Title: *The Relevance of Law and Economics for Fire Safety*

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Abstract

This article investigates how Law and Economics ("L&E") can guide legal frameworks around fire safety by aligning legal rules, economic incentives, and engineering practices. We first introduce core L&E concepts—externalities, information asymmetries, public-goods provision, and liability structures—and their relevance for fire safety. We then develop a formal model contrasting prescriptive and performance-based regimes under three liability standards (strict liability, code-compliance negligence, and due-diligence negligence), illustrating their effects on optimal investment, innovation, and enforcement costs. Finally, we analyze the efficiency losses from fragmented regulations and propose some best practices for legal frameworks to incentivize cost-effective safety investment and innovation.

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1 Introduction

Fire safety is a fundamental concern in the design and maintenance of buildings, influencing public safety and infrastructure resilience. Fire safety engineers play a central role in designing buildings and systems that mitigate fire risk and protect human life, property, and societal well-being. However, they operate within legal frameworks and economic realities that both shape and, at times, constrain their decisions. In this context, legal frameworks set minimum safety standards and determine liability for non-compliance, while economic realities influence the feasibility of safety measures and the incentives for stakeholders to comply with or circumvent the legal framework.

The work of a fire safety engineer can be constrained by a legal framework that is overly rigid, economically inefficient, or outdated in light of modern construction techniques. Many existing legal frameworks prioritize life safety while often neglecting broader considerations such as economic feasibility, property protection, and business continuity (Vaidogas & Sakenaite, 2011).

Historically, these frameworks have been prescriptive, specifying exact requirements such as material choices or escape route dimensions (Spinardi et al., 2017). However, such prescriptive codes often fail to adapt to the complexities of modern construction, such as the use of lightweight materials, open-plan designs, and sustainable building technologies (Spinardi et al., 2017; Kodur et al., 2019). Additionally, they are not always subject to an objective evaluation of their performance, raising concerns about their real-world effectiveness. For instance, (Chow, 2015) notes that in the Asia-Oceania regions, rapid economic development and innovative architectural designs, such as high-rise and green buildings, frequently fail to comply with traditional prescriptive fire codes, which may indicate the need for a shift toward performance-based design (PBD), enabling engineers to tailor safety solutions to the unique characteristics of a building while balancing regulatory compliance, design flexibility, and economic feasibility (Chow, 2015; Meacham, 2023).

Yet, the transition to PBD introduces its own challenges. (Spinardi et al. 2017) argue that performance-based approaches, while innovative, rely heavily on the competence of engineers and the rigor of oversight, both of which can be compromised by economic pressures and regulatory leniency. The expertise asymmetry between regulators and fire safety engineers, as noted by (Spinardi, 2016), exacerbates these challenges, as regulators often lack the technical knowledge to evaluate complex PBD solutions, leading to reliance on industry-provided data and potential self-regulation risks. In deregulated environments, (Cook and Tailor, 2022) describe a 'climate of imperceptibility,' where performance-based codes and privatized inspections allow developers to conceal unsafe practices—such as installing combustible cladding—behind a façade of compliance. (Chow, 2015) further highlights PBD's potential misuse to cut costs, leading to inadequate design fire values that compromise safety. This underscores the need for rigorous oversight to ensure that PBD achieves its intended safety outcomes without being exploited for economic gain.

Recent highly publicized fire events, such as the Grenfell (London) and Lacrosse (Melbourne) tower fires in the United Kingdom and Australia, respectively, underscore regulatory failures and economic inefficiencies in fire safety (Oswald et al., 2021; Spinardi and Law, 2019; Bell, 2017).[3] These disasters exposed significant shortcomings in building codes, enforcement mechanisms, and economic incentives for compliance. In both cases, cost-cutting measures, coupled with fragmented regulatory oversight and weak enforcement, created catastrophic safety failures.[4] Such incidents highlight the need for a more integrated approach towards the legal framework around fire safety—one that incorporates both legal principles and economic analysis to ensure the legal framework is effective, adaptable, and cost-efficient.

These disasters exemplify how safety cannot be treated as purely a technical issue — it is inherently tied to economic incentives and the effectiveness of legal rules. As (Spinardi et al., 2017; Spinardi and Law, 2019) note, the legal framework around fire safety often lags behind evolving building practices, leaving gaps where risks accumulate unnoticed. Furthermore, (Bell, 2017)[5] highlights how rapid urbanization and the rise of high-rise buildings have outpaced existing construction legislation, leaving cities vulnerable to fire safety failures. For example, (Kodur et al., 2019) highlight that modern construction materials, such as composite panels and increased fuel loads from furnishings, amplify fire hazards in ways that building codes fail to address. Similarly, (Meacham, 2023) emphasizes the overlooked risks in existing buildings, where under-maintenance, illegal modifications, and socioeconomic disparities compound vulnerabilities, particularly for low-income populations. These gaps illustrate the

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[3] (Oswold et al. 2021) frame Grenfell as a symptom of systemic issues within the construction industry, pointing to inadequate regulation, fragmented oversight, and a pervasive culture of prioritizing profit over safety. Similarly, (Spinardi and Law, 2019) frame the Grenfell disaster as a symptom of systemic failings in the UK, including ignorance, indifference, and unclear roles within the construction industry. (Bell, 2017) argues that Australia's construction legislation has struggled to keep pace with rapid urbanization and the proliferation of high-rise residential buildings, a vulnerability starkly illustrated by the Lacrosse fire, where non-compliant materials and inadequate enforcement led to significant safety breaches.

[4] Idem.

[5] NB: for the context of Australia.

need for regulatory frameworks that evolve with technological and societal changes, rather than relying on static or reactionary measures.

The two earlier mentioned disasters have sparked regulatory reforms, yet the literature suggests that reactionary policy shifts often lead to overly prescriptive measures, increasing costs without proportionate safety gains. For example, (Law and Spinardi, 2021) note that the Grenfell disaster prompted a ban on combustible cladding for buildings over 18 meters in the UK, a decision driven more by public outrage than by systematic cost-benefit analysis. They caution that such reactionary policies, while addressing immediate concerns, may impose significant retrofitting costs and disrupt property markets without tackling underlying systemic flaws, such as poor enforcement or inadequate risk assessment (Law & Spinardi, 2021). (Oswald et al., 2021) extend this critique, arguing that Grenfell reflects broader market-driven pressures, where deregulation and cost prioritization erode safety standards across the industry.

