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Hyperloop: New Heights (Literally!) For Mumbai and Pune

Indradeep Ghosh and Tushar Kanade
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Author Bios:
Indradeep Ghosh is Associate Professor & Dean (Faculty), Meghnad Desai Academy of Economics. Contact email: indradeep.ghosh2@gmail.com
Tushar Kanade is Chief Minister's Fellow, Government of Maharashtra, & Class of 2017, Meghnad Desai Academy of Economics.

Contact email: tusharkanwork@gmail.com

Section 1: Introduction

In this paper, we undertake a first pass or a preliminary attempt at assessing the economic impact of a Mumbai-Pune Hyperloop Corridor. Hyperloop technology, as articulated by Elon Musk in a 2013 white paper, enables a high-speed mode of transport that would significantly reduce the time of a journey from Mumbai to Pune, or vice versa, from the present-day 3.5 hours by car to a mere 11-15 minutes. Although the specific details of how this technology will actually work remain a topic of active research, there is a great deal of excitement in India about the possibility of Hyperloop lines criss-crossing the country, connecting its very large urban centres, of which Mumbai and Pune are two of the fastest growing and most densely populated.

We begin in Section 2 by surveying the literature on urban economics, and discovering that traditional notions of arbitrage and spatial equilibrium are not adequate for capturing the impact of a Hyperloop line between Mumbai and Pune. This leads us to propose a new and foundational idea called “cost of distance arbitrage” that will allow us to imagine the changes likely to be wrought by the new technology. In Section 3, we describe these changes, posit the emergence of a Mumbai-Pune “megalopolis,” and propose alternative scenarios that will capture the possible dynamics of transformation. In Section 4, we embed the force of arbitrage and our thoughts about the emergence of a megalopolis within the specific context of Mumbai’s geophysical, regulatory and infrastructural contexts. This allows us to provide much more definition around how policymaking may hope to play a role in shaping the contours of the Hyperloop line. In Section 5, we call for the formation of a single policymaking body by first describing the likely components of policy formulation and then claiming that planned development requires clear, decisive leadership. Finally, Section 6 concludes.

Section 2: Urban Economics & Other Perspectives

Urban economics concerns itself with a very wide array of questions. In what follows, we will restrict our attention to the broad contours of this literature, which, for the most part, function as explanations for the existence of cities, urban spatial structures, the different experiences of different cities with regard to growth and prosperity, the patterns of housing prices within and between cities; etc.

A number of key concepts emerge as important for framing the issues.

One of these is the idea of economies (of scale and agglomeration) that drive spatial concentration of individuals, families, firms, and jobs, giving rise to cities. Scale economies are internal to a producing unit and favour large size because they spread fixed costs over greater units produced. Agglomeration economies are external to a producing unit and have to do with the firm locating close to other firms and/or final consumers. The gains to the firm from such co-location can come from the reduced cost of moving goods across

space, or the benefits of moving labour across firms, or the spread of ideas that facilitate innovation. Although the relative importance of these different sources of agglomeration economies remains in question, urban economists agree that the general thrust of such effects is to reduce transport costs, and thus favour concentration. In turn, concentration or clustering can help a city that has already established itself over the years as a significant centre of economic activity to maintain and even grow its gains relative to poorer regions that are unable to catch up because historical or other forms of contingency did not favour them in the same way.

Another important idea is the canonical representation of a city possessing a monocentric spatial structure, with a single business district located at the city centre. This kind of approach facilitates the modelling of housing demand, housing supply, and population density, and yields testable predictions about urban spatial structure, for e.g., that more populous cities should be spatially larger, denser, and more expensive than less populous cities. The models can be extrapolated to think about dynamic effects such as the steady decentralization of cities as incomes rise, transport costs fall, and populations grow. In time, a city that possesses a monocentric orientation may morph into one that exhibits a polycentric orientation depending on the evolution of economic activity and transport modes. Just as well, a city may languish and become de-populated if cost considerations and technological progress cause capital, and therefore economic activity, to shift elsewhere, as has happened in many parts of the West following the recent decades of increasing automation and increasing globalization.

A third concept that urban economists often employ is spatial arbitrage whereby an equilibrium is achieved such that an individual is indifferent between living in two different cities. Elevated incomes in one city may then co-exist with depressed incomes in another because a rational actor choosing between the two locations might set off the benefits of higher incomes in the first city against the benefits of lower housing costs in the second city. In general, the choices of where individuals will locate, where firms will hire, and where builders will build, are all modelled explicitly as arising from exogenous differences across space in productivity, amenities, and the construction sector. Such a modelling approach yields insights into why some cities grow and others don’t – for example, the reasons may have to do with factors *other* than agglomeration economies or the quality of available amenities, and instead with housing supply and the scope for housing development.

Rendered analytically powerful by such ideas, urban economics has proved to be useful for rationalizing many of the empirical regularities of modern Western cities, and also for charting a way forward for those cities to continue to expand and develop. And yet, the contingent, path-dependent nature of city formation leaves sufficient room to doubt that any single theoretical framework or even collection of frameworks can do justice to the tremendous diversity of

cities around the world. Especially in much of the developing world, the growth of cities has hardly followed any kind of systematic urban planning logic. Indian cities such as Mumbai have had centuries to develop, and that development has been and remains even today, for the most part, haphazard and unplanned. Institutional inertia not only precludes a proper assessment of the challenges posed by such chaotic development, but also the arrival of Hyperloop technology presents newer uncertainties about what it means for Indian cities to avail of such technology for intercity transport. Shirgaokar (2013)[1] argues, for instance, that most Indian cities are not monocentric, and that the Greater Mumbai region, in particular, is comprised of multiple sub-centres or nodal developments. If it were clear, therefore, that the conventional models of urban economics will not readily describe cities such as Mumbai and Pune, then it is even clearer that the prospect of connecting these two cities by a Hyperloop transit network will throw up unique challenges of conceptualization for urban economics.

The reason is primarily the dramatic reductions of travel time made possible by this new technology. While the notion of agglomeration economies may well give us a handle on how reductions in travel time between the two cities will favour the growth of both cities, there is the added complexity of understanding exactly how these cities will co-evolve if the new technology essentially makes each one a neighbouring community relative to the other. There is no precedent for the "cost of distance" between two large cities to suddenly fall from hours to minutes – which is probably the reason that one does not even see the cost of distance appearing as a meaningful variable in arbitrage models of spatial equilibrium.

