SPECTRUM AUCTIONS

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CONTENTS

ABSTRACT

In this essay, I have talked about the spectrum auctions- spectrum is a band of frequencies which companies may utilise for transmission of calls, videos, file transfer, emails, WiFi, Bluetooth etc. It is a scarce and valued resource, and its allocation can be done satisfactorily by suitable auction design. Instead of focusing on any singular mathematical formulation, I have looked at established models, their pros, cons and utility. Further, I have also proposed some relaxation of assumptions that can be integrated in a model using intuitive mathematics. Further, I have talked about the same in the Indian context, and how India faced and dealt with the problems it faced in the course of implementation. Lastly, I have discussed spectrum policy design and highlighted its importance for realisation of any auction.

1 INTRODUCTION

1.1 Why spectrum?

Spectrum, in this specific context, refers to a range of radio waves, making it a critical resource for a wide range of applications like telecommunications (by companies providing phone and data services) and other wireless communication systems like WiFi, Bluetooth etc. The numeric value attached with this quantity is *frequency*. The number of spectrum bands available are only finite and hence scarce.
What makes every band desirable is its applicability. A higher frequency is associated with higher value of energy ($E = h\nu$), and with more data transmission. The distribution of spectrum bands can broadly be visualised as follows-
AM and FM: 100MHz - 200MHz
Telecommunication spectrum: 800MHz - 2300MHz
Unlicensed bands occur beyond this - Wi-Fi used to be 2.4GHz (2400MHz) and has started to shift to the 5GHz band
It is important to differentiate among available spectrum bands to ensure that signals of a certain frequency do not interfere with those of another one.

1.2 Why auctions?

Resources to be auctioned are *scarce* meaning they are unique and finite, and they cannot be accessed by those who have lost the right to do so via this mechanism.
John McMillan has described the ways of allocation of spectrum as (i)administrative process, (ii)lottery, (iii)first come first serve, and (iv) auctions.
Out of these, economic theory and experience of various countries tout auctions as the best mechanism for allocation in terms if revenue generated and fairness of procedure. Reenue maximization and maximizing social welfare are two possible objectives that have to be balanced by auction organisations (here, governments). Administrative process is used by The EU, Canada and most of South Asia, including Japan, Singapore, Hong Kong and South Korea, and criteria and weights assigned to the same are vague, hence questionable. There is always a balance to be maintained between public welfare and industry capitalisation, and different countries consider this differently. The US held administrative hearings for companies, and in order to escape the cumbersome process, introduced the faster, more economical alternative, which emerged as a huge failure, lotteries in 1982. A huge number of underskilled firms and speculators joined the race and random allocation gave rise to frivolity in this process. By 1993, it established the auction mechanism.
Now, auctions cover up for a number of loose ends listed above. They, without being

cumbersome like hearings, reveal valuation of each company and allocate resources efficiently. In addition to this, they also give government the flexibility to implement it as a public policy tool, preventing monopolization or non-optimal revenue sale. By controlling the mechanism design in this case, governments can have the bargaining power, and auction the spectrum at its discretion at a reasonable revenue so that it gets the money without raising the price of spectrum so much so that customers have to pay a lot. Thus a government's possible wish is encompassed in auction, as it may be in administrative hearing. Further, it can ensure smooth functioning of the system by appropriately controlling license rights of the spectrum. In a departure from the generic, Australia and New Zealand rely on market methods for spectrum allocation.
The auction design should address the fact that one company does not have to buy one license, but actually has to aggregate several ones and thus its valuation is interdependent. Milgrom and Wilson's paper talks about simultaneous auctions to cater to this possible problem.

