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THE GEOMETRY OF PROPERTY

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Abstract

Our legal regimes are crafted in a way that asserts control over a certain physical three-dimensional space. Some property regimes assert dominion over a vertical three-dimensional column, such as ownership of land that includes certain resources that are vertically related to it above and below the ground. Other property regimes, however, control resources on the horizontal axis. For example, legal control over a footpath exerts a kind of horizontal dominion over the space of and around the footpath. This Article offers a conceptual framework for unpacking the spatial geometry of our property regimes and underscores its significance for policy and institutional design. It shows, importantly, that the compatibility between the space over which a regime holds control and the space that is occupied by a particular resource, has profound implications. A misalignment between the two – for example, when a vertical regime is applied to a horizontal resource – implicates how well the regime functions. After laying out the conceptual framework, the Article illustrates its application to a contemporary problem of extracting wind energy.

Key words: Property, Resources, Infrastructure, Energy, Space, Slicing, Functional analysis, Institutional design.

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I. INTRODUCTION

Our property regimes exert control over a certain three-dimensional space. Property law students are taught, for example, that although we demarcate land boundaries on a two-dimensional map, the property right is not two-dimensional. Rather, ownership of land affords its holder control over a three-dimensional vertical column, below and above the crust of the earth. The *ad coelum* rule in Anglo-American legal thought embodies this kind of vertical property assumption.² Yet control over resources is not limited to vertical columns. Other regimes assert control over three-dimensional spaces on the horizontal axis. I call these ‘horizontal regimes’. Such are, for example, the rights to footpaths, pipelines, transmission lines and underground aquifers.

The interplay between horizontal and vertical regimes lies at the heart of contemporary scholarly debates. On December 7, 2016, Amazon.com made its first commercial delivery by

² The full statement of the maxim is *cujus est solum, ejus est usque ad coelum et ad inferos*, which has been translated into English as ‘the owner of the soil owns to the heavens and also to the lowest depths.’ *Black’s Law Dictionary* (6th edn, West Publishing, 1990).

drone to a customer in Cambridgeshire, England.³ The drone flew for about two miles, at an altitude of 400 feet, before landing in the back yard of a customer with a package. The once unused resource – the low airways above rural Cambridge – is now rapidly becoming an important resource. Who controls this resource? Should the low-airspace, through which drones fly, be governed by a vertical property regime, in which case control would accrue to the underlying landowners, or should it be horizontally controlled much like the navigable airspace used for commercial aviation?⁴

A few days after Amazon delivered its first package by drone, on the other side of the Atlantic, the first offshore wind farm spun to life off the coast of Rhode Island, in the United States.⁵ For the first time in US history, coastal winds are now being harvested for energy production. Wind energy in the US, although until recently focused solely on land, has grown tremendously in recent years, roughly 30 percent per year since 2000,⁶ and as of 2018 supplied 6.5 percent of the total electricity generated in the US.⁷ Importantly, extracting energy from the airstream, in the way wind turbines do, profoundly impacts its surroundings.⁸ But, who controls the wind? Does it necessarily need to be the landowners underlying the airstream (a vertical regime), or could the wind be controlled in the strata of airspace in which it takes place (by a horizontal regime)?

Faced with the management of a particular resource, we thus must decide which one of these legal institutions prevails in a given situation. The question then becomes – is a resource best managed vertically or horizontally? Understanding the trade-offs involved in each type of regime is especially significant in our times due to the shifting land uses and rapid urbanization, as well as the development of energy resources, including wind energy and hydrofracking technologies, the utilization of groundwater at times of drought, and emergent technologies such as drones – all of which interact on both the vertical and horizontal axes.

A preliminary note on terminology is in order. First, I use the term ‘property’ here to refer, generally, to legal institutions for regulating the use of resources, in various forms. In so far as property is the conceptual category that allows us to divide up control of resources in our

³ Nick Wingfield & Mark Scott, “In Major Step for Drone Delivery, Amazon Flies Package to Customer in England”, *The New York Times*, (14 December 2016).

⁴ Most countries recognise some form of horizontal control over the strata of airspace that is typically used for commercial aviation. See notes 58-63 *infra*.

⁵ Kayana Szymczak, “America’s First Offshore Wind Farm Spins to Life”, *The New York Times* (14 December 2016).

⁶ US Dep’t of Energy, ‘Wind Vision: A New Era for Wind Power in the United States’ (2015) at 1-3.

⁷ US Dep’t of Energy, *WINDEXchange: Utility-Scale Wind Energy*, online: <<https://windexchange.energy.gov/markets/utility-scale>>.

⁸ For a discussion of the impacts of extracting energy from the airstream see notes 72-81 *infra* and accompanying text.

world in a distributed manner, property regimes are the instruments of that category. This, to be clear, goes far beyond ownership of land. It includes many types of resource governance, encompassing use-rights and access-rights of different sorts as well as ownership, both individual and shared. It also includes many different types of resources, ranging from natural resources such as air, water, wind and oil, to transportation and transmission resources such as bridges, tunnels, roads, navigable airways and more. I do so because, as the examples below will show, although these types of entitlements differ in some respects, the analysis of their spatial dimension proves to be similar.⁹

Second, the terms ‘horizontal’ and ‘vertical’ are used here to refer to the spatial domain over which a property regime exerts its control.¹⁰ Imagine if you were drawing out the geometrical shapes in the physical space all around you. Our legal regimes are crafted in a way that asserts dominion over a three-dimensional space, which can either be perched parallel to the surface of the earth, perpendicular to it, or, have elements of both. At the same time, our physical resources, whether they be water, air, oil, parking spots in busy cities, footpaths or plots of land, occupy a certain three-dimensional space in the world. Resources thus likewise can be thought of in terms of space they predominantly occupy – whether vertical, horizontal or something in between.

The aim here is not to impose a dichotomy between vertical and horizontal regimes. Rather, mapping out the geometry of property in this way is intended to set up the grid, to serve as a starting point for analysing the spatial dimension of resource control, and for gaining a deeper understanding of its significance. The key issue here is how we carve out the space around us, and how well that carving functions. This is a way of analysing property by looking at its geometrical presence.

The contribution of this Article is thus, first, in calling attention to the spatial analysis of property and more broadly resource management. The second contribution of this Article is in underscoring the significance of the spatial dimension of property for policy and institutional design. The claim is that the compatibility between the space over which a regime holds control and the space that is occupied by a particular resource, has profound implications. A

⁹ I have used a similar definition of ‘property’ elsewhere as well: [*anonymised*]

¹⁰ The terms ‘vertical’ and ‘horizontal,’ as they are used here, are separate from their use in other contexts, including the rich body of literature that studies questions pertaining to multi-tiered governance, international law and competition law. The term ‘horizontal’ has also been used in property scholarship, albeit in a different manner than the one offered here. Michael A. Heller, “The Tragedy of the Anticommons: Property in the Transition from Marx to Markets” (1998) 111 Harv L Rev 621 at 670 (‘anticommons property creates “horizontal” relations among competing owners of overlapping rights in an object’).

misalignment between the two – for example, when a vertical regime is applied to a horizontal resource – implicates how well the regime functions. A spatial mismatch – between the regime and the resource – is costly since it increases the number and complexity of interactions incurred by users seeking to employ or enjoy the resource. Although such spatial mismatches have in some instances been resolved or partially mitigated¹¹, these resolutions have been, thus far, on an ad hoc basis. This Article provides a tool for a more systematic analysis, which is otherwise lacking in the discourse.

Unpacking the geometry of property also underscores the fact that seemingly separate issues in fact stem from the same problem of spatial misalignment. The first issue that stems from a spatial misalignment is one of aggregation – that is the need to seek many authorisations to enable a particular activity. Aggregation issues exist in both the contexts of infrastructure (roads, tunnels, navigable airways) and in natural resources (oil and gas, wind). The second issue that results from spatial misalignment is overuse. The example of over-extraction from groundwater reserves, serves as a useful illustration of this problem. Both types of problems, however, are rooted in the same spatial mismatch between the type of regime and the resource.

The significance of the geometry of property has yet to be fully explored in the literature. Scholars have, indeed, pointed to the significance of the ‘scope’ of a resource in tailoring a property regime to fit it.¹² The idea, put simply, is that a broader resource calls for a broader management regime, which typically means plotting out a bigger parcel of land, or piecing together multiple plots of land. Yet the question of scope does not fully capture the nuances of our three-dimensional regimes and the different axes on which they operate. A pipeline

¹¹ The examples of creating the navigable airways in the 20th century and the unitization of oil and gas fields are illustrative. See notes 58–63, 65–66 and accompanying text *infra*, discussing the resolution of spatial mismatches with regards to commercial aviation and oil and gas, respectively. The latter issue has been studied in property scholarship specifically with regards to facilitating contractual solutions to solve fragmented rights in natural resources. Gary Libecap’s work on contracting among landowners toward control of oil and gas reserves serves as an illustrative example of this strand of scholarship: Gary Libecap, *Contracting for Property Rights* (Cambridge, 1989) [Libecap, *Contracting for Property*]. Dean Lueck and Karen Bradshaw examine the role of private contracting in governing ‘landscape-level resources’, which are resources ‘that exceed the scope of individual parcels of land and hence are beyond the control of a single landowner’. Karen Bradshaw & Dean Lueck, “Contracting for Control of Landscape-Level Resources” (2015) 100 Iowa L Rev 2508 at 2511 n7 [Bradshaw & Lueck, “Landscape-Level Resources”]. In later work, Karen Bradshaw and Bryan Leonard analyse the coordination of resource management among landholders, where such resources are ‘grouped at scales different than land parcels’. Karen Bradshaw & Bryan Leonard, ‘Virtual Parceling: Coordinated Resource Management in an Era of Privatization’ (2020) Int’l J Commons (*forthcoming*) [Bradshaw & Leonard, “Virtual Parceling”].

