Surge Pricing and its Spatial Supply Response

In pricing and revenue management the primary focus has been to investigate tactical pricing decisions given the dynamic evolution of inventories, with prototypical examples coming from the airline, hospitality and retail industries. With the emergence and multiplication of two-sided marketplaces, a new question has emerged: how to price when capacity/supply units are strategic and can decide when and where to participate. This is particularly relevant for ride-hailing platforms such as Uber and Lyft. In these platforms, drivers are independent contractors who have the ability to relocate strategically within their cities to boost their own profits. On the one hand, this leads to a more flexible supply. On the other hand, one is not able to simply reallocate supply across locations when needed, but rather a platform needs to ensure that incentives are in place for a “good” reallocation to take place. Consider the spatial pricing problem within a city with different demand and supply conditions faced by a platform. The platform may want to increase prices at locations with high demand and low supply. Such an increase would have two effects. The first effect pushes riders who are not willing to pay a higher price away from the system. The second effect is global in nature, as drivers throughout the city may find the locations with high prices more attractive than the ones where they are currently located and may decide to relocate. In turn, this may create a deficit of drivers at some locations. Hence, prices set in one region of a city impact demand and supply at this region, but also potentially impact supply in other regions. This brings to the foreground the question of how to price in space when supply units are strategic.

The central focus of this paper is to understand how to optimally set prices across locations in a city, and what the impact of those prices is on the strategic repositioning of drivers. We consider a revenue-maximizing platform that sets prices to match price-sensitive riders (demand) to strategic drivers (supply) who receive a fixed commission. In making their decisions, drivers take into account prices, supply levels across the city, and transportation costs. More formally, we consider a measure-theoretical Stackelberg game with three groups of players: a platform, drivers and potential customers. Supply and demand are
non-atomic agents, who are initially arbitrarily positioned. Players interact with each other in a linear city. Every location can admit different levels of supply and demand. The platform first selects prices for the different locations. Once prices are set, the set of customers willing to pay such levels is determined. Then, drivers move in equilibrium in a simultaneous move game, choosing where to reposition based on prices, supply levels and driving costs. In fact, besides prices and transportation costs, supply levels across the city are a key element for drivers to optimize their repositioning. If too many other drivers are at a given location, a driver relocating there will be less likely to be matched to a rider, negatively affecting that driver’s utility. The platform’s optimization problem consists of finding optimal prices for all locations given that drivers move in equilibrium.

**Main contributions.** Our first set of contributions is methodological. We propose a general measure-theoretical framework that can be used to study spatial interactions in both discrete and continuous settings. In this general framework, we develop structural properties of the equilibrium utilities of drivers and prove that the city admits a form of spatial decomposition. Furthermore, we establish that the equilibrium utility of drivers admits a fundamental upper bound driven by the local driver congestion level. In turn, we leverage these properties to provide a crisp structural characterization of an optimal pricing solution and its corresponding supply response. This characterization provides a one-to-one mapping between the equilibrium utilities and the optimal prices and equilibrium flows.

In our second set of contributions, we shed light on the scope of prices as an incentive mechanism for drivers and provide insights into the structure of an optimal policy. To that end, we study a special family of cases in which a central location in the city, the origin, experiences a shock of demand. We first characterize an optimal *local price response* policy, a pricing policy that only optimizes the price at the demand shock location. Such a policy increases prices at the demand shock location leading to an attraction region around the shock in which drivers move toward the origin.

The optimal policy admits a much richer structure: it induces movement toward the demand shock but potentially also *away* from the demand shock. The platform may create *damaged regions* through both prices and congestion to steer the flow of drivers toward more profitable regions. Compared to the *local price response* policy, the optimal solution or *global price response* incentivizes more drivers to travel toward the demand shock.
The optimal pricing policy splits the city into six regions around the origin (Figure 1). The mass of customers needing rides at the location of the shock is serviced by three subregions around it: the origin, the inner center and the outer center. The origin is the most profitable location and so the platform surges its price, encouraging the movement of a mass of drivers to meet its high levels of demand. These drivers come from both the inner and outer center. In the former, locations are positively affected by the shock, and some drivers choose to stay in them while others travel toward the origin. In the latter, drivers are too far from the demand shock and so the platform has to deliberately damage this region through prices (e.g., by using excessively high prices) to create incentives for drivers to relocate toward the origin. However, drivers in this region have an option: instead of driving toward the demand shock at the origin, they could drive away from it. This gives rise to the next region, the inner periphery. Consider the marginal driver, i.e., the furthest driver willing to travel to the origin. To incentivize the marginal driver to move to the origin, the platform is obligated to also damage conditions in the inner periphery. The optimal solution creates two subregions within the inner periphery. In the first, conditions are degraded through prices that make it unattractive for drivers. Drivers in this region leave toward the second region. That is, they drive in the direction opposite to the demand shock. The action of the platform in the second region is more subtle. The platform does not need to play with prices, the mere fact that drivers from the first region run away to this area creates congestion, and this is sufficient degradation to make the region unattractive for the marginal driver. The final region is the outer periphery, which is too far from the origin to be affected by the shock.

We complement our analysis with a set of numerics that highlights that the optimal policy can generate significantly more revenues than a local price response. Thus, anticipating the global supply response and taking advantage of the full flexibility of spatial pricing plays a key role in revenue optimization.