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Service provider strategies in telecommunications markets: analytical and simulation analysis

AMITOJ SINGH CHOUHAN, V SRIDHAR and SHRISHA RAO*

International Institute of Information Technology, Bangalore, India
e-mail: hiamtj@gmail.com; vsridhar@iiitb.ac.in; shrao@ieee.org

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Abstract. The telecommunications industry has evolved from voice-centric to provisioning of broadband data services. As witnessed in countries around the world, the industry has an oligopoly market structure with a few operators providing services. The services offered by the operators differ in both price and quality of service. On the other hand, consumers differ in their preferences over price and quality with some displaying sensitivity towards price and others towards quality. In this paper, we provide the standard microeconomic framework of supply and demand for telecom services and derive equilibria under varying supply and demand conditions. In particular, we analyse the strategies of new entrants vis-à-vis incumbents in offering service plans over varying price and quality dimensions. We also analyse the equilibria for varying elasticities of demand of consumers. We then validate the analytical results by simulation using an agent-based model with operator and consumer agents. Our results show that new entrants ought to target relatively elastic consumers as their market entry strategy, by offering a combination of low price, high-quality service plans to gain market share. On the other hand, incumbent operators ought to continue to target relatively inelastic consumers who have loyalty towards them due to larger network effects and associated higher switching costs. Our simulation results also confirm the analytical results. Telecom regulators can use the study results in assessing and regulating (i) market power dynamics of incumbents and new entrants, (ii) tariff plans offered by operators for possible predatory pricing and (iii) quality of service to meet threshold minimum quality of standard levels.

Keywords. Telecommunications; broadband; economics; market strategies; oligopoly market; agent-based modelling.

1. Introduction

The telecommunications industry typically exhibits an oligopoly market structure with a few operators providing similar services [1]. The services offered by telecom operators are not completely identical, being differentiated based on price, quality, availability or the targeted group of consumers [2]. The traditional microeconomic principles of supply and demand hold good in telecommunications services as well. The intersection of supply and demand curves dictates the equilibrium conditions of price and quantity of services produced and consumed in such a telecom market [3]. Apart from the typical relationship between price and quantity that determines the equilibrium conditions, quality of service (QoS) is also becoming very important in telecommunications services to manage consumer relationships as pointed out in a recent study [4]. One of the biggest challenges faced when dealing with QoS over the Internet is maintaining quality given an unregulated, connectionless network that is designed, deployed, operated, managed and commercialized without any QoS perspectives [5]. The QoS and experience in data services is primarily dependent upon the network speeds offered by service providers [6]. There are typically two sets of service providers: (i) incumbents who have been providing services for a long time (e.g. AT&T in the U.S., and Bharti Airtel in India); (ii) new entrants who are late entrants in the telecom markets (e.g. the erstwhile Clearwire Corp. in the U.S., and Reliance Jio in India). In such oligopoly-focused markets, new entrants challenge incumbent firms by offering services at a suitable combination of price and quality as has been witnessed recently in many telecom markets [7]. However, incumbents enjoy market power and consumer loyalty due to the presence of network effects [1]. This dynamics of competition between incumbents and new entrants is analysed in this paper using analytical models, and is simulated based on agent-based modelling (ABM).

On the demand side, though consumers are price sensitive in general, they simultaneously consider the quality of the products/services before making purchasing decisions, as noted in a recent study of telecom consumers in

*For correspondence
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Bangladesh [8]. We model the purchasing decisions of both price- and quality-sensitive consumers of the telecom market and the resultant equilibrium conditions.

The rest of the paper is structured as follows. Section 2 describes the characteristics of the telecommunications market. A supply–demand model of telecommunications services using microeconomic principles is laid out in section 3. The ABM model and results of the simulation under varying supply and demand conditions are presented in section 4. Limitations of the study and future research directions are presented in section 5. The concluding remarks are provided in sections 6.

