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Economics of Air Traffic Management in the Drone Era

By **Dr. Hector Lopez** and **Richard Marsden**

Industry Economics Series

As Chair of NERA's Global Energy, Environment, Communications & Infrastructure Practice, it is my pleasure to introduce a new series of papers called Industry Economics. This series will highlight how NERA leverages our in-depth industry expertise to provide robust and uniquely rigorous economic analysis. Our experts draw on decades of experience combined with specialized knowledge and deep expertise in regulated industries and competitive markets.

For our first paper in the series, NERA Associate Director Dr. Hector Lopez and Managing Director Richard Marsden—drawing on their expertise in auctions, high tech, and market design—have teamed up to bring you a dynamic and cutting-edge look at allocation systems facilitating the integration of drones into our airspace. They examine the definition of "flight rights"—where, when, and who can fly—and weigh the economic trade-offs of applicable allocation methods.

This is an exciting topic and certainly an issue that is foremost in the minds of regulators globally as our airspace becomes increasingly crowded. Dr. Lopez and Mr. Marsden compellingly demonstrate the economic benefits and challenges of different mechanisms to allocate crowded airspace to keep pace with technology. Enjoy this paper and keep an eye out for more to come.

Dr. Christian Dippon, Managing Director

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Drones and air taxis will soon join commercial aviation to provide a multitude of flight services encompassing delivery, imaging, security, maintenance, freight, and mobility. By 2035, millions of units, thousands of people, and products worth billions of dollars could continuously be flying over our cities.

The integration of drones into our airspace will require a clear definition of "flight rights": where, when, and who can fly. At least four classes of allocation systems have been discussed: open road (developed by NASA), first-come first-served (FCFS, similar to commercial aviation), licensing (similar to spectrum), and real-time markets (similar to electricity or online advertising).

In this paper, we consider the economic trade-offs of these four models and argue that none of them on their own will be able to ensure the efficient allocation of flight rights in the long term. To address this, we propose a hybrid framework that provides for both the short-term and long-term allocation of flight rights using a combination of real-time and forward markets for airspace. The real-time market would manage congestion whenever it arises, and the forward market would provide certainty of access to support long-term investments.

The implementation of the hybrid system would involve imposing an additional layer of rules on a nascent industry, but could help avoid unmitigated congestion allowed by open road systems, and the competition problems linked to incumbency advantages under the FCFS and licensing systems.

Air Traffic Management for New Services

In coming years, it is anticipated that three new classes of aircraft will be introduced to skies around the world on a large scale:

- **Unmanned Aircraft Systems (UAS)**, commonly known as drones, are usually small aircraft without human pilots on board. UASs will have many applications, including package delivery, video capturing, safety inspection, and infrastructure management. The global UAS market was valued at $25.59 billion in 2018 and is expected to reach $70 billion by 2029.[1] Amazon, Google Wing, Zipline, SF Express, and Airbus Skyways are already testing services. Currently, 86% of Amazon deliveries weigh less than five pounds and could be delivered by drones.[2]

- **Electric Vertical Take-Off and Landing (eVTOL)**, commonly known as air taxis, are mobility air solutions that will allow people to move around cities more quickly and affordably than they can in helicopters today. More than 70 companies have already invested in the development of air taxis.[3] It has been estimated that, by 2035, eVTOLs will serve a global market worth more than $74 billion, with over 23,000 air taxis transporting over 740 million passengers.[4,5] Companies such as Uber Elevate, Blade, and Airbus Voom are planning to provide services, and Kitty Hawk, Cora, Airbus, Vahana, CityBus, Aurora eVTOL, and Joby S4 are developing aircraft. Uber has public plans to initiate commercial services in Dallas, Los Angeles, and Melbourne in 2023.[6]

- **High-Altitude Platforms (HAPs)** are unmanned aircraft that fly at altitudes around 65,000 feet—above current commercial aircraft. HAPs are expected to provide connectivity services similar to satellites but at lower cost and with lower latency. Airbus, Loon, and HAPS Mobile are already offering or plan to offer services.

The integration of these types of new aircraft to the skies brings significant operational, regulatory, and economic challenges.