Yet, we would argue that the notion of arbitrage is axiomatically about distance and the time it takes to traverse a given distance. In trade economics, arbitrage is easy or difficult as impediments to the flow of goods and services between two locations are minimal or maximal – when arbitrage is easy, similar goods and services cannot sell at different prices in different locations. Likewise, in finance, arbitrage is easy or difficult as impediments to the flow of capital between two locations are minimal or maximal – when arbitrage is easy, similar assets cannot offer different rates of return in different locations. One of the main contributions of our paper is to argue that the impact of Hyperloop technology will be primarily to activate this kind of arbitrage. Essentially, we are proposing that the fundamental impact of a multiple-tube Hyperloop network connecting a majority of Mumbai and Pune will be an arbitraging away of existing differences, along various different dimensions (spatial structure and densities, valuations of residential and commercial real estate, demographic characteristics, etc.), between these two cities.

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[1] Manish Shirgaokar, "Limitations of the Anti-Floor Space Index Position," *Economic & Political Weekly*, July 20, 2013, Vol. XLVIII No. 29

We call this “cost-of-distance arbitrage” and it is to be understood as an *actual mechanism unfolding in real time*, as opposed to the idea of arbitrage embedded in conventional models of spatial equilibrium, in which time is virtual. In those models, the same principles presumably apply for explaining the differences between proximate cities like New York and Philadelphia and explaining the differences between distant cities like New York and Chicago. What would happen, however, if Chicago were to become, via Hyperloop technology, even closer to New York than Philadelphia? Could the principle of arbitrage as articulated in models of spatial equilibrium be applied to think about this new development? We think not, since commuting cost *between* cities does not explicitly enter those models. Rather, it is presumed right from the start that commuting cost is a vanishing variable in all pairwise comparisons. This vanishing quality of commuting cost renders time effectively virtual in the model.

In our framework, which is not an explicitly mathematical model but nevertheless yields analytical implications, arbitrage unfolds in real time, as the close-ness of the two cities in respect of distance becomes the driving force for a growing alike-ness of the two cities in terms of spatial and demographic attributes, in exactly the same way that the close-ness of two locations in respect of distance becomes the driving force for a growing alike-ness of prices of goods and services across those locations. Indeed, the latter mechanism is more than a mere metaphor – it is at the heart of the transformation, since prices will be the first to reflect the information content of the transformation wrought by Hyperloop technology.

We should, at this point, make a very important clarification. We have claimed that the insights of urban economics are limited insofar as they cannot capture the complexity of actual city agglomerations. This is also how scholars in the fields of urban studies and urban planning tend to view the problems of urban development in that they eschew the idea of a paradigmatic theoretical core (such as one involving rational actors and utility maximization, for example) and instead take a more contextual approach, focusing on the actual “on-the-ground” realities of cities’ geophysical, political and real estate limitations. This is also our approach in this paper. That is to say, we do not think of our “cost-of-distance arbitrage” argument as a generic framework applicable to the study of urban agglomerations, but rather as an organizing principle that will help us to think through the specific ramifications of a Mumbai-Pune Hyperloop network. It was necessary to review, albeit very briefly, the contributions of urban economics, so as to develop and situate the concept we have proposed, and while we will argue that this kind of arbitrage will be a key driver of change following the network’s inauguration, we will nevertheless remain very mindful that the actualized reality will depend on the specific characteristics of the two cities under study and the nature of the relationships between them in the present day.

The issues studied in more contextual approaches belong to a wider palate than that of urban economics, involving considerations variously of social equity, economic growth, environmental sensitivity, and aesthetic appeal, among other imperatives, as well as assessments of the trade-offs and conflicts between these various demands. As such, the methodological approach is interdisciplinary, since a number of distinct spheres of human activity are implicated in the analysis, such as – the technological and organizational forms by which cities function and grow; the legal, institutional and administrative arrangements by which cities are governed; the production and labour processes by which cities generate livelihoods and incomes; the social relations that exist between city residents and between different classes of city residents; the relations of residents to nature and the environment; and the mental conceptions of the world that undergird residents' normative ideals, to name but a few. Given such a wide range of subject matter, it is impossible to systematize the thinking in these contextual approaches in the way that we have done for urban economics. Urban planning alone boasts seven or eight different theoretical frames through which the planning procedure may be viewed. Nevertheless, the contextual approach itself, and the questions that its various formulations raise and inquire into, become as well guiding principles for us as we embark on our task in Sections 3 and 4.

Section 3: Imagining a Megalopolis

By some measures, Mumbai is the most populous city in India, and Pune the seventh-most populous. The difference between first and seventh place is quite large, Mumbai being more than three times the size of Pune, the two together accounting for more than 23 million inhabitants. Separated by a distance of about 150 kilometres, the two cities are of historical importance as well, with Mumbai being the older city, having functioned as a natural harbour for at least a few centuries, while Pune rose to strategic importance in the 18th century as one of the capitals of the Maratha Empire, and is often regarded as the cultural capital of the state of Maharashtra, which houses both cities.

Their respective development trajectories over the last 100 years have been marked by one important difference – Mumbai is water-locked whereas Pune faces no obvious geological restrictions. Partly as a result of this unique feature of Mumbai, but also to a large extent because of administrative negligence, the city has spawned many problems of infrastructure and overcrowding as it has grown rapidly. From burgeoning air traffic demand that exceeds capacity by 5 million passengers annually, to over-congested roadways, and from sluggish progress in transportation projects due to delays in land acquisition and clearance, to an overwhelming 62% of the population living in slums, Mumbai is a site for some of the worst urban bottlenecks of any developing country. By contrast, Pune has grown without any apparent limit. Present-day administrative authorities such as the PMRDA and the PMC operate with a geographical mandate that, stretching across 3500 square kilometres, is the second-largest in the country. Where Mumbai lacks land

tracts to accord to any single developmental authority, Pune tends to seek out private entities to augment and enhance its real estate developmental profile. As such, Pune's development has been more structured, in a relative sense, and its population density (at approximately 4000 per square kilometre) is about a fifth of Mumbai's.