2. Characteristics of telecommunications markets

2.1 *Network effects*

Network effects are characteristics of specific goods and services such that they become more valuable to each user as the overall number of users of the same increases. Thus, for users considering the adoption of such technologies, the potential return they can realize depends on the number of existing users. This relationship is very strong for various telephone and computer networks. Once there is a critical mass of adopters for such innovations and technologies, network effects can enable further growth [9]. The applicability of network effects is evident in telecom markets [10]. Network effects have been used extensively in modelling operator and consumer behaviour in telecom, especially for voice services [11, 12]. Though the direct network effects arising from the accumulation of subscribers may not be present in data and broadband services, there exist considerable *cross-side* network effects between the application providers and consumers as indicated in prior research [13]. The cross-side network effects enable growth of one side (i.e. applications) to have an effect on the other side (i.e. growth of consumers who use the applications) and vice versa. It has been noted [14] that more research is needed to include network effects in the deployment and penetration of broadband services.

The network effect and economies of scale are closely related to each other. The essential economic characteristics of many network industries such as telecom include very high fixed cost, very low marginal cost, inelastic demand, lags in supply, network effects and technological uncertainties—all of which encourage firms to seek market share to gain economies of scale on the supply side and network effects on the demand side [1]. Increasing the scale of operations of the service provider reduces the marginal cost of production, thereby offering services at competitive prices, which in turn helps in retaining existing consumers and attracting a new set of consumers [15]. Network effects promote consumer lock-in and increase switching costs, thereby enabling service providers to retain their consumer base despite competition effects [16].

Traditionally, economists have viewed the world from two perspectives: (i) the supply side that defines the production of goods and services and (ii) the demand side that defines how the produced goods and services are consumed in the market [3]. In the following sections we describe the specific supply and demand side characteristics as applicable to the telecom markets.

2.2 *Supply side of telecom*

Telecommunications, notably mobile services, is regulated worldwide, due to the assignment of scarce radio spectrum for its operations [17]. Moreover, there are substantial entry barriers in the mobile services market due to (i) the large network infrastructure investments needed to create such services and (ii) the price to be paid also for radio spectrum for them [18]. Hence, to enable telecommunications operators to recover the considerable sunk cost, licenses for telecommunications services are usually given for longer terms of 10–20 years. This further restricts competition. Any new entrant in the market has to compete with the incumbents on both price and QoS to garner market share.

Several parameters define the price and quality of telecom services provided by operators: the amount of radio spectrum the operator has for providing access services, the backhaul capacity of the network and the technology such as 4G/5G used to determine the QoS offered. The QoS also varies between different types of services. For voice, which is synchronous, QoS is determined by parameters such as call connection time, call blockage probability and voice quality. However, for Internet data services, download speed is the primary QoS parameter for synchronous data services, while the reliability of the connection is the essential one for asynchronous services such as electronic mail.

The capital and operational costs incurred by an operator, such as price paid for radio spectrum, the infrastructure costs, including the cost of fibre and the cost of tower infrastructure and that of the Base Transceiver Stations (BTS), determine the capital and operating costs, and hence the price at which services are offered by operators to consumers. Based on both the fixed and operational costs, the operators offer different types of pricing plans. In general, such plans vary from fixed monthly charges for a specified download volume to a pure variable pricing plan that charges for the data volume consumed [9]. However, recently, operators have started offering *smart data pricing* based on various parameters such as type of applications used, location, time of day, etc. [19].

The incumbents' strategic choices on price and quality of their service offerings are often dictated by their expected profits and the size of their captive subscriber base recorded due to their incumbency [20]. However, new entrants lack network effects due to their smaller subscriber bases and hence have to strategically position their service offerings using a judicious combination of price and quality [21].

Supply-side elasticity is the percentage change in the quantity supplied (e.g., the number of voice calls and data provided) in response to a 1 percent change in the price of the goods (all else remaining equal). It is a measure of how responsive supply is to price. In general, incumbents have a relatively inelastic supply curve as the capacities of their networks limit how much they can change in response to changes in price. On the other hand new entrants have relatively unused and under-used capacities, and are more responsive, and hence are more elastic in their supply of capacities with changes in price.

