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SPECIAL SECTION

TRAGEDY OF THE COMMONS, CIVIL DRONES AND HYBRID MODES OF TECHNOLOGY REGULATION: A COMPARATIVE LAW AND ECONOMICS PERSPECTIVE

Abstract

This paper provides a multidisciplinary assessment of the growing use and importance of civil drones, evaluates the related problem of the commons, and seeks to assess its impact on the research & development processes in companies that develop or employ civil drones in their daily operations. Recommendations are given to ensure optimal regulatory intervention covering potential, uncontemplated automated civil drone-related hazards. If it evolves in ways not intended by its designers or users, the judgement-proof automated civil drone could create unforeseeable losses wherever current tort and contract law regimes do not ensure optimal risk internalisation and precaution, while also not deterring opportunism. Moreover, it is argued in the paper that the identified shortcomings mean the debate on the different approaches to controlling hazardous activities boils down to the question of efficient ex ante safety regulation and allocation of property rights (resembling those in the aviation industry). Hybrid modes of regulation are also investigated with a focus on the inclusive growth of the AI-drone industry in the EU and a set of economically informed normative suggestions is presented for an improved hybrid regulatory response, which should achieve optimal risk internalisation, precaution, and firm-level innovation.

JEL CLASSIFICATION: C23, C26, C51, K42, O43

SUMMARY

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** The author acknowledges financial support from the Slovenian Research Agency (research core funding No. P5-0128).

DOI 10.13135/2785-7867/10741

1 Introduction

Drone use around the world skyrocketed off in recent years, bolstered by rapid technological innovations, business needs, and societal changes. Nowadays, people have become used to seeing small, unmanned aircraft flying above city streets, local fields, touristic harbours, beaches and residential and commercial properties, and very soon autonomous AI-operated drones[1] will be able to automatedly take off, fly, and land virtually anywhere using real-time data. As of February 2024, 375,226 commercial drones and 400,858 recreational drones were registered in the USA alone.[2] The global commercial drone market size was estimated at USD 19.89 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 13.9% from 2023 to 2030.[3] Drones' employability in military, scientific, leisure and commercial uses and their capability to deliver packages and transport goods more efficiently and quickly than ever before are revolutionising our everyday way of life.[4]

Snead and Siebler stress that drones are one of many emerging technologies that can legitimately be both celebrated and feared.[5] Clark reports that there is an increasing regulatory activity and that "several governments have already introduced specific drone regulations" and, for example, "banned drone flights over selected facilities and locations

[1] Autonomous drones are unmanned aerial vehicles (UAVs) that operate using Artificial Intelligence (AI)-powered navigation and operational software, and do not require a human pilot. An autonomous drone is able to conduct a safe flight without the intervention of a pilot. It does so with the help of artificial intelligence, enabling it to cope with all kinds of unforeseen and unpredictable emergency situations. This is different from automatic operations, where the drone flies pre-determined routes defined by the drone operator before starting the flight. For this type of drone, it is essential for the remote pilot to take control of the drone to intervene in unforeseen events for which the drone has not been programmed. See for example Dario Floreano, and Robert Wood, 'Science, Technology and the Future of Small Autonomous Drones' (2015) 521 Nature 460; and Patrick Fabiani, Vincent Fuertes, Alain Piquereau, Roger Mampey and Florent Teichteil-Königsbuch, 'Autonomous Flight and Navigation of VTOL UAVs: from Autonomy Demonstrations to Out-of-sight Flights' (2007) 11 (2-3) Aerospace Science and Technology 183.

[2] Federal Aviation Administration, *Drones by the Numbers* (United States Department of Transportation, 2024). The annual Drone Market Report by Drone Industry Insights, published in August 2023, predicts a global drone market size of USD 54.6 billion by 2030, with the commercial market growing at a 7.7% CAGR. These commercial CAGR figures are 0.1% lower than in the same study in the previous year; Drone Industry Insights, *Global Drone Market Report 2023-2030* (Drone Industry Insights 2023).

[3] Market Analysis Report, *Commercial Drone Market Size, Share & Trends Analysis Report by Product, by Application, by End-use, by Propulsion Type, by Range, by Operating Mode, by Endurance, by Region, and Segment Forecasts, 2023 - 2030* (Grand View research 2023).

[4] See eg, Panagiotis Radoglou-Grammatikis, Panagiotis Sarigiannidis, Thomas Lagkas, and Ioannis Moscholios, 'A Compilation of UAS Applications for Precision Agriculture' (2020) 172 Computer Networks 107148; Jake McRae, Christopher Gay, Brandon Nielsen, and Pieter Hunt, 'Using an Unmanned Aircraft System (Drone) to Conduct a Complex High-Altitude Search and Rescue Operation: A Case Study' (2019) 30(3) Wilderness & Environmental Medicine, 287 and Dante Tezza, and Marvin Andujar, 'The State-of-the-Art of Human–Drone Interaction: A Survey' (2019) 7 IEEE Access 167438.

[5] John Snead and Jonathan Seibler, *The FAA Drone Registry: A Two-Month Crash Course in How to Over-criminalize Innovation* (The Heritage Foundation 2016).

in support of national security and people's safety."[6] It must be noted that drones are today categorised as aircraft and thus fall within the regulatory framework that governs aircraft.[7] Legislators, landowners and businesses are exploring their future roles in the commercialisation of low-altitude airspace. Nevertheless few, if any, theories of airspace rights and economic regulation have generated a viable legal, economic and regulatory framework that balances the often-competing business imperatives of a robust drone economy, the property rights of landowners, safety, and the interests of local governments.

Dor and Hoffman, for example, focus on unsettled questions of airspace property rights and argue that landowners should exclusively own and control the "superadjacent", low-altitude airspace directly above their land, and should be free to commercialise and sell access to their private airspace, or to prohibit drones from entering it.[8] Namely, in the U.S. the Supreme Court in the famous Causby case[9] adopted a middle ground theory where landowners own all the "superadjacent" airspace above their property, and an invasion of that airspace should be treated as if an actual invasion of the surface has occurred.[10] The U.S. Supreme Court did not determine the precise limits of this "superadjacent" airspace—all that was certain was that it fell somewhere between the eighty-three feet (12m) above ground where the Causbys' property had been invaded and the 500-foot (150m) minimum safe altitude of flight where public navigable airspace in the U.S.

[6] See eg, Robert Clarke, 'Understanding the Drone Epidemic' (2014) 30 (3) Computer Law & Security Review 230. See also Benjamin Harber, 'Eyes in the Sky: Constitutional and Regulatory Approaches to Domestic Drone Deployment' (2014) 64(1) Syracuse Law Review; Katharine Suominen, 'The Planet of the Drones: Comparing the Regulation of Commercial Drones in the United States and the United Kingdom' (2016) 29 (2) New York International Law Review 37; and Timothy Ravich, 'A Comparative Global Analysis of Drone Laws: Best Practices and Policies' in Bart Custers (ed), *The Future of Drone Use. Opportunities and Threats from Ethical and Legal Perspectives.* Information Technology and Law Series Vol 27 (T.M.C. Asser Press 2016).

[7] In the addition to all other legislation that governs any product such as contractual and third-party liability rules, insurance, security and environmental laws, GDPR and AI regulation that apply to civil drones as a type of aircraft.

[8] Lavi Ben Dor and Jonathan Hoffmann, 'The Emerging Airspace Economy: A Framework for Airspace Rights in the Age of Drones' (2022) 4 Wisconsin Law Review 953. See also Sarah Kreps, *Drones: What Everyone Needs to Know* (Oxford University Press 2016); and Ella Atkins , Anibal Ollero and Anonios Tsourdos, *Unmanned Aircraft Systems* (Wiley 2016).

[9] *United States v. Causby* [1946] US 60, [1946] 328 U.S. 256.

[10] The Court stated: "We have said that the airspace is a public highway. Yet it is obvious that if the landowner is to have full enjoyment of the land, he must have exclusive control of the immediate reaches of the enveloping atmosphere. Otherwise buildings could not be erected, trees could not be planted, and even fences could not be run. The principle is recognized when the law gives a remedy in case overhanging structures are erected on adjoining land. The landowner owns at least as much of the space above the ground as he can occupy or use in connection with the land. The fact that he does not occupy it in a physical sense—by the erection of buildings and the like—is not material. As we have said, the flight of airplanes, which skim the surface but do not touch it, is as much an appropriation of the use of the land as a more conventional entry upon it. . . . The reason is that there would be an intrusion so immediate and direct as to subtract from the owner's full enjoyment of the property and to limit his exploitation of it. While the owner does not in any physical manner occupy that stratum of airspace or make use of it in the conventional sense, he does use it in somewhat the same sense that airspace left between buildings for the purpose of light and air is used. The superadjacent airspace at this low altitude is so close to the land that continuous invasions of it affect the use of the surface of the land itself. We think that the landowner, as an incident to ownership, has a claim to it and that invasions of it are in the same category as invasions of the surface;" ibid 264, 68.

begins.[11] Several subsequent cases made clear that landowners in the U.S are entitled to the exclusive control and ownership of the low-altitude airspace they seek, or could potentially seek, to use or enjoy above their land, and that they must be compensated fair market value for any overflights in that airspace.[12] More recently, the U.S. Supreme Court held in Cedar Point Nursery case that a California law requiring certain agricultural employers to permit union organisers (who are private entities) onto their property for certain periods of time every year constituted a per se physical taking.[13] The Court reasoned that the regulation "appropriate[d] for the enjoyment of third parties the owners' right to exclude," one of the "most treasured" rights belonging to a property owner.[14] Dor and Hoffmann also predict the emergence of a marketplace for parties to buy, sell and lease valuable airspace to accommodate drone delivery such that companies like Amazon or Walmart will compensate landowners, or even governments that own city streets and highways, for the airspace where drones will one day fly.[15] In addition, they argue that so as to effectuate that marketplace the FAA must redefine the public "navigable airspace" for it to lawfully regulate drone flight paths below 150 metres.[16]

Hodgkinson and Johnston state that one of the key challenges for lawmakers is to regulate drones in a way that allows society to reap the benefits of drones while simultaneously preserving the privacy, safety, and security of individuals.[17] For example, the Australian aviation safety regulator has made progress in establishing a regime that balances safety and usability by introducing a new category of drones below 2 kilograms

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[11] The Court expressly confirmed that landowners have a "paramount and exclusive right to exercise the prerogatives of ownership in all of the airspace" that they possess, "or can effectively possess" in the future, and in any further amount of valuable airspace necessary to ensure full enjoyment of the property. "[T]he practical effect . . . [was] to constrict the landowner's rights within the boundaries of reason, or to put it another way, within the boundaries of value;" ibid 263, 65.

[12] See eg *Griggs v. County of Allegheny* [1962] 369 U.S. 84 [1962]; *Branning v. United States* [1986] 654 F.2d 88 Ct. Cl. 1981 [1986]; and *Brown v. United States*, [1996] 73 F.3d 1100 [1996]. See also Lindsey P Gustafson, Arkansas Airspace Ownership and the Challenge of Drones (2017) 39 (2) University of Arkansas at Little Rock Law Review 245, 270, 273.

[13] *Cedar Point Nursery v. Hassid* [2021] 141 S. Ct. 2063 [2021]. See also *Loretto v. Teleprompter* [1928] Manhattan CATV Co., 458 U.S. 419 [1928].

[14] Cedar Point case makes clear that granting UAS operators carte blanche to invade landowners' superadjacent airspace would, absent just compensation to the landowner, constitute an unconstitutional taking; Dor and Hoffman (n 8) 980.

[15] Dor and Hoffmann (n 8) 953. See also Roger Clarke (n 6) and Mostafa Hassanalian and Abdessattar Abdelkefi, 'Classifications, Applications and Design Challenges of Drones: A Review' (2017) 91 Progress in Aerospace Sciences 99, 107.

[16] They also call for the division of airspace into four distinct regions, with different rights and responsibilities for those operating in each domain; ibid.