Comparatively, the Lacrosse fire in Melbourne revealed similar dynamics. (Cook and Tailor, 2022) detail how privatized building inspections failed to flag the use of non-compliant cladding, enabled by a performance-based code system that lacked sufficient oversight. This incident spurred reforms in Victoria, Australia, but (Bell, 2017) warns that excessively complex regulatory schemes can create compliance confusion, especially for small builders and property owners, who may lack the resources to navigate intricate legal requirements, potentially driving up costs without proportional safety improvements. On the other hand, (Cook and Tailor, 2022), describe a 'climate of imperceptibility',[6] in the case of deregulated performance-based codes combined with privatized inspections which obscure unsafe practices like the use of combustible cladding. Furthermore, (Cook & Tailor, 2022) add that the financialization of housing markets has exacerbated these issues, incentivizing developers to prioritize short-term profits over long-term safety, with legal mechanisms like corporate 'phoenixing'[7] shielding them from accountability. These examples underscore a recurring theme: regulatory responses to fire disasters often oscillate between leniency and over-correction, rarely achieving an optimal balance of safety and economic efficiency. They also reveal a deeper tension: while legal frameworks are designed to enforce safety, economic incentives may not only encourage

[6] NB: also for the context of Australia.

[7] **Corporate phoenixing** refers to the practice where company directors deliberately liquidate a business to avoid paying its debts, then start a new company that continues the same operations, often under a similar name and with the same assets (Cook & Tailor, 2022).

non-compliance but may also drive actors to actively seek out loopholes and exploit regulatory grey areas.

1.1 The Need for an Interdisciplinary Approach

Fire safety engineers are accustomed to thinking in terms of technical risk assessments, material properties, and structural integrity. However, to fully grasp the complexities of fire safety regulation — and to advocate for more effective systems — it's crucial to understand the legal and economic forces that shape those regulations. Law and economics, as an interdisciplinary subdiscipline of both the legal and the economic disciplines, offers valuable insights into how safety rules can be created, enforced, and optimized.

In this context, legal systems define safety requirements, enforcement mechanisms, and liability rules, while economics offers tools to assess the cost-effectiveness of safety measures and predict behavioral responses to incentives (see also: Kornhauser, 2001). Economics also explains why regulation is needed in the first place. In a perfectly efficient market, rational actors would naturally invest in the optimal level of fire safety to protect their interests and we would not want to use the legal system at all (as legal intervention itself also implies a cost). But in reality, several types of market failures could prevent this from happening, creating space for welfare enhancing use of the legal system:

Externalities: Externalities arise when fire risks extend beyond a single property (as Van den Bergh & Visscher, 2008 also note in their analysis of safety law enforcement), affecting neighboring properties and posing broader societal risks, including loss of life, environmental damage, and the strain on public resources such as fire departments and hospitals. Without regulation, builders might underinvest in safety, knowing that some of the costs of a fire will be borne by others (e.g., the public fire department, neighboring properties). (Shavell, 2004; Coglianese, 2020) argue that legal rules can internalize these external costs, forcing actors to account for the broader societal impacts of their decisions.[8]

Information Asymmetries: The complexity of fire safety engineering means that property owners, occupants, and even some regulators often lack the expertise to evaluate safety measures effectively. As a result of this information asymmetry, builders might cut corners to

[8] As an illustration, Shokouhi, 2019 highlights how inadequate fire safety in Iranian residential buildings poses communal risks, particularly in densely built urban areas. These spillover effects underscore the need for strong regulatory oversight to protect broader communities.

reduce costs without the end user realizing the increased risk.[9] The law helps to correct this by setting minimum standards or mandatory information disclosures, while economics helps determine how stringent those standards should be to avoid excessive burdens (see also: Van den Bergh & Visscher, 2008; Pacces & Visscher, 2011). With regards to information asymmetries, current regulations often fail to address critical issues such as ensuring a building's repairability or structural stability after a fire. For example, a business owner may not realize that a fire in their newly constructed multi-story office building could render the entire structure unusable, potentially leading to complete operational shutdown. To mitigate such risks, a regulator could implement targeted interventions aimed directly at reducing information asymmetries. These might include mandatory disclosure requirements that compel developers to provide clear and accessible data on the fire resilience of their buildings, ensuring more informed decision-making.

Public Goods and Free Riding Problem: Fire safety benefits society broadly, but individual actors may underinvest as it is not privately profitable to install safety measures (up to a sufficiently high standard). Besides that, individual actors may expect others to bear the cost. Therefore, without public intervention, this public good is likely to be underprovided.[10] In this context, (Kunreuther, 2006) provides a valuable parallel from disaster mitigation efforts after Hurricane Katrina. He describes the "natural disaster syndrome," a pattern in which individuals and firms underinvest in preventive measures due to underestimated risks and financial constraints, relying instead on insurance or government aid in the aftermath. Applied to fire safety, one could imagine builders may forgo expensive upgrades—like fire-resistant materials—shifting the financial burden to insurers or taxpayers. To address these misaligned incentives, (Kunreuther, 2006) advocates for public-private partnerships, proposing tools such as insurance discounts, linking insurance premiums to mandatory fire safety upgrades or subsidized loans to promote proactive safety investments by distributing mitigation costs across stakeholders. This approach reduces reliance on post-disaster aid and leverages market mechanisms to reinforce legal mandates, aligning private risk management with public safety

[9] Cook and Tailor (2022) illustrate this dynamic in the context of combustible cladding scandals, where developers took advantage of buyers' limited knowledge to install unsafe materials—an issue worsened by weak regulatory transparency in the aftermath of the Grenfell fire. Law and Spinardi (2021) add that the Grenfell Inquiry exposed how reliance on expert intermediaries deepened informational asymmetries, leaving regulators ill-equipped to evaluate conflicting safety claims and highlighting the need for clearer legal mandates.