We characterize the supply based on two types of suppliers as described by Fransman [22]:

1. Incumbents, who already have an existing consumer base and network capacity, and strategize to expand consumer base with additional network capacity.
2. Entrants, who are new to the telecommunications market and do not have any existing consumer base or network capacity and strategize to acquire a consumer base with newly set-up network capacity.

2.3 *Demand side of telecom*

As discussed earlier, apart from price, QoS is also important in consumers' decisions regarding telecom services. Download speeds, upload speeds, data offered, performance during peak hours and latency are some of the QoS parameters taken into consideration by consumers. Further, the price elasticity of demand is a key parameter that determines consumer welfare. A recent empirical study of the mobile services market in Bahrain finds that the market elasticity of demand for mobile services is low (equivalently, the market is inelastic), reflecting the fact that consumers do not have good substitutes [23].

Unlike voice, where the consumption is loosely homogeneous among all consumers, consumption patterns tend to vary widely among consumers of data services, ranging from bandwidth-intensive to light-use consumers [24]. In tune with the demand, operators also have started providing data plans that offer a variety of pricing plans to the consumers depending on download data speed and data consumption patterns [24].

We characterize the demand originating from the following two types of consumers as described by Tellis and Wernerfelt [25].

1. Quality-sensitive consumers: these consumers have a certain minimum expectation of QoS = K_{min}, and subscribe to the lowest-priced option of the service that satisfies their minimum quality constraint; these consumers will not subscribe to a pricing plan if their quality constraint is not met.
2. Price-sensitive consumers: they have a certain maximum limit on the price = P_{max} that they want to spend, and they subscribe to the best-quality plan available that satisfies their price constraint. These consumers will not subscribe to any plan if their price constraint is not met.

Taking into account these essential characteristics of the telecommunications data market, such as market structure, pricing strategy and QoS provisioning, we build a model of supply–demand and determine equilibria under varying conditions. We build models for a duopoly market similar to that presented by Lambertini and Orsini [26], consisting of an incumbent operator and a new entrant.

The model variables are indicated in table 1.

To incorporate both price and QoS into the supply and demand equations, we include the ratio of price to QoS as R. The value of R is directly proportional to the price, and inversely proportional to quantity.

Table 2 summarizes the equations used in our different models.

3. Analytical results and discussion

In this section, we present analytical results on the equilibrium conditions of price and quantity. Specifically we provide solutions for varying supply and demand elasticities as noted in previous literature [27, 28]. We also provide

Table 1. Model variables.

Variable description	Variable symbol
Price of services	P
Quantity of services offered	Q
Quality of services offered	K
Ratio of price to quality	$R = \frac{P}{K}$
Price/quality services offered by the incumbent	R_I
Price/quality of services offered by the new entrant	R_N
Quantity of services offered by the incumbent	Q_I
Quantity of services offered by the new entrant	Q_N
Equilibrium quantity	Q^*
Equilibrium price/quantity ratio	R^*
Slope of the demand curve of telecommunications services	$-\infty < \alpha = \frac{\partial R}{\partial Q^D} \leq -1$
Slope of the supply curve of telecommunications services	$\beta = \frac{\partial R}{\partial Q^S} \geq 1$
Demand elasticity	$\epsilon^D = \frac{1}{\alpha}$
Supply elasticity	$\epsilon^S = \frac{1}{\beta}$
Slope/elasticity of the supply curve of the incumbent service provider	β_I/ϵ_I
Slope/elasticity of the supply curve of the new entrant	β_N/ϵ_N

Table 2. Equations used in the model.

Description	Model equations
Demand for telecom services	$R = c_1 + \alpha Q$ (1)
Supply of telecom services	$R = c_2 + \beta Q$ (2)

insights into the market equilibrium conditions for the incumbents *vis-à-vis* new entrants [29].