1.3 Auction Design

The desired properties of a spectrum auction are:

- *Revenue maximisation*- The government allocating the license of use of spectrum to a certain company receives money because there is competition in the market and the resource in question has high demand. It would like to extract as much as it can without making the resource too expensive, else the service will become to expensive for a consumer too.
- *Social welfare*- Maximisation of agent utility participating in the auction.
- *Incentive Compatibility*- The auction should induce truth revelation from companies.
- *Individual Rationality*- Willingness to take part for every potential agent.
- *Computational Complexity*- Run time for the algorithm should be feasible. For instance, that of VCG is generally high.
- *Renegotiation proof*- A weakly interim efficient auction is renegotiation proof, and if the construct is not so, then either the principal, or the agent, or both can do better by renegotiating. This adds extra time and administrative cost.
- *Collusion proof*- The companies may decide to collude among themselves in order to tilt the auctions in their favour. The design should be robust for its prevention.
- *Signalling and screening*- The auction should be able to hold against such incentives and reach an efficient equilibrium. This is possible when the aforementioned actions do not affect the results.

1.4 Simultaneous Ascending Auction

Milgrom, McAfee and Wilson laid the methodology of this form of auction, which can be implemented to the purpose of auction the spectrum as was the purpose for FCC. I first talk about that, and then proceed to propose some extensions. I have adopted this methodology for all the models described below.
This form of auction is a generalisation of the English auction projected on the sale of multiple goods. For the English auction, the seller proposes an opening bid. Bidding starts with a low price, which is raised as progressively higher bids are solicited until either the auction is either closed or no higher bids are received. This can be extended to the sale of other divisible goods like electricity, gas and environmental markets.
The critical elements of the simultaneous ascending auction are (1) open bidding, (2) simultaneous sale, and (3) no package bids. These features create a Walrasian pricing process that yields a competitive equilibrium provided (1) items are substitutes, (2) bidders are price takers, and (3) bid increments are negligible (Milgrom 2000, 2004).
These assumptions are too rigid because essentially, companies would place utility higher for a certain kind of resource, and items would not be substitutes, bidders would also have some bargaining power, and bid increments have to be substantial for the auction to progress. also, realistically, the bid increments are not even supposed to be uniform to cater to a logical price discovery and proceeding at later stages of the auction.
The steps for auction are as listed below:

- Divisible resources with interdependent prices are auctioned.
- The agent can report its bid for multiple resources simultaneously.
- The auction concludes with allocations when no new bids are made.
- A quantity cap ensures fair competition by restricting the number of resources an agent can buy. This depends on price paid for participation in the beginning, according to suitable payment rules, helping the principal gauge valuation.
- Minimum bid increments- To reach a conclusion, there are minimum bid increments required, and are typically between 5 and 20 percent.
- A agent is supposed to maintain a minimum level of activity in the auction to continue to be considered for allocation. This helps principal in price discovery.
- Rounds of auctions per day are numbered, and increased subsequently, as initial slower rounds aid price discovery for the principal.
- Bid information can be controlled by the principal, wherein it may decide to post complete information of agents' bids and identities after each round for transparency, or at the end of each day.
- An agent may withdraw its bid, but has to pay a penalty for the same.

In case of a singular item being sold, simultaneous auction prompts the agent to reveal its valuation, and truth telling is the dominant strategy. But in case of multiple items, say identical objects, an agent may continue to bid for one item, raising its price. As a result, the agent with the highest value for the second item may be outbid by an agent demanding just a single unit. In multi-unit uniform-price auctions, typically every equilibrium is inefficient (Ausubel and Cramton 1996). Agents are incentivised to shade their bids for multiple units. Further, the incentive to shade increases with the quantity being demanded. Hence, large agents will shade more than small agents. This differential shading creates an inefficiency. The small agents will tend to inefficiently win items, that, in case of efficient auctions, should have actually gone to the lasrge agent. The intuition for this result is analogous to why a monopolist's marginal revenue curve lies below its demand curve: bringing more items to market reduces the price received on all items. In the auction, demanding more items raises the price paid on all items. Hence, the incentive to reduce demand.

Further, in such kinds of auctions, the agents have an incentive to collude to redistribute licenses among themselves, thereby lowering the overall revenue and completely shattering price discovery. Such loopholes will always be taken advantage of by companies. The inefficiencies of demand reduction can be eliminated with a Vickrey auction or with an ascending proxy auction in a more realistic setting.