¹² Robert C. Ellickson, “Property in Land” (1993) 102 Yale LJ 1315 at 1335 [Ellickson, “Property in Land”]. See also Dean Lueck, “The Economic Nature of Wildlife Law” (1989) 18 J Legal Stud 291 [Lueck, “Wildlife Law”]; Lee A. Fennell, “Commons, Anticommons, Semicommons”, Kenneth Ayotte & Henry E. Smith, eds, *Research Handbook on the Economics of Property Law* (Edward Elgar, 2011) at 35, 37–40.

tunnel, for example, is not merely a bigger plot of land. Describing it as such would be missing a key feature about it and about the way it operates. A tunnel has directionality in space, which otherwise is not fully captured by the concept of ‘scope’. The framework offered here thus underscores the fact that not only the scale of the activity matters, but also the physical dimension on which it takes place.

After laying out the conceptual framework, the Article illustrates its application to a range of resources, from natural ones such as oil and gas, water law and wildlife, to infrastructure, including tunnels, roads, bridges, pipelines and transmission lines. Applying the framework also sheds light on contemporary ongoing debates, including the control of drone flights, the extraction of groundwater and hydrofracking drilling. One particularly interesting example is that of wind energy. Using a novel case study of wind energy in the US, the Article shows that ‘wind rights’ are currently designed in a way that presents a spatial mismatch. Resolving the spatial mismatch in the case of wind, this Article argues, would warrant a shift toward a more horizontal regime which would be more in harmony with the resource. It proposes this can be achieved in several ways, including, applying a ‘unitization-like’ regime or establishing a ‘wind market’ that facilitates trade, horizontally, among users.

II. MAPPING OUT THE GEOMETRY OF PROPERTY

(A) Horizontal and Vertical Regimes

Property regimes can be analysed by mapping out the spatial domain of control they exert. ‘Vertical property’ regimes are ones that assert dominion over a three-dimensional cylinder or prism that is predominantly perpendicular to the surface of the earth. Ownership of land is the paradigmatic example. Although the boundaries of land parcels are marked on a two-dimensional map according to their ‘planar’ dimensions, ownership of land is in fact three-dimensional, since it extends below and above the surface of the earth. The *ad coelum* rule is the embodiment of the vertical approach to landownership. According to the *ad coelum* rule, an entitlement in land includes certain rights to utilize natural resources in the column below the surface and above it. This may include, for instance, the ability to dig below the surface to place foundations for a home, and the right to build upwards into the airspace above the earth to erect that same home. The *ad coelum* rule may also accrue to the landowner control over

resources such as crops growing in the ground, subsurface minerals and underground caves.¹³ Importantly for our purposes, the cylinder of control that accrues to the landowner is vertical in the sense that it provides control upwards and downwards in relation to the surface of the earth.

The *ad coelum* rule is well established in Anglo-American law. Dating back to Roman Law and featuring prominently in Blackstone's account, in English Law, it was most recently endorsed by the Supreme Court in *Bocardo SA v Star Energy UK Onshore Ltd* [2010]. The court was called upon to decide whether the owner of land retains control over the deep subterranean strata, despite the fact that the Crown owns the petroleum underground. The court endorsed the vertical conception, finding the *ad coelum* principle affords the owner of the surface control also over the subterranean layers of the earth. The maxim, explained the court, 'still has value in English law as encapsulating, in simple language, a proposition of law which has commanded general acceptance'.¹⁴ The verticality extends also to the area above the crust of the earth.¹⁵

Horizontal property, in contrast, exerts control over a three-dimensional domain on the horizontal axis. Think of a footpath or an easement to pass through your neighbours' lawn. Underground pipelines serve as another illustrative example. They are horizontal in the sense that they exert control (albeit not always *private* control) over a domain that is that the is

¹³ See Thomas W. Merrill, "Trespass, Nuisance, and the Costs of Determining Property Rights" (1985) 14 J Legal Stud 13 at 16 n12, 35-36; Henry E. Smith, "Exclusion and Property Rules in the Law of Nuisance" (2004) 90 Va L Rev 965 at 992; Thomas W. Merrill & Henry E. Smith, *Property: Principles and Policies* (3rd edn, Foundation Press 2017) at 13-14. The doctrine of *ratione soli*, by reason of the soil, is another example of a doctrinal – mostly vertical – link between land and related resources. Thomas W. Merrill, "Accession and Original Ownership" (2009) 1 J Legal Analysis 459 at 470 [Merrill, "Accession"].

Ownership of land is indeed the most prominent example of vertical property. Yet it is not the only example. A vertical conception of control can be found even in simple daily delineations, such as seats in the cinema. A patron visiting the cinema receives (albeit temporary) use-rights for a chair, and some portion of the airspace above it – on the vertical axis.

¹⁴ *Bocardo SA v Star Energy UK Onshore Ltd* (2010) UKSC 35, (2011) 1 AC 380 at 398.

¹⁵ The *ad coelum* maxim also means that control extended, at least at one point, to the heavens. Although the height to which such control extends today has been curtailed in most jurisdictions, primarily to allow for aviation. In English Law, the control afforded to the landowner no longer extends to all the way to heavens, but rather extends to the height which is required for the ordinary use and enjoyment of land, following *Baron Bernstein of Leigh v Skyviews & General Ltd* [1978] QB 479. In the US, the 'navigable air space' is defined by reference to altitude and thus curtails the height of landowner control (Air Commerce Act of 1926, 44 Stat. 568, 49 U.S.C. § 171 et seq., as amended by the Civil Aeronautics Act of 1938, 52 Stat. 973, 49 U.S.C. § 401 et seq; *United States v. Causby*, 328 U.S. 256, 260-61 (1946) ('[t]he air is a public highway', otherwise landowner control over airways would 'clog these highways, seriously interfere with their control and development in the public interest...'). Nonetheless, the landowner still retains a significant degree of control, up until that height, within the vertical column of control above the land. As will be discussed below, curtailment of *ad coelum* to allow for aviation can be seen as an example of an ad-hoc solution to the spatial mismatch between vertical landownership and horizontal air-flight. See notes 58-63 *infra* and accompanying text.

positioned parallel to the surface of the earth.¹⁶ Many other forms of transportation and infrastructure resources serve as similar examples, including railways, trails, bridges, roads,¹⁷ pipelines and transmission lines and even linear parks.¹⁸ Navigable waterways are another similar example of a resource that is controlled along the watercourse or within the lake, on the horizontal axis, rather than being split up into vertical slices.¹⁹

All these examples – from railways to pipelines – are what I think of as ‘noodles’, in the sense that they are, generally, long and narrow.²⁰ A second category of horizontal resources can be described as ‘pancakes’, since they are, generally, flat and wide. Examples of such pancakes include pools of oil and gas, groundwater reserves, wildlife habitats, grazing meadows, forests and the winds.

Three-dimensional geometry is such that every domain has both a ‘planar’ base and a height. In the example of landownership, the planar area is the equivalent of the land boundaries as marked on a typical two-dimensional map. The height is defined by the *ad coelum* rule and extends a certain distance below and above the surface. As a result of this three-dimensionality, each vertical column of control also has some horizontal breadth, which is represented in the planar area. A building, for example, occupies a space that is both vertical (the height of the building above ground and the foundations dug below ground) and horizontal (the breadth of the building). Likewise, a horizontal domain of control has a vertical aspect.

¹⁶ The concept of carving-up the resources in the world horizontally has been mentioned before, although not fully analysed in the way the framework offered here does. Kevin Gray provides the following example, albeit in a slightly different context: ‘there can be multiple... fee simple estates in the same ‘land’, as for example where X owns the fee simple in the surface layer of the earth and Y owns the fee simple in a subterranean stratum and Z is simultaneously entitled in fee simple to the standing timber’. K. Gray, “Property in Thin Air” (1991) 50 Cambridge L J 252 at 258. The notion of creating horizontal slices has also been recognised by the courts, although not fully developed in the way the framework here does. *Ramroop v Ishmael* (2010) WL 2832924 (‘as a matter of principle land can be owned in horizontal layers, as every purpose-built block of residential flats illustrates’).

¹⁷ In a recent example, the city of San Francisco sold a street and the adjacent sidewalks to two private owners. See Matier & Ross, “Rich SF Residents Get a Shock: Someone Bought Their Street”, San Francisco Chronicle (7 August 2017).

¹⁸ Consider, for instance, the High Line in New York City, an old elevated railway which has in recent years been converted to an elevated linear public park. See Friends of the High Line, *The Non-Profit Caretakers of the High Line*, online: <<http://www.thehighline.org/about>>.

¹⁹ Barton H. Thompson Jr, John D. Leshy & Robert H. Abrams, *Legal Control of Water Resources: Cases and Materials* (5th edn, West Academic, 2013) at 589.

²⁰ Richard Epstein uses the term ‘long and skinny’ to describe resources such as rivers, beaches and trails as ‘ways in which societies connect different individuals’, a category of resources I would think of as horizontal ‘noodles’. Richard Epstein, “Property Rights and Governance Strategies: How Best to Deal with Land, Water, Intellectual Property, and Spectrum” (2016) 14 Colo Tech LJ 181 at 185.

An underground tunnel has a circular planar diameter. If it was completely flat of course it would be (nearly) impossible to conduct any activity within the domain.

However, the geometrical shapes can also have directionality, in the sense that they can be positioned one way or another within in a three-dimensional space. If one views the surface of the earth as the reference or base plane, a three-dimensional geometrical shape can be either perpendicular to the surface of the earth, parallel to it (and in some cases, somewhere in between).²¹ Figure 1 provides a schematic illustration of three-dimensional domains that are perpendicular to the surface of the earth; Figure 2 illustrates domains that are parallel to it.

Figure 1: Vertical Domains of Control

²¹ We can, of course, imagine a three-dimensional shape that is either a perfect cube or a perfect sphere, such that it is hard to point to a direction in which the shape faces in a meaningful way. Although presumably most property regimes will not exert control over such perfect geometrical shapes.