3.1 *Service providers: incumbent versus new entrant*

As indicated earlier, the supply elasticity of an incumbent ϵ_I is often lower than that of a new entrant ϵ_N. This is because the incumbent supplier allocates the capacity among its existing, typically large, consumer base, and is constrained. However the new entrant, having acquired radio spectrum and deployed network capacity, is typically not similarly constrained. Hence the new entrant can react with larger increases in Q either due to price decrease or increase in QoS, compared with the incumbent.

Lemma 1 *$Q_N^* > Q_I^*$ and $R_N^* < R_I^*$, where Q_N, Q_I, R_N and R_I are the Q and R values at equilibrium, respectively.*

Starting at the origin for the supply curve with intercept in (2) set to zero the equilibrium quantities and price/quality rations can be derived algebraically using (1) and (2), as follows:

$$Q_N^* = \frac{c}{\beta_N - \alpha}, \quad (3)$$

$$R_N^* = \frac{\beta_N c}{\beta_N - \alpha}. \quad (4)$$

Similarly, for the same demand curve, the equilibrium quantity and price/quality ratio supplied by the incumbent are as follows:

$$Q_I^* = \frac{c}{\beta_I - \alpha}, \quad (5)$$

$$R_I^* = \frac{\beta_I c}{\beta_I - \alpha}. \quad (6)$$

Using (3) and (5), $\beta_N < \beta_I$, we can conclude that

$$Q_N^* > Q_I^*$$

and using (4) and (6), we can conclude that

$$R_N^* < R_I^*.$$

We can also observe this graphically in figure 1, indicating that, at equilibrium, entrants can supply more Q than incumbents at lower R. This result shows that entrants can provide better quality at lower prices to compete effectively against the incumbents in the market.

Incumbents, on the other hand, should target high-paying quality-conscious consumers in order to gain additional share in the market.

3.2 *Consumers: price versus quality sensitive*

As indicated earlier, consumers can be unit elastic with $\alpha = -1$ wherein their demand is balanced in terms of price and QoS. On the other hand, relatively inelastic consumers

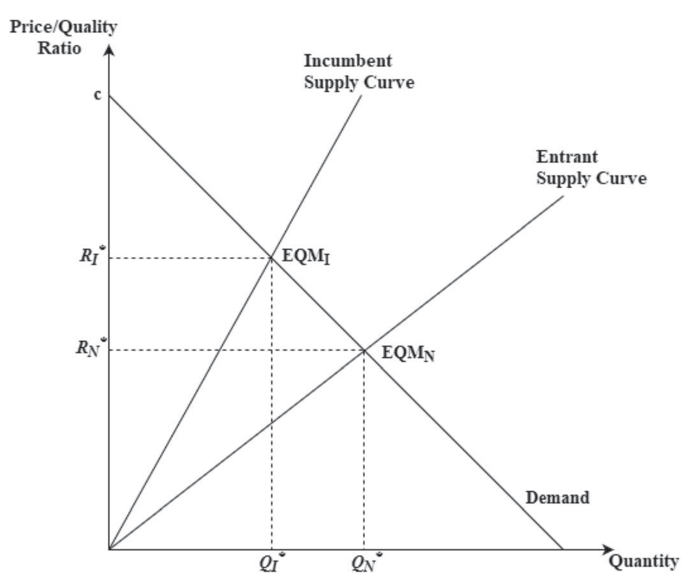

Figure 1. Equilibrium: incumbent versus new entrant.