For ensuring that such practices do not affect the outcome of the game, the principal may design the mechanism such that:

- The resource is in larger chunks, so that it cannot be divided into many parts.
- The information revealed at each round or day is limited, especially agent identities. So other than a case where anonymity is imperative, it should be implemented.
- If the reserve prices are higher, agents do not benefit from demand reduction.

This auction may not be practical if the market is not competitive. In that case, collusion and signalling is highly incentivised for the agents. Further, in case the items are complementary, it is possible that the agent is able to secure an item, but not its complement. In that case, it would be unfair to impose the penalty. This can be avoided by including package bids in the purview of auctions.

This auction is extensively used by governments, generates high revenue, and results in efficient equilibrium (near market prices). They perform well in practice largely because of the benefits of price discovery that come from open bidding and simultaneous sale. Interdependent valuations mean that the winner's curse is reduced, and agents can bid aggressively since they know the valuation posed by others. They also allow for policy implementation to avoid monopolization of the market, or fighting frivolity that comes in because of less competent companies.

1.5 Combinatorial Clock Auction

A variation of the sequential ascending auction is the clock auction. A clock keeps track of the tentative per unit price for each divisible good, and agents report quantities at the current prices. For those goods with excess demand the price is raised and bidders again report their quantities at the new prices. This goes on until supply equals demand. The tentative prices and assignments then become final.
If we assume no market power and bidding is continuous, then the clock auction is efficient with prices equal to the competitive equilibrium (Ausubel and Cramton 2004).
Information policy and reserve pricing allow the principal to control the auction by combating collusion and unfairly distributed market power. The combinatorial clock auction also accomodates for variation in technology, and is useful if the principal is unaware of the type of technology that can make best use of a certain spectrum band, for instance, an auction that allows bids for both paired (like LTE) and unpaired (like WiMAX) technologies. So such an auction can, in addition to allocation, also establish the band plan.
For example, consider the case of calling service providers. Wherever a certain user has primary access, it will be able to provide its service. Else, there will be roaming charges. So in this case, the companies have to bid for spectrum bands in regions. Moreover, to accommodate multiple technologies, the auction has to be *technology neutral*. But if the traffic in a certain band is extremely specific, then the auctions can be done in two rounds- first, the specified auction, and second, the generic auction among those who are shortlisted in the specific one, thus yielding the desired subset of agents.
Ofcom in UK is the independent regulator and competition authority for the communications industries there. It was the first was the first to identify and implement the technology neutral auction in the form of combinatorial clock auction. The primary objectives of Ofcom are:

- The auction should be technologically neutral, permittng alternative viable technologies to compete for the spectrum on an equal basis.
- It should accommodate flexible spectrum usage rights, which permits the user to decide how the spectrum would be used, minimizing interference externalities with neighbors.
- It should promote an efficient assignment of the spectrum, which puts the spectrum to its best use.

While revenue maximisation is excluded as an objective, implicitly, reaching an efficient allocation should naturally address to this objective.
There are two primary rules that form the basis of this auction design.

1. *The Pricing Rule: Vickrey-Nearest-Core Pricing*: Pay-as-bid pricing in a clock auction or a simultaneous ascending auction creates incentives for demand reduction (Ausubel and Cramton 2002). So, pricing rule has a role to play in ensuring Incentive Compatibility. On the other hand, Vickrey pricing prompts truth revelation.

The winner pays social opportunity cost of its winnings, and receives 100 percent of the incremental value created by its bids. This aligns the maximization of social value with the maximization of individual value for every bidder. Thus, with private values, it is a dominant strategy to bid truthfully. Collusion proofness can be incorporated by providing consistency with core pricing. The principal finds the lowest payments that are in the core; that is, such that no alternative coalition of bidders has offered the seller more than the winning coalition is paying. For one item, the problem can be reduced to the Second price auction. But the payment minimizing core prices would not be unique in this construct. Thus, in order to arrive at a unique optimal, Cramton uses the phrase "nearest-core-pricing". Ofcom uses the base prices and the assignment prices as payment minimizing core prices are closest to Vickrey prices. Not only are the prices unique, but since they are bidder-optimal-core prices, they also maximize the incentive for truthful bidding among all prices that satisfy core constraints (Day and Milgrom 2008). The methodology for finding these prices are discussed in detail by Cramton, and by Day and Raghavan.