[17] David Hodgkinson and Rebecca Johnston, *Aviation Law and Drones: Unmanned Aircraft and the Future of Aviation* (Routledge 2017). See also Bart Custers (ed), *The Future of Drone Use: Opportunities and Threats from Ethical and Legal Perspectives* (T.M.C. Asser Press The Hague 2016); Brian F Havel, and John Q Mulligan, "Unmanned Aircraft Systems: A Challenge to Global Regulators" (2016) 65(1) DePaul Law Review 107; and Henry Perritt and Eliot Sprague, *Domesticating Drones: The Technology, Law and Economics of Unmanned Aircraft* (Routledge 2016).

for commercial use that does not require the operator to hold a licence.[18] As to the liability issue, Hodgkinson and Johnston suggest that the drone operator shall be liable for damage sustained by third parties only upon the condition that the damage was caused by a drone in flight.[19] Watson argues that a combination of a state law that clarifies landowners' property rights "by focusing on proxies that measure ever smaller classes of uses", such as the further delineation of landowners' rights based on their location and governance rules through municipal drone zoning ordinances, may increase efficiency by filling in the gaps not currently addressed by the common law aerial trespass doctrine.[20] Most of other scholarly literature focuses on drones' potential impact on privacy rights, tort claims, and criminal evidence gathering.[21]

This paper joins this critical debate and takes a law and economics perspective while focusing on the issue of liability and property rights held by individual property owners and the use of automated civil drones by various stakeholders in the EU.[22] Compared to the mentioned literature on the employment of civil drones and associated issues of property rights, this paper attempts to show that the combined problem of prohibitively high transaction costs and tragedy of the commons phenomena might make the operation of classic property and contract law instruments (eg, trespassing and contracting between the owners of a given space and drone operators) inadequate for addressing the rising use of automated civil drones and for not inhibiting drone-linked R&D processes in companies. While employing the relevant insights from the economic literature on regulatory techniques, in addition to the already mentioned literature this paper also sets out recommendations to ensure improved regulatory intervention covering potential, uncontemplated civil drone-related hazards. The paper also argues that the identified shortcomings mean the debate on the different approaches to controlling hazardous activities in fact boils down to the question of efficient ex ante safety regulation and allocation of property rights (akin to those in the aviation industry). Further, it investigates hybrid modes of regulation with a focus on the inclusive growth of the civil drone industry in the EU and outlines a set of normative suggestions for an improved hybrid regulatory response, which should achieve optimal risk internalisation, precaution, and

[18] Commercially Unmanned Flight – Remotely Piloted Aircraft Under 2 kg (2 November 2017) Civil Aviation Safety Authority https://www.casa.gov.au/standard-page/commercial-unmanned-flight-remotely-piloted-aircraft-under-2kg accessed 10 June 2024.

[19] They also suggest that states should require their drone operators to maintain adequate insurance or guarantee covering their liability; Hodgkinson and Johnston (n 17) 106.

[20] Tyler Watson, 'Maximizing the Value of America's Newest Resource, Low-Altitude Airspace: An Economic Analysis of Aerial Trespass and Drones (2020) 95 (4) Indiana Law Journal 1399, 1434.

[21] See eg Hillary Farber, 'Keep Out! The Efficacy of Trespass, Nuisance and Privacy Torts as Applied to Drones' (2017) 33 Georgia State University Law Review 359; Hillary Farber, 'Eyes in the Sky: Constitutional and Regulatory Approaches to Domestic Drone Deployment' (2014) 64 (1) Syracuse Law Review 13; and Troy Rule, 'Airspace in an Age of Drones' (2015) 95 Boston University Law Review 155, 158.

[22] It focuses merely on civil drones since a comparison with the military sector might due to its specific features (natural security issues, defence policy etc) fall outside the scope of this paper.

firm-level innovation. The regulatory regime should namely help the unmanned civil drone flight industry flourish by adopting an approach that ensures airspace safety while respecting landowners, drone operators, and the public alike and by recognising the value of both EU and local oversight of the skies.

The analysis presented here is both positive and normative. The analytical approach engages in interdisciplinary analysis and enriches it with concepts used in the economic analysis of law. To make the economic analysis accessible to readers not acquainted with sophisticated mathematical reasoning, the law and economics toolkit relied upon follows the traditional comparative law and economics approach.

This paper is structured as follows. The first part presents the general background and recapitulates literature on the main regulatory approaches. The second part provides a set of normative suggestions for an improved hybrid regulatory response which should achieve optimal risk internalisation, precaution, and firm-level innovation. The third part briefly comments on recent EU regulatory approaches. Finally, some conclusions are presented.

2 Conceptual and theoretical framework

This section surveys the crucial debate in law and economics and also in other social sciences concerning the balance between the state and the market. Which activities should be left to markets and which to the purview of the state? The short overview of these concepts also offers a theoretical justification for the drone-specific regulatory intervention recently enacted in the EU that thus needs to be briefly addressed. Classic law and economics textbooks suggest that such intervention is only warranted when 'market failures' materialise.[23] Among others, these include the presence of "negative externalities", which appear when actions by individual actors hold major negative consequences for others that are not mediated via markets, paving the way for an excessive level of certain activities.[24] Economically speaking, the potential hazards and damages caused by the uncontemplated activity of civil drones are a classic example of negative externalities and the asymmetric information problem. Namely, the problem of positive transaction costs and asymmetric information leads to so-called market failures which cause a suboptimal (inefficient) amount of economic activity and inefficient allocation of resources (eg, potential drone congestion in populated areas).[25] The collective-action problem, agency problem, tragedy of the commons, and the game theoretical prisoner's dilemma phenomena are the notorious embodiment of positive

[23] George Akerlof, 'The Market for 'Lemons': Quality Uncertainty and the Market Mechanism' (1970) 84 (3) The Quarterly Journal of Economics 488.
[24] Daron Acemoglu and James Robinson, *The Narrow Corridor: States, Societies, and the Fate of Liberty* (Penguin Press 2019).
[25] Akerlof (n 23) 489.

transaction costs and asymmetric information problems that generate negative externalities. The appearance of these negative externalities accompanied by the 'failure of private law' prima facie also warrants the employment of civil-drone-specific regulatory intervention in the public interest.[26]

Still, it must be emphasised that the mere existence of market failures *per se* is not an adequate basis for regulatory intervention. Regulatory intervention should take place if and only if the costs of the intervention (regulating civil drones) do not exceed its benefits. That is, the efficiency gains arising from such an intervention may be outweighed by market distortions, increased transaction costs and other misallocations in other sectors of the economy fuelled by the intervention.[27] Further, as Tinbergen suggests, in principle N problems require N legal rules — the One Instrument Per Problem Rule, meaning that every source of inefficiency in drone-related activity should be addressed with a separate regulatory policy.[28] In addition, the notorious "tragedy of the commons" concept suggests that individuals and/or firms might not see themselves as responsible for common resources like public safety and might eventually destroy such a common resource.[29]

Where market failures are accompanied by private law failures there is a *prima facie* case for regulatory intervention. However, does the mere existence of any market failures justify corrective government intervention? Many instances of market failures are remediable "by private law and thus by instruments which are compatible with the market system in the sense that collective action is not required".[30] Yet, as Professor Ogus convincingly shows, private law cannot always provide an effective solution.[31] Thus, where the 'market failure' is accompanied with a 'private law failure' there is, at least in theory, a *prima facie* (but not a conclusive) case for regulatory intervention. A series of empirical studies thus reveals that the mere presence of suspected market imperfections does not in itself warrant government corrective action and regulatory intervention.[32] Therefore, once government steps in, it might often exclude private initiative that could, in good entrepreneurial fashion, have invented ways of alleviating the suspected market

[26] Anthony Ogus, *Regulation: Legal Form and Economic Theory* (Hart Publishing 2004).
[27] ibid.
[28] Policymakers generally tend to use a single instrument to solve many problems at once. However, doing so is problematic for two reasons. First, such a single rule will be a compromise rule, which is not very effective at solving all the problems. Second, choosing the right compromise requires information on the relative social importance of all the problems; such information is nearly impossible to obtain, and therefore makes the discussion indeterminate; Jan Tinbergen, *On the Theory of Economic Policy* (North-Holland 1952). See also Mitja Kovac, *Judgement-Proof Robots and Artificial Intelligence*: *A Comparative Law and Economics Approach* (Palgrave MacMillan 2020) 109, 144; and Gerrit De Geest, 'Old Law is Cheap Law' in Michael Faure, Wicher Schreuders and Louis Visscher (eds), *Don't Take it Seriously: Essays in Law and Economics in Honour of Roger Van den Bergh* (Intersentia 2018) 505.
[29] Garret Hardin, 'The Tragedy of the Commons' (1968) 162 Science 1243. See also Scott Gordon, 'The Economic Theory of a Common-Property Resource: The Fishery' (1954) 62 (2) Journal of Political Economy 124.
[30] Ogus (n 26).
[31] ibid.
[32] Steven Cheung, 'The Fable of the Bees: An Economic Investigation' (1973) 16(1) The Journal of Law and Economics 11; and Ronald Coase, 'The Lighthouse in Economics' (1974) 17(2) The Journal of Law and Economics 357.

imperfection.[33] "Government intervention tends to foreclose such demonstration and thereby to become a self-perpetuating process."[34] Literature also suggests that even in instances of repeated market failures, the costs stemming from those imperfections should be weighed against those which the government intervention itself generates.[35] That is, for such optimal governmental intervention one assumes the perfect functioning of public administration that merely maximises social benefits.

However, while seeking to address certain market failure like for example drone-related congestion or different hazards (and maybe to even effectively cure a particular, individual market failure) governmental intervention may unintentionally impose even higher costs on society and its citizens while distorting the rest of the markets.[36] In other words, as a rule of thumb, regulatory intervention is warranted if and only if the costs of the intervention do not exceed its benefits. The argument used here is that either a regulatory solution may be no more successful in correcting the inefficiencies than the market or private law, or that any efficiency gains it gives rise to may be outweighed by the increased transaction costs or misallocations created in other sectors of the economy.[37]

In addition, poor policy may result from inadequate information, failure to anticipate significant side-effects of certain behaviour, phenomena (eg, unmanned drones delivering packages) or regulatory instruments.[38] Poor regulatory intervention along these lines may occur where the government has needed to be seen as respond rapidly to widespread calls for action, following a disaster that captured the public's attention,[39] or when it lacks resources or adapting a passive, compromising approach to contraventions.[40] Public choice theory therefore offers further support for our rule of thumb stating that "state interventions are only justified if they produce less harm than market inefficiencies".[41]

In recent years, the study of regulation has become a multi-disciplinary field featuring substantial contributions to regulatory debates being made by lawyers, political scientists, psychologists, behavioural economists, and others.[42] Regulation has actually become central to the interaction of economic, legal, political, entrepreneurial and innovation

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33 Ejan MacKaay, *Law and Economics for Civil Law Systems* (Edward Elgar 2015).

34 ibid.

35 MacKaay (n 33). See also Ogus (n 26) and Richard Posner, *Economic Analysis of Law* (9th edn, Aspen Publishing 2014).

36 Posner (n 33).

37 See Ogus (n 26); Kip Viscusi, John M Vernon, and Joseph E. Harrington, *Economics of Regulation and Antitrust* (MIT Press 1992); and Alfred Kahn, *The Economics of Regulation: Principles and Institutions* (MIT Press 1971).

38 Michael Levine, and Jennifer L Florence, 'Regulatory Capture, Public Interest, and the Public Agenda: Towards a Synthesis' (1990) 6 (4) Journal of Law, Economics and Organization 167.

39 ibid.

40 See Ross Cranston, *Regulating Business-Law and Consumer Agencies* (Palgrave MacMillan 1979); and Neil Gunningham, *Pollution, Social Interest and the Law* (M. Robertson 1974).

41 ibid.