Figure 2: Horizontal Domains of Control

Horizontal and vertical property regimes need not exist in isolation, but rather can, and in fact do, interact and mix with each other in different ways. Indeed, some property regimes can have elements of both horizontal and vertical management. Ownership of land awards vertical rights, while a foot-path easement cutting through the same land awards horizontal rights.²² Figure 3 illustrates this type of mixture.

²² One may argue that to some extent all horizontal regimes can be seen as encompassed within a very large vertical column. While as a geometric matter that could be true, I would resist that characterization as a matter of a functional distinction.

Figure 3: Horizontal and Vertical Within

Elevated highways and railways are another example of interacting vertical-horizontal regimes. The High Line in New York City, for instance, overlays, in the most literal sense, the property regimes below it.²³ Notice that in the latter case, some of the underlying structures might be vertical (residential apartments, commercial space), while others could be horizontal (streets, roads). The High Line's horizontal structure thus overlays both vertical regimes and horizontal ones. The Subway or Underground systems in New York and London would serve as similar (although reverse) examples. Figure 4 schematically illustrates such overlays, where H represents the High Line and S represents the Subway or Underground.

²³ Friends of the High Line, *The Non-Profit Caretakers of the High Line*, online: <<http://www.thehighline.org/about>>. The High Line also crosses *under* property regimes that overlay it from above. Most famously, it crosses under the Standard Hotel. *The Standard*, online: <http://www.standardhotels.com/new-york/properties/high-line?utm_source=google&utm_campaign=google_my_business&utm_medium=organic>.

Figure 4: Overlays (e.g. the High-Line and Subway tunnel)

Riparian water rights in the US illustrate a slightly different type of mixture. The right to access water under riparianism is granted to owners of land that abuts or underlies the watercourse, which is a determination that is based on a vertical regime. However, the extent to which riparians can use the water is governed by principles of reasonability and correlativity²⁴ which operate on the horizontal axis.

(B) Directionality of Resources

Not only property regimes can be analysed through their geometrical domains. The resources themselves (to which the regimes apply) can be subject to a similar classification. A vertical resource, under the framework offered here, is one that either interacts with the world, or that the activity within it takes place – primarily – on the vertical axis. Land is again the paradigmatic example in this regard. A horizontal resource, in contrast, occupies a space that is predominantly parallel to the surface of the earth, or facilitates an activity within it that operates parallel to the ground. Examples include roads, radio waves, pools of oil and gas, groundwater aquifers and flowing surface water.

²⁴ Yael R. Lifshitz, 'Rethinking Original Ownership' (2016) 66 U Toronto LJ 515 at 549 n159 [Lifshitz, "Original Ownership"]; Thompson, Leshy & Abrams, *supra* note 19 at 29, 33.

To be sure, many resources interact with the world on both the vertical and the horizontal axes. Indeed, the relationship between these modes of interaction is perhaps best characterised as a matter of degree rather than a binary split. The point, as mentioned, is not to find perfectly aligned cylinders on either the vertical or horizontal axes, but rather to set up the grid, to provide a tool for thinking about the spatial dimension of our resources.

To understand the spatial dimension of a resource, under the framework offered here, consider what is the *predominant* interaction or activity that characterises the resource. Is a footpath more vertical or more horizontal? Notice that the horizontality (or verticality) of resources under this definition can either be a product of their natural attributes or the type of activity that takes place within them. Resources such as wind, groundwater, oil and gas and wildlife, all have an inherent feature of horizontality. Other resources gain their horizontality from the type of activity that takes place within them. Such are, for instance, roads and underground tunnels.

Although the interaction on the horizontal axis itself does not entail any specific type of resource, it appears the horizontal resources are often moving themselves (wildlife, water) or enable movement within them (roads, navigable airways). There are perhaps a few examples, such as the scenic or landscape value of an area that can be considered horizontal but not mobile.²⁵ Vertical resources, under the framework offered, are more often immobile, but a few examples of vertical movement do exist, such as elevators and certain types of extractive drilling.²⁶

The analysis of resources as either vertical or horizontal can also change over time. Consider again the example of the low airspace, fairly close to the ground. At one time it was used almost solely for vertical activities such as erecting buildings. Today however, it is also increasingly used on the horizontal axis for drone flights. Two points are important to notice in this example. First, the same airspace thus can in theory be both a vertical and a horizontal resource, depending on how it is primarily utilised. Second, the dominant axis of interaction can shift over time as the uses of the resource are altered.²⁷ The categorization of resources can thus be elastic over time.

²⁵ Other examples of non-moving horizontal resources could be forests (as resources for timber but also, for instance, as carbon sinks) and geological formations.

²⁶ See note 52 *infra*, discussing examples of vertical movement.

²⁷ One may wonder at what point does an activity amount to a 'dominant' one so as to warrant classifying the resource as either vertical or horizontal based on that activity. Since I view the relationship between horizontality and verticality as one that exists on a scale, rather than a dichotomy, it is somewhat difficult in the abstract to draw a precise line between the two.

(C) *Scope Versus Directionality: Situating the Framework in the Literature*

Analysing the spatial dimension of our property regimes and our resources, in the way the framework offered here does, reflects an approach that envisions a deep connection between the characteristics of a resource and the management thereof. It is tied, inherently, to the physical space occupied by the resource.

The framework offered here thus relates to the scholarship on the connection between the characteristics of a resource and its management, including Lee Anne Fennell's work on 'slicing' resources.²⁸ Fennell studies the role of 'resource segmentation' as 'the natural or artificial division of resources into appropriable units' and the significance such division holds for resource utilization. A pie, for example, can be divided into single-serving slices, which makes it 'easy for a group to share in a strife-free manner,' or it can be divided otherwise sub-optimally. The point is that the choice of how to slice the pie, literally, impacts how it is used. The same rationale applies, according to Fennell, to many other resources.²⁹ Fennell's work relates to the framework here, first, in that both share the view that particular features of a resource impact the way it is utilised; and second, in the sense that classifying resources as either vertical or horizontal could be seen as a type of 'segmentation' per Fennell.

Property scholarship has also discussed the importance of 'scope' in fitting a regime to a resource. The idea, put simply, is that a broad resource calls for a broad regime to control it. Robert Ellickson introduces the concept of scope specifically with regards to land-ownership. Ellickson's scope principle implies that the division of land should follow the scope of the activity for which it is used.³⁰ 'Small events,' such as cultivating a tomato plant, fit well with individual parcels of land. Even 'medium events,' such as building a small dam on a local stream to create a pond, could possibly work with individual plots assuming bargaining with the one or two affected neighbours is reasonably easy. Larger events, however, such as a fire that emits fumes over its surroundings, require larger holdings of land.³¹ Ellickson's key

Although that does not mean one cannot, in most cases, place the resource as closer to either one end of the scale or the other.

²⁸ Lee A. Fennell, "Slicing Spontaneity" (2015) 100 Iowa LR 2365 [Fennell, "Slicing"].

²⁹ Fennell's central thesis is that 'the appropriate segmentation of resources can reduce informal governance burdens and help to produce convergence between privately optimal and socially optimal choices'. *Ibid* at 2367.

³⁰ Ellickson, "Property in Land", *supra* note 12.

³¹ *Ibid* at 1325, 1327-1328 (on small events), at 1330-1331 (on medium events).

insight pertains to the economies of scale that can be achieved for some land uses by adjusting the size of the plots.³²

Dean Lueck's work on wildlife follows the same notion of scope. Lueck shows how the range of the species' habitats correlates with the range of the jurisdiction charged with managing the wildlife. Affirming the scope idea, Lueck finds that '[t]he larger the territory of a wildlife stock... the greater will be the geographic jurisdiction of the controlling party, whether it is a single landowner, a group of landowners, a government agency, or a group of agencies'.³³

The scholarship on scope has underscored the resource-regime connection, a connection which I fully embrace within the framework offered here. Although the framework here underscores that the question of scope does not fully capture the nuances of our three-dimensional property. The Underground or Subway tunnels, for example, are not just bigger chunks of land. Describing them as such would be missing one of their key features. A tunnel has directionality. The concept of 'scope' does not fully capture the question of directionality nor the different axes on which activities take place.

Although Ellickson acknowledges at one point the vertical-horizontal interactions that might occur in certain instances, when the vertical reach of the *ad coelum* doctrine is curtailed in order to enable activities that require horizontal breadth which is greater than an individual plot can typically provide,³⁴ his analysis does not account for the directionality of the activities or the axes on which they take place. For instance, in his seminal discussion of scale efficiencies, Ellickson provides the following example: the optimal scale for a college dorm room is approximately 75 square feet; whereas for the entire campus the optimal scale is 200 acres; and exploitation of an oil pool below the surface ideally needs 7777 acres.³⁵ These examples show, indeed, that different activities require different scales to optimally operate. But notice that the activities in this example not only require different scales but also, and regardless, operate on two different axes: the dorm room interacts on the vertical axis; the oil pool interacts horizontally; and the college campus is perhaps a mixed example which interacts both vertically and horizontally to varying degrees. Thus, the indication of scale alone does not fully capture the essence of the resource.

³² Lee A. Fennell, "Scaling Property with Professor Ellickson" (2019) 18 William and Marry Bill of Rights J 173 at 174.

³³ Dean Lueck, "Wildlife Law", *supra* note 12 at 308. Put in the terms of this Article, Lueck's work in this context provides examples of well correlated regimes (ones that do not have a spatial misalignment), namely on the horizontal axis.

³⁴ Ellickson, "Property in Land", *supra* note 12 at 1363.

³⁵ *Ibid* at 1332-1333.

Moreover, one might also assume that a vertical resource is inevitably smaller in scope, while a horizontal resource larger in scope. It is true that since horizontal resources typically span over larger geographical areas, they might tend to be larger in scope. However, that need not be the case. A foot-path, for instance, can be considered a small event under the scope principle, and a horizontal regime under the framework offered here.