Based on public statements, we imagine that a Hyperloop network between the two cities might connect some central hub in Mumbai, such as Dadar or Bandra-Kurla Complex, to some central hub in Pune, such as Shivajinagar or the Pune station area. This main corridor might then offer access to an airport in either city, with Navi Mumbai International Airport offering itself at the Mumbai end as a favoured node over the more centrally located Chhatrapati Shivaji International Airport because, among other restrictions, the latter is already functioning at excess capacity and the two airports may anyway be connected by a planned Metro line. The planned Metro line could itself be replaced by a Hyperloop line, creating a single mega-airport, capable of eventually serving over 100 million passengers. At the Pune end, Hyperloop could connect the Chhatrapati Sambhaji Raje International Airport, being constructed around 40 kilometres outside Pune's city centre, to the city centre in minutes.

The possibility that Hyperloop technology could create one airport out of two has received some attention from the technology providers themselves. Airport capacity is already a significant problem in India, as it is elsewhere around the globe. Rather than add new runways and terminals to existing airports, which is anyway an unlikely prospect given the challenge of land availability, Hyperloop could connect two distant airports that are 40-70 kilometres apart, effectively rendering the travel between airports akin to transiting between terminals at a single airport or between different gates within a terminal. So-called mega-airports are thought to offer several benefits. For airlines, greater capacity means the ability to service more routes with greater reliability and flexibility. For passengers, greater capacity translates into more options and cheaper travel. For the communities around airports, greater capacity means more jobs and other economic benefits.

In theory, a completely different route might connect the industrial area of Chakan in Pune to the extremely critical JNPT port in Mumbai, and might piggyback on the Mumbai Trans Harbour Link to offer easy access to central Mumbai. Such a route would be particularly beneficial for freight transport between coastal regions of Maharashtra and the interiors of the state, especially if an extension to Nagpur, the third largest city in the state and lying several hundred kilometres east of Pune, were to become feasible.

In sum, a mixture of airports and major transit hubs is probably a good framework for thinking about the effects of the proposed Hyperloop line, but whatever the precise layout of the network, we imagine that it will create a

Mumbai-Pune megalopolis, unlike anything hitherto seen in India or elsewhere in the world.

Cost-of-distance arbitrage will be the primary economic force at work, its most likely manifestation being a levelling of prices across the two cities, with Pune's significantly lower cost of living (presently, about 30% lower than Mumbai's owing largely to their respective housing ownership and rental costs) rapidly rising to Mumbai's levels, and thereafter growing at roughly the same rate. As this happens, large swathes of the distance presently separating the two cities will come under development, and the development will be faster and wider at the Pune end than at the Mumbai end. Further, we expect that overall, Pune, because it is not water-locked like Mumbai, will grow much faster than Mumbai, and will experience large amounts of in-migration of individuals, families, and businesses, from adjoining regions and also from Mumbai. The state of present-day regulations governing the construction of high-rises, much more draconian in Mumbai than in Pune, will also favour the latter city in this regard, and will reinforce the arbitrage process.

We further illustrate this process of arbitrage with two examples, the first having to do straightforwardly with the differences between two locations in respect of real estate demand and supply, and the second digging deeper, and dealing with qualitative differences such as the advantage that one location has over another in respect of agglomeration economies.

According to a recent real estate development report published by Knight Frank India[2] covering the July-December 2017 period, Pune has witnessed a dramatic downturn in both residential and commercial real estate, while Mumbai has witnessed an upsurge in commercial and residential property demand, particularly in central Mumbai. A Hyperloop route has the potential to reverse the effects in Pune's real estate market, while not necessarily halting new launches in Mumbai. Insofar as the route enables a transfer of Mumbai-based residents belonging to the appropriate socioeconomic classes to Pune's middle income real estate market, we may witness a higher demand for residences and commercial properties in the latter city. This demand may exactly match the class of real estate stock units that form the bulk of Pune's unsold inventory, or call into existence a greater supply via higher real estate prices. Precise conjectures about such real estate appreciation scenarios will need to be informed by a number of specific considerations, such as the finalized fare values for the route (to be decided at a much later date in the project plan), the specific station locations (of which there only exist rough area-plans in the public domain), and the policy responses (FSI regime; zoning regulations etc.) around the immediate areas connected by the Hyperloop route.

[2] http://www.knightfrank.co.in/research/india-real-estate-july-december-2017-5176.aspx

A more interesting scenario for arbitrage arises in the context of "coworking spaces", which are a nascent consequence of the so-called "gig economy"[3]. The latter term refers to the increased number of short-term contracts executed between companies seeking temporary labour and workers seeking remote-working arrangements, a number that has been increasing each year since the early 2000s. This is possible due to certain components of the workplace (entire divisions such as operations, quality control, and project management, or specific functions such as human resources, marketing, and business strategy) no longer requiring simultaneous physical interactions between all relevant employees, as has been the norm in company structures originating in the 20th century, owing to advances in high-speed internet and related information technologies. Coworking spaces are an innovation in this new arena of working arrangements, originating in San Francisco in 2005, and quickly becoming an international movement, with unicorn companies such as New York-based WeWork raising as much as $4.4 billion in a single fundraising round[4] and investing as much as ₹4.3 crores per month in a Bandra-Kurla Complex property[5] to establish a 16-storey coworking space (notice that BKC is one of the proposed station locations in the proposed Mumbai-Pune route).

Coworking spaces, more than any other big-city cluster concept, require tremendous agglomeration economies to be profitable and sustainable. The business model of a coworking space is to lease out desks and cabins, from as little as one desk to a single professional to as much as an entire floor to a medium-sized start-up. For them to be successful, the city harbouring such coworking spaces needs to represent a wide mix of professions, sectors, and markets. Hence, the existence of a panoply of professionals (usually found in a megacity such as Mumbai, Hong Kong, or New York) fuels this business model and ensures profitability in the long-run. Smaller cities, with lesser economic output and a narrower range of representative professions, tend to be unattractive to big coworking spaces, such as those established by WeWork and Rocketspace. It is interesting to note that the existence of a megacity is central to the mushrooming of coworking spaces as nearly all but the biggest of cities, some even as big as Pune, suffer from a lower intensity of agglomeration economies and cluster effects. Pune's skilled workforce distribution is dominated by the IT and ITES sectors, resulting in an overabundance of a relatively homogeneous and highly specialized class of workforce. Mumbai, on the other hand, has a balanced mix of professionals representing nearly all major employing sectors, and also has a surplus number of professionals in most of these sectors, with the differences

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[3] https://www.forbes.com/sites/larryalton/2018/01/24/why-the-gig-economy-is-the-best-and-worst-development-for-workers-under-30/#5d0ac4506d76

[44] https://www.forbes.com/sites/alexkonrad/2017/08/24/wework-confirms-massive-4-4-billion-investment-from-softbank-and-its-vision-fund/#6c8225d85b3c

[5] http://www.livemint.com/Companies/hF45YW1fMjorr3OIRhYa2M/WeWork-leases-19-lakh-sqft-space-at-BKC-to-set-up-first-M.html

between Mumbai and Pune estimated to be at least a few million owing to the population gap.