2. *The Activity Rule: Revealed Preference*: To promote price discovery, activity rule is employed. In simultaneous ascending auctions and clock auctions, the activity rule is based on the quantity that an agent bids for. And in order to have a larger allocation in the end of the auction, the agent must have a large bid throughout the auction. This quantity can either be a measure of spectrum band, or it can be the quantity the agent is capable of by the virtue of its initial deposit. The agent has to bid 80 to 100 percent of its eligibility, else it gets reduced for subsequent rounds. Now if we consider the clock auction, then we cannot ignore the fact that there is a bid, and then there are supplementary bids. So, the activity rule has to align with both else agents will take advantage of this ambiguity. Ofcom proposed the following eligibility point rule: During the clock stage the bidder cannot increase the package size. Moreover, whenever the bidder reduces the package size, the bid on all larger packages is capped by the prices at the time of the reduction. For example, if during the clock stage a bidder drops from a package of size 10–6 at prices p, then for all packages q of size 7–10, the supplementary bid cannot be more than $p * q$.

If we compare this arrangement with the previous simultaneous ascending auctions, we see that there is no more the problem of price discovery. Moreover, it encourages competition by accommodating for technology neutrality. In addition to this, substitution is promoted, and it also makes space for complementary items' bidding by allowing package bids subject to the activity rule.
This form of auction can be employed in various scenarios, where the items going for bid are substitutes or complements in different combinations. For instance, it was used by NYC airports for take off and landing slot timings.

1.6 Cognitive Radio Networks

Spectrum, as we have discussed previously, is a scarce resource. With the advent of a multitude of communication technologies, speculations of the spectrum becoming over crowded have emerged. Contrary to this popular belief, Kasbekar and Sarkar highlight in their paper how spectrum measurements indicate that the allocated spectrum is under-utilized, and at any given time and location, much of the spectrum is unused. Cognitive radio networks allow for the addressal of this problem by allowing for two levels of networks on a channel, primary and secondary. FCC defines this using the terminology "Exclusive use" for primary access and "Commons" for a finite number of secondary users. A primary user has prioritized access to the channel, and it transmits on a channel irrespective of the presence of secondary ones. In contrast, secondary network can transmit on the channel provided primary nodes are not transmitting. Cognitive recognition allows secondary nodes to identify the unoccupied channels, thus establishing dynamic spectrum access. FCC Spectrum Policy Task Force have published surveys that supplement the need for the study of this technology. Subsequently, the right to be primary or secondary a channel can be auctioned.
The traffic passing through a channel can be either delay sensitive (like calls), or delay insensitive (like emails). Those which are delay sensitive can be transmitted on the primary channel, because there is not wait time. Delay insensitive traffic, on the other hand, can be ascribed to the secondary channel.
$x_i(k)$ is the valuation the the i^{th} bidder attaches to channel allocation $k \in K$.
The VCG mechanism (Vickrey-Clarke-Groves) ensures incentive compatibility (truth revelation is the optimal startegy) and maximised utility with highest expected payoff, and can be used to model this problem in the following manner:
Utility, $u_i(k, x_i, \tau_i) = x_i(k) - \tau_i$
where τ is the monetary transfer.
Social welfare = $\sum\limits_{i=1}^{n} x_(k)$
Given the bids $z_i \in Z$, an allocation k^* maximises revenue if
$\sum\limits_{i=1}^{n} z_i(k^*) \geqslant \sum\limits_{i=1}^{n} z_i(k^*) \forall k \in K$
For VCG, $\tau_i = \sum\limits_{j=1, j\neq i}^{N} z_j(k^*_{-i} - \sum\limits_{j=1, j\neq i}^{N} z_j(k^*_i)$
To find the allocation k^* that satisfies the above constraints, we can set up a simple algorithmic solution by reducing the given statement to a maximum weight matching problem in a graph. P. Cramton, Y. Shoham, and R. Steinberg, in their paper on combinatorial auctions, give a solution using Dynamic Programming for this purpose.
Further, the primary user can choose either to utilize the spectrum for itself or to sell the spectrum to secondary users. Utility of the primary user should be the maximum between the profit that they can obtain if it choose to self-utilize the spectrum and the payment that they can obtain if they choose to sell the spectrum to secondary users. This

opens the doors to a newer kind of market structure, as illustrated in the figure from [7].