In the United States, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the Department of Transportation (DOT), and industry participants such as Airbus, Uber, Boeing, and Amazon are collaborating to develop a regulatory framework that would allow the safe and successful integration of UASs, eVTOLs, HAPs, and other aircraft into our skies.[7,8] The regulatory agenda contemplates the full integration of all three types of aircraft into the National Airspace System. Several steps have already been accomplished—for example, Small UAS rules (Part 107) and Remote ID regulations—but the design and implementation of many regulations still needs to be done.[9]

The proposed US framework involves the development of parallel systems to manage traffic for different kinds of aircraft, as illustrated in Figure 1. Under the proposed framework:

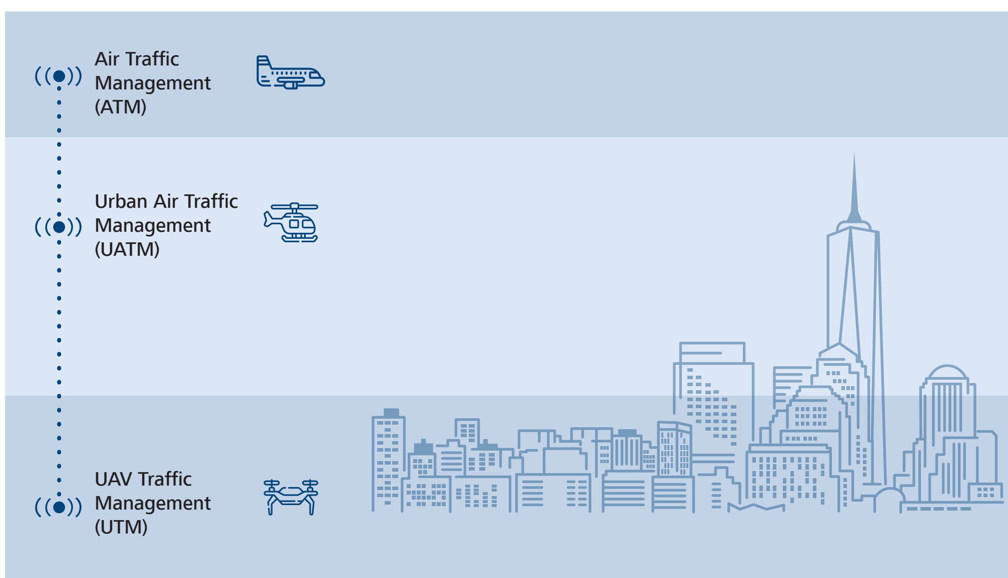
1. Air Traffic Management (ATM) will continue to manage commercial aircraft;

2. Urban Air Traffic Management (UATM) will manage eVTOLs; and

3. Unmanned Aircraft System Traffic Management (UTM) will manage UASs at low altitudes—typically under 400 ft above ground level.

Regulators in other countries are expected to adopt similar tiered systems.

Figure 1. **Air Traffic Management Systems**



For drones, the lowest UTM tier is based on a federated architecture in which UAS Operators engage with at least one information exchange called UAS Service Supplier (USS) to support planning, intent sharing, strategic and tactical deconfliction, and other services. USSs deconflict all the aircraft under management and coordinate with other USSs to deconflict aircraft belonging to different service suppliers. The FAA will be actively involved in the UTM framework through the Flight Information Management System as an interface between commercial aviation and drones, with linkages to both the ATM and UATM systems.[10,11]

Within the UTM architecture, tactical and strategic deconfliction occurs at two levels:

1. Within each USS via prioritization, negotiation, and intersection protocols; and

2. Across USSs via coordination protocols.

Deconfliction protocols have avoidance of collision (4-D intersections of time, latitude, longitude, and altitude intersection) as the main objective. The protocols are also deterministic, (technically) efficient and unilaterally calculable, and minimize human interaction, with the objective of providing certainty, transparency, and simplicity of operations for users. Notably missing from this list are any economic principles, meaning there are no mechanisms to prioritize efficient use in situations where airspace become scarce.[12]

Economics of Air Traffic Management

Two aircraft cannot be in the same place—including any buffer distance—at the same time. The set of *rules* and *infrastructure* used to determine which aircraft must adjust is called an Air Traffic Management System. In aviation terms, aircraft must *deconflict* their operations. In many locations and at most times of day, there may exist many near-perfect substitute air slots. In situations where all demand can be accommodated, air traffic management is essentially just a matter of coordination, as there is no meaningful scarcity. However, as demand for air slots increases or supply is constrained by regulation, the availability of near-perfect substitute slots may be exhausted, requiring air trips to be shifted to less desired times or locations, or not take place. In economic terms, air slots become a *scarce resource*.