Setting up coworking spaces also require one-time “lumpy” investments, resulting in companies being compelled to make best-fit choices when choosing between any two or three shortlisted cities. Ordinarily, one could argue that companies driving the rise of coworking spaces (WeWork; Rocketspace etc.) would be reluctant to expand majorly in Pune, given Mumbai's regional proximity and much higher levels of agglomeration and cluster benefits. But the Hyperloop changes this equation in the context of Mumbai and Pune. With Pune being a 25-minute ride away from BKC, while potentially offering up to 60% savings in real estate rentals when compared to prices offered in key business districts in Mumbai, both coworking spaces and their intended customers will invariably be attracted by the economics of setting up their respective businesses in Pune, at much lower costs of operations. Furthermore, the agglomeration and cluster benefits that, in the present day, remain a traditional hallmark of a megacity such as Mumbai, will likely be distributed to central Pune, as the immediate area around the Pune node would be spatiotemporally equivalent to a suburb in northern Mumbai or the CBD situated in South Mumbai. Pune’s workforce mix will also likely change, with a greater number and variety of professionals being able to either commute via daily trips to Pune or being able to relocate to central Pune, while working in such Pune-based coworking spaces.

The scenario laid out above also suggests that a Hyperloop route may constitute an important element of the so-called “Fourth Industrial Revolution”[6] as defined by the World Economic Forum[7], as it is the pioneering case of a physical technology enabling cyber-physical transformations of society, such as the atomization of the office space into physically and geographically distinct workplaces. It is even possible to imagine that the Mumbai-Pune megalopolis will leapfrog many global cities, such as New York and Tokyo, in terms of the sheer number, variety, and frequency of interchange, of workers available to leverage a “platform” such as a coworking space. Modern platform-driven business models, such as Uber, Zomato, WeWork, and so on, are entirely dependent on the scale of participants engaging with these respective platforms. A mega-agglomeration of 26 million citizens will offer a scale that is likely unmatched by any other agglomeration in the world.

Unlike conventional models of agglomeration, driven by a city-centre that feeds economic life into the fringes of its ever-expanding borders, we are here being called to imagine the unique instance of two agglomerations that were considerably distant from one another, now connected with a major transit line. It is clearly impossible to map out all of the details of the geographical

[6] https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/
[7] https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab

unit that will emerge as a result of this change, and what we have attempted here is only a first approximation of sorts. Such a first approximation leaves open the possibility that the emergence of a Mumbai-Pune megalopolis could involve both the trend of greater density at the end points of the network and the trend of greater suburbanization around the edges of the two cities. The trend toward suburbanization reflects a general pattern by which cities grow – namely, that they decentralize when populations increase, incomes rise, and transport costs fall, all three of which are predicted to happen with the introduction of a Hyperloop line. Some scholars have hypothesized that the decentralization of cities will lead to the emergence of an “endless suburb” or “infinite suburb” over time. Yet, whether we can expect this to happen in the case of Hyperloop remains uncertain, because of the so-called “tunnel effect”.

The tunnel effect postulates how two distant areas connected by a transit line will concentrate development only in the connected regions, at the expense of inter-nodal development. Interestingly, this phenomenon is quite pronounced in its effects when we refer to point-to-point connectivity, since the avenues to exit the connecting route may be limited to the nodes (or stations) on the route. If we were to draw a spectrum of transportation modes which are more or less conducive to the prevalence of the tunnel effect, we will notice how point-to-point modes (such as rail and air) augment the tunnel effect than do modes (such as road) which have multiple entry and exit points across the region and throughout the route. In the case of a high-speed rail line or even an airport-to-airport route, the only manner in which a commuter can exit the route is at either of the two stations or nodes. Therefore, any intermittent area that is covered by this route is not connected at all and thus cannot be reached by the commuter through such direct modes of transport. In the case of a road network, however, it is possible that the inter-nodal area (eg. the area between Mumbai and Pune) be still connected by a single lane road or by unpaved roads, through various entry and exit points which may be planned (paved entries/exits) or unplanned (unfenced exits from a highway).

The Hyperloop remains a technology that, by nature, will augment the tunnel effect. Even in the case of rail, you can still add more stations along the route. Also, a railway route will generally have many more stations along the route to begin with, as is the case of the Mumbai-Ahmedabad High-Speed Rail route. But in the case of the Hyperloop, the technological advantages of having point-to-point connectivity, as well as the economic demand for such a longer distance direct-to-destination journey, together establish the case for excluding any such nodes along the route. Therefore, when compared with rail, the inter-nodal area of a typical Hyperloop route is not just relatively more disconnected but is also greater (in total area) than the inter-nodal area between any two railway stations on a comparable rail route. There are as many as five stations that a Mumbai-Pune train halts at in a single one-way journey, while in the case of a Mumbai-Pune Hyperloop, the number of halts

will be zero. Thus, any development that will be influenced by the Hyperloop route may primarily focus on its two nodes, at each of the cities' city-centres.

And yet, the ambiguity about which of the two trends identified earlier will dominate returns when we consider that restrictions on land density (such as FSI limits) may nullify such an augmented tunnel effect, and accentuate further the already-extant trend of suburbanization of both cities, and perhaps especially Pune. Some part of the tendency to suburbanize may also be supplanted by the growth of exurbs and satellite cities, which are urban formations located some distance away from a city's suburbs, and this is yet another mechanism through which the cost-of-distance arbitrage may manifest in the years ahead.