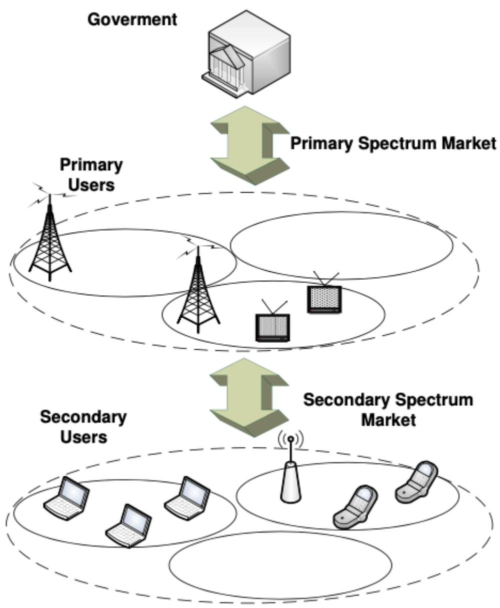

Figure 1: Market Structure

Since the primary user end has been described at length previously, or by establishing VCG for maximising social welfare, we now look at the market between primary and secondary user.

- In contrast with the market, the clear cut objective in this particular market is revenue maximisation, since this part is not moderated by the government.
- Secondary service providers come in and thereby result in finer spectrum reuse. For these part, primary users cannot afford interference. They must have a fairly accurate knowledge of their own spectrum use, and the use by secondary users. Secondary wireless service providers must obey certain rules to avoid harmful interference, which many study on opportunistic spectrum access on the packet level seek to exploit. Further, spectrum usage opportunity can depend on the band of spectrum in question. For example, this opportunity may be lower due to higher traffic in big cities like New Delhi.

The secondary user can submit bids for any number of channels across networks. These bids may be rejected, partially accepted, or accepted, depending on the judgement of primary user. Further, the requirement posed by secondary user can also be constrained. So both the user have bargaining power.
The optimal auction can be again modelled as the VCG, with revenue maximisation as objective function. As it is the case for VCG, this modelling is based on virtual valuation maximisation. But as it was discussed previously, VCG has high computational complexity. So, if the requirement for running aution is real time or even near real time realisation, a sub optimal, near VCG auction can be implemented. This sub optimal allocation satisies the two properties of VCG- allocation is monotonic and there is a threshold value above which an agent has to bid in order to secure the product.
Spectrum resource can be allocated in a strategy-proof manner and for multiple winners. Under the mechanism discussed above, a primary user can grant access to its unused or under-utilized spectrum resources in the form of certain fine-grained spectrum-space-time unit.

1.7 Collusion-Proof Auctions

Agents would not restrict themselves from collusion if there is any incentive to collude. Further, in the secondary market, as the number of participants increase (for example, the number of WiFi providers in New Delhi), the incentive to collude grows.
This collusion can be broadly of three types, and we try to address each progressively:

- *Collusion among losing agents*: The tentative winner has some valuation. But for a subset of losers with lower valuation, it is ideal to collude. They can bid over their valuation, and win the spectrum band. The price they pay is still eventually lower than their true valuation because they are mutually non interfering.
- *Collusion for subleasing*: The secondary users who win the band may collude to further sublease this band to other secondary agents who lost at the auction at an agreed price, as long as they earn profit. But this profit should actually have gone to the primary user by right, and the auction should have this provision inbuilt.
- *Interference collusion*: There is incentive to collude to misreport interference for secondary users, thereby completely eliminating certain users and allowing for entry of the collusive party. This would decrease the possible revenue for principal.