42 For a synthesis, see Robert Baldwin, Martin Cave and Martin Lodge, *The Oxford Handbook of Regulation* (Oxford University Press 2010). See also Malcom Sparrow, *Fundamentals of Regulatory Design* (Harvard University Press 2020).

spheres. The rise of a better regulation agenda was then designed to ensure consistency between "red-tape" and "regulatory quality" developments.[43] The so-called command-and-control (top-down approach) was the initial starting point of regulators, which later evolved into less-restrictive and incentive-based regulatory policies.[44]

3 Towards an improved regulatory response

The question of what is a 'good' regulation is extensively discussed in the literature[45] and, even though what constitutes a 'good' regulation is difficult to establish, generally five criteria should be met.[46] Literature offers a range of different legal instruments including rules of civil liability, command and control public regulations, market-based instruments, 'suasive' and voluntary instruments, smart regulatory mixes, and hybrid regulatory approaches. This section presents a set of law and economics recommendations for an improved, EU-wide, regulatory intervention which should deter hazards, induce optimal precaution and simultaneously preserve dynamic efficiency – incentives to innovate undistorted.

3.1 Tragedy of the commons, prohibitive transaction costs, and drones

The specific phenomena of interest to us in the investigation of automated drones concern the tragedy of the commons and related external effects or externalities, also known as spillover effects. A negative externality arises when one person's decision affects someone else, but where there is lack of an institutional mechanism to induce the decision-maker to fully account for the spillover effect of their action or inaction.[47] These negative externalities can then also lead to market failures since the generator of the externality does not have to pay for harming others, and so exercises too little self-restraint.[48] In other words, the private cost to the person who creates the negative externality is lower than the social cost, which is the sum of that private cost and the cost incurred by third persons.[49] Corresponding public policies are then one of the most

[43] ibid 7. See also Michael Lodge, and Kai Wegrich, 'High Quality Regulation: Its Popularity, Its Tools and Its Future' (2009) 29(3) Public Money and Management 145.
[44] Baldwin and others (n 42).
[45] See eg Robert Baldwin and Christopher McCrudden, *Regulation and Public Law* (Weidenfeld and Nicolson 1987); and Claudio Radaelli and Fabrizio De Francesco, *Regulatory Quality in Europe: Concepts, Measures and Policy Processes* (Manchester University Press 2011).
[46] Legislative mandate, accountability, due process, expertise, efficiency; Robert Baldwin, Martin Cave and Martin Lodge, *Understanding Regulation: Theory, Strategy, and Practice* (2nd edn, Oxford University Press 2012).
[47] See eg Arthur Pigou, *The Economics of Welfare* (Macmillan 1932); Ronald Coase, 'The Federal Communications Commission' (1959) 2 (1) Journal of Law and Economics; and Kip Viscusi, *Fatal Trade-offs: Public and Private Responsibilities for Risk* (Oxford University Press 1992).
[48] See eg Jack Hirshleifer, *Price Theory and Applications* (Cambridge University Press 1984); and Roger Miller, Daniel K Benjamin and Douglas C North, *The Economics of Public Policy Issues* (Pearson 2017).
[49] Pigou (n 47).

effective remedies for correcting this failing. Institutional response and political decision-making should hence aim at the internalisation of these negative externalities, inducing decision-makers (drone operators) to respond to the impacts of their choices on others just as if those impacts were experienced by the decision-maker directly.[50] Inadequate internalisation of such negative externalities might also materialise as the notorious "tragedy of the commons". Coined by Hardin[51] and Gordon,[52] this "tragedy of the commons" concept suggests that individuals might not see themselves as responsible for common resources such as common, public air-space above the streets and by excessively employing drones might eventually destroy such a common resource.[53] For example, the number of commercial drone deliveries rose from 34,000 in 2019 to 482,000 in 2021 and was estimated to reach 1.4 million by the end of 2022 while the overall number of packages delivered by drone increased by over 80 percent from 2021 to 2022, amounting to almost 875,000 deliveries worldwide.[54] The greater employment of civil drones may thus cause a typical materialisation of the tragedy of the commons phenomena such as air congestion in densely populated areas (and at low altitudes), the collapse of current pre-flight air route network planning, the collapse of drone delivery applications, as well as potential accidents and hazards.

Transportation literature also highlights that no currently existing method can directly address the challenge of air route network planning and resulting congestion.[55] Yet, when multiple paths utilise the same airspace, conflicts and interdependencies arise, calling for system-level optimisation.[56] When paths are optimised individually, the allocation of scarce urban airspace is not optimised, which can lead to air traffic conflicts and congestion, potentially causing system failure.[57] Moreover, civil-drone-based delivery services are also limited by several binding factors, such as low battery capacities and short delivery range, which in turn require the simultaneous use of a large fleet for

[50] See eg Leitzel Jim, *Concepts in Law and Economics* (Oxford University Press 2015) 108.
[51] Hardin (n 29).
[52] Scott (n 29).
[53] See eg Harold Demsetz, 'Toward a Theory of Property Rights' (1967) 57(2) American Economic Review 347, 351, 353.
[54] See eg Cornell Andrea, Mahan Sarina and Robin Riedel, *Commercial Drone Deliveries are Demonstrating Continued Momentum in 2023* (McKinsey and Company 2023).
[55] The main challenge lies in achieving a balance between optimising individual paths and optimising the system or infrastructure as a whole. Single-path planning, which aims to minimise factors like path length, energy consumption, and ground impact for a given origin-destination pair, has been extensively studied; Xinyu He, Lishuai Li, Yanfang Mo, Jianxiang Huang, S Joe Qin, 'A Distributed Route Network Planning Method with Congestion Pricing for Drone Delivery Services in Cities' (2024) 160 Transportation Research Part C: Emerging Technologies.
[56] ibid.
[57] Centralised planning can achieve system-level optimisation, but may also result in inefficiencies and inequities in the allocation of valuable urban airspace to individual paths; ibid.

commercial scale operations.[58] In these cases, congestion — the materialisation of tragedy of the commons phenomena — in low-altitude air will inevitably arise.[59]

In addition, Israel and China have recently already been preparing infrastructure for a national airspace network of large drones designed to carry passengers and heavy cargo[60] which will consequently lead to further congestion and, if not regulated, to the manifestation of tragedy of the commons phenomena. As an anecdotal example, one may note that in just the USA there are roughly 870,000 registered drones, which is four times the number of commercial and private planes.[61] Strikingly, about 350,000 of them are used for commercial purposes like inspecting railroad tracks, bridges and pipelines; the rest are recreational drones and within a couple of years urban air mobility companies also will begin testing their electric air taxis in several cities around the globe.[62] In fact, civil drones have often been reported as causing hazards to aircraft, or to people or property on the ground.[63] Safety concerns have been raised due to the potential for an ingested drone to rapidly disable an aircraft engine, and several near-misses and verified collisions have involved hobbyist drone operators flying in violation of aviation safety regulations.[64] Finally, one may also note a famous incident that happened in December 2015 when a civil drone filming a slalom event in Madonna di Campiglio nearly hit Marcel Hirscher.[65] Namely, while the International Ski Federation had agreed to use of the unmanned aerial vehicles (UAS), the pilot was not allowed to fly the drone directly over the race course.[66]

[58] Ruifeng She, Yanfeng Ouyang, 'Efficiency of UAS-based Last-mile Delivery under Congestion in Low-altitude Air' (2021) 122 Transportation Research Part C: Emerging Technologies.

[59] ibid.

[60] Sharon Wrobel, 'Drone Taxis Take First Test Spin in Israel in Bid to Ease Traffic Congestion' *The Times of Israel* (Tel Aviv, 6 June 2023) <https://www.timesofisrael.com/drone-taxis-take-first-test-spin-in-israel-in-bid-to-ease-traffic-congestion/> accessed 10 June 2024.

[61] Joann Mueller, 'Managing Traffic in the Skies is Becoming a Lot Harder' *Axios* (20 September 2021) <https://www.axios.com/2021/09/20/air-traffic-drones-airplanes-skies-crowded> accessed 10 June 2024.

[62] ibid.

[63] See eg John Pyrgies, 'The UASs Threat to Airport Security: Risk Analysis and Mitigation' (2019) 9 (2) Journal of Airline and Airport Management 63; and Dothang Truong and Woojin Choi 'Using Machine Learning Algorithms to Predict the Risk of Small Unmanned Aircraft System Violations in the National Airspace System' (2020) 86 Journal of Air Transport Management.

[64] See eg Julie Tellman 'First-ever recorded drone-hot air balloon collision prompts safety conversation' *Teton Valley News* (Teton Valley, 28 September 2018) <https://www.tetonvalleynews.net/news/drone-balloon-collision-prompts-safety-conversation/article_e08fc158-c269-11e8-904f-8b5d2e21fb4e.html> accessed 10 June 2024; Boise, Idaho, United States: Boise Post-Register, 'After Drone Hits Plane in Canada, New Fears About Air Safety' *The New York Times* (New York, 17 October 2017) <https://www.nytimes.com/2017/10/17/world/canada/canada-drone-plane.html> accessed 10 June 2014.

[65] Eric Willemsen, 'Ski Federation Bans Drones after Camera Nearly Hits Marcel Hirscher' *USA Today Sport* (23 December 2015) <https://eu.usatoday.com/story/sports/olympics/2015/12/23/ski-federation-ban-drones-marcel-hirscher/77838818/> accessed 6 May 2024.

[66] Camera UASs have since been banned from the Federation's World Cup races; ibid.

The lack of excludability in such instances thus creates incentives for the overexploitation of natural resources (air space in densely populated areas) and this leads to a reduction of social welfare as a whole. Extrapolation of these concepts of negative externality and the "tragedy of the commons" to the potential employment of automated civil drones enables us to argue that such unregulated employment might generate systemic negative externalities where the actions of drone operators affect bystanders, other drone operators and all other stakeholders in certain, generally densely populated, areas. The generator of the externality — an individual drone operator — who does not have to pay for harming others namely exercises too little self-restraint (an excessive number of drones in the air). He or she acts as if the cost of employing drones is zero, when in fact there are real costs involved (nuisance, noise, air congestion, potential hazards and harm, overcrowded air space, pollution etc.). The "tragedy of the commons" concept thus forms a prima facie argument for a legal intervention. This intervention may either employ classic ex post private law instruments (ie, property law) or ex ante regulatory intervention.

However, as we will show, the problem of prohibitively high transaction costs means the private law solution may be ineffective, with ex-ante regulatory intervention featuring as the only feasible solution. Namely, in the original formulation by Coase and North transaction costs are defined as "the cost of using the price mechanism" or "the cost of carrying out a transaction by means of an exchange on the open market".[67] Arrow, De Geest, Williamson and Parisi and Posner define transaction costs as the costs of running the economic system of exchange.[68] In the ideal world of zero transactions costs, parties would always efficiently bargain for the optimal allocation of scarce resources and the tragedy of the commons would never materialise. In such a world, the property rights system should namely act as an effective mechanism for mitigating the 'tragedy of the commons' problem and automatically regulating the employment of commercial drones. In the mentioned hypothetical world, landowners exclusively own and control the 'super-adjacent' low-altitude airspace directly above their land, and are free to commercialise and sell access to, or to prohibit drones from entering, their private airspace. As Ben Dor and Hoffmann argue, a marketplace will spontaneously emerge for parties to buy, sell and lease valuable airspace to accommodate drone delivery, such that companies like Amazon or Walmart will compensate landowners, even governments that own city streets and

[67] See Ronald Coase, "The Nature of the Firm" (1937) 4 (16) Econometrica386; Ronald Coase, "The Problem of Social Cost" (1960) 3 The Journal of Law and Economics 1; Ronald Coase R., *The Firm, the Market and the Law* (University of Chicago Press 1988); and Douglas C North, *Institutions, Institutional Change and Economic Performance* (Cambridge University Press 1990).

[68] See Kenneth J Arrow, "The Organization of Economic Activity: Issues Pertinent to the Choice of Market Versus Nonmarket Allocation" in *The Analysis and Evaluation of Public Expenditures: The PBB System, Joint Economic Committee Compendium* (Washington 1969); Gerrit De Geest, *Economische Analyse van het Contracten- en Quasi-contractenrecht* (Maklu 1994); Oliver Williamson, *Markets and Hierarchies* (Free Press 1975); and Francesco Parisi and Richard A Posner (eds), *The Coase Theorem* (Edward Elgar 2013).

highways, for the airspace where drones will one day fly.[69] However, such a solution based on market/property law relies on the assumption that transaction costs are trivial and requires parties to freely bargain.[70] Yet, in reality where for example an individual owner of 'super-adjacent' low-altitude airspace would have to negotiate with thousands of individual drone operators numerous contracts for the use of airspace (and related conditions) such transaction costs might actually be prohibitively high (preventing mutually beneficial transactions from materialising). The problem of non-trivial transaction costs actually renders such a market/property law-based solution ineffective (ie, private law failure) and calls for an ex-ante regulatory intervention.

