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Quantifying intermodal mobility: A parsimonious model and simulation

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What is intermodal mobility, why does it matter?

Merriam-Webster defines intermodal transportation as “being or involving transportation by more than one form of carrier during a single journey” (Merriam-Webster 2020-04-11). This definition has been refined to distinguish between modes (air, land, etc.) and means (vehicles) of transportation: Intermodal transportation is “the shipment of cargo and the movement of people involving more than one mode of transportation during a single, seamless journey” (Jones et al. 2000). “Different modes of transport are air, water and land [... which includes] rails, road and off-road transport. [...] Each mode has its own infrastructure, vehicles (also means of transport) and operations” (Wikipedia 2020-04-11).

Intermodal mobility is widely seen as one solution to the many problems with traffic in urban settings. Today, these problems include ever more vehicles and trips, longer commute times, air pollution, noise, and accidents. The outlook is bleak: China has become known for its severe air pollution and ever-increasing traffic jams (NASA Earth Observatory 2020, link). In Europe, too, commute times seem to be getting longer every year (Eurostat 2019, link) and have lengthened by approximately 10 percent over the past decade (Trades Union Congress 2019, link). In Germany, Berlin is one of the most congested larger cities (only Hamburg is worse) with a 2019 congestion level of 32 percent, meaning that a 30-minute trip will take 32 percent more time than it would during Berlin's baseline uncongested conditions (TomTom Traffic Index Ranking 2019, link).

One solution: Restrict traffic. Early on the Chinese government resorted to restricting individual motorized mobility. In China's capital Beijing, for example, two-stroke mopeds were banned in 2000 (Viard & Fu 2015), which instantly created the world's largest fleet of electric bikes and scooters. The city then banned vehicles from the road one day per week … which was followed by the introduction of a vehicle license plate lottery (China Daily 2019, link). In 2019, many cities in Germany resorted to banning certain engines in inner cities and even introducing total road closures to mitigate air pollution, particularly CO_2 emissions (ZDF Heute 2019, link).

The German mobility dilemma

This situation presents a major dilemma for Germany, because its economy is highly dependent on making and selling motor vehicles. Germany is home to the world's largest automaker, Volkswagen, based on units sold globally (in 2019) and the three car manufacturers that dominate the world's premium segment, Daimler's Mercedes-Benz, BMW, and VW's Audi. The premium segment is particularly important, because it is the most lucrative, and therefore, can provide the funds for innovation and high-paying jobs in Germany. In 2018, more than 800,000 German jobs depended on automotive, which brought in more than 400 billion euros in revenue, more than two-thirds of which came from abroad (New York Times 2019, link).

A top-down solution: National Platform Future of Mobility (NPM)

In order to solve the dilemma, to find a way forward for Germany, the Federal Government convened the National Platform Future of Mobility. Launched by the Federal Minister of Transport, Andreas Scheuer, in September 2018, NPM is headed by the former CEO of SAP, Prof. Dr. Kagermann. Its goal is "to develop multi-modal and intermodal paths for [... an] environmentally friendly transport system. The aim is to make [...] transport an integral part of an efficient, high-quality, flexible [...] and affordable mobility system and to contribute to ensuring a competitive mobility economy and to promoting [...] employment" (NPM 2020, link).

Bottom-up solution: Experiments

Another route to seeking solutions to the mobility dilemma is a very traditional one: pilots, trials … or, as a scientist would put it, experiments. They can come in many flavors: They can be conducted in real life, with actual vehicles and drivers in everyday situations. Or they can be carried out in much more controlled environments or synthetically, using synthetically generated parameter and measurement errors. Real-life experiments are a gold standard but very expensive. They require test fleets, user samples, sensor instrumentation, performance monitoring … and insurance and legal arrangements for use of test vehicles on public roads, compliance with safety regulation, as well as data security and privacy rules, such as the General Data Protection Regulation in Europe (GDPR 2016/679, European Commission 2018, link) and the California Consumer Privacy Act of 2018 (CCPA), which became effective in 2020 (Cal. Civ. Code §§ 1798.100-1798.199). Despite the effort involved, some automakers, including BMW, Toyota, and the Renault-Nissan-Mitsubishi Alliance, have conducted such pilots. For example, the Renault-Nissan-Mitsubishi Alliance operated real-life MaaS services using actual vehicles, like the all-electric Nissan Leaf and Renault Twizy in Japan and the United States (link), in order to acquire data of the highest quality and information content possible for best descriptive and predictive analytics.