A horizontal property regime is also not necessarily a shared or public one. Consider again the example of an access-road easement that runs horizontally through a few plots of land. Such an easement is, under the framework offered here, a horizontal property regime, even though it can apply to a single individual or a large group of people just the same. Although it is possible that horizontal regimes, to the extent they extend over larger geographical areas, may lend themselves to shared regimes more often. A vertical property regime is likewise not necessarily a private one. Think of property in a public building, like a library. It is just as vertical as family residence, yet, the former is (typically) publicly owned.

Lastly, one may wonder how the framework offered here relates to the distinction between Exclusion and Governance, as drawn by Henry Smith.³⁶ Smith posits, and shows in a series of works,³⁷ that property law employs a range of strategies that fall on a spectrum between exclusion to governance. The exclusionary strategy, according to Smith, broadly allocates management decisions to the right-holder and has fairly simple ‘keep out’ rules. The governance strategy, in contrast, uses more detailed rules to deal with more complex and nuanced situations.³⁸ How does the exclusion-governance distinction relate to the horizontal-vertical distinction? Although both frameworks speak to the institutional design of property, the exclusion-governance distinction is focused on the *type* of management strategy employed, whereas the framework offered here is concerned with the *spatial, physical*, domain of control of a property regime. The questions asked by each framework are thus separate. The type of management (either exclusion or governance) does not have to be correlated with the domain of control (either vertical or horizontal). To illustrate, consider the following: under the framework offered here, and small foot-path and a home built on a parcel of land operate on two separate axes (the former – horizontal, the latter – vertical). Both however, could easily employ an exclusionary strategy, under the exclusion-governance framework. I return to the

³⁶ Henry E. Smith, “Exclusion Versus Governance: Two Strategies for Delineating Property Rights” (2002) 31 J Legal Stud S453 [Smith, “Exclusion Versus Governance”].

³⁷ Henry E. Smith, “Intellectual Property as Property: Delineating Entitlements in Information” (2007) 116 Yale LJ 1742; Henry E. Smith, “Governing Water: The Semicommons of Fluid Property Rights” (2008) 51 Ariz L Rev 445 [Smith, “Governing Water”].

³⁸ Smith, “Exclusion Versus Governance”, *supra* note 36 at S454-S455.

exclusion-governance distinction below within the discussion of a spatial mismatch, to show how the two frameworks further relate to each other.

III. A SPATIAL MISMATCH AND ITS CONSEQUENCES

Property regimes control a certain three-dimensional space, that can be vertical, horizontal or a mix of the two. Resources likewise occupy a certain three-dimensional space, that can be characterised as between vertical and horizontal. The claim here is that the spatial compatibility between the two – the property regime and the resource – has implications for resource access and control.

When a regime and a resource are not well correlated on the spatial dimension, a spatial mismatch occurs. The following examples illustrate the difficulties a spatial mismatch can pose.

(A) *Examples of Spatial Mismatches*

The example of groundwater in the nineteenth century nicely illustrates the spatial mismatch between a ‘pancake’-like horizontal resource and vertical columns of control that are (typically) based on landownership. Groundwater, both in England and in the US, was governed by the ‘English Rule,’ which was named after and adopted from the English case of *Acton v Blundell*.³⁹ The rule allowed only landowners who held land directly above the aquifer to access it and draw water from it.⁴⁰ The English Rule thus embodied a vertical conception of property (based on landownership). Notice however that the resource in question – the aquifer – is a horizontal one, since it flows parallel to the surface of the earth.⁴¹ And indeed, imposing

³⁹ *Acton v Blundell* (1843) 152 ER 1223. For a discussion of the Acton case and its adoption by American courts see Michael Taggart, *Private Property and Abuse of Rights in Victorian England: The Story of Edward Pickles and the Bradford Water Supply* (OUP, 2002) at 107, 134.

⁴⁰ David H. Getches, *Water Law in a Nutshell* (4th edn, Thompson West, 2009) at 268-269 [Getches, *Water Law*].

Importantly, to complete the entitlement in a specific bucket of water from the aquifer landowners still needed to pump it to the surface. [*anonymised*]

⁴¹ Getches, *Water Law*, *ibid* at 259. Although there is some vertical movement within the aquifer, as water percolates through the rock formation downwards to the lower bedrock. *Ibid* at 260.

a vertical structure on the horizontal resource proved problematic as it led to premature and inefficient withdrawals from the aquifer.⁴²

The same could be said about the regimes governing the extraction of oil and gas in the United States in the late nineteenth and early twentieth century. The rule, at the time, was that each landowner could drill under their land and drain the oil pool.⁴³ This rule, however, led to fundamental problems of over-drilling and premature exploitation, the difficulties and the related inefficiencies of which have been well studied.⁴⁴ Notice the mismatch here again: the horizontal oil pool was controlled through the vertical silos of landownership.

Wildlife management is yet another interesting example. Although wildlife is generally horizontal in nature, at least in some instances it is controlled by the landowners, that is, via a vertical property structure.⁴⁵ And indeed, scholars of natural resource law have noted the tension that is created as a result of the disjuncture between the management of wildlife through land parcels and the range of the natural habitat.⁴⁶

A strand of scholarship in natural resource law is concerned with the role of private contracting among landowners with regards to certain natural resources. Gary Libecap, for example, studies contracting among landowners toward control of oil and gas reserves.⁴⁷ Dean

⁴² Barton H. Thompson, Jr., “Essay, Tragically Difficult: The Obstacles to Governing the Commons” (2000) 30 *Envtl L* 241 at 250 (discussing the tendency to over extract groundwater). Today, many states have legislation that treats groundwater as ‘a public resource and not property of overlying landowners’. Getches, *Water Law*, *supra* note 40 at 269, 273-274.

⁴³ Lifshitz, “Original Ownership”, *supra* note 24 at 525-526 (discussing the allocation of access rights to surface owners in the early days of oil and gas exploration in the United States).

⁴⁴ When production rights are split among multiple right-holders, the result is ‘excessive investment’, in ‘wells, pipelines and surface storage’, along with ‘too-rapid extraction’. Gary D. Libecap, “Unitization”, Peter Newman, ed, *The New Palgrave Dictionary of Economics and the Law* (Stockton Press, 1998) at 641 [Libecap, “Unitization”]. See also Gary Libecap & James E. Smith, “The Economic Evolution of Petroleum Property Rights in the United States” (2002) 31 *J Legal Stud* S589 at S591-S592 (discussing the costs associated with over-extraction) [Libecap & Smith, “Petroleum Property Rights”].

⁴⁵ Lueck, “Wildlife Law”, *supra* note 12 (underscoring the differences between the US and Great Britain in this regard and showing specifically how land-ownership based management was often adopted in Great Britain); Merrill, “Accession”, *supra* note 13 at 470 (discussing when rights to wildlife are awarded ‘to the owner of the land on which they are killed or captured’).

⁴⁶ Anthony B. Schutz, “Toward a More Multi-Functional Rural Landscape: Community Approaches to Rural Land Stewardship” (2011) 22 *Fordham Env'tl L Rev* 633 at 650–51 (arguing that manmade land divisions have negative impacts on wildlife diversity). In recent work, Karen Bradshaw and Bryan Leonard analyse the coordination of resource management among landholders, where such resources are ‘grouped at scales different than land parcels’. They provide examples of oil and gas drilling that requires assembling authorizations from multiple landowners, as well as ‘habitat corridors’ which likewise require coordination among many landowners. Bradshaw & Leonard, “Virtual Parceling”, *supra* note 11.

⁴⁷ Libecap, *Contracting for Property*, *supra* note 11 at 2535-2537.

Lueck and Karen Bradshaw, provide an account of how some homeowners purchase insurance against wildfire losses, and in doing so dramatically affect the outcome of a wildfire in a particular area.⁴⁸ These studies are focused on the question of the capacity of private parties to manage landscape-level resources and under what conditions parties will enter into such contracts. For our purposes, what is important to notice is that the fact that private landowners are in the position to contract toward or against these resources to begin with, is precisely because a spatial mismatch exists: a vertical structure (based on land-ownership) is applied to a horizontal resource (wildfire, oil and gas or wildlife).

(B) The Functional Consequences of Spatial Mismatches

The claim is that all things being equal horizontal regimes are best suited for horizontal resources that are layered parallel to the surface of the earth; whereas vertical regimes are best suited for vertical resources that are perpendicular to the surface of the earth. When, however, there is a disjuncture between the resource and the regime employed to control it, for instance when a vertical property regime is applied to a horizontal resource – a spatial mismatch occurs.⁴⁹ This disjuncture is costly since it increases both the number and the complexity of the interactions among users.

A spatial misalignment can, broadly, lead to two types of problems: one, of aggregation and the second, of coordination. The two are seemingly different problems. And yet the framework offered here underscores the fact that, in fact, they are both manifestations of spatial misalignments. Moreover, while both the problems of aggregation and cooperation are indeed familiar to scholars from different contexts, unpacking the *spatial* aspect of resource management sheds light on the *circumstances* in which such dilemmas arise, or anticipates the situations in which they will do so.

⁴⁸ Bradshaw & Lueck, “Landscape-Level Resources”, *supra* note 11 at 2530.

⁴⁹ It is also theoretically possible that a resource would be equally vertical and horizontal, in a sense shaped like a perfect sphere or a perfect cube. In such case, the goal would be to align the spatial dimension of the property to that perfect cube or sphere, or any other shape. The exercise is one of fitting the regime to the resource, whatever shape that may be.

(i) Aggregation Costs

One type of problem that arises due to a spatial mismatch can be termed ‘aggregation costs’, that is the costs of assembling multiple authorizations that are necessary in order to enable a particular activity.

To illustrate, consider what happens when a horizontal resource is forced into a vertical management structure. At its core, the difficulty stems from the fact that in order to use a resource that runs parallel to the ground, a potential user has to cross through multiple vertical silos of control on the way. The simple and intuitive example of a road is illustrative. Assume the plots of land through which the road crosses are each controlled individually by a vertical landownership structure, and that the road is likewise controlled by the same landowners – each in the section of the road over their land. Now imagine a traveller along that road and consider the numerous interactions she must encounter along the way in order to enable her journey. The need to seek numerous authorizations in this way may ultimately be prohibitive.