We anticipate that scarcity will be driven primarily by safety, noise, and visual pollution regulations, rather than absolute lack of airspace. Cities may allow a very limited number of drones in urban and suburban areas to maintain safety.

In situations of scarcity, in order to promote efficient use, the operational principles for traffic management may be enriched with economic principles that prioritize those goods and services that generate the greatest benefits for society. Economic principles recognize that the rules that govern traffic management not only determine the specific deconfliction process between two aircraft but also define the entry, investment, and competitive behavior of the firms participating in the market.

Based on lessons from other designed markets—such as electricity, spectrum, and online advertising—the following principles appear relevant when considering the economics of allocating scarce airspace:

- **Allocative Efficiency**. Allocating air slots to the aircraft and use that values the airspace the most.

- **Investment Efficiency.** Providing a positive environment for investment in drones and air taxis. This could be aimed at increasing certainty of access (which could, therefore, encourage investment) while discouraging overinvestment that may be aimed at shutting other players out of the market.

- **Open Access**. Ensuring every eligible aircraft has access to the airspace whenever there are no conflicts (subject to any restrictions on activities created by governments to protect societal interests).

- **Flexibility**. Ensuring the system is open to entry of innovative modes of operation or business models as well as the continued business of incumbent operators.

- **Autonomy**. Enabling firms to self-operate their fleets and business models without the need for excessive communication with the administrator or rival firms.

- **Efficient Pricing**. Prices that reflect the *social opportunity cost*—including any private opportunity cost and externalities such as congestion (excessive entry) or pollution (noise, visual, or environmental).

The challenge for regulators and industry participants is to balance these principles when designing the air traffic management systems for UASs and eVTOLs. For example, a traffic management system that overemphasizes open access may introduce inefficient congestion in the air, as we already see on land on many city streets and roads.[13] Airspace congestion may look entirely different from road congestion. Owing to safety regulations, congestion will not necessarily be observed as a high-density of drones in the sky but as an unobserved number of flights and services that could not be delivered because the airspace was not available.

Similarly, a traffic management system that overemphasizes autonomy may introduce holdout problems as has been alleged in the management of spectrum using exclusive licenses[14] and landing slots at major airports.[15] In both these cases, new entrants may have a hard time identifying and acquiring portfolios of underutilized resources (i.e., frequency blocks or airport slots) sufficient to support entry.

Furthermore, both mobile operators and airlines tend to hold resources as an option for future expansion, which is a rational business practice in the absence of a liquid short-term market.

Applying Economics to Deconfliction Protocols

There are four commonly recognized levels of deconfliction protocols for aircraft based on the time scale in which the conflict may occur:

1. **Detect and Avoid**. Whenever two or more aircraft are closer than the minimum distance to allow safety operations, aircraft must avoid collision.

2. **Tactical Deconfliction**. Wherever two already airborne aircraft are projected to conflict, one or both must change route. Tactical deconfliction is usually the result of changes in the availability of airspace—owing to weather, for example—or changes in plans.

3. **Strategic Deconfliction**. Wherever two grounded aircraft are planning to use the same air slot, one or both must change route or time of departure.

4. **Long-Term Deconfliction**. Wherever two potential participants (firms, fleets, or aircraft) are planning to enter operations that may increase potential strategic or tactical conflicts, one or both must adjust their operational plans before entering the market.

The specific implementation of each level of deconfliction protocols could have significant economic consequences for participants, if and when airspace for drones and air taxis becomes congested.

Detect and avoid protocols may impact the overall sustainability of the ecosystem and entry decisions but may have a limited impact on the remaining three deconfliction levels. For example, detect and avoid protocols that require drone-to-drone and drone-to-system communications may restrict participation compared to a system that relies on drone-to-drone communication exclusively.

Tactical deconfliction allows the system to react to change in supply (availability of air slots owing to weather or other events) or demand (route changes). When conditions change, and air slots must be reallocated, it is in the public interest that the air slots are allocated efficiently. For example, it may be more efficient to allocate an air slot to a company whose business model is based on punctuality than to a firm whose business model is based on affordability. Traditional tactical protocols, such as first-come first-served, do not take such factors into account so are unlikely to be efficient.

Strategic deconfliction allows the system to balance short-term expected supply and demand. In commercial aviation, strategic deconfliction relies heavily on schedules and use-it-or-lose-it rules. Airlines that have scheduled flights and use them continue to get the air slots. This system—based on past performance to allocate *future* resources—has clear potential downsides because the airline that has used the slots in the past is not necessarily the airline best able to service demand in the future. It can also create perverse incentives; for example, in the early months of the COVID-19 crisis, some airlines spent money flying empty planes so that they could keep the air slots.[16] Eventually, use-it-or-lose-it rules were suspended but it required collective action by airlines and regulators.