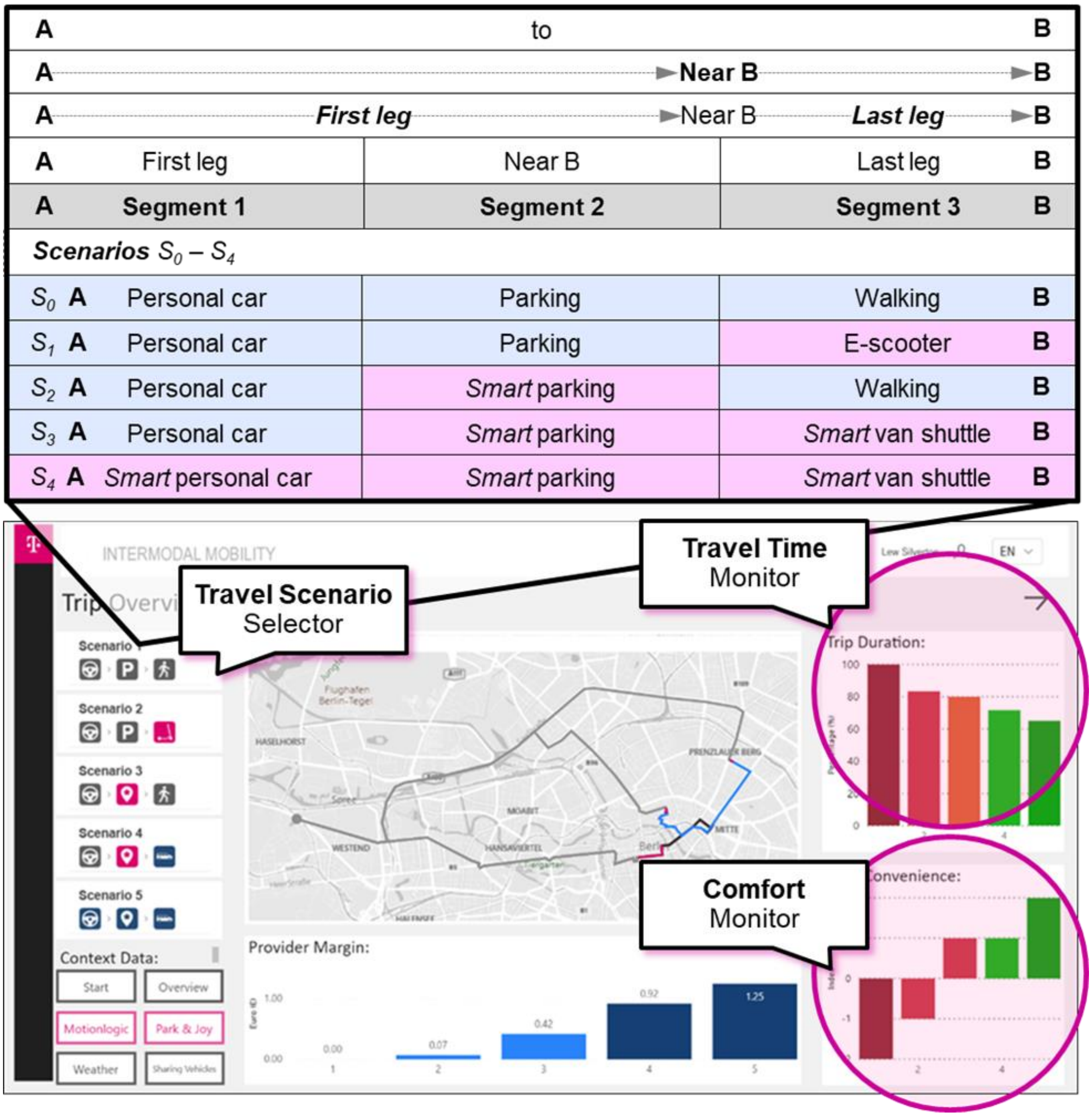

Figure 1: A parsimonious model of intermodal mobility and control panel implementation