A possible variation to the standard VCG, which is prone to collusion, is to club the agents without mutual interference in all possible groups, and look at their virtual valuations in this specific scenario. Then the principal can bring in the revenue objective function to efficiently allocate resources.
By ensuring that the winner bid goes beyond the valuation of loser party, collusion among losing agents can be completely eliminated. But the winning party can still benefit from subleasing. So, this mechanism is a partially collusion-resistant pricing strategy. In order to make it fully collusion proof, more considerations are involved. This collusion takes place when a set of winners sublease to a set of losers. Given any colluding-winner subset, the potential users who may be interested in subleasing the band should have no mutual interference with the remaining winners; otherwise, the band turns out to be unusable. So by ensuring the complement of this case, sublease collusion.
Andreas Blume and Paul Heidhues have written about modelling tacit collusion, and their results indicate that, relative to standard non cooperative models, acknowledging the strategic uncertainty created by by not communicating severely limits the ability of agents to collude in one-shot games or in mechanisms where the discount factor is low. They say that this lack of communication leads to strategic uncertainty. They also look at the relation between lack of communication and lack of information about past bids. However, a patient bidder may overcome the attainable strategy, and for such a case, constraints on information are more important than inducing strategic uncertainty.
However, all the auction designs use symmetric bidding constraints and justify this with the overall revertion to mean argument.

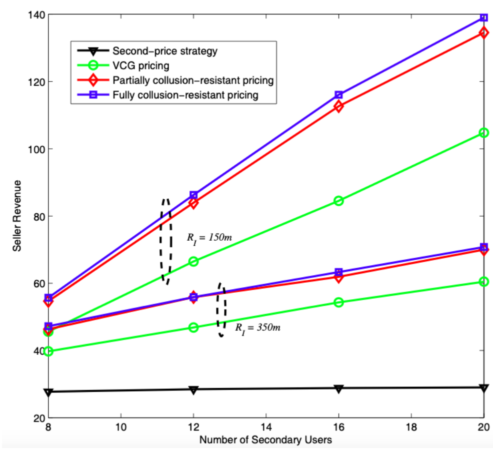

Figure 2: Comparing revenue

Yongle Wu, Beibei Wang, K. J. Ray Liu and T. Charles Clancy's simualtion result for multiwinner spectrum auction is presented in the given figure. Typically, the collusion is broken by employing two strategies:

- Reducing group utility: This is done by invoking the threshold price discussed above.
- Breaking groups: This is by inducing non compatibility in the light of interference among possible colluding party.

Xia Zhou and Haitao Zheng propose an algorithm which combats collusion by implementing a three stage decision process, as described in the figure from [10] below. They first applies a spectrum allocation algorithm in Divide to enable spectrum reuse, and then applies two layers of collusion-resistant designs in both Conquer and Combine to resist intra-segment and inter-segment collusion This enables spectrum reuse and diminishing collusion gain.

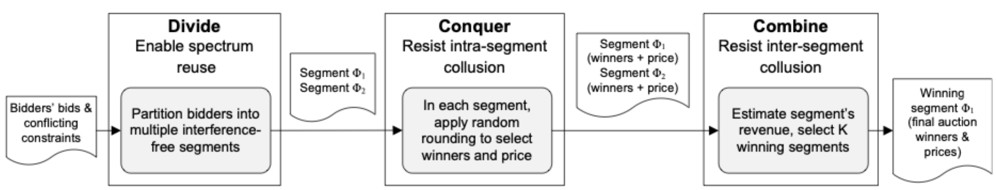

Figure 3: Strategy for auction design

An auction achieves the (t,p)- truthfulness if with a probability of p or higher, no collusion group of size t or less can improve its group utility by rigging the bids. This holds even if multiple collusion groups are present, as long as each group is of size t or less. So, for most cases, this breaking of collusion either constraints the solution to be sub optimal, or the probability of collusion is reduced.

In practice, collusion behaviors are highly complex and hard to predict, especially in large-scale auctions. So, typecasting the collusion may not address all its manifestations in the real world. Further, computational modelling of multi channel bidding has not been done yet.