Long-term deconfliction allows the system to balance expected future supply and demand. This level is important to plan entry, re-scaling, and exit of operations for participating firms. In commercial aviation, long-term allocation of slots is based on a potential reallocation every six months where airlines are guaranteed to obtain the allocations they had as long as they used the slot at least 80% of the time. While the rule is applied every six months (which is not in itself long-term), the persistence built into the rule implies that the rights over slots can have a tenure as long as the holder desires by maintaining utilization. This system favors incumbents—even if they are inefficient—over new entrants.

Unlike detect and avoid, the tactical, strategic, and long-term deconfliction protocols are closely interrelated and produce cascading economic effects. For example, a system that manages air slots using long-term exclusive licenses for well-defined air slices mostly solves the necessity to mediate strategic and tactical conflicts between different operators. However, it achieves this objective at the expense of promoting competitive pressure to use the slots efficiently, owing to the barriers to entry and incentives for holding on to slots even if they are underutilized.

Market Models for Air Management

This section considers four possible models for how the UTM framework may evolve:

- **Open Road:** The existing UTM framework.
- **First-Come First-Served:** Existing UTM framework plus first-come first-served and use-it-or-lose-it rules to manage strategic and long-term conflicts.
- **Licensing Model:** Existing UTM framework plus long-term licenses for air slots (similar to how radio spectrum is allocated to mobile operators) to manage long-term conflicts.[17]
- **Real-Time Market:** Existing UTM framework plus real-time pricing (similar to how electricity is priced in local power markets) to manage strategic and tactical conflicts.[18]

We describe each model below. As we explain, a model that is initially based on open road may evolve into other models on a location basis as rules are added to address congestion. Some models could also be combined; as an example, we describe a fifth approach that is a **hybrid model** that overlays the open road model with forward markets for long-term licenses and real-time markets for immediate access.

Open Road

In its current form, UTM and UTM-like management systems for air mobility can be described as an open road: every aircraft will be allowed access as long as it is deemed safe. Aside from the stricter safety requirements and other limits on flight rights that local governments may impose for aesthetic reasons, this is how roads are managed. In due course, air traffic will probably be organized using air corridors that create a well-structured network.

This is a simple and effective system provided airspace is not scarce. However, as with road traffic in and between cities, congestion can be expected once demand for drone and air taxi use takes off. As with any network, congestion can be expected to spread from its most restricted nodes to the rest.[19] It is likely that the most congested parts will be take-off and landing areas, as well as the air in dense cities (for example, imagine drone delivery shopping during Christmas in New York City). In an open road system, aircraft requesting a flight path have no incentive to take into account the impact on future requests. Hence, a low-value flight may force a subsequently requested high-value flight to delay its departure or alter its route.

In conclusion, although an open road may be a good starting point for a regulatory framework, the model can be expected to encourage inefficient congestion as demand for air mobility grows.

First-Come First-Served

A simple regulatory solution to limit congestion would be to mimic the first-come first-served and use-it-or-lose-it rules that are already applied in the management of commercial aircraft. Such rules would give priority to existing users over new users, and favor repetitive flight paths. The main advantages of this approach are simplicity and predictability. However, there are serious downsides. Absent additional regulation, such a system has no mechanism to differentiate between services, limiting the ability of service providers to differentiate services and compete openly. For example, a high-value service may find it difficult to gradually displace low-value services owing to the historical allocation of flight rights. In turn, this rigidity increases the risk of developing high-value services. The system may also be too rigid, given the expectation that drones and air taxis will fly much more varied routes that today's aircraft. Use-it-or-lose-it may also introduce technological lock-in, competitive entry problems, and unwarranted first-mover advantages.[20] In a FCFS system, rights are allocated to those who entered first, whether or not they are the ones that can provide the most valuable services.

Such rules may also imply that the regulator will need to make a judgment on the size of the market and the level of congestion that may be tolerated. This may lead to disputes and inefficient negotiations between operators and regulators. Predictably, those looking to enter or expand operations will argue that more operations can still be introduced safely, while those affected will argue that any additional operation will increase the risk of accidents.