In addition to imagining the emergence of a megalopolis, we can also offer some conjectures about the size of traffic along the network. In the present day, the Mumbai-Pune highway witnesses one of the highest daily inter-city traffic numbers over a 150 kilometre distance. At roughly 80,000 private four-wheelers, and another few thousand buses, there is an approximate exchange of 200,000 people between the two cities each day. Given such a large amount of traffic, not matched perhaps by any other pair of cities in the world, it is not inconceivable that the Hyperloop network will witness full capacity even in its initial stages. To appreciate how this might come about, consider the following scenario (the numbers that follow are based on discussions with company officials at Hyperloop One and experts). At 50-passenger pod capacities and a frequency of one pod every 20 seconds, we arrive at a figure of approximately 10,000 passengers per hour that depart from or arrive at a given station. If we were to assume an operational cycle of 10 hours each day, we arrive at an approximate figure of 100,000 passenger capacity each day, per tube in a single direction. If we apply these calculations to the other tube facing in the opposite direction, we arrive at an identical figure, barring further assumptions. The total line capacity of a two-tube Hyperloop route therefore becomes 200,000 per day, or 20,000 per hour. This is a huge figure that still requires us to make fairly optimistic assumptions about the capacity of the Hyperloop system, yet it only just matches the existing pre-Hyperloop demand on the Mumbai-Pune corridor. Assuming, then, that the presence of the network will likely increase inter-city transit demand, we are called to extrapolate still further, and consider a multiple-tube Hyperloop network.

Such an exercise is important not just for the sake of this paper but also for the sake of future expansions of any such corridor, since the full manifestation of this technology's capacity and its consequent effects on the two agglomerations' growth trajectories can only be mapped when we are allowed to consider a higher line capacity of the proposed routes. However, since line capacity in the context of the Hyperloop technology is somewhat static, hovering around the 10,000 per hour mark, we can only assume multiple such lines in our bid to expand the overall capacity of the network between any two

nodes. Thus, we assume up to three two-way/six one-way Hyperloop tubes at a maximum, while assuming a median figure of four tubes, two carrying pods from Mumbai to Pune, and two carrying pods from Pune to Mumbai. This then raises the maximum capacity of the network to 600,000 passengers a day.

For the sake of even more flexible scenario-building exercises, we can assume three other per-hour capacity figures: a scenario that has a pod-frequency of 30 seconds, yielding a per-hour capacity of 6,000 one-way passengers; a scenario that has a pod-frequency of 40 seconds, yielding a per-hour capacity of 4,500 one-way passengers; and a scenario that has a pod-frequency of 60 seconds, yielding a per-hour capacity of 3,000 one-way passengers.

All in all, the above possibilities afford a wide array of choices for the design of the network.

Section 4: Geophysical, Infrastructural & Regulatory Contexts

In the previous section, we have described the broad contours of how the introduction of a Hyperloop line will activate a force of arbitrage that will begin to shape a megalopolis. Much of that discussion presumes that certain geophysical, infrastructural and regulatory constraints that currently prevail in Mumbai will continue to be in place before, during and after the construction of the Hyperloop line. Such a presumption is, needless to say, very simplistic. It is quite likely, indeed perhaps imperative, that policymakers give the force of arbitrage some direction and purpose by assessing and then relaxing some of the constraints prevailing in Mumbai.

The most important of these are the water-locked nature of Mumbai coupled with its very low (by international standards) floor space index (henceforth, FSI). FSI is the amount of floor area that can be built on any plot of land, expressed as a share (or multiple, as the case may be) of the plot area, and is therefore a ratio. Mumbai is not a “skyscraper city” because regulations severely restrict vertical growth. Set against those of other financial capitals like New York City, Singapore and Hong Kong, that are also, like Mumbai, built on islands, Mumbai’s FSI limits have been criticized by urban planners as severely distortionary, if not outright absurd. The principal charge levelled by such critics is that the low FSI limits make Mumbai’s real estate artificially expensive and unaffordable for many with lower incomes. Whereas planners and regulators are reluctant to relax existing limits, because they fear that this would lead to more congestion in an already overcrowded city, critics of Mumbai’s FSI regime argue that raising the FSI limit would increase floor space per person rather than persons per unit floor space. In what follows, we briefly recount this debate, as it provides a frame for considering the infrastructural and regulatory innovations that a Hyperloop line might occasion, and perhaps even make necessary.

Mumbai's FSI regime began in 1964 with a regulatory policy that divided the city into various zones and specified an FSI for each of them. The stated objective of the specific numbers chosen was to control congestion. Various zones had their own historical norms, and in some zones (such as Colaba and Marine Drive), these norms were maintained, while in others (such as Worli, Dadar and Sion, which were believed to be able to support a higher population density), they were increased, while in still others (such as Kalbadevi, Girgaon and Mandvi, which were believed to already be quite congested) they were lowered. As such, different zones ended up with different FSI numbers and this seemed to make sense as the imperative of decongestion was presumed to be felt differently in different zones.

Patel (2015)[8] argues, however, that restricting FSI is not an effective means of controlling congestion. There may only be a weak correlation between density of buildings and density of people, so that restricting FSI may have an effect opposite to the one that is desired. If migration into a city increases the demand for land, then FSI restrictions will cause the price of real estate to rise, but this will not necessarily decelerate or stall the rate of migration – rather, it may only create more crowding as the available floor space is carved up into smaller and smaller living units, and also occasion the widespread emergence of slums as affordable housing is increasingly placed out of the reach of the poor (slums typically escape FSI regulations). Bertaud (2011)[9] points out that such problems are considerably exacerbated by archaic rent control regulations and the lack of clearly articulated property rights, that prevent the efficient purchase and sale, or redevelopment and resale, of land.

Mumbai, with more than half of its population living in slums, is a classic illustration of all of the above. Whereas the sensible thing to do, as a city grows, is to accommodate more building density in "downtown" areas and along transportation corridors, and to expand primary infrastructure networks (not only transport but also support utilities such as sewage, sanitation, power, etc.), Mumbai's experience has been just the opposite. Since 1964, as the city's population has exploded, Mumbai's FSI regime has regressed, becoming on the one hand mostly uniform across the city, and on the other, even more restrictive than before. The road and transport system (rail, bus, etc.) too remains underdeveloped and inadequate, if not a mere vestige of the past. As a result, congestion in Mumbai is much worse today than ever before. For instance, residential floor space consumption (square metres per person) in Mumbai is one of the lowest in the world (Bertaud, 2011)[10], and the number of vehicles per kilometre of the road network is among the highest in the country (Reddy & Balachandra, 2010[11]). Clearly, additional population density

[8] http://www.idfcinstitute.org/blog/2015/may/why-mumbai-should-embrace-mcgms-new-fsi-policy/
[9] http://alainbertaud.com/wp-content/uploads/2013/06/AB-Mumbai-FSI-Conundrun-Revised_June-2013_kk-ab1.pdf
[10] Ibid.
[11] http://www.igidr.ac.in/pdf/publication/WP-2010-023.pdf

in the limited area within the confines of Mumbai will only mean adding more pedestrian and vehicular traffic to the overcrowded and extremely stressed road network (Shirgaokar, 2013[12]; Patel, 2013[13]).

