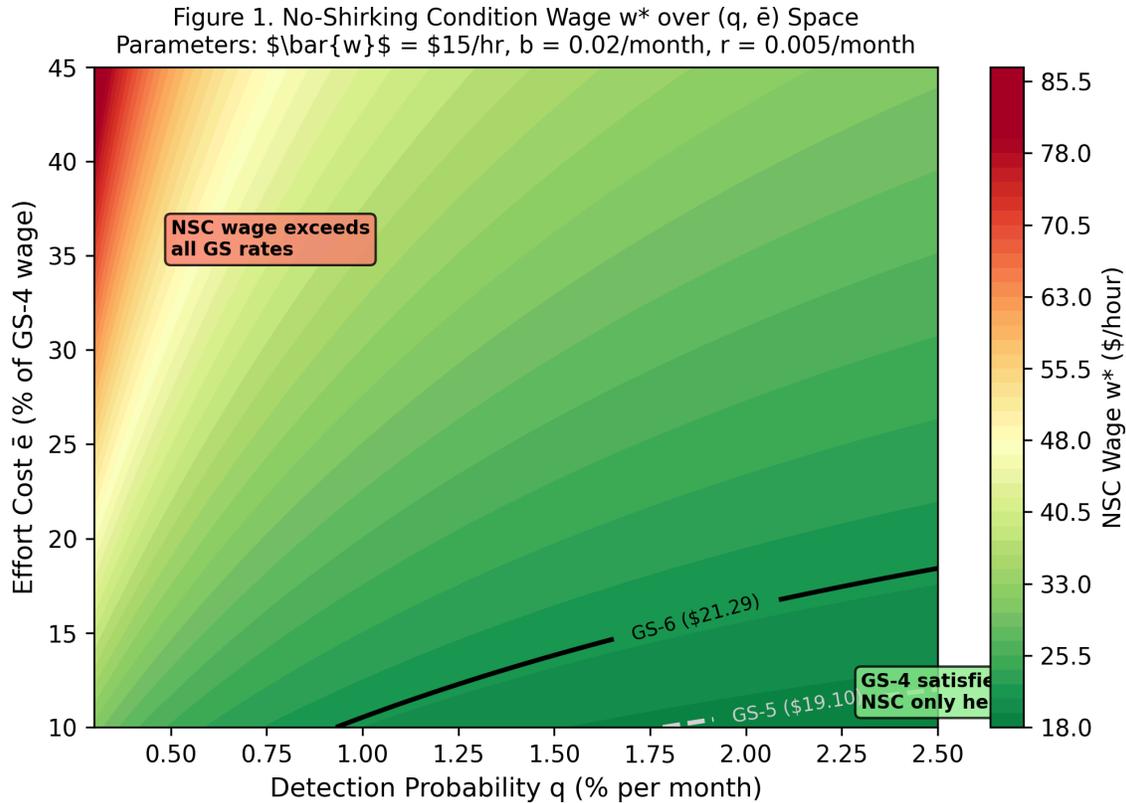


Figure 1. NSC wage  $w^*$  as a continuous function of detection probability  $q$  and effort cost  $\bar{e}$ . Green region: actual GS wages satisfy the NSC. Red region: NSC wage substantially exceeds all federal pay grades. Dashed lines indicate GS-4 and GS-5 wage thresholds; solid line indicates GS-6. Parameters:  $\bar{w} = \$15/\text{hr}$ ,  $b = 0.02/\text{month}$ ,  $r = 0.005/\text{month}$ .

The results are striking. Under every parameterization in Table 1, the GS-4 wage (\$17.07/hour) falls below the no-shirking condition—in most cases substantially. At the central estimate ( $\bar{e} = 25\%$  of wage,  $q = 0.01$  per month), the NSC wage is \$29.95/hour, approximately 75% above the GS-4 rate. Even under the most favorable assumptions—low effort cost (15%), high detection probability ( $q = 0.02$ ), and low within-season separation ( $b = 0.01$ )—the NSC wage is \$19.48/hour, which still exceeds the GS-4 wage and falls just below the GS-5 rate. The GS-6 wage (\$21.29/hour) satisfies the NSC only under this most optimistic parameterization. In the language of the model, field inventory programs pay wages at which the rational response—absent countervailing intrinsic motivation—is to shirk.