Aggregation costs arise also in the realm of natural resources. The need to assemble oil and gas rights from multiple landowners, which is necessary in order to drill, is an illustrative example.⁵⁰ Likewise, developers seeking to construct a wind farm need to assemble rights from multiple landowners.⁵¹

Although movement across the surface of the earth is more often horizontal, the problem of aggregation that a horizontal road-traveller faces (the need to seek multiple authorizations) can also take place on the vertical axis. Imagine an elevator that needs to travel vertically up and down a tall building. Much like the road, to enable its movement (albeit on the vertical axis) it needs to cut through other property structures.⁵²

⁵⁰ Bradshaw & Leonard, “Virtual Parceling”, *supra* note 11 (discussing the need to assemble authorizations from multiple landowners in order to drill for oil and gas).

⁵¹ See notes 82-84 *infra* and accompanying text, discussing the need to seek permission from multiple landowners in order to construct a wind farm.

⁵² Of course, if the entire building belongs to the same entity, no permissions are technically needed, but conceptually, the way the space is used within a building is such that an elevator cuts vertically through the floors. Other similar examples of vertical movement include mail-piers, garbage shafts and even drainage pipes that take water from the roof to the ground. Vertical movement can also be found (albeit in combination with horizontal movement) in the take-off and landing of various kinds of aircrafts; and in extractive drilling (especially in traditional oil and gas drilling, but even in hydrofracking, where drilling first occurs vertically downwards, and only then horizontally to the sides).

Importantly, the fact that a road-traveller or a wind-developer need to aggregate numerous authorizations in order enable the desired activity is a result of the fact that control over the horizontal resource has been inappropriately split into vertical slices. If, however, the resource is controlled on the same axis as the activity takes place – there is much less friction. Activities on the same axis, generally, have less interaction with each other, precisely because they operate in parallel domains rather than perpendicular, intersecting, ones. The number of interactions thus increases when the structure is perpendicular to the axis of the activity.

Assuming each interaction is costly,⁵³ increasing the number of interactions by a spatial mismatch also increases the overall costs of using and controlling the resource.⁵⁴ When, however, the resource and the structure employed to control it are in harmony, the number of interactions decreases. Thus, all things being equal, avoiding a spatial mismatch can decrease the friction associated with resource use and control.

(ii) Problems of Coordination

A second type of challenge that arises from a spatial mismatch can be broadly understood as one of coordination. The example of groundwater is helpful here again. Recall that the mismatch was rooted in the fact that a horizontal aquifer was controlled, initially, through vertical regimes that were based on landownership. That is, each landowner could drill under their land and extract the groundwater, not only from under their land but from under their neighbours' land as well. This mismatch regime resulted in largely inefficient patterns of extraction, namely premature exploitation and over-exploitation.⁵⁵ At heart, again, these inefficiencies result from the fact that each landowner sees only her vertical silo of control.

Another way to think of the spatial mismatch problem is by asking the question 'who is the best manager'? Specifically, with regards to land, the *ad coelum* doctrine, at least from a functional perspective, embodies the assumption that landowners are the best-placed

⁵³ The term 'interaction costs' is used here, somewhat broadly, to refer to the costs incurred by users who seek to employ or enjoy the resource, when they come across pressure or resistance with regard to that use. Interaction costs are one aspect or iteration of transaction costs, where the latter is understood broadly as the costs of establishing and maintaining a property regime. For a similar understanding of transaction costs see Smith, "Governing Water", *supra* note 37 at 447.

⁵⁴ In addition to each interaction being costly in itself adding interactions along the way can also increase their complexity to the extent that multi-party interactions are more complex those among a smaller number of parties.

⁵⁵ See notes 39-42 *supra*, discussing the rule governing groundwater and the tendency to over-extract groundwater that followed as a result.

managers, and hold an advantage over others (non-landowners) in managing the resources that interact with the land. This assumption holds true when the resource interacts vertically with the land. However, when the resource is horizontal, that assumption does not necessarily hold.⁵⁶ In such a situation, each landowner's view is confined to her own vertical silo of control, and her confined view thus misses the significance of the horizontal character of the resource. In a sense, this may be another way of framing an externalities problem, through a spatial lens: since each landowner reaps only the immediate benefits within her vertical realm of control, she is not incentivised (absent external constraints forcing her otherwise) to consider the impacts of her actions on the horizontal axis.

(iii) Strategic Mismatches

Spatial mismatches can lead to both aggregation costs and problems of coordination. The discussion thus far has been framed as one that seeks to avoid such costs. Although mismatches could, in theory, be used strategically to deliberately add 'friction' to the use of a resource or activity. Consider, for instance, the example of commercial drone flights. The implication of the horizontal-vertical framework offered here is that in order to enable the development of commercial drones, the resource in question – the low airways – needs to be managed as a horizontal resource. Avoiding the mismatch would indeed enable the activity, yet the reverse could be true as well: creating a mismatch, deliberately, would be one way to inhibit the activity, to the extent one wishes to do so. The point is that once the functional implications of a mismatch are better understood, the mismatch could be used as a tool to achieve various policy goals, whether to enable or inhibit a specific activity or resource use.

C. Moving from ad hoc Resolutions to a Systematic Analysis

A mismatch between the structure of control and the resource, as illustrated above, can be costly since it increases the interaction costs a user seeking to use the resource encounters. The key, thus, is to seek alignment between the nature of the resource and the control structure. Such a shift toward a better-aligned regime has in fact occurred, to varying degrees, in several cases. Importantly, however, as the following discussion illustrates, these responses are largely

⁵⁶ An exception might be in situations where a horizontal resource is fully contained within a vertical realm of control. For example, a foot-path that is fully contained within one's land and does not cross over to any other domains.

ad hoc solutions, while a systematic analysis of the underlying spatial issues that underpin these types of situations is lacking from the discourse.

Illustrating the shifts that have occurred also serves a secondary purpose, which is to underlie the fact that the classification of regimes according to their spatial domain of control is dynamic rather than static and can be subject to change over time.⁵⁷

A first illustration of a shift toward spatial alignment is the ‘navigable airways’. In the nineteenth century, the common understanding of the vertical conception of property in land extended all the way to the heavens, as the Blackstonian articulation of the *ad coelum* rule suggests.⁵⁸ As aviation grew, however, the spatial mismatch became apparent: while the resource in question (the navigable airspace) was a horizontal one, the regime applied to control it was a vertical one (landownership). As a response to the mismatch and the growing need to use the higher airspace for aviation, the management of airspace indeed gradually changed.⁵⁹ In English Law, the case of *Lord Bernstein v. Skyviews* articulated the revised principle, under which the scope of one’s vertical control in land was limited only to a certain height, so as to allow planes to fly horizontally across the skies.⁶⁰ A similar view was articulated by the US Supreme Court in the famous case of *US v. Causby*.⁶¹ Today, in most countries in the world the navigable airspace is not allocated to any specific individual through ownership of land, but rather controlled horizontally (typically by a public entity).⁶² The navigable airways thus serve as an example in which a *full* shift in the control structures has occurred in order to better fit the resource and its use.⁶³

⁵⁷ See similarly note 27 *supra* and accompanying text.

⁵⁸ Stuart Banner, *Who Owns the Sky? The Struggle to Control Airspace from the Wright Brothers On* (Harvard U Press, 2008) at 16-20 (discussing the perception of *ad coelum* in the nineteenth century) [Banner, *Who Owns the Sky*]; Cf. Eric R. Claeys, “On the Use and Abuse of Overflight Column Doctrine” (2013) 2 Brigham-Kanner Property Rights Conf J 61 (challenging whether that was indeed the conception, even at the time).

⁵⁹ For an insightful account of the history of control over navigable airspace and the changes that occurred in this regard see Banner, *Who Owns the Sky*, *ibid*.

⁶⁰ *Lord Bernstein v Skyviews and General Ltd* (1978) QB 479 (finding that the public should be allowed ‘to take advantage of all that science now offers in the use of air space’ and thus, ‘restricting the rights of an owner in the air space above his land to such height as is necessary for the ordinary use and enjoyment of his land...’).

⁶¹ *United States v Causby*, 328 US 256, 260-261 (1946) (‘[t]he air is a public highway’, otherwise landowner control over airways would ‘clog these highways, seriously interfere with their control and development in the public interest...’).

⁶² In the US, for example, the Federal government asserts jurisdiction over the slice of the sky that is known as the ‘navigable air space’ under Air Commerce Act of 1926, 44 Stat 568, 49 USC § 171 et seq., as amended by the Civil Aeronautics Act of 1938, 52 Stat 973, 49 USC § 401 et seq; *United States v Causby*, *ibid*.

⁶³ There are other examples where a central-planner (of some sort) eventually asserted control over a horizontal resource that was previously controlled through landownership. ‘[C]oastal zones, air, waterways, and wildlife’, are examples where ‘laws

In other cases, rather than a full shift, a partial shift has occurred as some adjustments have been made to accommodate the spatial mismatch. The example of a foot-path easement is useful here again. The horizontal easement is carved out from within the otherwise vertical landownership structure. This can be seen as an adjustment of the structure, based on the understanding that the activity along the path takes place on the horizontal axis. In this case, the assumption is that other activities upon the land are still better managed under a vertical structure, such that it makes sense to stick to it, while solving the horizontal clash through a small carve-out.

In some cases, the spatial alignment occurred ‘bottom-up’ in the form of contracting among landowners to facilitate the management of horizontal resources. Examples of such contracting, which have been studied in the scholarship, include wildfire and wildlife.⁶⁴ Absent such organic cooperation among landowners, in some cases the spatial alignment occurred in the form of legislation that forced the landowners to cooperate. Notably, the ‘unitization laws’ that were adopted in many of the US states are a response to over-drilling of oil and gas. Unitization laws force landowners to cooperate under a unified management system.⁶⁵ These types of solutions address the horizontal nature of the resource in question (the oil reserve) by aggregating the contracting force of multiple landowners. By doing so, they create a joint control regime that amounts to a horizontal one by virtue of aggregation.⁶⁶

Lastly, another form of seeking alignment between the resource and the domain of control could be employing governance rules (as opposed to exclusionary rules, under Henry Smith’s framework).⁶⁷ Put differently, perhaps spatial mismatches give rise to governance rules, because exclusion is more difficult in cases of spatial misalignment, due to the fact that activities are perpendicular to each other rather than parallel.