The perverse effect of an inadequate infrastructure network interacting with restrictive land-use (i.e., FSI) policies is to bolster the resistance of Mumbai's municipal authorities to any impulse towards a relaxation of the FSI regime, on the grounds that higher FSI limits will only worsen the congestion problem by increasing Mumbai's population density. The regime itself, however, remains amenable to discretionary exceptions and arbitrary concessions, giving rise to monopoly rents accruing to developers and corrupt civil servants. Such rents may also be the reasons that "insiders" resist change. Yet, to what extent is the stated reason for resistance valid? Is it true that higher FSI limits will increase population density? If, as we have already seen, lower FSI limits will not effectively decongest an area, then prima facie, higher FSI limits cannot be expected to exacerbate congestion either. More floor space in a particular area of the city will most likely allow existing residents in that area to enjoy a greater amount of floor space per person than before, as well as incentivize migration into that area by residents from other areas of the city. In the latter instance, however, the migration is not into the city but intra-city, and therefore it is unlikely that the city as a whole will experience a higher population density merely because FSI limits have gone up in certain parts of the city. And yet, to truly make this kind of selective FSI relaxation work to the benefit of the city, other reforms (that use land more efficiently, expand the available land area, and improve road and transport infrastructure) must also be implemented. This is the kind of argument offered by Bertaud (2011)[14], Patel (2013)[15], and Patel (2015)[16]. Patel (2013)[17], in particular, takes issue with the singular focus by such institutions as the World Bank (in recommending how Indian cities must change) on FSI alone, and proposes a new set of "crowding" metrics that will be more useful for policymakers because such metrics will more effectively capture the dynamics of congestion and move the issue of congestion beyond the scope of a simple one-to-one relationship with FSI limits.

Turning now to consider the case of a Hyperloop line connecting Mumbai and Pune, we propose that the reform of land-use laws, coupled with synergistic regulatory changes and infrastructural developments, will allow policymakers to override Mumbai's primary geophysical constraint that would otherwise, as described in Section 3, distribute most of the economic gains from a Hyperloop line away from Mumbai and towards Pune. The location of new

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[12] Ibid.
[13] Shirish B. Patel, "Life Between Buildings: The Use and Abuse of FSI," *Economic & Political Weekly*, February 9, 2013, Vol. XLVIII No. 6
[14] Ibid.
[15] Ibid.
[16] Ibid.
[17] Ibid.

economic activity that the Hyperloop line would enable is critically dependent on the force of arbitrage, but the quantum of this force is itself critically dependent on whether or not the geophysical, infrastructural and regulatory environments at the Mumbai end are mutable.

To understand this point, consider the following very simplified example. Suppose that prior to any change, real estate prices in Mumbai are rising at a rate of 3% per annum, while those in Pune are rising at a rate of 2% per annum. Clearly, in both cities, demand for real estate is rising faster than supply, and moreover, this difference between the rate of growth of demand and the rate of growth of supply is greater in Mumbai than in Pune (as we might expect given the supply constraints operating in Mumbai). First, consider a scenario in which only a Hyperloop line is introduced but there are no changes to Mumbai's constraints. Then, cost-of-distance arbitrage will cause the demand for real estate in Pune to increase faster than before, and the demand for real estate in Mumbai to increase slower than before. This would, in turn, cause the supply of real estate in Pune to increase faster than before and the supply of real estate in Mumbai to increase slower than before, and moreover, these supply responses would be *endogenous* in their nature, i.e., coming about as responses to the changes in demand. Over time, these changes in the rates of growth of demand and supply will tend to equalize real estate inflation rates across the two cities. The tendency to equalize will, in turn, be greater the greater is the diminution of the cost of distance between Mumbai and Pune. Since a Hyperloop line achieves a significant cost diminution, the force of arbitrage will be quite strong, and we might, for the sake of simplicity, presume that the inflation rates are fully equalized, and moreover that this equalized rate is 2.5% per annum. Now, consider a different scenario, where alongside the introduction of a Hyperloop line, some of the geophysical, infrastructural and regulatory constraints in Mumbai are also relaxed. The effect of the latter set of changes would be to *exogenously* raise real estate supply, and therefore also the rate at which such supply is increasing, in Mumbai. Consequently, even without considering the impact of a Hyperloop line, there is a tendency for equalization of inflation rates between Mumbai and Pune, by virtue of a diminution of Mumbai's inflation rate from 3% to some smaller number, say 2.8%. The force of arbitrage activated by a Hyperloop line might then cause the equalized rate in this second scenario to be lower than 2.5% per annum in the two cities. It is as if the intensity of arbitrage is muted, because the difference to be arbitraged is now smaller, but buyers of real estate in both cities still benefit in a way that they do not in the first scenario.

Thus, in assessing the impact of a Hyperloop line between Mumbai and Pune, policymakers are urged to pay special attention to the ways in which policy might shape the force of arbitrage by altering the geophysical, infrastructural and regulatory contexts in which the two cities, but especially Mumbai, are embedded. What might such alterations entail in a concrete sense?

In the domain of transport infrastructure, we conjecture that an integrated transit system incorporating multi-modal connectivity is central to any effective solution for Mumbai, since it not only allows for FSI restrictions to be gradually lifted, but also allows for a systematic reduction of road-based congestion, by providing an avenue to the city's commuters to access other non-road alternatives. In fact, multi-modal connectivity has been one of the longest-standing planning projects being undertaken by the M.M.R.D.A. There are several Metro lines already under construction[18] in Mumbai with targeted commissioning in the 2020s, and a few more lines were recently proposed both in Mumbai and in Pune. Similarly, an ambitious project that will double the capacity of Mumbai's transit heart-line, the Western Railway commuter rail route, is the proposed Western Railway Elevated Corridor that will run from the Oval Maidan in the island city, to Virar in the northernmost portion of Mumbai. At the same time, the country's first and only bullet train route from Ahmedabad to Mumbai will terminate in the Bandra-Kurla Complex (BKC) area, with dedicated development possible in the area just above the underground bullet train terminus. BKC traditionally has been awarded the highest FSI limits in the entire city, reaching as high as 4.0 for commercial development. This combination of a high speed rail terminus, metro connectivity (through the most significant route, the Metro Line 3 running from Colaba through BKC and terminating at SEEPZ), available land, and historically relaxed FSI policies, make the BKC area one of the most ideal terminus locations for the Mumbai-Pune Hyperloop route. Only Dadar topples it in terms of multi-modal connectivity options, still losing out on FSI policies and available land. In the end, a BKC end-node with concentrated cluster development (of commercial and retail nature, primarily) appears to be the most attractive economic case within the context of this paper. A terminus anywhere else, except in the equally promising area of Dadar, will be a grossly suboptimal utilization of the benefits afforded by Hyperloop technology. If a passenger were to land in anywhere other than BKC or Dadar (or SEEPZ, a possible third alternative), the last-mile connectivity options for a Pune-to-Mumbai Hyperloop commuter (and likewise the first-mile connectivity options for a Mumbai-to-Pune Hyperloop commuter) will be riddled with congestion and lack of multiple options.