[10] In this regard, see also (Van den Bergh & Visscher, 2008) who describe safety itself as "a school book example of a public good, even though it may be privatized by offering protection only to people paying for the safety services (club goods)." Hence, "also legal rules on safety have characteristics of public goods" (Van den Bergh & Visscher, 2008).

goals. Finally, Spinardi et al. 2017 add that the socioeconomic distribution of fire risks means wealthier areas may invest more, leaving disadvantaged communities reliant on public intervention to level the playing field.

These market failures highlight why a purely market-driven approach to fire safety is insufficient. Legal rules can correct externalities by imposing liability, reduce information asymmetries through standards and transparency, and ensure public goods provision via mandatory compliance. Economics complements this by offering tools to evaluate the cost-effectiveness of regulations and predict behavioral responses to incentives (Pacces & Visscher, 2011). (Gehandler, 2017) critiques traditional prescriptive fire safety rules for ignoring these economic dynamics, proposing instead a systems-based approach that balances risk reduction with practical costs, informed by interdisciplinary insights. (Maluk et al., 2017) extend this by advocating for fire safety integration across the building design process, suggesting that involving diverse stakeholders can align incentives more effectively than top-down mandates alone.

(Viscusi, 2007)'s work on health and safety regulation underscores the importance of balancing risk reduction against opportunity costs, arguing that overly strict regulations can lead to diminishing returns,[11] while lenient ones can incentivize dangerous cost-cutting practices. (Kunreuther and Heal, 2003) introduce the concept of interdependent security, where individual actors underinvest in safety unless regulatory or market-based mechanisms align incentives. This insight is particularly relevant to fire safety, where decisions made by one builder can have cascading effects on an entire society's risk profile. (Pacces and Visscher, 2011) extend this through behavioral law and economics, suggesting that cognitive biases - like underestimating fire risks - necessitate regulations that account for irrational decision-making. (Wright, 2003) ties this to engineers' legal responsibilities, noting that foreseeability of fire hazards underpins liability, requiring designs that mitigate risks in ways that align with both legal standards and economic rationality. These insights collectively argue for a regulatory approach that not only sets technical standards but also aligns incentives and addresses human behavior.

This paper aims to explore how integrating law and economics into fire safety regulation can enhance both safety outcomes and economic efficiency, because one of the key insights from

[11] There are even studies indicating safety regulations with a net disbenefit to society, see e.g. (Sunstein, 2018; Arnott et al., 2021).

this field is that legal rules can be designed to align individual incentives with societal welfare, thereby addressing market failures and promoting efficient outcomes (Posner, 1977). In the context of fire safety, this means that legal frameworks should be designed to internalize externalities, correct information asymmetries, and ensure the provision of public goods. Furthermore, the concept of efficiency is central to the economic analysis of law. Efficiency refers to the optimal allocation of resources to maximize societal welfare. In the context of fire safety, this means that regulations should be designed to achieve the highest level of safety at the lowest possible cost. This requires a careful balancing of competing interests, such as the need to protect human life and property against the economic costs of safety measures. Finally, efficiency requires also optimal enforcement strategies, balancing sanctions and monitoring costs to maximize compliance without overburdening stakeholders (see also: Van den Bergh & Visscher, 2008).

The hypothesis is therefore that an interdisciplinary approach can identify regulatory failures, promote cost-effective safety innovations, and optimize regulatory systems to empower engineers to design resilient buildings without undue financial burdens. By analyzing fire safety from a law and economics (theoretical) angle, this article will lay the groundwork for further research on the costs and benefits of different regulatory systems, and/or the development of a new regulatory model that balances safety, cost-effectiveness and innovation.

1.2 The Role of the Law and Legal Framework

The legal framework provides the rules and enforcement mechanisms that define and regulate fire safety requirements and responsibilities. First, by establishing fire safety requirements, which broadly refer to the rules and enforcement mechanisms that (implicitly) define adequate levels of fire risk in buildings. These requirements are closely linked to questions of responsibility and liability, which dictate who is accountable for ensuring compliance and who bears the consequences when failures (and resulting damages) occur. In this context, it’s important to note that legal frameworks vary across jurisdictions and encompass both prescriptive and performance-based approaches, each influencing how fire safety is achieved and enforced (Spinardi, 2016; Meacham et al., 2005).

1.2.1 Fire Safety Regulation

What constitutes a fire safety requirement varies depending on jurisdiction and regulatory philosophy. In Belgium (Royal Decree of 7 July 1994[12]), fire safety regulations are highly prescriptive, specifying detailed technical criteria such as minimum fire resistance ratings, compartmentation rules, and evacuation facilities. In contrast, the UK's Building Regulations provide a more performance-based approach, defining fire safety objectives rather than rigid design solutions (Vaidogas & Sakenaite, 2011). This distinction also affects legal accountability (see also: Wright, 2003):

- In a prescriptive system (e.g., Belgium), compliance is primarily a matter of following explicit technical standards, making liability more straightforward—if a design meets the code, legal responsibility is typically limited. However, this does not fully shield actors from liability. Negligence may still be established if, for example, the chosen solution—although technically compliant—was foreseeably inadequate given the specific context, or if the actor failed to account for risks not addressed by the technical standards. Courts may also find negligence where there is a lack of due diligence, failure to update designs in light of new knowledge, or disregard for best practices that go beyond the minimum legal standards. (Wright, 2003) emphasizes that professional negligence, requires engineers to meet the standard of an ordinary skilled professional, meaning that compliance with prescriptive codes may not suffice if new risks, such as those posed by modern materials, are foreseeable.
- In a performance-based system (e.g., UK), liability is more complex, as architects and engineers must prove that their solutions achieve adequate safety. This increases the potential for disputes in case of failure and shifts responsibility from regulators to professionals (Wright, 2003). (Spinardi, 2016) notes that the shift to PBD increases engineers' exposure to liability due to the need to justify their designs against probabilistic fire risks, which are inherently uncertain and difficult to quantify. Finally, (Meacham et al., 2005) note that globally, performance-based building regulations face challenges in defining measurable safety criteria and ensuring accountability, particularly as societal expectations evolve with climate change and urbanization. This flexibility can drive cost-effective innovation in fire safety but risks inconsistent

[12] Royal Decree of 7 July 1994 laying down the basic standards for the prevention of fire and explosion which buildings must meet], Belgisch Staatsblad [Belgian Official Gazette], 31 December 1994.

enforcement, underscoring the need for robust legal frameworks to support PBD's economic benefits.