2 SPECTRUM AUCTIONS IN INDIA

2.1 The evolving scenario

India opened its spectrum for auction in 900 MhZ band first in 1994. Since then many rounds of auctions have taken pace from 2G to 4G. Auction of 5G which was supposed to happen this year just got delay again as telecom operators feel that the Government has kept prices too high, moreover Indian Space Research Organisation (ISRO) has demand for similar frequency band. This has jeopordised frequency planning for 5G and India may not go with International standard. India is lobbying at UN-ITU for lower frequency but all over the world, 26GHZ is being planned and equipment being designed for that. By allowing ISRO in the same 26GHZ band, most telecom operators feel that very little bandwidth will be available for 5G roll out. Though Telecom Regulatory Authority of India (TRAI) has rolled out consultative paper for 5G, roll out plan operators are hesitant with high price and little frequency band which may not be sufficient.
Prior to this case too, India start auctioning 900 MHz only in 1994 as 1800 Mhz was being used by defence, and after lot of persuasion and investment, Indian defence system vacated this frequency to be auctioned first time in 2001.
Despite claiming fairness and transparency, Indian auction has never been free of allegations and controversies. There always have been cases of favouring few operators at the cost of others and allegation of corruption has reached in the past up to the Supreme Court of India. Recently, the Government auctioned 2100 MHz band. After the auction, successful bidders are allowed to pay full amount either upfront or in installments.
Most of the operators are taking bank loans and paying for spectrum in installments. Thus, in case of failure of a particular Telecom company (like Reliance Communication) banks are left with NPA in thousands of Crores. Indian mobile operators have report huge losses in this quarter Except Jio Communication which entered Indian telecom market very late. There was a time when there were more than half a dozen mobile operators in India, however due to controversies in spectrum auctions, its high price and predatory pricing of new operator Jio which offered free connections, many either shut the operation (Reliance Communication, Aicel Maxis) or were forced to merge (like Vodafone and Idea).
While Indian spectrum is costly, the mobile tariff in India is one of the lowest in the world. Now operators after incurring heavy loss due to recent Supreme Court of India order on revenue sharing have decided to increase the tariffs. It is yet to be seen that whether this tariff increase and Government realizing woes of Telecom operators and thereby deferring installment of spectrum auction payment will be able to save them or not. The telecom industry is crucial to any nation's economy, and the unstable nature and uncertainty have hit India's industry too hard.

2.2 Indian auction design and policy

Some key points unique to Indian auction design owing to market conditions and the Government policy are listed below:

- Department of Telecom (DoT), the government policy maker, regulator and service provider, auctioned licenses for calling services to companies, to begin with.
- But this license was auctioned where agents were barred by the entry condition that they had to seek partnership with foreign service providers, because they were not self sufficient. Separate licenses for the major cities were sold. In this first round of auctions, a single company won nine circles as there was no upper cap to the bid. But the question of whether it could pay its bid was imminent, since the company's entire turnover was a mere fraction of its bid. So the principal had asked it to choose three. Another problem that would have come if all the licenses were awarded to a single one would be private monopolization of the market just when it was selling public ownership. Also, the minimum reserve price from this transaction was a lost opportunity. Due to inefficient coordination and low reserve price, several licenses remained unsold and service providers were inadequate.
- A Group on Telecom (GOT) was set up subsequently, that worked on National Telecom Policy, in effect from 1999. In addition to this, technology neutrality was also realised by DoT. Earlier, the single round bidding had attracted a lot of criticism for imminent price inflation. The Government then used ascending price process for three rounds, wherein the highest bid for a previous round was used as the reserve price for subsequent rounds. The unit of bidding was circles, which was not commercially attractive and only catered to administrative ease. Also, bidding for contiguous circles was not permitted.
- A fair, consistent and strict policy is required to handle defaulters, else the potential assets become liabilities. Also, just pinning a penalty on not providing service to rural areas is inadequate, since telecom companies found it optimal to pay penalty instead of extending its services.