3.2 Drone technologies and THE judgement-proof problem

A vital aspect of an effective regulatory approach to drones is the problem of automated drone technologies. Automated civil drones namely already have the ability to access and independently utilise their sensory motors to react to external conditions.[71] For example, in 2017 the Swiss start-up company Wingtra launched an autonomous agricultural surveying drone. With a total wingspan of 125 centimetres and total weight of 3.7 kilograms, the drone is incredibly small. It has a payload capacity of 800 grams and is capable of automated vertical take-off and landing. As shown, the property law alone might be inadequate for mitigating potential harms, hazards and other 'tragedy of the commons' linked problems. Here, one may turn to classic tort law mechanisms where

[69] They suggest that rather than sitting empty, the low altitude airspace should be commercialised through a marketplace in which landowners sell their consent to overflights over their properties. Delivery services and other heavy-duty drone operators can aggregate those consents into viable flight paths, and landowners can be compensated for the use of their airspace; Ben Dor and Hoffmann (n 8) 993.

[70] They also suggest that such a marketplace for airspace would only further innovation and commercial development while appropriately balancing the rights and concerns of individuals, businesses, and governments; ibid.

[71] Dario Floreano and Robert J Wood (n 1). See also Hassanalian and Abdelkefi (n 15).

indeed the existing tort law and economics literature[72] seeks to address the role of tort law and related civil liability for damage caused by such automated products.[73]

Nevertheless, automated drones may cause harm to others but their operators may not be unable to make victims whole for the harm incurred and might not have incentives for safety efforts created by standard tort law enforced through monetary sanctions. These phenomena, known in the law and economics literature as a the "judgement-proof problem", is a standard argument in law-making discussions while operationalising policies, doctrines and rules.[74]

A tortfeasor who cannot fully pay for the harms that they have caused and for which they have been found legally liable is namely said to be "judgement proof". Shavell shows that the existence of the judgement-proof problem seriously undermines the deterrence and insurance goals of tort law.[75] He notes that judgement-proof parties also do not have the appropriate incentive to prevent accidents or purchase liability insurance.[76] In other words, the judgement-proof problem is very important since if injurers are unable to pay fully for the harm they may cause, their incentives to engage in risky activities will be greater than otherwise. Summers also shows that the judgement-proof injurers tend to take too little precaution under strict liability because the costs of accidents are only partly internalised.[77] Accordingly, the classic debate on the two different means of controlling hazardous activities – *ex post* liability for harm done and *ex ante* safety regulation – may, due to the shortcomings of classic tort and contract law instruments,

[72] See eg, Alberto Galasso and Hong Luo, "Punishing Robots: Issues in the Economics of Tort Liability and Innovation in Artificial Intelligence" in Ajay Agrawal, Joshua Gans and Avi Goldfarb (eds), *The Economics of Artificial Intelligence: An Agenda* (University of Chicago Press 2019) 493, 504; Hans-Bernd Schaefer and Claus Ott, *The Economic Analysis of Civil Law* (Edward Elgar 2004) 107, 273; Michael Faure, "Toward a Harmonized Tort Law in Europe? An Economic Perspective" (2001) 8 (4) Maastricht Journal of European and Comparative Law 339; Hans-Bernd Schaefer, 'Tort Law: General' in Boudewijn Bouckaert and Gerrit De Geest Gerrit (eds), *Encyclopedia of Law and Economics* (Edward Elgar 2000) 569; Emons Winand and Joel Sobel, 'On the Effectiveness of Liability Rules when Agents are not Identical' (1991) 58 (2) Review of Economic Studies 375; Steven Shavell, *Economic Analysis of Accident Law* (Harvard University Press 1987); Mitchell Polinsky, and William P Rogerson, 'Product Liability, Consumer Misperceptions and Market Power' (1983) 14 (2) Bell Journal of Economics 581; Steven Shavell, "Strict Liability Versus Negligence" (1980) 9 (1) Journal of Legal Studies 1; Kenneth Arrow, 'Optimal Insurance and Generalized Deductibles' (1974) 1 Scandinavian Actuarial Journal 1; Richard Posner, 'A Theory of Negligence' (1972) 1 (1) Journal of Legal Studies 29; Richard Posner, 'Strict Liability: A Comment' (1973) 2 (1) Journal of Legal Studies 205; Guido Calabresi, 'Some Thoughts on Risk Distribution and the Law of Torts' (1961) 70 (4) Yale Law Journal 499; Guido Calabresi, 'The Decision for Accidents: An Approach to Non-fault Allocation of Costs' (1965) 78 (4) Harvard Law Review 713; and Guido Calabresi, *The Costs of Accidents: A Legal and Economic Analysis* (Yale University Press 1970).

[73] Aviation actually has specific rules for contractual and third-party liability as well as compulsory insurance. However, despite this, the main law and economics principles on tort law and economics are analytically applicable and informative also with respect to such specific rules.

[74] Steven Shavell, 'The Judgement Proof Problem' (1986) 6 (1) International Review of Law and Economics 45.

[75] ibid.

[76] John Summers, 'The Case of the Disappearing Defendant: An Economic Analysis' (1983) 132 University of Pennsylvania Law Review 145; and Steven Shavell, 'The Judgement Proof Problem (1986) 6 (1) International Review of Law and Economics 45.

[77] Summers (n 76).

boil down to the question of efficient *ex ante* regulation.[78] The problem is that if you have standing but you cannot represent yourself, society is effectively only left with regulation.

Law and economics literature offers several potential types of policy responses to address the identified judgement-proof problem. The first instrument is the introduction of vicarious liability.[79] Shavell, for example, suggests that if there is another party (principal) who has some control over the behaviour of the party whose assets are limited (agent), then the principal can be held vicariously liable for the losses caused by the agent.[80] Hence, vicarious liability (indirect reduction of risk) and a specific principal—agent relationship between the operator and their automated drone should be introduced. The operator (owner) should be held vicariously liable for the losses caused by the agent (automated drone). If the operator (principal) can observe the drone's (agent's) level of care then the imposition of vicarious liability will induce the principal to compel the agent to exercise optimal care. The extension of liability should in this way lead indirectly to a reduction of risk.

Yet, if the operator (owner) is unable to observe and control the drone's (agent's) level of care then he will generally not be able to induce the agent.[81] If, in contrast, the principal can control the agent's level of activity (and has no observation capacity) then such vicarious liability will induce the principal to reduce the agent's participation in risky activities.

However, what if a drone is indeed automated, self-learning, can develop emergent properties, can adapt its behaviour and actions to the environment? In these circumstances, the imposition of vicarious liability might be completely inadequate due to the extreme judgement-poof problem. Moreover, the product liability regime operates on the assumption that the product does not continue to change in an unpredictable manner once it has left the production line. Still, the new generation of drones may perhaps somewhere in future automatedly learn from their own variable experience and interact with their environment in unique and unforeseeable ways. In addition, companies also might be judgement-proof due to their size. In this scenario, law and economics suggests the introduction of a whole arsenal of economic/legal institutions that might address such an extreme drone operator's judgement-proof problem and continuous product changes.

[78] Patrick W Schmitz, 'On the Joint Use of Liability and Safety Regulation' (2000) 20 (3) International Review of Law and Economics 371.

[79] For a synthesis, see Alan Sykes, 'The Economics of Vicarious Liability' (1984) 93 (1) Yale Law Journal 168; and Reimer Kraakman, 'Vicarious and Corporate Civil Liability' in Gerrit De Geest and Boudewijn Bouckaert (eds), *Encyclopedia of Law and Economics, Volume II. Civil Law and Economics* (Edward Elgar 2000).

[80] Shavell (n 76). See also Steven Shavell, *Economic Analysis of Accident Law* (Harvard University Press 1987).

[81] Steven Shavell, *Foundations of Economic Analysis of Law* (Harvard University Press 2004) 180 *et seq*.

Law and economics scholarship has argued for the need to rethink legal remedies when applying them to AI-related torts.[82] For example, Shavell even claims that AI makes classic product liability law as currently designed is unable to create the optimal incentives for the use, production and adoption of safer AI technologies.[83] AI-related hazards are essentially unknown risks and the law and economics literature has addressed the problem of imposing liability for such unknown and unexpected risks and argues that whether "liability for unknown risks is desirable depends on what is more important: avoiding the marketing of products which are not safe enough, or not hindering the introduction of better new products".[84] Landes and Posner suggest that such liability might actually induce producers to invest in safer technologies.[85]

More recently, in their novel approach Guerra, Parisi and Pi state that AI-generated accidents should be clustered within the realm of "fault-based liability rather than product liability", where negligence-based rules should be blended with strict-liability rules to create precaution incentives for AI operators and their potential victims, and R&D incentives for manufacturers' development of safer AI.[86] They offer a novel liability regime, which they refer to as the "manufacturer residual liability" rule.[87] Under such a "manufacturer residual liability" regime, the primary liability is held by either the civil drone human operator or the victim, and the residual liability – the assignment of the accident cost when neither party is negligent – then falls on the manufacturer.[88] Namely, human operators and victims should bear accident losses attributable to their own negligent behaviour and manufacturers should only be held liable for non-negligent accidents. The negligence of the AI human operator also marks the boundary between a human operator's fault-based liability and the manufacturer's strict residual liability. Further, a manufacturer's liability would arise for two separate sources of accidents

[82] See eg Mark A Lemley and Bryan Casey, 'Remedies for Robots' (2019) 86 (5) The University of Chicago Law Review, 1311; and Eric Talley, 'Automators: How Should Accident Law Adapt to Autonomous Vehicles? Lessons from Law and Economics' [2019] Columbia Law School Working Papers Series No 19002.

[83] Steven Shavell, 'On the Redesign of Accident Liability for the World of Autonomous Vehicles' (2020) 49 (2) The Journal of Legal Studies 243.

[84] Michael Faure, Louis Visscher and Franziska Weber, "Liability for Unknown Risk – A Law and Economics Perspective" (2016) 7 (2) Journal of European Tort Law 198.

[85] William M Landes and Richard A Posner, "A Positive Economic Analysis of Products Liability" (1985) 14 The Journal of Legal Studies 535.

[86] Alice Guerra, Francesco Parisi and Daniel Pi, "Liability for Robots II: An Economic Analysis" (2021) 18 (4) Journal of Institutional Economics 553

[87] ibid 554.

[88] Such a liability regime makes operators and victims liable for accidents due to their negligence – hence, incentivising them to act diligently; and makes manufacturers residually liable for non-negligent accidents – thus incentivising them to make optimal investments in R&D for robots' safety. In turn, as Guerra, Parisi and Pi argue, such a rule would bring down the price of safer robots, driving unsafe technology out of the market and, due to the percolation effect of residual liability, would induce operators to adopt optimal activity levels in AI usage; ibid 554. See also Alice Guerra, Francesco Parisi and Daniel Pi, "Liability for Robots I: Legal Challenges" (2021) 18 (3) Journal of Institutional Economics 331

caused by AI: a) malfunctions;[89] and b) design limitations.[90] Finally, they show that such a liability regime might offer several advantages over simple negligence and strict liability, and might achieve four objectives of an AI tort law regime by inducing: a) efficient human precautionary care; b) efficient activity levels; c) investments in the R&D of safer AI; and d) the adoption of safer technology.[91]

In the author's previous work, several mechanisms were proposed to address such "judgement-proof" characteristics of existing legal persons (ie, manufacturers) and what follows is a brief summary of potential remedies: a) lawmakers could require any principal to have a certain minimum amount of assets in order to be allowed to engage in a completely automated drone-related activity; b) lawmakers could introduce the compulsory purchase of liability insurance coverage in order for any principal to be allowed to engage in an automated drone-related activity; c) lawmakers could directly *ex ante* regulate the drone's risk-creating behaviour (ie, regulatory agencies could *ex ante* set detailed standards for the behaviour, employment, operation and functioning of any automated drone); d) regulatory agencies could establish a detailed set of sector-specific safety standards (similar to those in the air travel or pharmaceutical industries); e) criminal liability for the human operator (ie, the principal) could be introduced to add pressure to optimise the principal's decision on whether to engage with the automated drone activity at all; f) lawmakers could extend liability from the actual injurer (the automated drone) to the company that engages or employs such a 'drone-agent'; g) lawmakers could establish a regime of compulsory compensation or a broad insurance fund for instances of catastrophic losses that is publicly and privately financed; and i) lawmakers could introduce the AI manufacturer's strict liability supplemented by the requirement that an unexcused violation of a statutory safety standard is negligence per se.[92]

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[89] Malfunctions should be dealt with by ordinary product liability law already in place where victims may sue manufacturers directly or by allowing operators to sue manufacturers in subrogating when operators face direct liability under conventional tort law; ibid.