Simulation

Simulation is a well-accepted scientific tool. It has benefited from Nobel-prize winning groundwork in economics by Simon and Smith. Simon has been credited with creating the disciplines of behavioral economics and the cognitive sciences. He understood simulation as “a technique for understanding and predicting the behavior of systems” (1996, p. 13). Smith established the tradition of laboratory experiments as a tool in empirical economic analysis (Smith 1962; overview in Kagel and Roth 1995): He "initiated the use of the laboratory as a ‘wind tunnel’ [a laboratory setup used to test prototypes for aircraft] in order to study the performance of proposed institutional mechanisms for deregulation, privatization, and the provision of public goods" (The Royal Swedish Academy of Sciences 2002, 9). Today, simulations typically run on computers, like a video game. A synthetic “real-life” experiment could be imagined along the lines of “The Matrix,” an iconic 1999 Hollywood movie in which humans are unknowingly kept inside a simulated reality (link).

For urban mobility and traffic experiments numerous universities and research institutions as well as consultancies have developed simulators. Examples in Germany include: Eclipse Sumo, Simulation of Urban Mobility by DLR, the German Aerospace Center [Deutsches Zentrum für Luft- und Raumfahrt], which is free and open source (DLR 2020, link; Krajzewicz et al. 2012), also VMC by the Fraunhofer Institute for Industrial Mathematics (Fraunhofer ITWM 2020, link). There are also commercial offers from companies, such as PTV Vissim (PTV Group 2002, link).