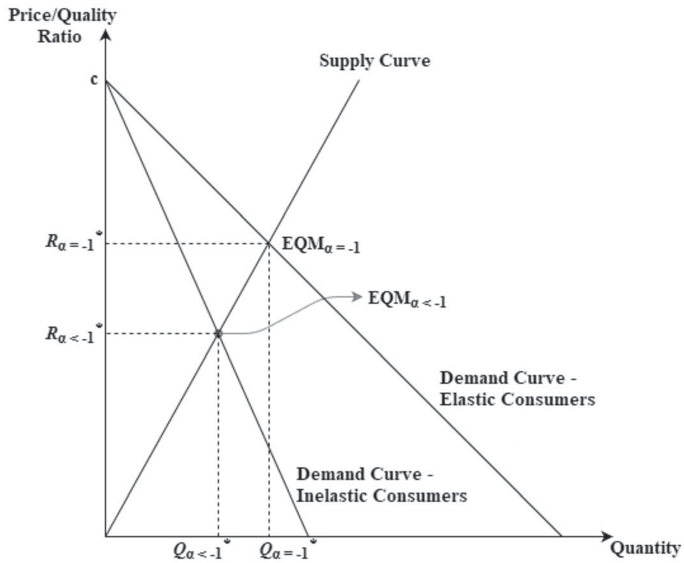

Figure 2. Equilibrium: elastic versus inelastic consumers.

with $\alpha < -1$ are comparatively less agile and are hesitant about switching service providers due to reduction in price or improvement in QoS of service offerings. While unit elastic consumers are agile and hence can be targeted by new entrants, inelastic consumers are locked-in with the incumbents. We explain this phenomenon of the consumer elasticities using the following explanation.

Lemma 2 *$Q^*_{\alpha<-1} < Q^*_{\alpha=-1}$ and $R^*_{\alpha<-1} < R^*_{\alpha=-1}$ where $Q^*_{\alpha<-1}$, $Q^*_{\alpha=-1}$, $R^*_{\alpha<-1}$ and $R^*_{\alpha=-1}$ are the quantity supplied and $\frac{P}{K}$ ratios, respectively, at corresponding elasticity of demand.*

As indicated in Lemma 1, the equilibrium quantities and price/quality ratios can be algebraically derived using (1) and (2) as follows:

$$Q^*_{\alpha<-1} = \frac{R_{\alpha<-1} - c}{\alpha},$$
$$Q^*_{\alpha=-1} = \frac{R_{\alpha=-1} - c}{\alpha}.$$

From this we can conclude that if $Q^*_{\alpha<-1} < Q^*_{\alpha=-1}$, then $R^*_{\alpha<-1} < R^*_{\alpha=-1}$ and vice versa.

These algebraic equations are illustrated in figure 2; here we can see that for a constant supply, Q^* is maximum at $\alpha = -1$ and that Q^* decreases with decrease in α. Also, R^* is maximum at $\alpha = -1$ and R^* decreases with α.

3.3 *Infinite supply*

Typically, new entrants lay down their networks with some initial capacity even before the first consumer subscribes to the service. In the initial phases of expansion a supplier is willing to increase the quantity of services supplied, even at lower prices or improved quality levels. Hence, in this phase, the supply curve is downward sloping where Q increases with a decrease in R. However, after the initial network capacity is used up, the standard upward-sloping supply curve is witnessed, wherein the operator will increase Q only with an increase in R. This results in a U-shaped supply curve. A phenomenon of this type on an inverted demand curve is illustrated by Shy [10].

As can be seen in figure 3, with the U-type supply curve, there are two equilibrium points, EQM_1 and EQM_2, where the downward sloping demand curve intersects. At EQM_1 the entrant provides services at a lower QoS and a higher price (i.e., a higher R). This strategy addresses neither price-sensitive consumers nor quality-sensitive consumers, resulting in a very low subscriber base. This produces a very unstable equilibrium as pointed out in earlier research [10]. On the other hand, at EQM_2, the entrant supplies a higher QoS at a lower price (i.e., at a lower R). This addresses both price-sensitive and quality-sensitive consumers, resulting in a larger subscriber base. This strategy is often pursued by many new entrants in the telecom sector to encourage the switching of subscribers from incumbents and to compete against the incumbents effectively.