Another kind of infrastructural innovation that will significantly ease the burden of congestion in Mumbai is the addition of "new land" to its topography.[19] Presently, the only direct way to add new land is to perform massive land reclamations (such as the Bandra reclamation project, which is not even relatively massive when compared with some projects in Dubai). An indirect way would be to build infrastructure projects that connect Mumbai with areas outside its municipal borders. The most important and immediately relevant

[18] Mumbai Metro Master Plan, M.M.R.D.A. - https://mmrda.maharashtra.gov.in/mumbai-metro-rail-project

[19] All the authors cited above make this point

example is the Mumbai Trans Harbor Sea Link (MTHL), whose construction will commence in December 2018, and which, when complete, will connect Nhava-Sheva to Sewri/Central Mumbai. But it turns out that a Hyperloop line will have a much more magnified impact. In respect of the projected volumes of passengers, time savings, and quality of new land added, a Hyperloop line will outperform the MTHL. The superior performance of a Hyperloop line along the second of these dimensions should be obvious, since the MTHL will only carry passenger vehicles to and fro, and the 21.8 kilometre journey along it will take 25 minutes or so. With regard to the first and third dimensions, Nhava-Sheva remains largely undeveloped, and therefore its quality or attractiveness to potential residents and commuters remains largely a speculative matter. On the other hand, a Hyperloop line will add new land to Mumbai by connecting the city to Pune and its surrounding areas, all of which are already partially-developed agglomerations in their own right. Yet, we recognize that it is not really a matter of choosing between the two projects as both are likely to become a reality – in which case, the instance of a Hyperloop line helping Mumbai to surmount a critical supply constraint only serves to underscore our point that policymakers must see the Hyperloop project as a major urban transformation tool.

Section 5: The Hand of Policy

While utilizing an inter-city infrastructure project such as a Hyperloop line as a major urban transformation tool, is not an entirely new conceptualization, the institutional structures that will enable such a utilization need to be. In status quo, two distinct cities operate within the jurisdictions of their respective municipal corporations and developmental authorities, which themselves execute policy decisions that benefit and prioritize their own cities. It is fairly conceivable to think of each city as being a self-maximizing decision-making unit. A regional perspective is only added by the state government in most cases, as the immediately superior plane of policymaking is executed at the scale of the state. Geographically, the policymaking dialogue in Maharashtra, and indeed elsewhere in India, has left open a vacuum at a scale of a few hundred square kilometres of area i.e. the approximate region comprising two to five districts. Cities, such as Mumbai, are governed by institutions such as the M.C.G.M. and the M.M.R.D.A., while mega-infrastructure projects, such as the “Maharashtra Samruddhi Mahamarg” (a 700-kilometer Mumbai-to-Nagpur Expressway that will pass through ten districts) are implemented by the Government of Maharashtra through its nodal agencies such as the M.S.R.D.C. The Mumbai-Pune Hyperloop line, however, will only pass through 3 districts, and will cover a fraction of the Mumbai-Nagpur Expressway’s area. It is at this scale that we find a lack of effective policymaking structures that possess a level of autonomy and overarching jurisdiction over multiple, yet a more localized number of, districts.

However, before we can comment on the specific manner in which any or all possible governmental agencies can give shape to the Hyperloop network, we

need to elaborate on four key policy variables that will become levers for any policymaking authority. Three of these four have already been discussed in previous sections – line capacity, FSI policy restrictions and multi-modal connectivity. The fourth is fare structure. Together, the settings for these four levers will determine the dynamics of demand and supply along the network. The fare structure need not offer clear arbitrage opportunities when compared with existing Mumbai-Pune trip fares (INR 500 for a bus, INR 1400 for a private taxi) because the time saved will surely allow the new network to command a "cost of distance" premium. On the other hand, the capacity to pay will be an important consideration and so the demographic profile of potential users will also need to be taken into account in determining appropriate fares.

To bring these four elements together, a comprehensive scoping exercise similar in nature to the Comprehensive Transportation Study (CTS) conducted and published by the M.M.R.D.A. may become an essential component of decision making. Such a study would produce scenario-based forecasts of usage and revenues, with each scenario grounded in a particular combination of settings for the four levers. Whereas the M.M.R.D.A.'s CTS is a decadal project, the Hyperloop CTS may be rolled out at higher frequencies given the rapidity with which the Mumbai-Pune megalopolis is likely to begin shaping up, following the introduction of a Hyperloop line. We propose surveys in 2018, 2021 (in time for the demonstration track), 2023, 2026 (in time for Phase 1 of the Mumbai-Pune Hyperloop consisting of a two-tube system), 2030, and finally, 2034 (in line with Mumbai's 2034 Development Plan).

An alternative sequencing for the successive scoping exercises might involve the following publication timeline:
(1) 2018 – looking ahead over a 5-year horizon till 2023, during which time two Metro lines will open up, a 2nd international airport will be completed in Navi Mumbai, and FSI restrictions will be relaxed in some low-to-moderately congested parts of Mumbai
(2) 2023 – looking ahead over a 3-year period till 2026, during which five Metro lines will become functional alongside the MTHL, Monorail, and Hyperloop Phase 1, a 3rd international airport will be completed in Purandar, and FSI restrictions will be relaxed in some moderate-to-highly congested parts of Mumbai
(3) 2026 – looking ahead over a 4-year period till 2030, during which all planned Metro lines will become functional, alongside the MTHL, Monorail, and Hyperloop Phase 2, and FSI restrictions will be relaxed in all major areas of development in Mumbai.