Figure 1 visualizes the NSC wage as a continuous function over the  $(q, \bar{e})$  parameter space, confirming that the wage gap is not an artifact of particular parameter choices. The calibration is robust across reasonable variation in the parameters. Varying the within-season

separation rate from  $b = 0.01$  to  $b = 0.03$  at central effort and detection estimates shifts the NSC wage from \$25.68 to \$34.21—a meaningful range, but one that leaves the qualitative conclusion unchanged. Varying the outside option from \$12 to \$17 per hour shifts the NSC wage linearly by the same amount, again without changing the finding that actual wages fall short. The dominant parameter is the detection probability  $q$ : because  $q$  enters the denominator of the effort-cost term, the NSC wage is highly sensitive to monitoring intensity. This sensitivity is itself informative—it quantifies the monitoring investment that would be required to bring actual wages into compliance with the NSC, and underscores the structural difficulty of resolving the shirking problem through wage or monitoring adjustments alone within current budget constraints.

Two important caveats qualify these results. First, as noted above, these are upper-bound estimates. The binary Shapiro–Stiglitz framework treats any deviation from full effort as equivalent to zero effort, whereas actual field behavior involves continuous effort allocation. A Holmström (1979) formulation with continuous effort would yield lower NSC wages, though still above current pay at plausible detection rates. The upper-bound interpretation strengthens rather than weakens the finding: if wages cannot satisfy even the most permissive shirking threshold, the equilibrium prediction is robust. Second, the within-season framing introduces a temporal dimension that the static model omits: as the season progresses and the remaining employment horizon shortens, the expected cost of detection falls, generating a prediction of increasing shirking intensity toward the end of the field season. This prediction is empirically testable and is distinct from the end-of-season patterns attributable to weather, leaf-on/leaf-off conditions, or accumulated crew fatigue.

### **3.4. Beyond Shirking: The Multi-Dimensional Quality Problem**

The binary shirking model, while analytically useful, understates the complexity of the timber inventory data quality problem. Real-world data degradation in field settings is not a binary choice between “work” and “shirk” but a continuous spectrum of effort allocation. A field technician may carefully measure DBH but estimate height; accurately identify common species but approximate uncommon ones; precisely locate subplot centers but accept imprecise placement of transect endpoints for down woody material. Holmström’s (1979) more general formulation of the moral hazard problem, in which effort is a continuous variable and the

principal designs contracts based on observable outcomes, captures this multi-dimensional quality landscape more accurately.

The empirical evidence supports this continuous rather than binary characterization. Barnett et al. (2023) found that measurement discrepancies between production and QA crews varied systematically by variable type: objective, easily verified measurements (e.g., DBH) showed smaller discrepancies, while subjective, judgment-dependent measurements (e.g., tree class, decay class, cause of mortality) showed substantially larger ones. This pattern is precisely what a multi-dimensional effort allocation model would predict: field technicians concentrate effort on the measurements most likely to be detected as erroneous in quality review and approximate those where discrepancies are attributable to legitimate inter-observer variability.

## **4. Data Provenance and the Verification Gap**

### **4.1. The Chain of Custody Problem**

Data provenance—the documented history of data from its point of origin through all transformations to its point of use—is a concept borrowed from archival science and increasingly central to data governance in fields ranging from financial regulation to pharmaceutical manufacturing (Buneman et al., 2001; Simmhan et al., 2005). In the context of timber inventory, data provenance encompasses the chain of custody from the moment a measurement is taken in the field through its recording on an electronic data collection device, its transmission to a regional database, its incorporation into national or state estimates, and its eventual use in policy decisions, market transactions, and scientific publications.