As mentioned earlier, the equilibria have been derived only for the new entrant's initial entry conditions. As the new entrant accumulates subscriber base and associated network effects, thereafter it might increase prices or decrease QoS due to supply constraints. Recent research has pointed out that, in broadband markets, though new entrants can initially penetrate the market due to superior technologies and aggressive price and quality plans, the incumbents will finally catch up with the new entrants [30].

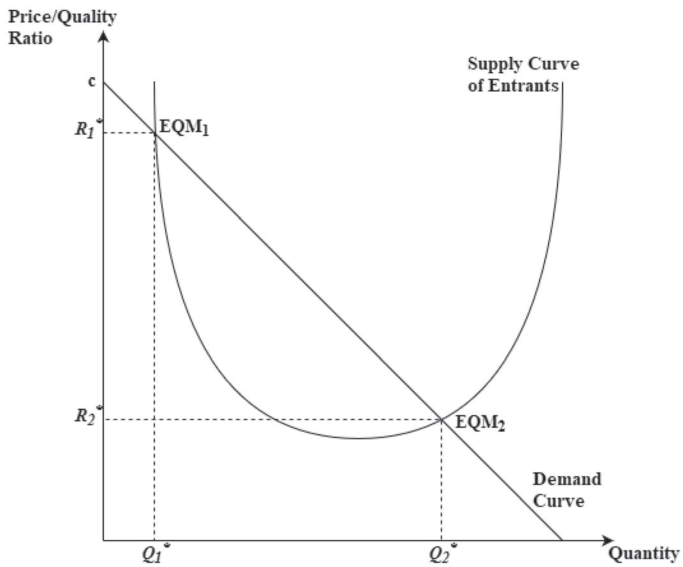

Figure 3. Supply curve with infinite capacity and the resultant equilibrium.

4. Simulation using ABM

Data: $K_i^C, P_i^C, K_j^S, P_j^S$
Result: $bestPlan$ = Best plan $j^* \in J$ for every consumer $i \in I$

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for $i \in I$ **do**
  `// quality-conscious consumer`
  if $K_i^C \geq K_{min}^C$ **then**
    for $j \in J$ **do**
      if $K_j^S \geq K_i^C$ **then**
        Assign plan $j* = \arg\min_j P_j^S$ to i
      end
    end
  end
  `// price-conscious consumer`
  if $P_i^C \leq P_{max}^C$ **then**
    for $j \in J$ **do**
      if $P_j^S \leq P_i^C$ **then**
        Assign plan $j* = \arg\max_j K_j^S$ to i
      end
    end
  end
end

Algorithm 1: Consumer and plan matching algorithm.

In this paper, we use an agent-based model to depict the different stakeholders and simulate their behaviours under varying market conditions. The ABM enables simulation of heterogeneous agents such as suppliers and consumers, the interaction effect among the agents and the system's resultant behaviour to form the patterns seen in the real world [31].

4.1 *Why ABM?*

As a deductive approach, the use of an ABM enables modellers to define rational agents' behaviour using well-defined mathematical equations. On the other hand, the abductive approach in an ABM enables the emergent behaviour of systems with multiple agents and their interactions over several iterations [32].

In this paper, the agents are modelled as rational that maximize their respective utility functions. The goal is to identify a specific set of micro-level entities, together with mechanisms, parameters and interaction rules, which jointly generate the macro-phenomenon of market equilibrium noted in existing work [33].

4.2 *Simulation parameters*

We simulate two types of agents—suppliers and consumers—whose parameters are provided in table 3. Suppliers produce goods of quantity Q at different combinations of $R = \frac{P}{K}$ values, thus characterizing the supply curve. As indicated earlier, there are two types of suppliers: incumbents with relatively high values of β indicating that they are relatively inelastic in their supplies, and new entrants with relatively low values of β. The consumer agents totalling about 100,000 are drawn randomly with varying values of price (P) and QoS (K) expectations, thus characterizing the demand curve. The consumers are price-sensitive if $P_i^C < P_{max}^C$, and are quality-

Table 3. Simulation parameters.