[90] Design limitations refer to accidents that occur when AI encounters a new unforeseen circumstance that causes it to behave in an undesired manner; ibid.

[91] ibid. In addition, Cooter and Porat offer a "total liability for excessive harm" rule for instances of multiple tortfeasors where officials can verify the total harm caused by all injurers but not the harm caused by an individual injurer. Under the mentioned rule, each individual injurer should be liable for the total harm that everyone causes in excess of the optimal harm. They suggest that a remarkable consequence of such a rule is that injurers respond to it by causing the optimal harm and their liability to be nil; Robert D Cooter and Ariel Porat, *Getting Incentives Right: Improving Torts, Contracts and Restitution* (Princeton University Press 2014) 74, 89. For example, an AI agency could establish a safety target and announce that each producer of AI systems in a certain area is liable for the damage caused by all producers of AI systems in excess of that target. As Cooter and Porat suggest, the agency gains control over the damages (ie, negative externalities) without having to monitor individual producers, while the producers do not have to pay damages or comply with bureaucratic regulations; ibid 74.

[92] See Mitja Kovac, *Judgement-Proof Robots and Artificial Intelligence: A Comparative Law and Economics Approach* (Palgrave Macmillan Springer Nature 2020); and Mitja Kovac, 'Autonomous Artificial Intelligence and Uncontemplated Hazards: Towards the Optimal Regulatory Framework' (2021) 13 (1) European Journal of Risk Regulation 94.

Further, lawmakers should also introduce corrective *ex ante* taxes that would equal the expected harm of drone usage.[93] The classic recommendation in economic literature for dealing with negative externalities is namely to tax the activity that produces them.[94] In our case, in order to deal with drone-related negative externalities (eg, air congestion), a lawmaker should introduce a tax on drone-related activity. The tax rate for each drone unit should be set equal to the estimated social costs created by such drone activity. By design, the firm (of an individual) operating drones and subject to such taxation will have to compare its tax costs (incurred if one employs a drone) with the costs of employing other, classical, non-flying means of transport, service, delivery and performance, or reducing its output or otherwise trying to reduce its activity level. If a net tax saving were generated by one of these measures, the firm (or individual) will adopt it; otherwise, it will pay the tax and employ the drone.[95]

This paper also suggests that regulation and tort law should be applied simultaneously. *Ex post* liability and *ex ante* regulation (safety standards) are generally viewed as substitutes for correcting externalities, and the usual recommendation is to employ the policy which leads to lower administrative costs. However, Schmitz shows that joint use of liability and regulation can enhance social wealth.[96] That is, regulation removes problems affecting liability, while liability limits the cost of regulation.[97] General regulatory standards should be settled on a lower level of care (lower than optimal) and combined with tort law instruments.[98] Namely, by introducing an *ex ante* regulatory standard, the principal and the agent (AI) might be prevented from taking low levels of precaution and might find the regulatory standard convenient despite the judgement-proof problem.

Moreover, an informed lawmaker should combine strict liability and vicarious liability — strict liability of the manufacturer and vicarious liability of the principal (principal as either a legal or physical person).[99] Nonetheless, since the product liability regime relies

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[93] The aim of such Piguvian tax is not to raise revenue but to discourage the taxed activity, in the present instance the drone-related 'tragedy of the commons' phenomena. See eg Alan Barnett, 'The Pigouvian Tax Rule Under Monopoly' (1980) 70 (5) American Economic Review 1037; and Judith Freeman, 'Responsive Regulation, Risk, and Rules: Applying the Theory to Tax Practice' (2011) 44 (3) University of British Columbia Law Review 627.

[94] See eg Lans Bovenberg and Lawrence Goulder, 'Environmental Taxation and Regulation' in Alan Auerbach and Martin Feldstein (eds), *Handbook of Public Economics, Vol 3.* (Elsevier 2002) 1471; John Theeuwes, 'Regulation or Taxation' in Dirk Jan Kraanand Roeland J in 't Veld (eds), *Environmental Protection: Public or Private Choice. Economy & Environment* (Springer 1991); and Peter Salib, 'The Pigouvian Constitution' (2021) 88 (5) The University of Chicago Law Review 1081.

[95] See also Richard Posner, *Economic Analysis of Law* (8th edn Aspen 2011) 502.

[96] Schmitz (n 78).

[97] Susan Rose-Ackerman, 'Regulation and the Law of Torts' (1991) 81 (1) American Economic Review 54.

[98] Gerrit De Geest and Giuseppe Dari-Mattiacci, 'Soft Regulators, Tough Judges' (2007) 15 (1) Supreme Court Economic Review 119.

[99] Insightfully, similar shifts and balancing of liability can be observed in manned aviation where such a balancing of liability between contractual and non-contractual liability has been discussed. For example, in 1929 the Warsaw

on the assumption that the product does not continue to change in an unpredictable manner once it has left the production line, such a combination might not be adequate. Drone companies might also be judgement-proof due to their size. If one then employs the 'let the machine learn' concept, the argument that the designer should have foreseen the risk becomes harder to sustain. The classic debate on the two different means of controlling hazardous activities, namely *ex post* liability for harm done and *ex ante* safety regulation may, due to the identified shortcomings boil down to the question of efficient regulatory timing and *ex ante* regulation. A specific EU regulatory intervention might thus be considered that encompasses the following: a) the principal's minimum asset requirement needed to engage in an activity; b) compulsory purchase of liability insurance coverage (for the principal); c) direct ex ante regulation of drones' risk-creating behaviour — an EU regulatory agency setting behaviour-employment-operating-functioning standards; d) safety standards (albeit alone these are inadequate); and registration (for both principal and agent); e) the principal's criminal liability; f) extension of liability from the actual injurer (AI) to the company — piercing the veil of incorporation; g) corrective taxes equal to the expected harm; and h) establishment of an EU-wide publicly-privately-financed insurance fund.

3.3 Regulatory strategies and the economics of federalism

Sparrow suggests that for some risks responsibilities (regulatory advantages) might be held close by the regulator (the classic top-down approach) whereas for others where regulated entities have appropriate motivations and competences the regulator may delegate certain aspects of the control task to industry (information advantage and accountability).[100] For example, changes in regulatory strategy around the world have led to new forms of regulation: responsive regulation, self-regulation, performance-based regulation, command-and-control regulation, right-touch regulation, outcome-based regulation, light-touch regulation, really-responsive-regulation, co-regulation, incentive-based regulation, market-harnessing control regulation, regulation by contract, disclosure regulation (eg, by naming and shaming), direct action regulation, nudge-based regulation, rights and liabilities regulation, public compensation & social insurance model regulation etc.[101]

Convention was drafted to govern passenger liability in the case of death or bodily injury and a balance between protecting airlines from absolute liability (incentives to innovate) vs. ensuring passengers to be compensated was discussed.

[100] Of course, regulators have to know which parts of the task they may safely delegate, for which types of risk and in what conditions; Sparrow (n 42) 100.

[101] See Sparrow (n 42), and Baldwin and others (n 46).

Literature emphasises that the best regulatory outcomes will generally involve mixtures of institutions and instruments (hybrid types of regulation).[102] The problem of how to design the optimal mixes or to state in advance which institutions and instruments will work together effectively can nevertheless hardly be overstated.[103] Sparrow, for example, suggests that risk-based regulation (problem-solving) should be placed at the centre of regulatory policymaking and stresses the need to define problems precisely, to monitor and measure performance, and to adjust strategy based on performance assessment.[104] The 'really-responsive' regulatory approach requires that while designing and developing regulatory systems attention must be paid to five core matters: the behaviour, attitudes, and cultures of regulatory actors; the institutional settings of the different regulators; the different logics of regulatory tools and strategies (and their interaction); the regime's own performance over time; and changes in each of these elements.[105]

In addition, one may invoke the "economics of federalism" literature that discusses the optimal allocation of regulatory competence among national and supra-national regulators. All regulatory systems namely require a number of tasks to be performed and while performing all of these different tasks important structural issues arise in determining how these tasks are to be allocated to different institutions. The law and economics of federalism[106] actually inform us with respect to which institutional arrangements can assist the implementation of the public interest goals of regulation and the extent to which they offer protection against the subversion (politicisation) of the law to meet the demands of private interests. Further, the law and economics of federalism offer guidance on the question of whether the appropriate source of regulatory rule-making should be at Brussels or in Rome.[107]

Literature also suggests that the primary reasons in support of decentralisation are: the diverging preferences of citizens, information advantages on lower levels of government, accountability (ie, regulators should be answerable for the manner in which they exercise

[102] See eg Andy Murray and Colin Scott, 'Controlling the New Media: Hybrid Responses to New Forms of Power' (2002) 65 (4) Modern Law Review 491.

[103] See eg Neil Gunningham and Peter Grabosky, *Smart Regulation: Designing Environmental Policy* (Clarendon Press 1998) 422, 53.

[104] Sparrow also advocates the dynamic nature of the risk control game and targeting key problems and solve these by developing interventions; Malcolm Sparrow, *The Regulatory Craft: Controlling Risks, Solving Problems, and Managing Compliance* (Brookings Institution Press 2003).

[105] Moreover, regulatory design should take account of the detection of undesirable or non-compliant behaviour, developing tools and strategies for responding to that behaviour, enforcing those tools and strategies on the ground, assessing their success or failure, and modifying them accordingly; Baldwin and others (n 46) 159. See also Julia Black, 'Decentring Regulation: The Role of Regulation and Self-Regulation in a Post-Regulatory World' (2001) 54 (1) Current Legal Problems 103.

[106] See eg Ogus (n 26); and Jacques Pelkmans, 'The Assignment of Public Functions in Economics Integration' (1982) 21 (2) Journal of Common Market Studies 97.

[107] Robert Inman and Daniel Rubinfeld, 'Economics of Federalism' in Francesco Parisi (ed), *The Oxford Handbook of Law and Economics, Volume 3: Public Law and Legal Institutions* (Oxford University Press 2017) 84.

their powers), monopoly problems on the side of central government[108] and the importance of the learning process.[109] In relation to the optimal government levels, one may argue that local governments will possess better information than distant central government about local conditions and preferences and also greater incentives to satisfy them. Zoning should hence be typically left to local government (ie, Member States), while defence should be left to the central government (ie, EU Commission).

These findings may however also be implemented in the optimal regulatory design for civil drones. A combination of a local (EU Member State) law that clarifies landowners' property rights "by focusing on proxies that measure ever smaller classes of uses",[110] such as the further delineation of landowners' rights based on their location and local governance rules through municipal drone-zoning ordinances, may, as Watson suggest, therefore increase efficiency by filling in the gaps not currently addressed by the current EU MS property law aerial trespass doctrines.[111] For example, a certain MS or local municipality may find that drones should generally be excluded below 30 or 50 metres in urban areas, where parcel sizes tend to be relatively small and closer together, because the ability of drones to capture detailed images adds to the likelihood of invasions of privacy by drones or completely banned in natural resorts and parks due to their harmful effects on local flora and fauna. The statute would be efficient provided that it also gives local municipalities 'broad regulatory authority' to regulate drones below this level through its zoning powers.[112] Watson adds that this might be done by creating a cause of action in trespass for landowners, subject to the local drone-zoning ordinances that may allow certain uses of that space by drones — for example, an ordinance may distinguish between commercial and recreation drone uses and allow commercial drones to operate only during business hours on weekdays but limit recreational drone activity by prohibiting it altogether or to a narrower set of places and times.[113] As proposed by Watson, such a combination of exclusion rules on the state level and governance rules on the local level would reduce drone delivery activity in communities by restricting drone operations in certain locations and at certain times where drones have the potential to cause a nuisance or anxiety over the intrusion of privacy.[114]

[108] Donald Wittman, *Economic Foundation of Law and Organization* (Cambridge University Press 2006).