The current data collection architecture—across federal FIA, state timber cruising, and commercial inventory programs—creates a fundamental provenance gap at the point of original measurement. When a field technician records a diameter at breast height of 24.5 inches for a particular tree, the data system records that number. It does not record whether the measurement was taken with a properly tensioned diameter tape at exactly 4.5 feet above ground on the uphill side of the tree, whether the tape was perpendicular to the axis of the stem, whether the measurement was rounded to the nearest tenth of an inch, or whether the technician eyeballed the diameter from a distance and recorded a plausible estimate. The data point arrives in the database stripped of all information about the process that produced it. This is not a failure of the data

management system; it is a structural limitation of human-mediated data collection. The measurement process is epistemically opaque—the data point carries no intrinsic evidence of its own reliability.

## **4.2. Consequences of the Provenance Gap for Policy and Science**

The consequences of this provenance gap cascade through every downstream use of forest inventory data. Carbon stock estimates, which inform both domestic climate policy and international reporting obligations, are built on allometric models that translate field-measured DBH and height into biomass estimates. Recent research using terrestrial laser scanning (TLS) has revealed that conventional allometric models may systematically underestimate forest above-ground biomass—Calders et al. (2022), using three-dimensional laser measurements across the full range of tree size and shape in a UK temperate forest, found that above-ground biomass was 1.77 times greater than current allometric estimates. If the underlying field measurements that feed these models are themselves degraded by systematic approximation, the compounded uncertainty is substantial and largely unquantifiable.

In the rapidly growing voluntary carbon market, the provenance gap takes on direct financial significance. Forest carbon offset projects require verifiable baseline data on forest carbon stocks—data that ultimately derives from field measurements collected by crews operating under the incentive conditions described in Section 3. Third-party verification bodies such as SCS Global Services conduct audits of carbon offset projects, but these audits assess conformance to methodological protocols, not the reliability of the underlying field measurements that feed the calculations (SCS Global Services, 2024). The carbon market thus inherits the provenance problem of the forest inventory system, with financial transactions worth billions of dollars resting on data whose chain of custody contains an epistemically opaque link at its foundation.

## **5. Commercial Timber Market Consequences**

### **5.1. Institutionalized Error Tolerance in Timber Transactions**

The gun-deck problem is not confined to federal policy and scientific applications. It translates directly into dollars lost in commercial timber transactions, where cruise data determines the financial terms of sales involving millions of dollars. The error tolerances published in federal

and state timber cruising standards—which represent the *best case* for data quality—reveal the scale of financial exposure that is institutionally accepted as routine.

The Wisconsin DNR Timber Sale Handbook establishes sampling error standards explicitly tied to sale value:  $\pm 20\%$  error with two standard deviations for sales appraised up to \$10,000, and  $\pm 15\%$  for sales exceeding \$10,000 (Wisconsin DNR, 2024). The USFS Timber Cruising Handbook (FSH 2409.12) sets its own tiered standards, permitting sampling errors of 20–30% at 95% confidence at the sale-as-a-whole level and up to 50% for individual strata, depending on sale value and payment method (USFS, 2009). Washington State DNR targets less than 10% sampling error—the tightest state standard identified in our review—but even this represents significant financial exposure on high-value transactions (Washington DNR, 2025). These standards are not outliers; they represent the institutional consensus on acceptable uncertainty in timber volume estimation.

Applied to commercial transactions, these error tolerances translate into concrete financial exposure. A 20% error on a timber stand appraised at \$1 million represents \$200,000 in misallocated value—transferred from one party to the other with no reconciliation mechanism on a lump sum sale. This is not a hypothetical scenario; it is within the range that published cruising standards explicitly permit.

## **5.2. Lump Sum Sales and the Concentration of Risk**

The distinction between scaled (pay-as-cut) and lump sum (sold-on-appraised-volume) timber sale payment methods determines how cruise error translates into financial risk. In a scaled sale, the buyer pays only for timber actually harvested as verified by post-harvest scaling; cruise error affects the seller’s initial appraisal but not the final payment. In a lump sum sale, the buyer pays for the entire estimated volume regardless of what is actually harvested—the buyer absorbs any volume discrepancy, whether overrun or underrun.