Licensing

An alternative approach is to use exclusive licensing, as in spectrum management, to organize long-term and short-term access to airspace. In the case of UTM, licensing could involve horizontal slices of air at different altitudes, while in UATM, licensing could involve areas of service or predefined corridors.[21] Licensing could be exclusive, shared, or based on priorities. These rights would be subject to competitive allocation and available for trading in a secondary market. To the extent rights are scarce, users would face an opportunity cost for holding them.

The two main benefits of licensing are congestion management and investment incentives:

- *Congestion*. Well-defined rights, especially if exclusive, allow operators to fully internalize their decisions. An operator should always be conscious that by operating specific routes, some other routes will be conflicted and this has an opportunity cost. In principle, this internalization should lead to the optimal level of congestion in the system for each type of operation. Operators favoring punctuality and speed will maintain a less dense operation while operators favoring affordability will maintain a denser operation—both with the same safety standards.

- *Investment*. Developing and operating a fleet of drones or air taxis will require continuous investment—which could be lost if, at some point, the operator loses access or reliability in part or in whole to sustain its operation. A framework for providing predictable long-term access to the skies should reduce risk for long-term investors.

A licensing model has worked well in other sectors that require long-term investment, notably in allocation of spectrum to mobile operators. However, it may be challenging to adapt this model over time: in other industries, introducing market reforms that allow for primary and secondary sales of such licenses has often been a slow process, owing to resistance from incumbents.

In spectrum, the first primary auctions began in the mid-1990s and reforms allowing secondary trading in the 2000s, but only recently have auctions become ubiquitous worldwide and many countries still restrict trading. In airport slots, auctions of new slots remain rare, although trading has become more prevalent.

The licensing model has some other potential downsides. Systems will be required to ensure the licensing process is not unnecessarily burdensome. Unduly long licenses may protect incumbents from competition, which in turn may introduce exclusionary motives for acquisition of licenses, and introduce holdout problems.[22] An emerging market for scarce air slot licenses could also be vulnerable to speculative bubbles, for example as happened with European 3G mobile spectrum[23] and New York taxi medallions.[24] Finally, by itself, a licensed model may also be insufficiently flexible, unless complemented by a supporting mechanism for real-time reallocation of air slots that would otherwise go unused.

Real-Time Market

A real-time market for access to airspace would enable participants to bid for a flight path and time slot to fly a specific drone, and a computer-based deconflict and pricing algorithm would ensure that each drone gets allocated a valid flight plan.[25] In effect, a real-time market adds a price component to the strategic and tactical deconfliction algorithms that facilitates allocation of scarce airspace to users that have the highest value.

This type of real-time bidding already exists at large scale in the management of electricity and internet advertising. Electricity markets continuously (every few milliseconds) balance supply and demand using frequent auctions. Similarly, companies like Google run auctions to place advertisements every time any user on the planet opens an application or requests information (millions of times per second).

These are very different types of markets but could still provide models for developing a real-time market for airspace.

The main concern with real-time markets is potential uncertainty over pricing. Prices may be volatile because they reflect ever-changing conditions owing to weather, season, hour, or special events. A reasonable expectation is that prices would be low most of the time in most places, with higher prices used to manage demand wherever congestion appears. By itself, this structure may be problematic, as firms that intend to operate aircraft managed by UTM or UATM will need certainty with respect to the level of access, the reliability, and the cost of accessing the skies. For example, a firm planning to run a drone delivery service may need continuous access for thousands of drones at a time. Deconfliction rules that do not provide certainty with respect to the level (number of drones), reliability (wait-time on the ground or air), and cost (in case of congestion) will introduce additional financial risk to the operations, reducing investments and innovation.

As in electricity markets, this could be addressed through forward markets that allow participants to manage risk. Forward markets provide participants with certainty over both *quantity* (availability of the areas and times of preferred flight) and *price* (the cost, if any, of accessing desired airspace). Both are important. A firm operating a drone fleet may strictly prefer to have guaranteed airspace access and cost certainty over having guaranteed airspace access but uncertain cost. The worst situation would be to have uncertainty on both quantity and price (i.e., the firm may be unsure if airspace will be available and, if available, at what cost).

In other industries, there are examples of situations where lack of forward markets has been damaging for market participants and the public. Electricity provides an example of price uncertainty. It is widely recognized that the lack of forward markets contributed to the 2001 electricity crisis in California in which there was a shortage of energy and very high prices, and several generating companies went bankrupt.[26] To address this risk, most electricity markets now include long-term contracts and capacity markets, as well as real-time markets.