We have already described in earlier Sections the haphazard course of Mumbai's urban growth. It is important to recognize that much of this is attributable to the absence of clear, decisive leadership from any single policymaking body. For instance, the vertical development of suburbs such as

Powai and Thane, driven by real estate developers such as Hiranandani in the 1990s and 2000s rather than the M.M.R.D.A., took place at the same time as the construction of thousands of illegal shanties and slums in the Dharavi area. Much of this simultaneous developmental chaos has co-existed with the M.M.R.D.A.'s long-term plans for the city, with many of its most important infrastructural landmarks, such as the Bandra-Worli Sea-Link or the Eastern Freeway, owing their existence to some unknown urban planner's nascent vision for this city. This is not just another farfetched claim, as projects such as the MTHL had been proposed at least several decades earlier than its actual implementation.

Building a framework for the formulation and implementation of policy that will work better than arbitrary planning will require us to first reflect on the status quo. An infrastructure project, especially one within sensitive domains such as transportation or defense, is likely to be bound by overarching central government agencies (such as the Ministry of Road Transport and Highways), statutes of common law (such as the Motor Vehicles Act), and the conflicting and overlapping jurisdictions of state government authorities (such as the M.M.R.D.A. and the P.M.R.D.A.). In such complex interactions among a panoply of public sector agencies and authorities, the most important stakeholders are usually the agencies that are uniquely positioned to shape the policy framework surrounding the infrastructure project.

In the case of the Mumbai-Pune Hyperloop line, there are approximately a dozen statutory agencies, developmental authorities, public sector undertakings, and governmental entities that play intersecting roles in determining policies relating to governance, real estate development and transit. The list includes the Maharashtra State Road Development Corporation (M.S.R.D.C.), the Maharashtra State Road Transport Corporation (M.S.R.T.C.), the City and Industrial Development Corporation (C.I.D.C.O.), the National Highways Authority of India (N.H.A.I.), the Municipal Corporation of Greater Mumbai (M.C.G.M.), the Pune Municipal Corporation (P.M.C.), the Brihanmumbai Electric Supply and Transport (B.E.S.T.) Undertaking, the Mumbai Metro Rail Corporation Limited (M.M.R.C.L.), the National High Speed Rail Corporation Limited (N.H.S.R.C.L.), the Indian Railways, and lastly the two cities' developmental authorities, the Mumbai Metropolitan Region Development Authority (M.M.R.D.A.) and the Pune Metropolitan Region Development Authority (P.M.R.D.A). Even this list may be partial, since there will be other ministries and authorities that represent the central government, such as the Ministry of Road Transport and Highways.

While all of the above organizations will shape the policy framework for the Hyperloop line, there are four critical organizations that will play an outsized role in setting the standards and bounds of this policy framework. They are the two developmental authorities (the M.M.R.D.A. and the P.M.R.D.A.), the Government of Maharashtra (specifically, the Chief Minister's Office), and a

special entity that may include officials from the Ministry of Road Transport and Highways as well as the Ministry of Railways, with oversight from the NITI Aayog.

As has been common in policymaking throughout the country, the existence of multiple agencies with overlapping jurisdictions (such as the M.M.R.D.A. and the B.M.C., for instance) often results in implementation paralysis. In the case of the Mumbai-Pune Hyperloop line, the effects of the entire route are also multifaceted and span domains that would intersect with many more agencies than any other infrastructure project of similar scale. Moreover, certain effects, such as a rise in real estate demand or an increase in congestion, may only occur in one of the two cities at any given point in time. For instance, with a Hyperloop node at Dadar, a greater number of vehicles may converge in that particular area, resulting in ever-greater levels of congestion. However, Dadar may be able to support a higher number of commuters that may be Pune-bound. This higher figure may be beneficial to Pune's real estate demand. It is possible that such a higher demand differential may compel Pune-based agencies' priorities to shift the node from anywhere else in Mumbai to Dadar, an option that may come at the expense of Mumbai's congestion levels. To avoid numerous such situations (many of which may be much more complex than this simplistic illustration), we need to seriously consider the formation of a single policymaking body that will work with the M.M.R.D.A. and the P.M.R.D.A. and recommend optimal planning scenarios that will develop the Mumbai-Pune megalopolis without unconditional preferences towards any one city. The mechanics of forming such a Special Planning Authority can be worked out more deeply with governmental research and inputs. But the claim that a single policymaking body will be much more effective is, intuitively at least, well grounded in the past record of Mumbai's developmental experience.

Section 6: Conclusion

We must understand that Mumbai and Pune are radically different cities with very unique geophysical contexts. As such, Mumbai will benefit from a Hyperloop line in ways distinct from Pune. For instance, the vehicular density in Mumbai, the highest in the country, continues to increase with an influx of cab aggregator firms and new vehicle purchases. With a shift to non-road transit modes and an eventual shift of base to Pune, many commuters can add to occupancy levels in the upcoming Metro networks and reduce dependencies on road-based transit. The P.M.C. or the P.M.R.D.A. may be indifferent to such developments, instead choosing to prioritize some other Pune-specific benefit that may not factor in the Mumbai case. Likewise, the M.C.G.M. or the M.M.R.D.A. may be indifferent to the local effects of Pune's station location, as their respective jurisdictions are limited to Mumbai. In the end, critical decisions such as the fare structure will perhaps allow a greater proportion of Mumbai's population that does not live in a slum to avail intercity transit at similar costs as public transport agencies.

In summary, for Mumbai and Pune to successfully merge their city centres into a novel geographical unit, the policymaking behaviour of local and regional governments, as well as the state government, will need to evolve as well. The first step towards effecting such a change is to formulate an autonomous, powerful decision-making entity that can effectively supervise this route and its allied developmental effects, in a way that benefits the entire region. This entity can then utilize available measures to tinker with the four features of the Hyperloop route. This may not be easy. The results may also not be straightforward. A significant number of statistical forecasts, pilot tests, and policy experimentation, will be the foundation on which such a new geo-economic phenomenon can be mapped and measured. The complexity of this project, however, is but a small cost to be set against the potential unveiling of a new mode of transport after a century of lacklustre innovation. With a radical new technology, there will always be hitherto unseen policymaking challenges. With a broader geographic lens, there are bound to be legislative and socioeconomic complexities. However, if implemented with a more regional set of principles and a transformational purpose, the Mumbai-Pune Hyperloop line may unlock a new level of socioeconomic and geo-economic potential for the entire region in western Maharashtra.