The transaction cost implications of presale measurement in timber auctions have been rigorously modeled by Leffler, Rucker, and Munn (2000), who demonstrated that buyer cruising effort constitutes “distributional measurement”—expenditures that redistribute wealth between buyer and seller without altering the underlying value of the timber. Because sellers ultimately bear the cost of buyer measurement through lower bid prices, rational sellers have incentives to

provide their own cruise data or adopt contract structures that reduce duplicative measurement. Leffler and Rucker (1991) showed that the choice between lump sum and per-unit payment provisions is itself driven by these measurement cost considerations: sellers adopt per-unit payments on tracts where buyer uncertainty—and therefore buyer cruising effort—would otherwise be greatest. Athey and Levin (2001), in an influential analysis of U.S. Forest Service timber auctions, demonstrated that bidders possess private information from their cruises about timber volumes and use it strategically through “bid skewing,” placing disproportionate bids on species they believe are underestimated in the seller’s appraisal. Their model treats the buyer’s cruise as generating a private signal whose precision is a monotonic function of measurement intensity—an assumption that allows elegant equilibrium characterization but that depends entirely on the reliability of the underlying field measurement process.

This assumption—that measurement effort maps reliably to information quality—is the unexamined foundation of the entire timber auction literature. Leffler et al. model the quantity of cruising; Athey and Levin model the strategic use of cruise-derived information; neither questions whether the measurement process itself produces trustworthy data. Yet the labor economics analysis developed in Sections 3 and 4 of this paper demonstrates that the incentive conditions facing the field workers who generate cruise data—modest wages, remote and unmonitorable working conditions, weak verification mechanisms, and institutional tolerance of substantial error—are precisely the conditions under which economic theory predicts systematic data quality degradation. If field crews gun-deck measurements, the theoretical edifice built on the assumption of honest-but-noisy signals requires fundamental reassessment. The transaction costs Leffler et al. document become doubly wasteful: buyers expend resources on information that does not actually reduce uncertainty, while sellers bear those costs through depressed bids without receiving the compensating benefit of informed pricing. The bid skewing Athey and Levin identify may reflect not genuine private information about timber volumes but artifacts of heterogeneous data corruption—different bidders cruising with different intensities of approximation, producing the appearance of private information where the actual signal content is degraded. The implications extend beyond timber markets: any auction-theoretic framework that models presale measurement as generating reliable private signals without examining the labor economics of the measurement process rests on an assumption that warrants empirical scrutiny.

Barron, Kilgore, and Blinn (2017), in a study of timber sales administered by St. Louis County's Minerals and Land Department in northern Minnesota, found no significant difference in gross revenue between the two payment methods—but documented critical asymmetries in risk allocation. Blinn and Kilgore (2005) found that stumpage buyers often lack the time or resources to conduct their own pre-sale estimates of merchantable timber volume on each tract to verify the accuracy of the timber appraisal. In such cases, bidders attempt to minimize the risk of a volume underrun by discounting their stumpage bid prices. Additionally, a timber sale purchaser's knowledge of the specific forester who set up the sale can influence the buyer's preferred payment method and bidding behavior—a form of reputation-based risk management that underscores the information asymmetry problem.

Reep, Blinn, and Kilgore (2017), in a national assessment of stumpage payment methods used by state and county timber sale programs, confirmed that the choice of payment method significantly affects both bidding behavior and administrative costs, with timber sale program administrators perceiving that lump sum sales require additional timber appraisal effort to minimize the risk of underestimating merchantable volume. The financial dynamics create a classic Akerlof (1970) lemons problem: uncertainty about cruise data quality depresses prices for all sellers, even those whose cruises are accurate, because buyers cannot distinguish high-quality data from low-quality data at the point of bidding.