The legal status of fire safety requirements further complicates matters. Some regulations function as mandatory laws, enforceable with penalties for non-compliance, while others act as guidance documents that offer best practices but allow for deviations if equivalent safety can be demonstrated.

1.2.2 Legal Responsibility and Liability

Legal responsibility in fire safety varies across jurisdictions and depends on the type of regulatory framework in place. Generally, multiple stakeholders can be held responsible for failures and resulting damages (see also: Wright, 2003):

- **Building Owners and Developers** – Often bear primary legal responsibility for ensuring that fire safety measures comply with fire safety regulations. If a fire occurs due to negligence or non-compliance, they may face fines, lawsuits, or criminal charges.[13]
- **Architects and Engineers** – architects and engineers can be held accountable for proving that their fire safety strategies achieve adequate protection. If a fire safety design fails in practice, liability (in the form of professional negligence) may fall on them.[14] In performance-based systems, their role is particularly critical, as they must demonstrate that innovative designs meet safety objectives, increasing their exposure to legal risks (see also: Spinardi, 2016). (Lange et al., 2022) argue that the lack of a standardized accreditation system for fire safety engineers exacerbates these risks, as inconsistent competency levels can lead to design failures and increased liability.
- **Contractors and Construction Firms** – Responsible for properly implementing fire safety measures (i.e. executing designs faithfully, using approved materials). If they use substandard materials or ignore fire codes, they may be liable.[15]

[13] Some examples include: (i.) in the UK, the Regulatory Reform (Fire Safety) Order 2005 mandates owners to mitigate risks proactively (see also: Spinardi & Law, 2019); (ii.) in the U.S., owners of vacant properties face fines up to $1,000/day for fire code violations (see also: Meacham, 2023).
[14] After the Lacrosse fire, architects were sued for approving flammable cladding, despite arguing it met performance goals (see also: Cook & Tailor, 2022)

[15] The Grenfell Tower fire revealed failures related to the use of combustible cladding, placing legal responsibility on contractors as well (see also: Oswald et al., 2021; Law & Spinardi, 2021).

- **Regulators and Authorities** – Government agencies play a supervisory role, ensuring that fire safety regulations are enforced and designs are approved. However, weak enforcement or unclear guidelines can lead to liability gaps, where no single party is fully accountable. Regulatory bodies will rarely be directly liable, but weak oversight invites criticism.[16]
- **Manufacturers and Suppliers** – If a fire disaster is caused, for example, by a defective fire-resistant material or faulty alarm system, liability may extend to the companies that supplied those products, under product liability rules.[17] (Nguyen et al., 2016) emphasize the role of manufacturers in ensuring the fire performance of (façade) materials, noting that incidents like Grenfell highlight the need for stricter product testing and certification to prevent liability disputes.

These varying responsibilities illustrate why legal clarity is essential in a legal framework around fire safety. If roles and liabilities are poorly defined, stakeholders may attempt to shift blame, as seen in the Grenfell Tower fire case, where contractors, architects, building owners, and regulators each deflected responsibility. The complexity of modern construction projects, with multiple layers of subcontracting and fragmented oversight, exacerbates these challenges, making it difficult to pinpoint accountability (Oswald et al., 2021). (McEvoy, 1995) provides a historical parallel with the Triangle Shirtwaist Factory fire of 1911, where unclear accountability and inadequate regulations allowed employers to externalize safety costs, leading to catastrophic losses. This underscores the need for legal frameworks that clearly define responsibilities to prevent such tragedies.

1.2.3 Risk and Insurance

Risk management and insurance play a critical role in risk-based decision making (in general), influencing both compliance and investment in safety measures. Insurance mechanisms can therefore incentivize proactive (fire) safety investments by offering premium reductions for buildings that exceed minimum safety standards (see e.g. Kunreuther, 2006). For example, insurers may provide discounts for properties equipped with sprinkler systems or fire-resistant materials, aligning private incentives with public safety goals (see e.g. Viscusi, 2007). However, insurance markets also face challenges in accurately pricing fire risks, particularly

[16] •E.g. post-Grenfell, the UK's Building Control was faulted for approving unsafe plans without site checks (see also: Spinardi & Law, 2019).
[17] The use of non-compliant cladding materials in high-rise buildings, as seen in Australia, has led to significant financial and legal repercussions for suppliers and manufacturers (see also: Cook & Tailor, 2022).

in regions with high wildfire exposure or aging building stock (Meacham, 2023). (Vaidogas and Sakenaite, 2011) highlight that insurance premiums can be integrated into multi-attribute selection models for fire safety decisions, encouraging investments in systems that reduce both risk and operational costs, such as sprinklers in hospitals.

From a law and economics perspective, insurance can help internalize the externalities of fire risks by distributing costs across policyholders and encouraging risk-reducing behaviors (Coglianese, 2020). For example, (Law, 2021) notes that insurers have increasingly excluded coverage for combustible cladding-related claims, creating market pressure for surveyors to exceed minimum compliance. This exemplifies how liability risks and insurance market dynamics intersect with legal frameworks, potentially incentivizing safer building practices when regulatory enforcement alone is insufficient.

Yet, moral hazard[18] remains a concern, as insured parties may underinvest in safety if they perceive insurance as a substitute for preventive measures (Kunreuther, 2006). To mitigate this, insurers often require compliance with regulations as a condition of coverage, reinforcing the role of legal frameworks in shaping risk management practices (Viscusi, 2007).

Moreover, the economic burden of fire disasters extends beyond insured losses, encompassing uninsured damages, business interruptions, and societal costs such as emergency response and environmental impacts (Kodur et al., 2019). This underscores the need for comprehensive risk management strategies that integrate insurance, regulation, and public investment in fire safety infrastructure (Swan, 2022).