To be sure, shifts toward harmonious alignments do not always occur. Specifically, it appears that the vertical property conception embodied under the *ad coelum* rule tends to be

exert federal [government] control over resources that exist on privately held land’. Bradshaw & Lueck, “Virtual Parceling”, *supra* note 11 at 2522.

⁶⁴ *Ibid.*

⁶⁵ Unitization is a regime ‘in which the separate producers exchange their individual holdings in the reservoir for shares of a single, commonly managed enterprise that encompasses the entire pool’. Libecap & Smith, “Petroleum Property Rights”, *supra* note 44 at S519. See also Gary D. Libecap & James L. Smith, “Regulatory Remedies to the Common Pool: The Limits to Oil Field Unitization” (2001) 22 Energy J 1.

⁶⁶ To be clear, I do not argue that such contractual solutions are more efficient or otherwise more desirable than other alternatives. In this part I seek only to underscore the fact that shifts toward resolving the mismatches have occurred, and that such shifts have taken on various forms.

⁶⁷ Smith, “Exclusion Versus Governance”, *supra* note 36.

applied to horizontal resources, despite the spatial mismatch that is created as a result. There seems to be something ‘sticky’ about the vertical *ad coelum* intuition that is rooted deep in our legal sensibilities and is not easy to shift away from, even when the resource in question calls for a different type of management structure.⁶⁸

More generally, the costs of applying a mismatched regime might not necessarily outweigh other considerations. In some instances, the costs of administering a regime – despite being ill-fitted to the resource – might be determinative. For example, if applying a regime based on landownership (a vertical structure) to wildlife (a horizontal resource) can significantly reduce the enforcement costs of the regime, perhaps the trade-off in that particular case leans in favour of maintaining such a regime, despite the spatial mismatch. Analysing the trade-off would of course be a function of the parameters in each particular case, given that the costs incurred are often case-specific. Yet it is important to understand the trade-offs involved in order to be able to engage in such an analysis. The point is, that the spatial dimension of a property is a significant consideration, since all things being equal, a spatial mismatch creates additional interaction costs that can be avoided or reduced by aligning the structure of the control to the nature of the resource.

IV. APPLYING THE FRAMEWORK

Recognising spatial mismatches could shed light on contemporary property debates. Consider the example of drones. Commercial drones, generally, fly through airspace at an altitude that is much lower than commercial aviation.⁶⁹ That is, they fly much closer to the ground, to homes, to shops and to roads. The drone activity, by its nature, is horizontal: the drone operated by Amazon that will deliver a package from the warehouse to your doorstep, must cross the airspace over other plots of land along the way in order to get to your home.⁷⁰ Thus, given the

⁶⁸ The question of why the *ad coelum* notion is so ‘sticky’, even when it is ill suited, is an interesting and separate question, which I reserve for future work.

⁶⁹ According to the United States Federal Aviation Administration regulations, generally, ‘[t]he altitude of the small unmanned aircraft cannot be higher than 400 feet above ground level’. 14 CFR § 107.51.

⁷⁰ Of course, there are some vertical elements to the drone’s flight. For instance, it must take off vertically from the land. Yet the dominant mode of interaction is nonetheless horizontal.

horizontal nature of the resource, the claim here is that a horizontal structure is likely best suited to control it.⁷¹

The elements of the framework offered here are all nicely illustrated by a contemporary and significant question – the control of wind energy. The remainder of the discussion thus focuses on the example of wind, which illustrates the utility of the framework and how it may shed light on an ongoing management challenge.

(A) The Spatial Mismatch in Wind Management

Wind is, essentially, a horizontal resource. It flows, generally, parallel to the surface of the earth. You can think of a wind-system as either a large floating pancake, or a web of intersecting (floating) noodles. Either way, it is generally not a vertical resource. The production of electricity from the wind also operates on the horizontal axis. Extracting energy from the airstream, as wind turbines do, has profound impacts on its surroundings. The introduction of wind energy to an area has been shown to cause changes in temperatures⁷² levels of precipitation⁷³ and even changes in climate.⁷⁴ Altering the wind can also affect local

⁷¹ Cf. Troy A. Rule, “Airspace in the Age of Drones” (2015) 95 BUL Rev 155, arguing for accruing control over drone-airspace to the underlying landowners. Under the framework offered here, however, such a solution would amount to a spatial mismatch.

⁷² Liming Zhou and others, “Impacts of Wind Farms on Land Surface Temperature” (2012) 2 Nature Climate Change 539 at 539 (finding a warming trend near wind farms); R. S. Baidya, J. J. Traiteur, “Impacts of Wind Farms on Surface Air Temperatures” (2010) 107 Proceedings Nat’l Academy Science 17899 (showing a warming effect at night and a cooling effect during the day near wind farms).

⁷³ B. H. Fiedler & M. S. Bukovsky, “The Effect of a Giant Wind Farm on Precipitation in a Regional Climate Model” (2011) 6 Environ Res Lett 1 at 3 (finding a ‘statistically significant 1.0% enhancement of precipitation in a multi-state area surrounding... the wind farm’).

⁷⁴ D. B. Kirk-Davidoff & D. W. Keith, “On the Climate Impact of Surface Roughness Anomalies” (2008) 65 J Atmos Sci 2215 (claiming that very large wind farms could change air patterns enough that it would also affect worldwide climate); D. Barrie & D. B. Kirk-Davidoff, “Weather Response to a Large Wind Turbine Array” (2010) 10 Atmos Chem Phys 769; L. M. Miller, F. Gans & A. Kleidon, “Estimating Maximum Global Land Surface Wind Power Extractability and Associated Climatic Consequences” (2011) 2 Earth Syst Dynam 2 (‘Inevitably, this [huge scale] removal of wind power from the Earth system must result in climatic impacts’).

ambient pollution levels,⁷⁵ seed pollination⁷⁶ and has been suggested to influence radar systems.⁷⁷

In addition to the area-wide impacts, in the airstream directly downwind of turbine, a funnel shaped ‘wind wake’ is created.⁷⁸ To illustrate, picture a wake created behind a boat sailing through the water. Within the area of the wake, the airstream is slowed down and more turbulent, which results in a significant decrease in energy potential.⁷⁹ These wind-wakes span over significant distances: a single wake can reach up to 1km (roughly 3,200 feet) behind a commercial-scale turbine.⁸⁰ Such a power deficit down-stream can translate into significant losses in monetary terms as well.⁸¹ This too, operates on the horizontal axis.

Who controls the wind? In the US, where the case study focuses, the majority of wind projects are built on private lands.⁸² Landowners contract with developers to lease their land and the wind blowing over it for the purpose of wind energy production. These contracts are known as ‘wind leases’.⁸³ Such practices embody a notion that winds blowing over one’s land are hers to extract (or deliberately refrain from doing so). The few cases that recognise wind rights also embody the same assumption.⁸⁴ Under the current approach, management decisions with regards to our wind resources are divided according to the real-property division.

For the purpose of our spatial analysis, notice that the starting point for the control of wind is ownership of land, that is, a *vertical* property regime. Taken together, vertical structures –

⁷⁵ Johnathan R. Nash & Richard L. Revesz, “Markets and Geography: Designing Marketable Permit Schemes to Control Local and Regional Pollutants” (2001) 28 Ecology LQ 569 at 601.

⁷⁶ James D. Mauseth, *Botany: An Introduction to Plant Biology* (Jones and Bartlett, 2008) at 208-211.

⁷⁷ Felix A. Losco & Thomas F. Collick, “When Wind, Wind Turbines, and Radar Mix – A Case Study” (2012) 68 AF L Rev 235.

⁷⁸ For but a few examples of studies analysing wakes see Rebecca J Barthelmie et al, “Modeling and Measuring Flow and Wind Turbine Wakes in Large Wind Farms Offshore” (2009) 12 Wind Energy 431; Rebecca J Barthelmie & L E Jensen, “Evaluation of Wind Farm Efficiency and Wind Turbine Wakes at the Nysted Offshore Wind Farm” (2010) 13 Wind Energy 573 at 573; Thomas E. Kissell, *Introduction to Wind Principles* (Pearson, 2011) at 31.

⁷⁹ Up to 40 percent. US Nat’l Renewable Energy Lab, ‘Predicting Wind Power with Greater Accuracy’ (2014), online: <<https://str.llnl.gov/content/pages/april-2014/pdf/04.14.1.pdf>>.

⁸⁰ [*anonymised].

⁸¹ For a more extensive review of the monetary implications of loss of kinetic energy potential see [*anonymised].

⁸² According to one estimate, in the US ‘over 98% of all wind energy projects [are] on private land’. Wind Solar Alliance, *About Wind*, online: <<https://windsolaralliance.org/wind>>. The study here focuses on private lands given their prevalence. [*anonymised*]

⁸³ For further discussion of the wind leases, wind easements and buffer leases see [*anonymised*]

⁸⁴ E.g. in *Contra Costa Water Dist v Vaquero Farms, Inc*, 58 Cal App 4th 883 (1997), the California Court of Appeal (First District) recognised wind as an explicit severable property interest for the landowner; in *Romero v Bernell*, 603 F Supp 2d 1333 (DNM 2009) at 1335, the court found that ‘[t]he right to ‘harvest’ wind energy is... an inchoate interest in the land,’ although such right ‘does not become ‘vested’ until reduced to ‘possession’ by employing it for a useful purpose’.

essentially based on the *ad coelum* rule – currently dominate the allocation of wind rights in the US.⁸⁵ However, since the wind is a predominantly horizontal resource, there is a spatial mismatch between the resource and the regime employed to control it.