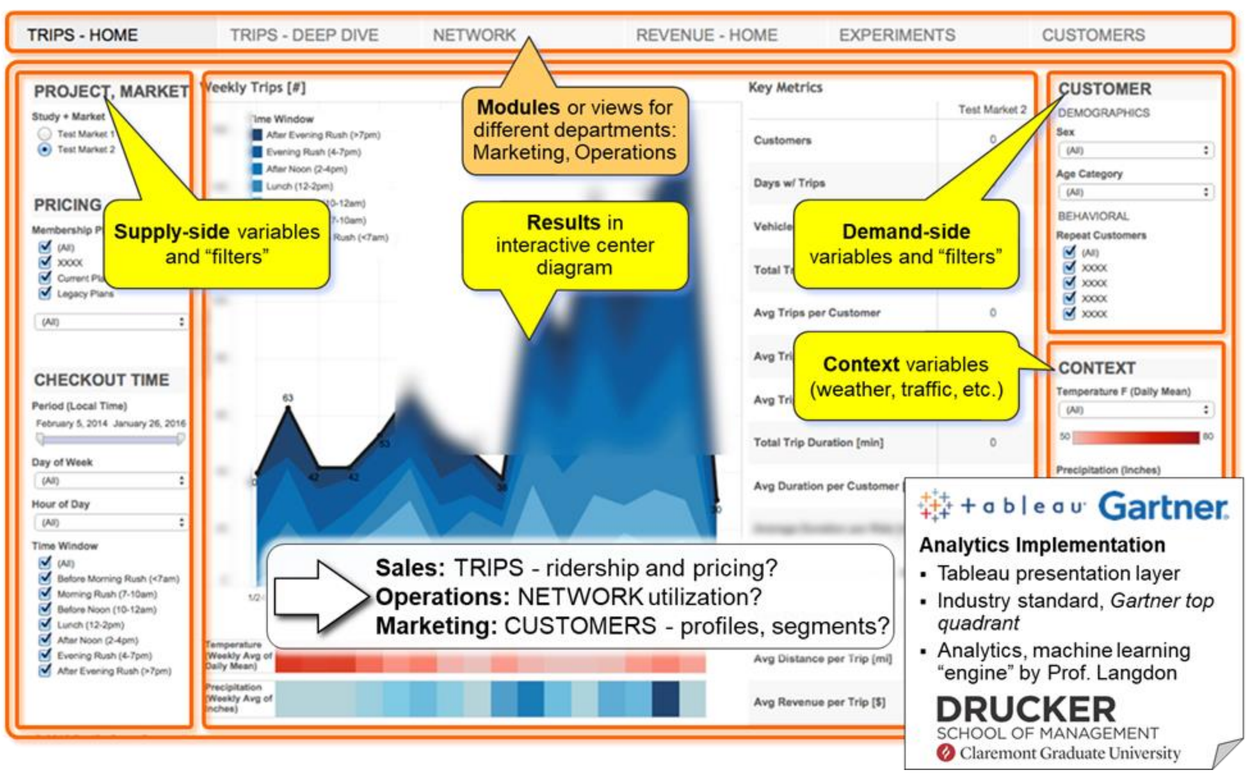

Figure 2: Mobility-as-a-Service dashboard powered by AI (Schlueter Langdon 2017)

The key to quick success with computational simulation is maximizing instrument validation while reducing complexity (e.g., Schlueter Langdon 2014, 2005): KISS – keep it simple stupid – the fewer variables, the better; the fewer interactions, the better. Some interactions, such as the feedback from the system as a whole to its (individual) parts creates non-linearities, which cannot be solved analytically and require more elaborate solutions, such as agent-based models (see Holland 1995 for a concise treatment how agent-based modeling aids the decomposition and study of complexity).

Experimental strategy

Figure 1 depicts a parsimonious model of intermodal mobility. It has evolved from (a) a research tradition of agent-based computational simulation (e.g., Schlueter Langdon & Sikora 2006, Sikora & Shaw 1998) and (b) insights from descriptive analytics and first root-cause analyses of data collected from around the world from different shared and electrified urban Mobility-as-a-Service (MaaS) operations and pilots. Figure 2 shows a screenshot of a prototype of the dashboard of a decision support system (DSS) for MaaS offerings. The dashboard is divided into five sections: a large center monitor for data visualization and four surrounding panels with controls and filters to select the data to be visualized. There are panels for:

1) Seller variables on the left (location, pricing, etc.)
2) Buyer variables at the top right (gender, age, etc.)
3) Context variables at the bottom right (temperature, precipitation, etc.)
4) Different MaaS departments at the top (Trips – Home/Sales, Network/Operations, etc.).

For example, a VP of Sales would click on “Trips – Home,” then select a market like ‘San Francisco’ and a pricing tier: Are weekends busier than weekdays … because of discounts? The center diagram would immediately display the number of trips for this selection. This result could then be filtered further by buyer demographics, such as age: Are students using the service … or tourists?

Figure 3: The three Tier founders and a “test driver” at Telekom Hubraum in Berlin

The key to the intermodal mobility model depicted in Figure 1 is the decomposition of an A-to-B journey. Specifically, the recognition of “near B” as an important segment that splits an A-to-B journey into the three segments of (1) first leg originating in A, (2) a “near B” element and (3) a last leg terminating in B. If there were 3 options for each segment and neither sequence (combinations, no permutations) nor repetition would matter, then this simple model would already result in 10 possible scenarios (k-combination with repetition: $((n + k - 1)\ over\ k)$). Based on insights from MaaS analytics (see Figure 2) not all options are repeatable, and sequence can matter, so for now our scenarios can be reduced to a set of five: S_0-S_4. Of these five, the first scenario is a default and serves as our baseline. It is our critical starting observation and data used for comparison and control: Someone drives from A in their car to near B, parks the car, and walks to destination B. A could be a driver's garage and B could be their office, a restaurant, or a shopping mall. This is a very common, and therefore, most useful baseline scenario: Nobody can drive all the way to B … through the front door, the reception area, up the stairs into the office on the 3rd floor. Cars need to be parked near B.