1.3 The Role of Economics

While law defines obligations and accountability, economics helps evaluate whether the legal framework is effective and efficient by analyzing its costs, benefits, and behavioral impacts. (Van den Bergh and Visscher, 2008) stress that enforcement strategies must be economically optimized, balancing deterrence with cost-efficiency. This is particularly pertinent in fire safety, where inspections are infrequent and violations can be concealed until audits occur. In such settings, precautionary strategies like requiring fire certification before occupancy may be more effective than post-incident penalties. In the context of licensing for rental properties, (Samuel

[18] Moral hazard refers to the individual tendency to take on greater risks when one does not bear the full costs of their actions. In the context of (fire) insurance, this means that insured parties may reduce their investment in preventive measures because they expect the insurer to cover losses in the event of a fire, which can undermine overall safety (see also: Botzen & Van Den Bergh, 2008).

et al., 2021) provide a calibrated economic model showing that while licensing and rental property compliance schemes (which typically include fire safety provisions) improve safety, they also raise rents and reduce the supply of low-cost housing. This highlights a critical trade-off in the broader context of (fire) safety regulation: overly stringent or poorly calibrated requirements may reduce building affordability. Fire safety policies must therefore balance cost, feasibility, and public safety, making economic analysis a crucial tool for regulators and engineers.

Some key economic principles relevant to legal frameworks around fire safety include:

Cost-Benefit Analysis (hereafter, "CBA"): Fire safety measures come with costs (e.g., sprinkler installations, fire-resistant construction products), and cost-benefit analyses help determine whether the safety benefits justify their expenses (Van Coile et al., 2023; Vaidogas & Sakenaite, 2011). Therefore, CBA helps policymakers and engineers assess the trade-offs between safety investments and economic feasibility. (Van Coile et al., 2023; Vaidogas & Sakenaite, 2011) demonstrate how CBA can guide decisions about protective measures, helping engineers prioritize interventions with the highest safety returns per dollar spent, avoiding both under- and over-investment. For example, (Van Coile et al., 2023) apply the Present Net Value (hereafter, "PNV") approach in a warehouse case study, demonstrating that optimal compartmentation often yields higher net benefits than excessive measures like combining sprinklers with over-compartmentation. Their analysis supports the idea that well-designed economic models can guide efficient safety design, provided they account for both direct and indirect costs and the value of risk reduction. (Viscusi's, 2007)'s work on risk regulation complements this by emphasizing the concept of opportunity costs, arguing that safety measures must be evaluated not just for their direct benefits but for their broader economic impacts. For instance, mandatory sprinkler systems may be life-saving in high-risk buildings but could impose unnecessary costs in low-risk settings, diverting resources from other valuable safety upgrades.

However, applying CBA to fire safety also comes with its challenges. (Ogus, 1998) highlights the difficulty of predicting compliance levels and assessing counterfactuals—i.e., what would happen without regulation—due to the probabilistic nature of safety risks (such as a fire) and the complexity of human behavior. For instance, regulators must estimate how often building owners will adhere to fire codes, a task complicated by incomplete data on fire incidents and compliance rates (Swan, 2022). (Swan, 2022) further notes that economic evaluations often suffer from underestimated fire losses due to gaps in historical data, making it hard to quantify benefits like averted deaths or property damage. This uncertainty is compounded by the long-term nature of fire safety benefits, which may not materialize for years, as (Vaidogas and Sakenaite, 2011) argue. They suggest that CBA must incorporate probabilistic models to account for rare but catastrophic fire events, ensuring that long-term safety gains justify upfront costs (Vaidogas & Sakenaite, 2011).

Moreover, (Meacham, 2023) adds a societal perspective, noting that CBA must extend beyond private costs and benefits to include public impacts, such as the economic ripple effects of fire disasters on communities—e.g., lost tax revenue or increased healthcare costs. Similarly, (Spinardi and Law, 2019) point out that CBA's effectiveness depends on the regulatory approach: prescriptive rules might inflate costs by mandating uniform solutions, while performance-based regulations could optimize resource allocation by allowing flexibility, though they require robust data to evaluate outcomes. Despite these complexities, should play an important role in (fire) safety policy, ensuring that regulations are neither overly burdensome nor insufficiently protective, as (Pacces and Visscher, 2013) argue in their broader analysis of law and economics methodologies.

Incentives and Market Behavior (Rational Choice Theory): The legal framework influences how businesses and individuals behave. In this regard, the rational choice theory, a cornerstone of law and economics, provides a useful lens for understanding how stakeholders respond to the law. According to this theory, individuals and organizations make decisions based on a rational assessment of costs and benefits: e.g. stronger penalties can deter non-compliance, while financial incentives (e.g., insurance discounts for safer buildings) can encourage proactive fire safety investments. (Hirshleifer, 2001) explores how penalties and rewards influence compliance, noting that well-calibrated financial penalties can deter unsafe practices, while tax incentives or subsidies can encourage proactive safety investments. (Viscusi, 1985) cautions that fire safety regulations, such as flammability standards for carpets, can yield unintended economic consequences if behavioral responses—such as reduced vigilance—are ignored. His analysis of the US Consumer Product Safety Act[19] reveals that safety benefits may be overstated without accounting for these offsets, urging a more dynamic cost-benefit approach that integrates human behavior into economic models. This literature suggests that poorly designed incentives can backfire — for example, excessively punitive liability laws may

[19] Consumer Product Safety Act, Pub. L. 92-573, § 2(a) and § 15(a), 86 Stat. 1207, 1221 (1972) (codified at 15 U.S.C. § 2064(a) (1982).

discourage builders from adopting innovative materials or designs, even when those innovations could enhance safety.

Externalities: Fire safety decisions impact not just individual building owners but also society at large. If one property lacks proper fire protection, neighboring buildings may be at higher risk. The legal framework must account for these broader societal costs.