Description	Simulation parameter
Set of all consumers	$i \in I$
Quality of service preferred by the consumer	K_i^C
Price offered by the consumer to buy the service	P_i^C
Minimum quality threshold of quality-sensitive consumers	K_{min}^C
Maximum price threshold of price-sensitive consumers	P_{max}^C
Set of all price, quality combination plans of services offered by suppliers	$j \in J$
Quality of service as offered by the operator in plan j	K_j^S
Price of service as offered by the operator in plan j	P_j^S

Table 4. Market share of incumbent and new entrants.

Supplier β	Consumers	Revenue
2	4.4%	11.33%
1	4.6%	11.48%
0.5	16.1%	21.42%
0.25	67.7%	55.77%
Total	92.8%	100%

Table 5. Infinite supply from the new entrant.

Equilibrium	Consumers	Revenue
EQM_1	7.77	25.89%
EQM_2	72.25	74.11%
Total	80.02%	100%

sensitive if $K_i^C > K_{min}^C$. We use Algorithm 1 to match consumers with the best $R - Q$ plan offered by the suppliers of services.

Table 3 gives the parameters used in the algorithm.

The assignment of consumer choices of P and K to the best plan offered by the suppliers is done as follows. For the quality-conscious consumer, Algorithm 1 considers only plans with $K_j^S \geq K_i^C$ and assigns the plan with the minimum price to the consumer. On the other hand, for the price-sensitive consumer, the algorithm considers plans that have $P_j^S \leq P_i^C$ and assigns the one with maximum quality.

4.3 *Results of the simulations*

We conducted 100,000 rounds of simulations to obtain the steady-state behaviour of the agents and the market equilibrium. The market is simulated for four types of suppliers with different β values, and the results are given in Table 4. Larger β values represent inelastic supply curves of incumbent operators, while smaller β values represent the new entrants with relatively elastic supply curves. As shown in Lemmas 1 and 2, for a given slope α of the demand curve, new entrants garner a larger market share of consumers, thus earning more revenue. The equilibrium in these cases has a lower R value, indicative of lower prices and higher quality. This is precisely the strategy practiced by the new entrants in telecom markets in the real world [9].

We then simulated the infinite supply case, as explained earlier. Table 5 provides the simulation results. The new entrant has two equilibrium points to choose from. The equilibrium EQM_1 is unstable, with a low market share and lower revenue. Correspondingly the R is also higher. On the other hand, EQM_2 is stable in which the operator can garner substantial market share and revenue at lower values of R. At this point the new entrant offers a low-price, high-quality plan, attracting both price-sensitive and quality-sensitive consumers, thereby effectively competing with the incumbent.

5. Limitations of the study and future research directions

5.1 *Economic modelling of the telecom markets*

On the demand side, we consider QoS as a single normalized parameter that is a function aggregating various parameters such as download speeds, upload speeds, data limits, performance at peak hours and latency. A single value of QoS representing an aggregate of many different metrics is also seen in auction theory [34] and domains such as cloud computing [35, 36], and can be achieved using the analytic hierarchy process [37].

Future work can study QoS for a specific category of users such as game players who prioritize low latency, or intense video streaming users that prefer higher download speeds. On the supply side, we consider QoS to be just a function of bandwidth provided. Extension of this work may also include a variation of supply-side parameters such as type of technology (3G, 4G, 5G), the frequency range of operation (sub-GHz, microwave, millimeter-wave) and different forms of network configuration (point-to-point, mesh). Consumers also have loyalty towards certain suppliers from whom they avail their services regularly, and prefer the same despite the presence of economic incentives to change [38]. Telecom operators often provide Closed

User Group (CUG) services, and the behaviours of CUGs in the context of 5G cellular networks are being studied [39]. These specific use cases have not been modelled in this paper but have the potential to be incorporated into an ABM to study the resultant market dynamics.