### **5.3. Institutional Timberland Holdings and Portfolio-Scale Exposure**

The financial consequences of the data provenance gap extend beyond individual transactions to portfolio-scale exposure for institutional timberland investors. The U.S. institutional timberland market—managed by Timber Investment Management Organizations (TIMOs) and Real Estate Investment Trusts (REITs) including Weyerhaeuser Company, Rayonier Inc., PotlatchDeltic Corporation, and CatchMark Timber Trust—exceeds \$90 billion in managed assets (Mei, 2020; Hood et al., 2015; this figure derives from circa-2015 data, and more recent industry estimates place the investable U.S. timberland universe at \$100–200 billion). Over 30 TIMOs manage institutional-grade timberland holdings on behalf of pension funds, endowments, and insurance companies, with inventory accuracy directly affecting asset valuation, harvest scheduling, and financial reporting.

At this scale, the data provenance gap creates systemic risk. Portfolio valuations depend on timber inventory estimates that inherit the same labor economics constraints documented throughout this paper. A systematic bias of even 5–10%—well within the error tolerances published in federal and state cruising standards—applied across billions of dollars in institutional holdings represents hundreds of millions of dollars in potential asset misvaluation. The SEC’s requirement for accurate asset disclosure in REIT filings adds a regulatory dimension to the problem: timber REIT valuations that rest on inventory data with broken provenance chains face latent disclosure risk that current audit practices do not address, because the audits assess methodology conformance rather than field data reliability.

## **6. Conclusion**

The gun-deck problem in timber inventory is not a problem of bad actors. It is a problem of institutional design—one that spans federal agencies, state programs, and commercial timber transactions. When labor economics offers a precise theoretical prediction—that modest wages, unmonitorable working conditions, weak verification mechanisms, and a small workforce stretched across an enormous geographic footprint will produce systematic data quality degradation—and the empirical evidence documents exactly the patterns those theories predict, the appropriate response is not to blame the workforce but to redesign the institution.

The Shapiro–Stiglitz framework clarifies that timber inventory programs’ current wage and monitoring structures may fall below the no-shirking condition, particularly for entry-level positions. The Holmström framework clarifies that the unobservability of field measurement effort creates a moral hazard that no feasible incentive contract can fully resolve within the existing institutional architecture. The commercial market analysis reveals that published error tolerances of 15–30% translate directly into financial exposure for timber purchasers and sellers, creating information asymmetries that depress market efficiency across a \$90+ billion institutional timberland market (Mei, 2020). The data provenance analysis reveals that even when measurement quality is adequate, the absence of auditable chains of custody undermines the credibility of downstream data products in carbon markets, timber planning, and policy applications.

The standard prescriptions of principal–agent theory for resolving moral hazard—increasing monitoring intensity, redesigning incentive contracts, introducing performance-based pay—face fundamental constraints in the timber inventory context. Increasing QA crew visits is prohibitively expensive given the geographic scale of the programs. Performance-based pay is difficult to implement when performance cannot be independently measured at the individual crew level. Raising wages to satisfy the no-shirking condition would require compensation substantially above current levels. Emerging autonomous sensing technologies, including terrestrial LiDAR and under-canopy drone systems, may offer a structural alternative by substituting machine-generated data with inherent provenance for human-collected data without it—but the economic case for such substitution, and its implications for workforce structure and institutional design, warrant separate and rigorous analysis.

The central finding of this paper is that the gun-deck problem is not a problem of bad actors but of institutional design—and that the institutional design is amenable to formal economic analysis. The Shapiro–Stiglitz calibration demonstrates that the gap between actual wages and no-shirking wages is large enough to be policy-relevant, and the empirical tests we propose offer a pathway to distinguishing systematic data fabrication from honest measurement error. The costs of the data provenance gap—to timber markets, carbon accounting, and forest policy—are largely invisible precisely because the gap itself makes them unmeasurable. Formalizing the problem is the first step toward quantifying those costs and evaluating potential remedies.

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