Recall, that in some cases the spatial mismatches have been mitigated. In the case of wind, the adaptation so far has been only partial. The mechanism at work here is based on voluntary contractual arrangements among landowners and developers. The wind leases can be seen as managing the horizontal resource, on a contractual basis, in so far as the extraction of wind energy is determined through the aggregate of individual landowner decisions.⁸⁶ Developers are protecting themselves from future upwind interferences by entering into agreements with those that are in a position to threaten their free-flowing wind, through ‘wind easements’ or ‘buffer leases’. These buffers do not host any turbines; they are committed only to refraining from blocking the wind.⁸⁷ Importantly, however, while the leases do internalise the costs developers might bear from any future *upwind* interference, they are not internalizing the costs they themselves impose in the *downwind* direction.⁸⁸ Figure 5 schematically illustrates this. Each square represents a plot owned by an individual landowner. Assume the wind blows predominantly from the North-East (the top left corner of the checkerboard). The darker-grey plots are the ones on which wind extraction occurs; the lighter-grey parcels are the buffer plots, that serve as protection from upwind interferences. Notice however, that there are several plots that are not shaded at all. Also notice that the non-shaded plots are both in the downwind direction (for example, plots B1, B2, etc.) and in the upwind direction but outside the reach of the buffer zone (for example H1).

⁸⁵ One outlier in the otherwise vertical management of wind does exist: since 2010 the state of Wyoming has imposed a tax ‘upon the privilege of producing electricity from wind resources in [the] state’ (Wyo Stat Ann § 39-22-103 (2010)). This example stands in contrast to most of other vertical measures currently employed to manage wind.

⁸⁶ This is similar in a sense to the examples of contracting toward control over oil and gas reserves or wildfire control. See notes 48, 64 *supra* and accompanying text.

⁸⁷ [*anonymised].

⁸⁸ Because the direction of the winds at a given location can alter, one may be either upwind or downwind from a wind project at different times. The buffer zone is therefore not necessarily linear or one-directional. In fact, it could encompass an area surrounding most of the wind project. US Nat’l Renewable Energy Lab, *Land-Use Requirements of Modern Wind Power Plants in the United States* (2009) at 22 Figure 11. Even a larger or multi-directional buffer zone, however, does not account for users beyond that zone.

Figure 5: Buffer Zones - Schematic Illustration

In theory, the harmed downwind users should be able to ‘buy out’ the upwind interference, and their downwind neighbours should be able to similarly buy them out, and so on, until all the interferences are accounted for within the contractual framework. In practice, however, such downwind bargaining is not always possible, given the well-studied problems of collective action within a larger group.⁸⁹ In addition, even if, theoretically, the developers were to reach a compensatory agreement with their downwind neighbours, which might account for wake impacts on those downwind neighbours in close proximity, there would still be a larger issue to consider with regards to changes in temperatures and levels of precipitation. An arrangement between a set of neighbours is not likely to fully account for such area-wide, horizontal, effects.

One may argue that tying the ownership of wind to that of land makes sense, despite the spatial mismatch, given that under current technologies a turbine needs to be physically placed on the ground in order to harvest the wind. However, consider the practice of ‘buffer leasing,’ in which no turbines are placed on the ground and yet the ownership and control of the wind-flow is allocated to the landowners, nonetheless. Moreover, this invokes the question of the relationship between current technologies and the shaping of property interests. What if the turbine ‘footprint’ was significantly smaller? The next generation of wind power installations are actually not tethered to the ground the way current turbines are. These ‘airborne wind

⁸⁹ For a specific discussion of problems of collective action with regards to wind see Yael Lifshitz, “Gone with the Wind? The Potential Tragedy of the Common Wind” (2010) 28 UCLA J Envtl L & Pol’y 435.

energy systems' are like giant kites, drones or blimps which transmit the electricity back down to the ground.⁹⁰ While these high-flying systems would not be completely detached from the ground, their footprint will be considerably smaller, at least on an acres/per megawatt (MW) basis. At the point when these technologies are applied, would it still make sense to tether wind rights to land ownership?

The notion of grounding the property regime due to the turbine's 'footprint' is also challenged by the comparison to other resources which likewise require some kind of physical footprint on the ground yet are nonetheless managed horizontally. The example of radio waves is illustrative. One needs to place transmission equipment somewhere, as well as receiving equipment (at a different location). Yet radio waves are not controlled vertically, as addendums to landownership, but rather managed horizontally.⁹¹

(B) Moving Towards Horizontal Wind Management

Seeking to remedy the spatial mismatch in the case of wind would mean moving toward more horizontal control.⁹² Horizontal management, in itself, as mentioned does not necessarily imply public control (as opposed to private control). Notice also that the spatial analysis offered here holds a normative claim only with regards to the axis on which the regime should operate but does not speak directly to the question of which strategy within that axis is preferred. Thus, while it suggests that horizontal control of wind is preferred to a vertical one, it does not pertain to the selection among the alternatives for horizontal management.

Once the idea of the horizontal management of wind is recognised, the questions then are, first, can we shift away from the current structure; and second, what type of horizontal management might we apply to control our winds.

⁹⁰ Cristina L. Archer, "An Introduction to Meteorology for Airborne Wind Energy" in Ahrens and others eds, *Airborne Wind Energy* (Springer, 2013).

⁹¹ The rights to radio spectrum, today, are not tethered to the land on which transmission or receiving devices are placed. Thomas W. Hazlett, "Assigning Property Rights to Radio Spectrum Users: Why Did FCC License Auctions Take 67 Years?" (1998) 41 *JL & Econ* 529. Another example could be water rights under a prior appropriation regime, which are determined based on priority in time and with regards to the manner of the use, but not according to ownership of land. Getches, *supra* note 40 at 77.

⁹² Notice that the horizontal-vertical framework holds a normative claim only with regards to the axis on which the regime should operate but does not speak directly to the question of which strategy within that axis is preferred. Thus, while it suggests that horizontal control of wind is preferred to a vertical one, it does not pertain to the selection among the alternatives for horizontal management.

From a pragmatic point of view, given the current state of wind rights in the US, the transition toward horizontal control in the case of wind is complicated primarily by two factors. One, which is a common hurdle in any regime change, pertains to whether changing the existing property structure raises expropriation issues.⁹³ The second factor, relates to the ability – from a doctrinal perspective – to sever wind rights from land. At present, severability of wind rights from the land estate is limited in a few states by legislation. Nebraska, for instance, provides that ‘[n]o interest in any wind... may be severed from the surface estate’.⁹⁴ Severability of wind rights is also limited by legislation in Wyoming,⁹⁵ Montana,⁹⁶ South Dakota⁹⁷ and North Dakota.⁹⁸ Although, the relevant provisions in the latter four states specifically allow for the creation of wind leases and easements, despite the limitations on severability, which suggests that transferring wind rights for the purpose of energy production may not be prohibited. In New Mexico, one case noted that wind is analogous to water rights under the prior appropriation regime which are considered to be separate from land.⁹⁹ Other states are silent on the issue of severability.

The next question to consider is *what type* of horizontal management can be applied to wind. There are a number of alternatives for applying horizontal control to wind, ranging from a tax¹⁰⁰, to various land-use controls¹⁰¹ to mandating a review of the impacts of extracting wind, perhaps as part of the environmental review that presumably goes into siting wind installations.¹⁰² The following discussion will focus briefly on two novel proposals – first, a system of ‘unitization,’ and second, a market for trading wind rights.

⁹³ Although if one takes the existing assignments of wind rights as the starting point, facilitating trade between current right-holders in itself is less likely to be seen as a change to these rights. A comparable example might be water rights, where in the context of shifting toward a trading system in California, the California Water Resources Board stressed that the shift, in itself, does not create new rights or change existing ones, it only facilitates the trade in existing rights. California Environmental Protection Agency, *A Guide to Water Transfers* (1999) at 3-2.

⁹⁴ Neb Rev Stat Ann § 66-912.02 (2012).

⁹⁵ Wyo Stat Ann § 34-27-103 (West 2011).

⁹⁶ Mont Code Ann § 70-17-404 (West).

⁹⁷ SD Codified Laws § 43-13-19 (2004 & Supp 2009).

⁹⁸ ND Cent Code Ann § 17-04-04 (2009). For a discussion of the severability see K K DuVivier, “Animal, Vegetable, Mineral—Wind? The Severed Wind Power Rights Conundrum” (2009) 49 Washburn LJ 69; Michael J. Stephan, “Wind Severance” (2010) 40 Tex Env’tl LJ 73 at 77.

⁹⁹ *Romero v Bernell*, 603 F Supp 2d 1333 (DNM 2009) at 1335.

¹⁰⁰ See discussion of the Wyoming wind tax note 85 *supra*.

¹⁰¹ ‘Setbacks’ are one example of such land-use controls, where turbines cannot be set within a certain distance of the adjacent property border or infrastructure such as schools and roads.

¹⁰² Such an area-wide review could include, for instance, studying the effects of extracting airborne kinetic energy, at different levels, on weather patterns and precipitation in the region; the impact on organisms that rely on wind for seed pollination or reproduction; or the effect on farming activities that likewise utilise the airstream. At present, however,

(i) Unitization

The process of ‘unitization’ is best known from the context of oil and gas. As a response to the problem of over-drilling, beginning in the 1920s, many US states enacted variations of what is known as ‘unitization’ laws.¹⁰³ For our purposes, the important point is that unitization essentially aggregates entitlements from multiple vertical right-holders, into a unified horizontal regime. It overcomes the spatial misalignment in that sense. Applying this notion to wind would entail setting up a mechanism for pooling the rights of multiple landowners into a unified management of wind over a given area.¹⁰⁴

(ii) Creating a ‘wind market’

A ‘wind market’ is one potential strategy for applying horizontal management to wind. In brief,¹⁰⁵ imagine a framework where people can trade their right to wind, just like they buy and sell other resources such as land, water or clean air. The idea of creating a market for trading wind rights can be thought of as similar, but opposite, to pollution trading regimes: instead of trading the rights to emit into the airstream one trades the right to extract energy from the airstream. Such markets have been applied in a wide range of contexts,¹⁰⁶ including carbon

reviews do not account for such impacts. New York State Energy Research and Development Authority, *Wind Energy Toolkit* (2009) at 57 [NYSERDA, *Wind Energy Toolkit*].