Research on the inclusion of network effects in the modelling of broadband services is still limited, as pointed out by Abrardi and Cambini [14]. The presence of the cross-side network effect in telecom broadband networks is noted in recent work by Ruutu *et al* [40]. In this study, we have not explicitly incorporated the cross-side network effect as applicable for telecom broadband services. The presence of network effects and their effect on the market equilibria is a topic for future studies. Apart from cross-side network effects, there are other aspects specific to broadband telecom markets. Bundling of voice, data and video services introduces economies of scope effects and can alter the way in which pricing plans are offered by the operators and how consumers demand these services [9].

Further, broadband networks often use Content Distribution Networks (CDNs) that can provide superior QoS and can affect the equilibrium as noted by Baake and Sudaric [41]. Some of the Over The Top (OTT) media service providers such as Netflix and Hulu prefer to host their content in local servers within countries to improve response time and quality of experience. For example, Netflix uses Open Connect Appliances to push content to the local Internet Service Providers or telecom operators to conserve bandwidth consumption and improve quality of delivery [42]. These real-world practical scenarios may be included in the model to obtain practically significant results.

5.2 *Limitations of ABMs*

An ABM is characterized by the bottom-up approach, heterogeneous agents, bounded rationality of the agents and direct interactions between the agents. They have bothered the neoclassical economists, as an ABM tends to produce varying results and these results are not often comparable to the empirical data in the real world [43].

It is typical in discrete event simulations for the designer of a simulation to pre-specify all possible transitions and closely control events, assuming fixed behaviour. However agents represent entities in the real world such as business organizations and individuals who do have the intelligence to adapt their behaviour depending on the outcome of events, and take into account temporal changes in the environment. Hence an ABM can be constructed with reinforcement learning, in which agents can be endowed with a form of intelligence. With this approach, agents learn from their observations about the simulation environment and the experience of other agents and rely minimally on centralized control as described in [44]. In our model, the agents are passive and do not learn and react to feedback gathered from repeated simulations. Future research with learning agents that incorporate adaptive behaviour of agents depending on the ever-changing data localization regime is needed.

Another learned criticism of ABM is that it lacks the explanatory power of the real world. While simulations generate large quantities of synthetic data as per the model formulation, such data may diverge significantly from that of the real world. In this work, the model parameters are derived from the available empirical data and cited throughout the paper. However, we have not validated our model both at the micro- as well as at macro-levels with real-world data. The branch of agent-based computational economics (ACE) models agents as active gatherers of data that can dynamically learn and alter their behaviour and interactions [45]. Recently, researchers have built simulators using ACE to investigate market dynamics [46].

6. Conclusion

In this paper, we have adapted the standard econometric modelling of supply and demand in the telecommunications market to analyse incumbent and entrant service providers' strategies. Apart from the traditional factors of price and quantity that determine the supply–demand equilibrium conditions, we have also included QoS as an essential parameter that defines both the supply and demand curves. We characterize two types of consumers, namely price-sensitive and quality-sensitive ones. We then prove that under finite capacity constraints, the new entrant whose supply is more elastic compared with the incumbent acquires a larger subscriber base by offering service plans that are lower priced and of higher quality. On the other hand, the incumbent with substantial network effects and associated consumer base exhibits lower elasticity, thus acquiring a relatively smaller segment of additional consumers. We also prove that a new entrant with relatively larger capacities tends to address a larger portion of the demand curve by offering low-cost/high-quality service plans. Our simulation findings affirm the analytical results.

We thus establish stronger linkages among price, QoS and quantity of service offerings in the telecommunications broadband market in this work. The results can guide regulators in establishing significant market power of

Table 6. Summary of findings.

Type of supplier	Percentage of consumers	Percentage of revenue
Incumbent	Low	Medium
Entrant	High	High

incumbents, analysing predatory pricing behaviour of entrants and prescribing QoS regulation in the sector [47–49].

Our findings are summarized in table 6.

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