[109] See eg Wallace Oates, 'An Essay on Fiscal Federalism' (1999) 37 (3) Journal of Economic Literature 1120; Friederick A von Hayek, 'Competition as a Discovery Procedure' in Friederick von Hayek, *New Studies in Philosophy, Politics, Economics and the History of Idea* (University of Chicago Press 1978); and Charles M Tiebout, 'A Pure Theory of Local Expenditures' (1956) 64 (5) Journal of Political Economy 416.

[110] Henry E Smith, 'Exclusion Versus Governance: Two Strategies for Delineating Property Rights' (2002) 31 (S2) Journal of Legal Studies S453, S462, S463.

[111] Watson (n 20) 1434.

[112] ibid. See also William Fischel, *The Economics of Zoning Laws: A Property Rights Approach to American Land Use Controls* (Johns Hopkins University Press 1985) 22.

[113] ibid.

[114] Yet it would still allow companies and individuals to exploit the rising value of the airspace by implementing its drone delivery services in that community, which would benefit the community as well as companies and individuals; ibid.

Still, on the other hand, such a regulatory combination of different rules on the state level and on the local level might also entail considerable enforcement costs (i.e., transaction costs) for local communities that will have to enforce and monitor the application of different regulatory regimes and hence involve a very robust regulatory environment on both local and state levels. The estimation of such administrative and enforcement costs depends on the institutional quality and capacity and of course varies among different countries. One may even argue that such costs may in some countries even be prohibitively high since the employment of additional policing and administrative force is entailed, making the enforcement of such laws unfeasible in the short run. A potential way to overcome this problem, essentially one of transaction costs, is to introduce novel technical regulatory innovation such as an AI-run novel distributed route planning method to support UAS operations in a high-density urban environment.[115] This method for minimising transaction costs would for instance allow each origin–destination (OD) pair to compete against other OD pairs for an optimised route (e.g., shortest distance), coordinated by a system-level evaluation, leading to a network design that maximises the performance of not only the individual routes but also the entire system and in turn also addresses any tragedy of the commons problem.

hus, as shown, economic arguments do not always offer a clear-cut answer but offer an insightful tool-kit for finding economically informed set of suggestions that may improve the current regulatory mix of national and local regulatory competences. For example, law and economics principles suggest decentralisation (allocating regulatory competences for regulating drone activity) in instances where one is dealing with a larger number of states, increased diverging preferences across regions, information benefits at decentralisation decision levels, increased scope for innovation through regulatory competition and accountability issues. In other words, an ill-designed vertical division of powers undermines the conditions for economic growth, prosperity and peaceful coexistence.[116]

Ultimately, Ilman and Rubinfeld argue that the choice of an "optimal" level of decentralisation depends on the relative importance one ascribes to economic efficiency and the potentially competing values of political participation, economic fairness, and personal rights and liberties.[117]

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[115] Xinyu He, Lishuai Li and others (n 55). See also Xinyu He, Fang He, Lishuai Li, Lei Zhang, Gang Xiao, "A Route Network Planning Method for Urban Air Delivery" (2022) 166 Transportation Research Part E: Logistics and Transportation Review; and Jacco M Hoekstra, Ronaldvan van Gent, Rob CJ Ruigrok, "Designing for Safety: the 'free flight' Air Traffic Management Concept" (2002) 75 (2) Reliability Engineering & System Safety 215.

[116] Roger Van den Bergh, 'The Subsidiarity Principle in European Community Law. Some Insights from Law and Economics' (1994) 1 (4) Maastricht Journal of European and Comparative Law 337; and Roger Van den Bergh, 'Economic Criteria for Applying the Subsidiarity Principle in the European Community: The Case of Competition Policy' (1996) 16 (3) International Review of Law and Economics 363.

[117] See Robert Inman and Daniel Rubinfeld, 'Rethinking Federalism' (1997) 11 (4) Journal of Economic Perspectives 43; and Inman and Rubinfeld (n 107).

4 Comment on the current EU and US legal frameworks

As described, to promote the widespread adoption of drones in the commercial space technological advancements and new regulatory frameworks are critical and solving the technical, regulatory and societal hurdles is essential to facilitate the advancement of commercial drone adoption. Moreover, ensuring that a regulatory framework is in place to support the nascent technology remains crucial for all who will be affected by the coming drone revolution.

All civil drones are presently defined as aircraft and fall within the general regulatory framework that governs aircraft. It must also be noted that alongside the general regulatory framework that governs aircraft there are currently also specific non-safety rules like contractual and third-party liability, insurance, security and environmental laws that also apply to civil drones as a special type of aircraft.[118] Today, the International Civil Aviation Organization (ICAO) classifies airspace into controlled and uncontrolled airspace using seven classes (A, B, C, D, E, F, G), depending on the air traffic services provided and flight requirements.[119] Controlled airspace covers classes A, B, C, D and E, while uncontrolled airspace covers classes F and G.[120] Each airspace class contains a set of rules indicating exactly how aircraft should fly and in which way ATC must interact with such aircraft.[121] Therefore, the ICAO defines each airspace class by the type of flight it services (instrument flight rules (IFR), visual flight rules (VFR)), provided separations (all aircraft, IFR flown aircraft from VFR flown aircraft, no separation), the type of air traffic service (ATC, traffic information about VFR flights, flight information service), speed limitation and altitude, radio communication requirements (continuous two-way, no communication) and ATC clearances.[122] As a regulatory body, the ICAO allows its member states to select airspace classes that fit their requirements.[123]

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[118] In addition, all general rules such as the GDPR, human rights, product liability and AI Act also apply to drones.
[119] ICAO Annex 11 – Air Traffic Services, International Standards, Annex 11 to the Convention on International Civil Aviation (15th edn, Montréal Canada 2018).
[120] ibid.
[121] ibid.
[122] ibid.
[123] For example, in the United States (Fig. 1), controlled airspace consists of Class A and B airspace (where clearance from air traffic control is mandatory), Class C and D airspace (where two-way ATC communications are mandatory), and Class E airspace (where it is not mandatory to contact the ATC or obtain clearance to enter). These five classes are further divided by altitudes: Class A, between altitudes 18,000 and 60,000 ft above sea level; Class B, around the nation's busiest airports; Class C, around medium-sized airports; Class D, around smaller airports with air traffic control towers; and Class E, around smaller airports without air traffic control towers. Uncontrolled airspace, defined as Class G, is airspace below 1200 ft, not equipped with any air traffic management service, where pilots rely on visual flight rules (VFR). Class F airspace is not used. Within the classes of airspace, safety is preserved by maintaining a required separation between two aircraft; Federal Aviation Administration Pilot's Handbook of Aeronautical Knowledge FAA-H-8083-25B, Chapter 15: Airspace, Washington DC (2016). See also Alexasandar Bauranov and Jasenka Rakas, 'Designing Airspace for Urban Air Mobility: A Review of Concepts and Approaches' (2021) 125 (1) Progress in Aerospace Sciences.

To safely incorporate civil drones into the national airspace, many countries and regions around the world task agencies to issue aviation laws.[124] Examples include the FAA for the USA or the European Union Aviation Safety Agency (EASA) for the European Union (EU). Herman provides a national review and comparison of UAS regulations between the USA and Europe and find that, although civil drones regulations are categorised differently in each framework, eg, based on weight, maximum flight height, or operator experience and certification, both frameworks limit the weight of the UAS to approximately 55 pounds (25 kg) and prohibit the use of civil drones around people not involved in its operation.[125] For example Stöcker and others review different national drone regulations from the perspectives of past, present and future along with criteria such as applicability (scope), technical prerequisites[126] and find that almost all countries incorporate a maximum take-off mass, whereas only two countries introduce a minimum threshold in their regulations.[127] They also suggest that UASs heavier than "150 kg are not usually regulated by national aviation authorities but by international bodies like the EASA in Europe and tend to be regulated similarly as manned aircraft."[128] Mandourah and Hochmair also note that despite certain commonalities, such as mandatory portal registration, obligatory insurance coverage and pilot licensing procedures, there are considerable differences among national regulation, e.g., in terms of minimum distance requirements around people or airports, privacy policies, and insurance coverage.[129] In addition, Lee et al. in their comparative analysis establish that safety is a much more salient concern than privacy.[130] Further, safety is focused on the technical features of UASs, registration and certification, and differentiation by use case.[131]

The US congress legislated the recreational use of drones first in 2012 and then in 2015, where the Federal Aviation Administration (FAA) was mandated to register drones, including those for recreational use, due to the increasing number of drones and inherent threat of incidents and lack of collision insurance.[132] The FAA manages most of the

[124] Ammar Mandourah and Hartwig Hochmair, 'Analysing the Violation of Drone Regulations in Three VGI Drone Portals Across the US, the UK, and France' (2024) 27 (2) Geo-Spatial Information Science 364.

[125] Michele Herrmann, A Comparison of Unmanned Aerial Vehicle Regulations in the United States and Europe in *53rd ASC Annual International Conference* (Associated Schools of Construction 2017).

[126] For example, mandatory instruments, operational limitations (restrictions), application procedure, qualification of the pilot, and ethical constraints (eg, privacy and data protection regulations).

[127] Claudia Stöcker, Rohan Bennett, Francesco Nex, Markus Gerke, and Jaap Zevenbergen, 'Review of the Current State of UAS Regulations' (2017) 9 (5) Remote Sensing 459. See also Clarke (n 6), Harber (n 6), Suominen (n 6), and Ravich (n 6).

[128] All analysed countries except for China and Nigeria allow only low-altitude flights in the range between 90 m (Canada) and 152 m (Colombia) above ground level; Mandourah and Hochmair (n 124) 373.

[129] ibid.

[130] Lee Dasom, David J Hess, and Michiel A Heldeweg, 'Safety and Privacy Regulations for Unmanned Aerial Vehicles: A multiple Comparative Analysis' (2022) 71 Technology in Society.

[131] Whereas privacy regulations tend to follow broader digital privacy guidelines. Although there are some privacy rules that are UAS-specific, many of them do not yet directly address privacy challenges that are specific to UASs; ibid.

[132] Mandourah and Hochmair (n 124).

airspace in the United States and has recently outlined detailed regulations that every drone pilot operator in the USA must comply with. In short, the following regulations apply to both commercial and non-commercial (recreational) drone pilots: a) civil drones must fly at or below 400 feet (122m); b) all drones must be registered and should not weigh more than 55 pounds (25 kg); c) compulsory use of the B4UFLY Mobile App, a safety app from the FAA that uses a drone's GPS location to provide real-time information about airspace restrictions and other flying requirements; d) there are 'No Drone Zones' where civil drones are banned from the airspace;[133] e) civil drones may fly within the visual line of sight so that operator/observer can see the drone at all times; f) the drone operator must learn about airspace restrictions, especially around airports, so that the civil drone avoids potentially endangering people or other aircraft; g) civil drones can be flown without remote ID equipment within FAA-Recognised Identification Areas (FRIAs); and h) civil drones must give way to other aircraft and not interfere with other aircraft.[134]

On top of the general regulatory framework that governs aircraft and also applies to civil drones (alongside all other applicable legislation), following an informal agreement between the Council, the European Commission and the European Parliament in 2017 a new regulation (referred to as the "Basic Regulation") was adopted in 2018.[135] It extends the scope of the European aviation safety rules to all unmanned aircraft systems, regardless of weight. This regulation[136] sets the essential requirements applicable to unmanned aircraft and their engines, propellers, parts and non-installed equipment which should also cover matters relating to electromagnetic compatibility and the radio spectrum, in order to ensure that they do not cause harmful interference, that they use the radio spectrum effectively and that they support the efficient use of the radio spectrum. However, many types of aviation equipment are not necessarily intended

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[133] The No Drone Zone includes: a) Restricted Airspace: The FAA prohibits drone flight over certain areas of airspace; b) Local Restrictions: In some locations, drone take-offs and landings are restricted by state, local, territorial, or tribal government agencies. The FAA has provided a No Drone Zone sign that can be used by these governments to identify areas where there are local flight restrictions. It is important to note that these No Drone Zones only restrict taking off or landing and do not restrict flight in the airspace above the identified area; and c) Temporary Flight Restrictions (TFRs) define a certain area of airspace where air travel is limited for a period and may be in place for different reasons. The FAA may use the term "No Drone Zone" to identify an area where there is a TFR. Examples include: major sporting events, space launch and re-entry operations, presidential movements, or in security-sensitive areas designated by federal agencies; Federal Aviation Administration, *Unmanned Aircraft Systems (UAS*), United States Department of Transportation 2024.