Four intermodal scenarios

The remaining scenarios S_1-S_4 have been carefully designed to allow for experiments with innovation in urban mobility. Sticking with our KISS philosophy, we continue with a simple experimental strategy, resorting to the ceteris paribus strategy from economics. Ceteris paribus is a Latin phrase meaning "other things being equal or held constant." It describes an experimental strategy that changes only one variable at a time to isolate multiple independent variables. This strategy has proven very effective in determining effects and causation. The changes themselves have been chosen to reflect innovation in urban mobility, such as the emergence of e-scooters and the launch of parking apps for consumers. Based on our causal isolation strategy and urban mobility options, the following four S_1-S_4 will be considered:

- S_1: Recognizes the emergence of last-mile shared service innovation with various two-wheeled vehicles, such as bicycles, mopeds, and scooters. Particularly e-scooters are a very recent innovation in German cities. In 2019 German lawmakers voted to allow e-scooters to take to the streets and triggered the launch of established U.S. operators like Bird and Lime as well as home-grown companies such as Berlin startup Tier. Tier (link) was founded by Lawrence Leuschner, Dr. Julian Blessin, and Matthias Laug, and launched in Telekom's Hubraum incubator in Berlin in 2018 (Crunchbase 2020, link). Figure 3 depicts the Tier founders at Hubraum and this author "test driving" the Tier service. E-scooters have been welcomed because they "can be an ideal complement to bus and train for the last few kilometers to the destination. This makes public transport more attractive and can reduce car journeys," (Achim Berg, President of Bitkom, the country's largest digital association, link, 2019)
- S_2: Acknowledges innovative parking solutions, such as Telekom's Park and Joy (P&J; link). Launched in 2018 by Deutsche Telekom, P&J allows consumers to find, navigate to, and book and pay for a parking spot using their smartphone. It shows free parking in public spaces and private areas.
- S_3: Considers the fact that consumers value convenience with transportation (e.g., Jonuschat et al. 2015, Crosby & Schlueter Langdon 2014), and therefore, may be willing to pay for the linking of the last two segments into a single solution relieving them of the effort of self-coordination.

- S_4: Takes service orchestration to the extreme, completely reversing the baseline scenario. In the baseline scenario S_0 the user must coordinate each linkage between segments. It is self-service from start to finish. In S_4 a truly end-to-end or "seamless" intermodal mobility offer is provided. It recognizes that an app could capture key data for B (geographic coordinates: latitude, longitude) prior to the user leaving A. It could also collect preferences to compile entire user profiles, including relative importance of duration and comfort, and price elasticities (e.g., Crosby & Schlueter Langdon 2017).

First results: Impact and limitations

Figure 4 reveals the first quantitative results of our simulation. Despite having evolved from a rather simple model, it reveals some surprising outcomes. Overall, the results clearly demonstrate that there is value in intermodal mobility, and the value is significant. Trip duration and comfort can both be improved. So, there is value for the user.

Our primary dependent variable or the first performance parameter that the simulation is optimizing is travel time, the time it takes to get from A to B. Time is a primary factor only – not the only factor – because consumer or human decision-making is complicated as anybody with a family, a partner, or children can readily attest to. Any model – not just a simple one – has its limitations here.