By integrating law and economics, the legal framework around fire safety can be made more effective, adaptable, and economically sound, considering both safety outcomes and economic trade-offs. This paper argues that such integration is essential for creating a more adaptable, effective, and economically sound fire safety framework, providing appropriate incentives for fire safety engineers to make informed, balanced decisions in their practice. Hence, this article aims to: (i.) introduce Law and Economics as a research methodology and its relevance for fire safety engineers; (ii.) discuss current challenges in legal frameworks around fire safety, including regulatory gaps, inefficiencies, and their impact on fire safety engineers; (iii.) explore how law and economics principles can enhance legal frameworks around fire safety, particularly in incentive design, cost-benefit analysis, and risk allocation; (iv.) make suggestions for a novel regulatory framework that integrates economic efficiency with legal adaptability, improving fire safety outcomes while maintaining financial feasibility (i.e. a modernized fire safety regulatory framework informed by law and economics).

2 The Model. Theme: Challenges in Current Legal Frameworks around Fire Safety

Fire safety regulations aim to mitigate the risks of fire-related losses, yet their structure might have implications for economic efficiency. This subsection develops a formal economic model to compare various regulatory approaches, focusing on the decision-making of builders or fire safety engineers (hereafter, “the decision-maker”) and the resulting (in)efficiencies.

2.1 Prescriptive Rules versus PBD Rules: Investment, Innovation and Enforcement.

As discussed in Section 1, prescriptive fire safety regulations mandate specific safety measures, such as the thickness of fire-resistant walls or the number of exits, providing a clear compliance path but often at the expense of flexibility. PBD regulations, by contrast, specify safety outcomes (e.g., maximum allowable fire spread or evacuation time) and allow decision-makers to determine how to achieve them. This flexibility creates potential for aligning safety investments with economic efficiency.

Model setup. Consider a decision-maker who selects a fire safety investment level $I \geq 0$ to minimize the total expected costs from fire:

- **Direct Costs**: Investment on safety measures, denoted I (e.g. sprinklers, fireproofing).
- **Expected Loss**: $\rho(I)\cdot L$, where:
  - $\rho(I)$ is the probability of loss from a fire incident, assumed decreasing ($\rho'(I) < 0$) and convex ($\rho''(I) > 0$), and
  - L is the actual loss if a fire incident occurs (e.g. property damage, liability, etc.).

Thus, the total cost function is:

$$C(I) = I + \rho(I)\cdot L$$

Assume the loss from a fire incident probability follows:

$$\rho(I) = \frac{k}{I+a}$$

where $k > 0$ is baseline risk and $a > 0$ captures inherent safety (even without investment), satisfying convexity and ensuring $\rho'(I) = -\frac{k}{(I+a)^2} < 0$ and $\rho''(I) = \frac{2k}{(I+a)^3} > 0$, capturing diminishing returns to investment.

Optimal investment (I^*) under PBD Rule. Under a PBD rule, the decision-maker minimizes:

$$C(I) = I + \frac{kL}{I + a}$$

First order condition:

$$\frac{dC}{dI} = 1 - \frac{kL}{(I + a)^2} = 0 \Rightarrow I^* = \sqrt{kL} - a$$

This solution is feasible only if $\sqrt{kL} > a$.
The minimized cost is:

$$C(I^*) = I^* + \frac{kL}{I^* + a} = 2\sqrt{kL} - a$$

Prescriptive Rule. Prescriptive rules mandate investment $I = I_{pr}$, yielding cost:

$$C_{pr} = I_{pr} + \frac{kL}{I_{pr} + a}$$

If $I_{pr} \neq I^*$, then a deadweight loss (DWL) arises:

$$DWL = C_p - C(I^*)$$

Numerical example. Let $k = 1, a = 1 , L = 100$:

- Optimal Investment: $I^* = \sqrt{100} - 1 = 9$
- Minimum Cost: $C(I^*) = 9 + \frac{1}{10} \cdot 100 = 19$

Prescriptive investment scenarios:

- If $I_{pr} = 10$, then $C_{pr} = 10 + \frac{1}{11} \cdot 100 \approx 19.09 \Rightarrow DWL \approx 0.09$

- If $I_{pr} = 8$, then $C_{pr} = 8 + \frac{1}{9} \cdot 100 \approx 19.11 \Rightarrow DWL \approx 0.11$

These small deadweight losses illustrate how even modest over- or underinvestment relative to I^* can increase total costs without proportional safety gains.

Innovation Incentives. PBD rules can encourage innovation by allowing decision-makers to optimize not only the level of investment I but also the methods by which safety is achieved. Suppose the decision-maker can exert an innovation effort $b \geq 0$ (e.g., through design improvements or new technologies) that enhances fire safety. Innovation effort b represents actions such as design improvements or adoption of new fire suppression technologies, which shift the fire risk curve downward. By investing in b, the decision-maker effectively increases the efficiency of every unit of investment I. This modifies the fire probability function to:

$$\rho(I) = \frac{k}{I + a + b}$$

The cost of innovation is modeled as: $c(b) = b^2$

which is increasing and convex, reflecting rising marginal effort or expense.

The total cost function becomes:

$$C(I, b) = I + b^2 + \frac{kL}{I + a + b}$$

The decision-maker now minimizes $C(I, b)$ jointly over I and b. Compared to the baseline model without innovation, the optimal solution yields:

- A positive level of innovation ($b^* > 0$),
- A higher combined safety effort ($I + b$),
- And a lower total cost.

In contrast, under a prescriptive rule where the investment level is fixed at $I = I_{pr}$, innovation loses much of its economic value. Unless I_{pr} is adjustable - which in practice is not realistic as it would require time-consuming legislative amendments - the fixed nature of prescriptive codes constrains adaptive innovation, potentially leading to higher costs or forgone safety improvements.

Enforcement. Enforcement costs differ across regulatory approaches.[20] Under prescriptive rules, enforcement typically involves straightforward material checks or code compliance audits, denoted E_{pr}. In contrast, PBD rules require more complex and costly verification, such as fire simulations or real-scale testing, denoted E_{pb}, where:

$$E_{pb} > E_{pr}$$

[20] Note that Enforcement costs (E) reflect both cost and institutional capability (i.e. some regulators may not be able to enforce complex enforcement schemes such as a PBD rule, even if they're efficient in theory).

Let the social cost include:

- Investment (I),
- Expected loss from a fire ($\rho(I) \cdot L$), and
- Enforcement cost (E).