¹⁰³ Lincoln Davies et al., *Energy Law and Policy* (West, 2014) at 242. Notes 65-66 *supra*, discussing unitization; also see Jacqueline Lang Weaver & David F. Asmus, “Unitizing Oil and Gas Fields Around the World: A Comparative Analysis of National Laws and Private Contracts” (2006) 28 Hous J Int’l L 3.

¹⁰⁴ What might that area be? Setting a ‘wind shed’ as the area over which wind-streams interact, would be a first step in setting up such a unitization regime. Drawing an analogy, thinking about the wind shed could be similar to air-shed definitions for emissions trading or water-sheds in water-related trading programs.

¹⁰⁵ For a more robust discussion of the idea see [*anonymised*]

¹⁰⁶ Environmental markets have been ‘implemented on local, regional, and national scales’. Nash & Revesz, *supra* note 75 at 571. They have also been applied to multiple types of resources. Nathaniel O. Keohane et al, “The Choice of Regulatory Instruments in Environmental Policy” (1998) 22 Harv Envtl L Rev 313 at 317-318; James Salzman & JB Ruhl, “Currencies and the Commodification of Environmental Law” (2000) 53 Stan L Rev 607 at 616-617.

trading,¹⁰⁷ water quotas,¹⁰⁸ fisheries,¹⁰⁹ ecosystems services,¹¹⁰ endangered species habitat¹¹¹ and aquatic resources.¹¹² But the notion has yet to be applied to wind.

The wind market is a horizontal structure, due to the fact that a trading scheme requires policy-makers to set the ‘cap’ on extraction¹¹³ and thus to think in terms of the overall impacts that are created by wind energy production. A market-based policy of this sort, therefore, embodies precisely the horizontal outlook that is currently missing from most of the wind rights.¹¹⁴ The advantages of applying a trading mechanism as a means to control environmental resources have been well established in the literature.¹¹⁵ The key advantage of a trading regime, especially as compared to command-and-control strategies, is its ability to achieve the desired policy goal more cost-effectively than other alternatives.¹¹⁶

¹⁰⁷ E.g. the system of carbon trading that exists in the EU: European Commission, *The EU Emissions Trading System (EU ETS)*, online: <http://ec.europa.eu/clima/policies/ets/index_en.htm>.

¹⁰⁸ Vanessa Casado Perez, “Missing Water Markets: A Cautionary Tale of Governmental Failure” (2015) 21 NYU Envtl LJ.

¹⁰⁹ Katrina M. Wyman, “From Fur to Fish: Reconsidering the Evolution of Private Property” (2005) 80 NYU L Rev 117 at 155-157.

¹¹⁰ Philip Womble & Martin Doyle, “The Geography of Trading Ecosystem Services: A Case Study of Wetland and Stream Compensatory Mitigation Markets” (2012) 36 Harv Envtl L Rev 299 at 234.

¹¹¹ JB Ruhl et al., “A Practical Guide to Habitat Conservation Banking Law as Policy” (2005) 20 Nat Resources & Env’t 26.

¹¹² Womble & Doyle, *supra* note 111 at 230-231.

¹¹³ In that sense the permit trading schemes differ from a simple neighbour-to-neighbour land transaction. One may wonder – does every market amount to a horizontal structure? There is, so goes the argument, a market for land, does that make it a horizontal regime? The extent to which a market can be seen as ‘horizontal’ under the framework offered here depends on the extent to which the market seeks to achieve horizontal control, predominantly by setting a ‘cap’. Markets for controlling environmental externalities are premised on the notion of capping the overall degradation at a certain level, over a certain area. Doing so is the essence of the horizontal management in this case.

¹¹⁴ The outlier in this regard is the Wyoming Wind Tax, note 85 *supra*.

¹¹⁵ The advantages of using market-based mechanisms to control environmental resources, especially as compared to ‘command-and-control’, have been discussed in the scholarship starting in the mid-1980s: e.g. Bruce A. Ackerman & Richard B. Stewart, “Comment: Reforming Environmental Law” (1985) 37 Stan L Rev 1333 at 1341-1351. Environmental trading markets have generally been celebrated as the most cost-efficient mechanism. See e.g. Salzman & Ruhl, *supra* note 106 at 620-621 (reviewing the claims of efficiencies in market mechanism); Nash & Revesz, *supra* note 75 at 571-572; Richard L. Revesz, “Toward a More Rational Environmental Policy” (2015) 39 Harv Envtl L Rev 93 at 94.

¹¹⁶ Salzman & Ruhl, *supra* note 106 at above, 620-621; Nash & Revesz, *supra* note 75 at 571-572; Revesz, *ibid* at 94. To illustrate the difficulties posed by a command-and-control regime in the case of wind, consider the following example: ‘[A] setback decision made by a Town Board in Addison, Wisconsin, had the effect of reducing the number of proposed turbines by more than two-thirds for a wind project in their jurisdiction’; ‘... the developer had a limited ability to re-position the turbines on the remaining leased property while still maintaining an acceptable energy output from the project’.. as a result, ‘the number of proposed turbine sites was reduced from 28 to approximately 8’. Given this, ‘the developer elected to suspend the project because they were unable to satisfy the setbacks and maintain the project’s economic viability’. NYSERDA, *Wind Energy Toolkit*, *supra* note 102 at 42. In some instances, landowners could be allowed to waive the protection a setback affords them, which could allow for bargaining and mitigate some of the drawbacks of the mandatory buffers. However, absent an explicit allowance of that sort, the setback distances are generally obligatory. Thus,

To be sure, I envision that the wind market will not exist in isolation nor be adopted instead of all other mechanisms. Indeed, even under a market-based mechanism the siting of wind energy facilities will probably be subject to other restrictions such as prescribed safety distances from public buildings and so on. In addition, permission to locate turbines on a specific slot of land will still need to be obtained from the landowner, regardless of the fact that permission to extract energy flowing over the land is obtained separately. The location of the turbines themselves will thus not necessarily be determined through the market system. But importantly, the level of extraction of airborne kinetic energy, as such, will be determined by the market. To see the distinction, consider again the analogy to airborne emissions trading: setting a market for ambient emissions controls the overall level of extraction. The siting of a particular facility, however, (for example, a factory) will typically still be subject to zoning and other overlying regulations regardless of the emissions trading. Similarly, the question of physical location of turbines can be thought of separately from the question of how much kinetic energy to extract.

V. CONCLUSION

Property law is fundamentally concerned with the control of resources in our world, a concern which has shaped our traditional property understandings and continues to challenge our legal notions today, from energy extraction to drones flying the skies. This Article addresses this key concern by offering a framework for analysing the spatial dimension of resource control.

The central insight of this Article is that space matters. It matters because our legal institutions are crafted in a way that asserts control over a certain three-dimensional space, whether vertical or horizontal. It matters because the resources which we seek to control likewise occupy a certain three-dimensional space. And importantly, it matters because the compatibility between the two – the space over which a regime holds control and the space that is occupied by a particular resource – has implications for managing resource access and control, which are the fundamental tasks of property.

It is perhaps hard to abstract away from the historical dominance of land-based verticality. It is hard to imagine the space around us as blank-space. For the sake of the thought experiment, however, let us move away from land and consider the sea. Think of the ‘exclusive

if the policy goal is to optimise the extraction of airborne kinetic energy – a flexible market-based solution can be a cost-effective way to achieve that goal.

economic zone'¹¹⁷ or the shared control of the high-seas.¹¹⁸ Within these spaces, multiple activities take place, from drilling to wind energy, from fishing to navigation. The spaces in question here are not a pancakes, noodles or silos for that matter. If you were designing the regimes in this space from scratch, how would you slice up the space – would it be into horizontal strata, vertical silos or rather a mix of the two that is more specific per resource? That is the basic question this Article seeks to raise, and the basic point it makes: that space, in itself, is a significant consideration in property design.

Several open questions remain, all of which present potential avenues for future research. First, there are questions regarding the implementation of horizontal control (or vertical control for that matter), when such a structure is called for. The framework here analyses the spatial dimension of property control. But once the space over which a regime has control is ascertained, the framework does not speak (at least not directly) to the type of management strategy selected to enforce or maintain that control.¹¹⁹ The next step may be further unpacking the connection between the two aspects – spatial control and management within that domain of control. A second set of open questions pertains to an explanatory inquiry. Why is it the case that the spatial dimension of property is shaped in a particular manner? Why do spatial mismatches occur, and relatedly, why do they persist despite the inefficiencies that might stem from the mismatch? A third and final set of questions pertains to the temporal dimension of property. The analysis here focused explicitly on the spatial dimension of property, and yet property regimes also have an important temporal aspect. It would be interesting to further unpack the specific interactions between the two types of dimensions in property – temporal and spatial – and think about what those interactions can tell us about property design.

Unpacking the geometry of property law is, in any case, significant for both property scholars and policy-makers given the prevalence of spatial misalignments and their relevance to both traditional property debates and ongoing ones, from new advances such as drone flights, hydrofracking drilling and wind energy, as well as the use of groundwater in times of drought shifting land uses and rapid urbanization, all of which constantly interact both vertically and horizontally.

¹¹⁷ The Exclusive Economic Zone of a nation extends, generally, 200 nautical miles inward, as established under Part V of the United Nations Convention on Law of the Sea, 1982.

¹¹⁸ Under Part VII of the United Nations Convention on Law of the Sea, 1982. Control of outer space is perhaps another similar example. See Banner, *supra* note 58 at 284-285, discussing the Outer Space Treaty of 1967 and the historical events that led to its adoption.

¹¹⁹ See notes 36-38 *supra* and accompanying text, similarly discussing the distinction between mapping out the physical domain of control and the type of management strategy selected to implement that control.