The recent electric scooter rental industry provides an example of quantity uncertainty. Scooter services were banned in several cities around the world after they became flooded with scooters provided by competing companies. These bans destroyed millions of dollars in investment in supporting infrastructure by the associated companies. Arguably, the lack of long-term rights for road access induced congestion and made it impossible to distinguish between high-value companies and low-value companies. Since then, some cities have embraced forward markets for "road-access for electric scooters" in the form of long-term licenses allocated by auction.[27]

In a drones markets, similar situations could appear if flight rights are not properly allocated before companies start operations. For example, a city may reduce the allowed number of drones that may operate at a given time. The change may be reflected in "price volatility" of flight rights—either by actual price volatility of rights if there is a market or otherwise an increased volatility in the asset returns of companies operating drones. If the reduction is sufficiently large, the entire operation of companies may be threatened.

Long-term licenses provide a potential mechanism for enabling a forward market, with duration tailored to emerging business models for drones and air taxis. However, there are other options, such as the hybrid model we review next.

Hybrid Model

Given that each of these models have strengths and weaknesses, regulators may also consider hybrid approaches. For example, real-time and forward markets could be combined as follows:

1. A real-time market implemented as in electricity or internet auctions that assigns positive prices only to those air slots that are congested. Anyone can request access at any moment. Those who are willing to pay the congestion price get access.[28] Multiple algorithms are currently being developed for airspace.[29,30,31] Algorithms developed for road pricing could also be adapted to airspace.[32]

2. A series of forward markets that provide scheduling and balancing capabilities to the whole system. This could ultimately involve day-ahead, monthly, and yearly markets. Forward markets provide the ability to buy and sell air slots "in bulk." For example, they might enable a participant to buy one thousand per-hour air slots over New York City for a year. The owner of those slots could then adjust its position in monthly and day-ahead auctions.[33]

It should be noted that if the system overall has low congestion, then long-term rights are likely to have low value, with participants paying only small premiums to ensure predictability. Similarly, in this case, the real-time market would resemble an open road most of the time, with variable pricing only kicking in at critical times and locations. Subject to consumer protection rules, providers of drone services and air taxis would have flexibility with respect to whether and how they pass on these variable costs through the prices they charge their customers.

For example, air taxi users might be required to pay congestion surcharges if travelling at peak times or offered discounts to delay travel to a quieter time, based on current and projected real-time tariffs. These types of pricing innovations may mirror parallel changes in how we pay for terrestrial road use as society embraces autonomous vehicles (self-driving cars) and transitions away from car ownership toward Mobility as a Service (MaaS).[34]

Various other measures may be considered to promote competition and flexibility, depending on how the market develops. Ex-ante caps on access to air slots might be applied to ensure there are multiple potential providers of services. A proportion of capacity may be reserved for the real-time market, to ensure there is always flexibility for instant access, albeit at a price if demand exceeds supply. At the same time, a significant proportion of capacity could be auctioned as perpetual "depreciating licenses," subject to annual payments that are linked to the current market value.[35] By regularly repricing perpetual licenses, it is possible to ensure that firms have certainty over access but also have strong incentives to sell on air slots if they are not the most efficient user.

Conclusion

Based on developments to date, early deployment of drones and air taxis are likely to take place under an open road framework, with rules to promote safety, security, and equity. This system should be effective for as long as the airspace remains uncongested. However, if bold predictions for growth in demand for drones and air taxis are correct, then congestion will emerge, most likely in larger cities where local regulators may constrain use of airspace for safety and aesthetic reasons. Unless economic principles are built into the deconfliction principles, this may result in inefficient choices over how we use our skies, which would likely be manifested through reduced choice and lower quality in delivery and air taxi services.

Inefficient congestion could be avoided if regulators start building economic principles into rules for managing airspace now. Development of real-time and forward markets for air slots, including long-term licensing of some capacity, is a potential way forward for both the UTM and UATM systems that deserves study.

The implementation of the hybrid system would involve imposing an additional layer of rules on a nascent industry, but could help avoid the unmitigated congestion allowed by open road systems, and the competition problems created by incumbent advantages in the FCFS and licensing systems. Here, the experience of other sectors—including electricity, online advertising, spectrum management, and transport—in introducing market-based reforms is valuable, both in informing mechanism design but also in showing how difficult and slow it can be to add market-derived price signals later, owing to the emergence of stakeholders that have a vested interest in the status quo.

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