Then, total social welfare is defined as:

$$W(I) = -[I + \rho(I) \cdot L + E]$$

- **PBD Rule**: Under a PBD rule, the decision-maker chooses investment I^* to minimize private costs, which aligns with the social optimum under ideal conditions. Social welfare is:

$$W_{pb} = -[I^* + \rho(I^*) \cdot L + E_{pb}]$$

- **Prescriptive Rule**: Under a prescriptive rule, investment is fixed at I_{pr}. Social welfare becomes:

$$W_{pr} = -[I_{pr} + \rho(I_{pr}) \cdot L + E_{pr}]$$

If $I_{pr} = I^*$, the only welfare difference is due to enforcement costs. Since $E_{pb} > E_{pr}$, the prescriptive regime could yield higher welfare in purely homogeneous settings.

However, buildings vary significantly in their characteristics (which implies varying k, a, L). These differences suggest that a uniform prescriptive investment level (I_{pr}) may not always be well-suited across all contexts. In such cases, PBD rules, by enabling tailored investment decisions $I^*(k, a, L)$, could offer better alignment with actual risk and potentially improve efficiency, even if it involves higher enforcement costs.

2.2 Impact on Decision-makers: Innovation vs. Liability

The choice of regulatory and legal framework has direct consequences on the incentives faced by decision-makers. Legal liability, in particular, determines how much effort decision-makers will invest in ensuring fire safety and whether they will innovate or play it safe. We now examine three liability frameworks – Strict Liability, Negligence Based on Compliance with Code, and Negligence Based on Due-Diligence—each in terms of (i) the induced cost function, (ii) the investment incentive, and (iii) the scope for innovation.

2.2.1 Strict Liability (SL)

Under strict liability, the decision-maker is always held responsible for any losses L as a result of a fire, regardless of whether they followed regulations or acted reasonably. Their only way to avoid liability is to reduce the likelihood of losses as a result of fire altogether.

That is, liability probability equals the actual physical failure probability, which declines with increased investment *I*. The decision-maker minimizes:

$$C_{SL}(I) = I + \rho(I) \cdot L = I + \frac{KL}{I + a}$$

Minimizing C_{SL} yields the familiar first-order condition $1 - \frac{KL}{(I+a)^2} = 0$,

with interior optimum $I^* = \sqrt{kL} - a$.

Thus, strict liability perfectly aligns private incentives with the social optimum I^*, provided decision-makers are risk-neutral. However, any untested design carries uncertain $\rho(I)$ and thus full liability if it fails. Hence, decision-makers may become risk-averse and tend to "play it safe" with proven, low-risk measures, even at higher cost and regardless of whether (innovative/alternative) designs could offer superior safety or cost-effectiveness.

2.2.2 Negligence Based on Compliance with Code (NC)

Under this regime, decision-makers are only liable if their safety investment exceeds a legally prescribed minimum standard, I_{code}. If their investment falls below this threshold, they are deemed negligent and liable for the full loss *L* if a fire occurs. The expected cost function is:

$$C_{NC}(I) = \begin{cases} I, & I \geq I_{code,} \\ I + \rho(I) \cdot L, & I < I_{code.} \end{cases}$$

If the unconstrained optimum $I^* < I_{code}$, the decision-maker will invest exactly I^*, since any larger *I* raises cost without further liability reduction. Conversely, if $I^* \geq I_{code}$, the decision-maker invests I_{code}, thereby minimizing cost while escaping liability. In the latter case, however, fixing $I = I_{code}$ may generate deadweight loss whenever $I_{code} \neq I^*$:

$$DWL = I_{code} + \rho(I_{code}) \cdot L - I^* + \rho(I^*) \cdot L$$

The decision-maker meets I_{code} to avoid liability, but has no incentive to exceed it, even if additional investment could further reduce $\rho(I)$. Strict adherence to I_{code} discourages innovation. Deviating from the code (e.g., adopting a new technology) risks non-compliance and liability, even if it lowers $\rho(I)$. For example, a novel fire suppression system might not align with code specifications, deterring its adoption unless explicitly permitted.

2.2.3 Negligence Based on Due Diligence (ND).

Under this regime, liability depends on whether the decision-maker exercised reasonable care, as judged by professional standards rather than a fixed threshold. Here, courts assess liability based on whether the decision-maker exercised the care of a reasonably skilled professional. Now the decision-maker trades off safety investment against a gradual reduction in liability risk.

We capture this by introducing a negligence probability $\lambda(I)$ that declines with investment. Assume $\lambda(I) = e^{-bI}$ (where $b > 0$), so the probability of being found negligent decreases exponentially with investment, reflecting that higher effort aligns with professional standards of care. The resulting private cost function is:

$$C_{ND}(I) = I + \rho(I) \cdot \lambda(I) \cdot L = I + \frac{kL}{I + a} \cdot e^{-bI}$$

The first-order condition,

$$1 - \frac{kL}{(I + a)^2} e^{-bI} - \frac{kLb}{(I + a)} e^{-bI} = 0$$

balances the marginal cost of investment against the marginal benefits of reducing both the fire probability and the liability risk. Furthermore, this suggests a higher optimal I than under strict liability, as reducing liability incentivizes extra effort. Crucially, because design that demonstrably lowers either $\rho(I)$ or $\lambda(I)$ can reduce expected liability, the flexibility of this regime therefore allows for the adoption of new technologies, PBD or context-specific risk management, provided it meets a reasonable standard of care, fostering innovation over strict compliance with codes.

2.2.4 Liability Regimes: Comparative Perspective.

Summarizing, the design of liability regimes critically shapes the behavior of decision-makers in fire safety. In particular, it influences how much they invest in risk mitigation and whether they are inclined to innovate or conform to established practices.

- **Strict Liability** fully internalizes the risk of loss as a result of fire, thereby aligning private and social investment incentives. However, it discourages innovation due to uncertainty around the failure probability of novel approaches. In effect, the incentive to innovate is significantly reduced by the risk of full liability if a non-traditional solution fails—even if it is, in expectation, superior.