[134] ibid. See also Ravich (n 6).

[135] Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91; OJ L 212 22.8.2018.

[136] Amended by EU Commission Delegated Regulation (EU) 2021/1087 of 7 April 2021 amending Regulation (EU) 2018/1139 of the European Parliament and of the Council, as regards updating the references to the provisions of the Chicago Convention.

specifically for use in either unmanned aircraft or in manned aircraft but could rather be used in both. Therefore, those requirements relating to electromagnetic compatibility and the radio spectrum should only apply from the moment that, and in as far as, the design of the unmanned aircraft and of their engines, propellers, parts and non-installed equipment are subject to certification in accordance with this Regulation. The reason for this is to ensure that the regime applicable to such aviation equipment is aligned with the regime applicable to other aircraft and their engines, propellers, parts and non-installed equipment in respect of which such certification is also required under this Regulation. Provisions on the design, production, maintenance and operation of drones and their engines, propellers, parts, non-installed equipment and equipment to control them remotely, as well as the personnel, including the remote pilots, security and organisations involved in those activities are in line with law and economics recommendations and hence fit into previously discussed framework. The establishment of the EU aviation safety agency and its certification, enforcement, control, monitoring and standardisation functions is also a very important step towards regulatory compliance and control of the employment and industry of drones.

In 2019, the Commission adopted two regulations on drone operations. Implementing Regulation (EU) 2019/947[137] on the rules and procedures for the operation of unmanned aircraft classifies drones in three categories: open, specific and certified. The open category includes drones up to 25 kg to be used mostly for leisure purposes, not needing prior authorisation. The specific and certified categories largely concern the professional use of drones, requiring due authorisation from the competent authorities. The regulation also covers conditions for maximum flight distance from the surface, and training and competency requirements for remote pilots. All of these provisions are in line with previously emphasised economic suggestions and thus fit into the optimal regulatory framework.

Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems includes the technical requirements for drones to be operated in the open category. According to the EASA, these regulations make Europe “the first region in the world to have a comprehensive set of rules ensuring safe, secure and sustainable operations of drones”.[138] The Regulation also prescribes the requirements for the design and manufacture of unmanned aircraft systems (drones) intended to be operated under the rules and conditions defined in Implementing Regulation (EU) 2019/947 and of remote identification add-ons. It also defines the type of UAS whose design, production and maintenance is subject to

[137] Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft.

[138] Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems.

certification.[139] Further, Article 6 of this Regulation on the obligations of drone manufacturers provides that when placing their products on the EU market manufacturers shall ensure that it has been designed and manufactured in compliance with the requirements provided for in EU legislation, which in itself represents the highest standards of safety and strict product liability.[140] Article 40 also introduces special requirements — compulsory ex-ante certification — for drones operated in the "certified" and "specific" categories.[141] Such ex-ante requirements for compulsory certification, quality, design, security and maintenance control are all in line with law and economics recommendations and thus should be welcomed.

Finally, to ensure the safety of drone operations in airspace and their integration with manned aviation, in 2021 the Commission adopted a package of implementing regulations on U-space.[142] Implementing Regulation (EU) 2021/664 on a regulatory framework for U-space,[143] which lays down the technical and operational requirements for the U-space system. Implementing Regulation (EU) 2021/665 sets out common requirements for air traffic management and air navigation service providers to establish specific coordination procedures and communication facilities between air traffic service (ATS) units, U-space service providers and UAS operators.[144] Implementing Regulation (EU) 2021/666 establishes common rules for making the presence of manned aircraft operating in U-space airspace electronically visible. These provisions have applied since 26 January 2023.[145] From the law and economics perspective, all three of these regulations form a trajectory

[139] Moreover, it also establishes rules on making UAS intended for use in the "open" category and remote identification add-ons available on the market and on their free movement in the EU.

[140] For example, Article 38 of the Regulation states that, upon carrying out an evaluation of a drone, a Member State finds that, although the product is in compliance with this Regulation it presents a risk to the health or safety of persons or to other aspects of public interest protection covered by this Regulation, it shall require the relevant economic operator to take all appropriate measures to ensure that the product concerned, when placed on the market, no longer presents that risk, to withdraw the product from the market or to recall it within a reasonable period, commensurate with the nature of the risk, as it may prescribe.

[141] The design, production and maintenance of drones shall be certified if the drones meets any of the following conditions: a) it has a characteristic dimension of 3 m or more, and is designed to be operated over assemblies of people; (b) it is designed for transporting people; (c) it is designed for the purpose of transporting dangerous goods and requiring a high level of robustness to mitigate the risks for third parties in the case of an accident; (d) it is used in the 'specific' category of operations defined in Article 5 of Implementing Regulation (EU) 2019/947 and the operational authorisation issued by the competent authority, following a risk assessment provided for in Article 11 of Implementing Regulation (EU) 2019/947, considers that the risk of the operation cannot be adequately mitigated without the certification of the UAS.

[142]The U-space is UAS geographical area designated by the EU Member States where only UAS operations supported by U-space services are permitted.

[143] Commission Implementing Regulation (EU) 2021/664 of 22 April 2021 on a regulatory framework for the U-space.

[144] Commission Implementing Regulation (EU) 2021/665 of 22 April 2021 amending Implementing Regulation (EU) 2017/373 as regards requirements for providers of air traffic management/air navigation services and other air traffic management network functions in the U-space airspace designated in controlled airspace.

[145] Commission Implementing Regulation (EU) 2021/666 of 22 April 2021 amending Regulation (EU) No 923/2012 as regards requirements for manned aviation operating in U-space airspace (Text with EEA relevance).

that leads toward an optimal regulatory framework and are in line with the previously mentioned law and economics insights.

In addition, one must mention the US FAA's Notice of Proposed Rulemaking on Remote Identification (remote ID) of Unmanned Aircraft Systems published on 31 December 2019.[146] This remote ID concept is a novel approach that facilitates drone integration into US airspace following the consideration of concerns related to safety, national security, and law enforcement by sharing drone information, such as drone identification, geographic coordinates, and altitudes for both the vehicle and its control station. A Standard Remote ID drone is produced with built-in remote ID broadcast capability in accordance with the remote ID rule's requirements. The final rule became effective in the USA on 16 March 2021, and in the EU on 1 July 2020.[147]

A brief comparison of US and EU regulatory approaches reveals that the EU regulations are very similar to the recently enacted FAA rules and should also provide a similar level of certainty to UAS operators. However, despite all of this economically enlightened (and highly welcomed) EU regulatory activity, which is as stated generally in line with the previously discussed economic insights, some additional improvements could be made on the EU level. First, as suggested by Guerra, Parisi and Pi, AI-operated-drone-generated accidents should be clustered within the realm of "fault-based liability rather than product liability", where negligence-based rules should be blended with strict-liability rules to create precaution incentives for drone operators and their potential victims, and R&D incentives for manufacturers' development of safer drone technologies – drone manufacturer residual liability.[148]

Moreover, alongside the previously surveyed regulatory requirements lawmakers could also introduce: a) the principal's minimum asset requirement needed to engage in a drone-related activity; b) compulsory purchase of liability insurance coverage (for the principal); c) the drone operator's (principal's) criminal liability; d) an extension of liability from the actual injurer (automated drone) to the company – piercing the veil of incorporation; and d) establishment of an EU-wide publicly-privately-financed insurance fund. All these policy measures are actually already implemented in other areas of current regulatory

[146] "Federal Aviation Administration - UAS Remote Identification Overview" <https://www.faa.gov/uas/getting_started/remote_id/> accessed 10 June 2024; and Yulei Wu, HongNing Dai, Hao Wang and Kim Kwang Raymond Choo, "Blockchain-Based Privacy Preservation for 5G-Enabled Drone Communications" (2021) 35 (1) IEEE Network 50.

[147] EASA. 2019a. "European Union Aviation Safety Agency – Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on Unmanned Aircraft Systems and on Third-Country Operators of Unmanned Aircraft Systems" Official Journal of the European Union 152 (June): 1–40. C/2019/1821, L; Dronesafe. 2019b. "European Union Aviation Safety Agency – Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the Rules and Procedures for the Operation of Unmanned Aircraft (Text with EEA Relevance)." Official Journal of the European Union 152 (June): 45–71. C/2019/3824, L.; "Federal Aviation Administration - Remote Identification of Unmanned Aircraft" Federal Register <https://www.federalregister.gov/documents/2021/01/15/2020-28948/remote-identification-of-unmanned-aircraft> accessed 10 June 2024.

[148] Guerra and others (n 88).

activity, since cargo carriage by air is a highly regulated industry with a specialized body of law and hence are in line with previously discussed economic suggestions. For example, current aviation liability rules are applicable also to drones, since drones are aircraft and are regulated as such. Namely, The Montreal Convention[149] governs contractual liability for international transport and in its Article 18 imposes liability on air cargo carriers (including drone operators) for the destruction, loss, or damage to cargo during international flight unless the destruction, loss, or damage is caused by something or someone else. Moreover, the Rome Convention[150] on third-party liability, is relevant also for drones and drone operators and imposes strict (but limited in accordance with Article 4 of the Rome Convention) liability to the drone operator which is according to Article 3 of the Rome Convention strictly liable for damage sustained by third parties upon condition only that the damage was caused by an aircraft (drone) in flight.[151] In addition, in line with economic suggestions international and EU law provisions already require compulsory insurance, which also covers drones and drone operators.[152] Hence, current international instruments and EU legislation already provides a sound legal environment

[149] The Montreal Convention also provides for additional limits on carrier liability, establishes formulas for calculating damages, and prevents carriers from limiting liability through contract. Additionally, and significantly, Article 29 bars all other claims, including state-law claims, when an action for damages falls within the substantive scope of one of three liability-creating provisions. So if Article 18 were to apply, for example, the Montreal Convention would be the exclusive instrument by which a claimant could seek redress for his or her damages; Convention for the Unification of Certain Rules for International Carriage by Air (the Montreal Convention) (OJ L 194, 18.7.2001).

[150] The Rome Convention was developed to provide internationally harmonious arrangements to ensure adequate compensation for persons who suffer damage caused on the ground by foreign aircraft, while limiting the extent of the liabilities incurred for such damage in order not to hinder the development of international civil air transport; Convention on Damage caused by Foreign Aircraft to Third Parties on the Surface, done at Rome on 7 October 1952.

[151] Article 6 of the Rome Convention also states that where two or more aircraft (drones) have been involved in an event causing damage to which the Rome Convention applies, the operators of those aircraft (drones) are jointly and severally liable for any damage suffered by a third party. If two or more drone operators are so liable, the recourse between them shall depend on their respective limits of liability and their contribution to the damage. Finally, according to Rome Convention no drone operator shall be liable for a sum in excess of the limit, if any, applicable to its liability.