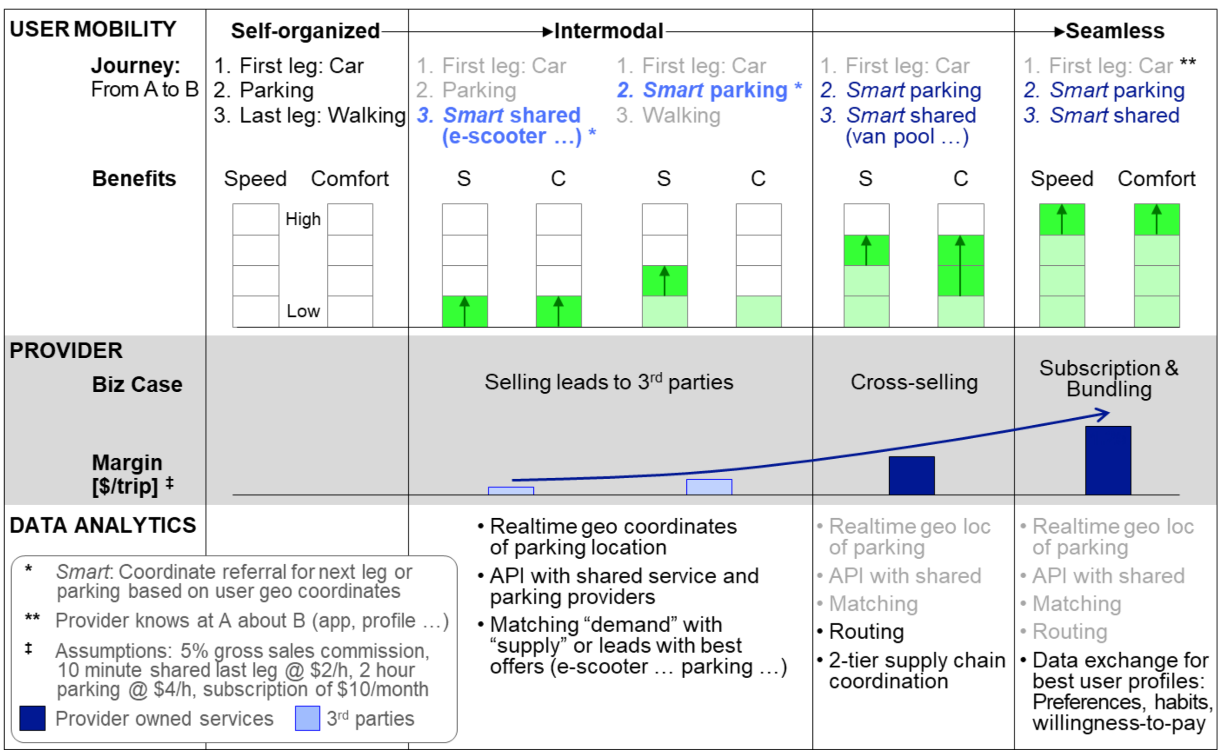

Figure 4: First results of intermodal mobility simulation (Schlueter Langdon 2019)

Our secondary performance parameter is comfort. Humans are creatures of habit and hardwired for laziness because evolution favors conserving energy. Not you, of course, you are not lazy, you are the exception, and therefore, the results do not apply to you, only to the rest, the vast majority. And what about cost? Wouldn't it matter, wouldn't it be more important than travel time? We love 50 percent off, "buy one, get one free" offers, a clearance sale (German *"Ausverkauf"*), discount airlines, etc. We certainly do. And economic theory conjures with conventional wisdom that the higher the price, the lower the demand. Yet, every 6 years we buy a car for 35,000 dollars (approx. U.S. average in 2019), which will have lost 85 percent of its value at the end (e.g., Kelley Blue book), and use it on 300 days a year but only for 90 minutes each day, which therefore, will cost us approx. 20 cent per minute of use. If you were a typical German who "takes on average 60 minutes per day to get to work" (Deutsche Bank 2019) you would pay $12 – without gas … without oil change … without repairs. A round trip using public transportation would at least be 50 percent off or a "buy one, get one free" deal. So, consumers are not entirely rational buyers. Not you, of course, you are neither susceptible to comfort nor social status. And you had already been excluded from this model earlier, because it is focused on the average guy, the mass market. For the average guy, our simulation indicates that there is value, because comfort can be improved.

Whether this value can be captured profitably or "monetized" is a different question. This would require a different model with other variables relating to (i) the structure of the market and (ii) the conduct of its participants, because actual firm profit depends on market structure and competitive strategy (see Structure-Conduct-Performance paradigm in economics, Chamberlain 1933, Bain 1968 and 1956): In a perfectly competitive or atomistic market, price equals marginal cost and firms earn an economic profit of zero. At the opposite end of market structure, in a seller monopoly, the price is set above marginal cost and the seller earns a positive economic profit (Tirole 1988). However, market structure and pricing may not be the only important variables, as real-world settings can involve many more variables. Porter has clustered possible factors into a set of "5 forces," which are largely mutually exclusive and collectively exhaustive (Porter 1979). He also provides a detailed catalog of candidates for each force (Porter 1980). In any case our simulation shows that there is value for average users in the first place. How to "monetize" it or how to divide it up among competing sellers is another question … and requires another model :)

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