- **Negligence Based on Compliance with Code** simplifies enforcement and ensures minimum safety standards by requiring compliance with a legally fixed threshold I_{code}. However, it creates a discontinuity in liability: small deviations below I_{code} trigger liability, while investments above yield no added protection. This "cliff effect" distorts incentives whenever $I_{code} \neq I^*$, potentially leading to over- or under-investment and suppressing innovation that falls outside codified norms.
- **Negligence Based on Due Diligence** introduces a smoother liability gradient: higher I progressively lowers both fire related losses and liability risk, encouraging decision-makers to invest beyond the social optimum if warranted by liability considerations, and to innovate so long as they can demonstrate adherence to the evolving standard of care. This regime thus best aligns efficiency with innovation — provided that professional standards are sufficiently clear and consistently enforced, but may lead to overinvestment $I > I^*$.

Aspect	**Strict Liability (SL)**	**Negligence Based on Code Compliance (NC)**	**Negligence Based on Due Diligence (ND)**
Investment Incentive	Aligns with social optimum I^*; decision-makers minimize total expected cost $I + \rho(I) \cdot L$	Decision-makers invest at least I_{code}; no incentive to exceed it	Smooth incentive to reduce both fire risk $\rho(I)$ and liability risk $\lambda(I)$; may lead to overinvestment $I > I^*$
Liability	Always liable based on actual losses	Liable only if $I < I_{code}$	Liable if investment falls below standard of care
Risk Allocation	Full burden on decision-maker; could lead to excessive caution or avoidance	Risk shifted to others once code is met; can create moral hazard if I_{code} is set too low, as decision-makers have no incentive to exceed the minimum standard	Risk shared dynamically based on professional judgment
Innovation Incentive	Low: uncertainty around $\rho(I)$ for new designs leads to risk aversion	Very low: deviation from code risks non-compliance and liability	High: innovation allowed if demonstrably safe and professionally justifiable
Efficiency	High under ideal conditions; may lead to over-caution in practice	Varies: efficient only if $I_{code} = I^*$, otherwise deadweight loss	Generally high, with flexibility to adjust to context; depends on clarity of professional

			standards/quality of oversight
Practical Suitability	Effective in high-risk or catastrophic loss scenarios; favors proven designs	Suitable for low-complexity or standardized projects; poor fit for PBD	Best suited for PBD and dynamic risk environments; requires competent oversight

2.3 Regulatory Gaps and Inconsistencies

The cost-minimization model discussed above assumes a single regulatory regime. However, in practice, fire safety requirements vary across jurisdictions, leading to fragmented compliance obligations. These regulatory gaps or inconsistencies introduce additional costs, particularly for stakeholders operating across multiple regions.

Recall that under a unified regulatory regime, the total cost of fire safety investment is given by $C(I) = I + \rho(I) \cdot L$. Suppose now that the decision-maker must comply with two non-aligned regulatory systems, for example in Region A and Region B, each requiring different documentation, inspections, or technical standards.

Let:

- I_A and I_B be the safety investments required to comply with each region's code.
- ϕ represent duplicated compliance costs, such as retraining, redesign, or dual certification ($\phi > 0$).

The total cost becomes:

$$C_{fragmented} = I_A + \rho(I_A) \cdot L + I_B + \rho(I_B) \cdot L + \phi$$

Even if the two investments are identical in magnitude (i.e. $I_A = I_B = I$), the duplication term ϕ increases total cost beyond the unified baseline[21]:

$$C_{fragmented} = 2[I + \rho(I\,) \cdot L] + \phi > C(I)$$

This expression captures the efficiency loss from regulatory inconsistency. Without harmonization, firms face higher direct and indirect costs, discouraging investment and

[21] E.g. due to redundant audits, certification, or incompatible documentation.

reducing compliance incentives - particularly in jurisdictions with weaker enforcement or higher regulatory uncertainty.

In contrast, under regulatory harmonization, compliance requirements are aligned, allowing for:

- Economies of scale in training and certification,
- Lower transaction costs in design and verification,
- Reduced uncertainty about liability across regions.

The harmonized cost function returns to the original single-regime form:

$$C_{harmonized} = I + \rho(I) \cdot L$$

The difference $\Delta C = C_{fragmented} - C_{harmonized}$ represents the cost savings from coordination. From a policy perspective, this underscores the economic rationale for harmonizing building codes across regions - such as through mutual recognition agreements, standard definitions of risk, or interoperable performance metrics. By reducing duplication, harmonization improves both economic efficiency and overall fire safety outcomes.

3 Conclusion

This article has demonstrated that the integration of law and economics into the fire safety discipline offers a pathway to remedy regulatory failures and to strengthen the discipline's overall impact. By applying economic analysis to legal frameworks around fire safety, we reveal how incentives shaped by liability rules and regulatory design influence stakeholder's behavior—insights that fire safety engineers and other stakeholders can leverage to balance safety objectives, innovation, and cost constraints.

Our central proposition is that law and economics provide powerful tools for understanding and reshaping the incentives embedded in legal frameworks around fire safety. Rigid, prescriptive standards often lead to over- or under-investment in preventive measures, while performance-based approaches, can align private incentives with socially optimal safety outcomes. Furthermore, an optimally calibrated liability standard can incentivize decision-makers in fire safety design to internalize the social costs of fire risk, thereby driving them toward efficient levels of prevention without imposing unnecessary costs.

By combining these two elements, we argue that a hybrid legal architecture—combining clear, outcome-focused performance standards with a liability regime that dynamically reflects risk externalities—achieves three complementary goals. First, it ensures effectiveness by aligning private incentives with socially optimal safety outcomes, since decision-makers bear the true cost of risk reduction. Second, it promotes efficiency by channelling resources toward the most cost-effective preventive innovations rather than compelling compliance with potentially obsolete standards. Third, it enhances adaptability, allowing the regulatory system to accommodate novel materials, emerging technologies, and shifting risk profiles without the need for continual, detailed code amendments.

While this article lays the conceptual groundwork, several avenues merit further exploration. Future research could for example:

1. develop case studies illustrating the application of law and economics integration in real-world settings to offer practical illustrations to guide both policymakers and practitioners;
2. refine and validate a proposal for a new legal framework, as inspiration for policymakers;
3. realize further empirical validation through empirical testing of the model section's predictions;
4. Examine how insurers price fire risk under differing regulatory and liability regimes to reveal additional market-based levers for safety promotion.

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