[152] Compulsory insurance is for example introduced by Montreal Convention for the Unification of Certain Rules for International Carriage by Air and by specific EU regulations where air carriers (including drone operators) must be insured up to a sufficient level that is adequate for all persons entitled to compensation to receive the full amount to which they are entitled under the regulation; ensure that a summary of the main provisions governing liability for passengers and their baggage is available to passengers at all points of sale, including by telephone and via the internet. Montreal Convention in its Article 50 states that States Parties shall require their carriers to maintain adequate insurance covering their liability under the Montreal Convention. A carrier may be also required by the State Party into which it operates to furnish evidence that it maintains adequate insurance covering its liability under this Convention. Moreover, in 1997, the EU adopted Regulation (EC) No 2027/97 (on air carrier liability in the event of accidents) which imposes unlimited liability on EU air carriers in the event of death or injury to passengers. Regulation (EC) No 889/2002 amends Regulation (EC) No 2027/97 and applies the rules of the Montreal Convention (including compulsory insurance) to all flights, whether domestic or international, operated by EU air carriers. This new Regulation (EC) No 889/2002 of the European Parliament and of the Council of 13 May 2002 amending Council Regulation (EC) No 2027/97 on air carrier liability in the event of accidents in its Article 3 provides that the obligation of insurance set out in Article 7 of Regulation (EEC) No 2407/92 as far as it relates to liability for passengers shall be understood as requiring that a Community air carrier shall be insured up to a level that is adequate to ensure that all persons entitled to compensation receive the full amount to which they are entitled in accordance with this Regulation.

in relation to various liability issues, regulatory operational requirements and insurance mechanisms that are also in line with previously emphasized law and economics suggestions. Hence, one has to note that the economic discussion and application of general liability rules is greatly limited and emphasized shortcomings of general liability rules are already adequately addressed (mitigated) by these specific international instruments and EU rules.[153] In addition, also other general rules, such as GDPR,[154] and recently implemented EU AI Act,[155] also apply to drones.[156]

In order to tackle the problem of potential congestion, lawmakers could in addition to previously discussed legal instruments and technical solutions[157] also introduce corrective (Piguvian) *ex ante* taxes that would equal the expected harm of drone usage.[158] As discussed, in order to deal with drone-related negative externalities (e.g., air congestion) lawmakers should introduce a tax on drone-related activity. The tax rate for each drone unit should be set equal to the estimated social costs created by such drone activity (and aim to prevent the race to the bottom set at the EU level). By design, the firm (of an individual) operating drones and subject to such taxation will then have to compare its tax costs (incurred by employing a drone) with the costs of employing other, classical, non-flying means of transport, service, delivery and performance, or reducing its output or otherwise trying to reduce its activity level. If a net tax saving were generated by one

[153] Moreover, EU Commission published a proposal for a directive on adapting non-contractual civil liability rules to artificial intelligence (the 'AI liability directive') in September 2022 which will, among other things, bring all types of software under the scope of the directive, both stand-alone and embedded, as well as digital services that affect the functionality of a product. This means that products such as drones, robots, navigation systems in cars and software in medical devices will be under Article 1 covered by this new Directive (COM(2022) 496 final, 28.9.2022). The Commission in this directive proposes to complement and modernise the EU liability framework to introduce new rules specific to damages caused by AI systems. The new rules intend to ensure that persons harmed by AI systems enjoy the same level of protection as persons harmed by other technologies in the EU. The AI liability directive would create a rebuttable 'presumption of causality', to ease the burden of proof for victims to establish damage caused by an AI system. It would furthermore give national courts in the EU the power to order disclosure of evidence about high-risk AI systems suspected of having caused damage. Stakeholders and academics are questioning, inter alia, the adequacy and effectiveness of the proposed liability regime, its coherence with the artificial intelligence act currently under negotiation, its potential detrimental impact on innovation, and the interplay between EU and national rules.

[154] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).

[155] Regulation of the European Parliament and of the Council Laying Down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act) and Amending certain Union Legislative Acts, COM/2021/206 final.

[156] All these rules complement our previous economic discussion and are adequately addressing other drone related issues (eg privacy and data protection, risks related issues).

[157] Technical solutions might restrict and govern the interactions between drones, objects, places and third parties. For example, low-risk drones may not be able to fly close to people and will be kept VLOS, whereas medium-risk drones might need to be authorised. Such authorisation will enable to precent drones flying close to people and property or will be restricted whereby nuisance will be considered.

[158] The aim of such Piguvian tax is not to raise revenue but to discourage the taxed activity, in the present instance the drone-related 'tragedy of the commons' phenomena. See eg Andy Barnett (n 93); and Judith Freeman (n 93).

of these measures, the firm (or individual) will adopt it; otherwise, it will pay the tax and employ the drone.[159]

Finally, a combination of a local (EU Member State) law that clarifies landowners' property rights "by focusing on proxies that measure ever smaller classes of uses", such as a further delineation of landowners' rights based on their location and local governance rules through municipal drone-zoning ordinances, may as shown, increase efficiency by filling in the gaps not addressed by the current MS property law aerial trespass doctrines.

In addition, the local municipalities should be given 'broad regulatory authority' to regulate drones below a certain level (e.g., 50 metres) through its zoning powers. As discussed, such a combination of exclusion rules on the state level and governance rules on the local level may then reduce drone delivery activity in communities by restricting drone operations in certain locations and at certain times where drones may potentially cause a nuisance or anxiety over the intrusion of privacy, protection of the environment, protection of cultural monuments and other broad social goals.

However, one should also note that the implementation of such a complex mix of regulatory policies and introduction of a complex hybrid regulatory system may entail considerable transaction costs (administrative, monitoring and enforcement costs) that may be even prohibitive and counterproductive. In other words, the proposed hybrid regulatory system requires a well-founded, human-capital intensive and very sophisticated institutional environment with highly skilled regulatory authorities and enforcement agencies capable of enforcing and implementing such a complex regulatory regime. In the absence of such a high-quality institutional environment, the implementation of complex hybrid regulatory system might actually induce uncertainty, increase transaction costs, consume a significant amount of resources (otherwise badly needed in other enforcement policies), overstretch the institutional capacity of regulatory agencies and end in a regulatory disaster (amplifying the tragedy of the commons and transaction costs problems).

To address these shortcomings, several potential remedies could be introduced. One potential remedy for such institutional restraints is for example the standardisation and simplification of certain regulatory approaches. For example, one could employ the previously mentioned concept of introducing a simple general rule that certain civil drones should be excluded below 30 or 50 metres in urban areas,[160] where parcel sizes tend to

[159] See also Richard Posner, *Economic Analysis of Law* (8th edn, Kluwer 2011) 502.

[160] For example, Amazon proposes that airspace below 500 feet be segregated into layers: a) Low-Speed, Localised Traffic – the area below 200 feet is reserved for applications such as recreation, surveying, inspection, surveillance, and videography, as well as low-tech aircraft without detect-and-avoid technology; b) High-speed transit – includes levels between 200 and 400 feet, and is reserved for well-equipped autonomous aircraft vehicles that operate beyond the line of sight. Technological capabilities required for this layer include detect-and-avoid capabilities, vehicle-to-vehicle (V2V) communication, and collision avoidance; c) No Fly Zone – is the area between 400 and 500 feet; and, d) predefined Low-Risk Locations – an area established by aviation authorities; Air, Amazon Prime. "Revising the airspace model for the safe integration of small unmanned aircraft systems." Amazon Prime Air 5 (2015): 36.

be relatively small and closer together, because flying in such low air space is simply too hazardous, often entails immediate congestion, and to capture detailed images adds to the likelihood of invasions of privacy by drones or completely banned around culture monuments, natural resorts and parks due to their harmful effects on local cultural heritage, flora and fauna. Yet, such a regulatory approach would be efficient provided that it also gives local municipalities 'broad regulatory authority' to regulate drones below this level through its zoning powers.[161] Some of the proposed solutions may also be implemented via existing regulatory mechanisms already employed to govern other social activities (e.g., taxation, education, private law enforcement). One may also argue that some regulatory enforcement can be done centrally at the EU level and that such regulatory proposals indeed also need serious improvements and capacity of the current institutional framework. Evidently, jurisdictions that will declare more no-fly zones will also need more code compliance officers or information campaigns to assure compliance with these restrictions.

Finally, one could introduce novel technical regulatory innovation[162] such as AI-run automatic enforcement and monitoring systems that would for example coordinate all civil drones in a certain area (preventing congestion and potential hazards from occurring) such as a novel distributed route planning method to support UAS operations in a high-density urban environment.[163] Namely, one may introduce automated AI air traffic management and control systems that should then be centralised and technologically able to accommodate, coordinate, monitor (and if needed enforce certain rules) all aircraft and all civil drones across a particular area on all levels of performance.[164]

The enforcement and compliance costs may be decreased further with the implementation of smart compliance and control mechanisms. For example, one may assess (and enforce) the compliance of the contribution to three drone image/video sharing portals (SkyPixel, DroneSpot, Flickr) with nationally and regionally issued restrictions. Mandourah and Hochmair suggest that using drone positions shared on crowd-

[161] As stated, this might be a done by creating a cause of action in trespass for landowners, subject to the local drone zoning ordinances that may allow certain uses of that space by drones – for example, an ordinance may distinguish between commercial and recreation drone uses and allow commercial drones to operate only during business hours on weekdays but limit recreational drone activity by prohibiting it altogether or to a narrower set of places and times.

[162] Namely, the inability of the current air traffic management (ATM) system to manage urban airspace is seen in the transportation literature as the primary inhibitor of the development of urban air transportation. Several challenges impede the integration of the existing NAS operations and urban operations: 1) higher number of operations, 2) greater density of operations, 3) lower altitudes of operations, and 4) varying performance of different operators and air vehicles; Bauranov and Rakas (n 123).

[163] Xinyu He and others (n 55), Xinyu He and others (n 115); and Hoekstra and others (n 115).

[164] Alternatively, one could also envisage autonomous civil drones technically equipped and having capacity to select their preferred routes while maintaining safety with onboard technology, such as sense-and-avoid, avoiding congestion etc. See eg Euclides Carlos Pinto Neto, Derick Moreira Baum, Jorge Rady de Almeida Júnior, João Battista Camargo Junior and Paulo Sérgio Cugnasca, "Trajectory-Based Urban Air Mobility (UAM) Operations Simulator (TUS)" (2019) abs/1908.08651 ArXiv.

sourced photo portals gives access to a new source of spatio-temporal data, which can be used to analyse violations of drone regulations even before any incidents occur.[165] Crowd-sourcing portals are only one source of geotagged data that is actively shared by the Web community, which is often referred to as Volunteered Geographic Information (VGI).[166]

5 Conclusions

The drone's applicability for military, scientific, leisure and commercial uses and its capability to deliver packages and transport goods more efficiently and quickly than ever before is revolutionising our everyday way of life. Legislators, landowners and businesses are exploring their future roles in the commercialisation of low-altitude airspace whereas European legislature has already produced an impressive number of regulatory interventions.

This paper seeks to show that the combined problem of prohibitively high transaction costs and tragedy of the commons phenomena might make the operation of classic property and contract law instruments (eg, trespassing and contracting between the space owners and drone operators) inadequate for addressing the growing use of automated civil drones and not to inhibit the related technological innovation and progress brought by drones. While recognising the merits of the novel European regulatory activity, the paper lists additional recommendations to ensure an improved regulatory intervention covering potential, uncontemplated civil drones-related hazards.

As highlighted in addition to discussed international legal instruments, different EU and national law provisions lawmakers may introduce also corrective ex-ante taxation that would equal the expected negative externalities (nuisance, congestion, cultural & environmental hazards etc.) of drone employment, the principal's minimum asset requirement needed to engage in a drone-related activity, extension of liability from the actual injurer (automated drone) to the company — piercing the veil of incorporation; establishment of an EU-wide publicly-privately-financed insurance fund; and of specific drone manufacturer residual liability. Local governments (municipalities) may also be given specific 'broad regulatory authority' that would clarify landowners' property rights to regulate the use of drones below a certain level (eg, 50 metres) through their zoning powers so as to mitigate the high-transaction-cost and tragedy of the commons problems. An improved regulatory regime should namely help the unmanned flight industry flourish by adopting an approach that ensures airspace safety while respecting landowners, drone operators, and the public alike and by recognising the value of both EU and local oversight of the skies.

[165] Mandourah and Hochmair (n 124).
[166] Michael F Goodchild, 'Citizens as Voluntary Sensors: Spatial Data Infrastructure in the World of Web 2.0' (2007) 2 International Journal of Spatial Data Infrastructures Research 24.