Thus we see that merely drafting a theory for auction design is inadequate. The realisation depends on market and bidder behaviour, which is unique to every location and must be incorporated accordingly. Further, the Government will always have to bear the onus of social welfare of the consumers, since in a competitive market, no company would go out of its way to provide for the same.

3 SPECTRUM POLICY DESIGN

3.1 Policy Design

While there are resources that can be left to the free market, few of them are fundamental to a standard of living for the citizens of any country, for instance, calling service or internet connectivity. If spectrum auction is left as a free market, then no company would ever agree to provide these services to remote areas, and rates for the same in metro cities would skyrocket. For this purpose, policies are efforts made by the governments to match ends to means for providing some standards. Policy design addresses to an analysis based process to design mechanisms which can realise the ends by using knowledge and experience of the receiving end of policy. Design, in this context, refers to both instruments and implementations.
The two significant properties of policy design are layering and temporality. Policies need to be updated as the scenario and technology evolves, and it has to keep pace with the new developments. So, instead of formulating a new policy every time, it is the old one which can simply be reestablished with suitable changes. Policy development strongly marked by layering in this way is typically one where new elements are added to the policy mix without the removal of older ones and existing elements are stretched to try to fit new goals and changing circumstances (van der Heijden, 2011). A key distinction among design formulation processes thus concerns whether they involve "packaging" a new policy mix or "patching" an old one. Patching or "smart layering" has often been thought to be inherently sub-optimal but patching in itself should be seen not as "non-design", but rather as constrained (re)design as a new layer is formulated in an effort to overcome anomalies or problems existing with earlier arrangements (Howlett and Rayner, 2013). But poor designing can result in inconsistencies and misalignment with the ultimate goals.
The difference between a policy design and non design would be that in case of design, the policy is characterised by a logical aim of matching means and ends in the vision of public policy goals and the constraints are imposed by rules of the society. In contrast, for a situation where the intention to instrumentally design is lacking, constraints on outcomes also exist in addition to varied and arbitrary choice of constraints on the objective in question.

3.2 Policy Design- Auctions

When the roads were free and cars few, people could drive as they would want. As the cars increased, so did the demand for cooperation and communication. Similarly, growing traffic on the spectrum calls for regulation. The role of policy in this context

is not just standardisation, but also promotion of growth and aiding technological advancement. In the purview of dynamic spectrum access through cognitive technologies, coexistence has to be established.
Since dynamic access and technological neutrality are the most relevant properties in current context, I will discuss some major points that have to be addressed by policy design.

- Sharing among primary users: In any commons model as discussed above, spectrum is shared, and no one is given an ordinal priority. The item can either cooperate or coexist. The coexistence model exists today in many (but not all) nations and has spurred tremendous innovation and productivity, as is demonstrated by the popularity of WiFi and cordless phones [13]. But it is not sufficient to say that the primary users sharing the space are able to cut off the interference caused due to them, since the companies are incentivised to devise implementation in a way that transmit with greater power, duration, or bandwidth than necessary. This can end up causing the *tragedy of commons*- excess usage by many drain the resource without efficient use. Sharing can be regulated by either capping the use, or by incentivising transmission without interference or with higher efficiency.

- Sharing among primary and secondary users: Sharing can again take two forms-coexistence or cooperation. In case of coexistence, primary users are unaffected, and secondary users can either transmit at low power and hence low interference, or they can transmit when the band is not in use by the primary user by cognitive detection. A cooperative case depends on the technological compatibility.

- Sharing among secondary users: Secondary users may be licensed or unlicensed. While the primary user cannot be interfered as a secured right by license, a licensed user secures this right too. The question in this case arises for the principal to allocate which all users are to be licensed, and which ones can be unlicensed. So, if licensing is done, interference is curbed. But by opening the spectrum in the alternative way, a greater number of technologies can access the spectrum.

The sharing schemes enlisted above cannot be deployed unless there is a policy governing the same. Now, the policy is implemented not just by the government, but also by the users (say, a primary user who allows secondary users on its channel), and we have already discussed how the goals of each of them diverge. Also, even after such a policy is implemented, detection of defaulters is difficult, latent and costly.
Lastly, under-utilisation, inefficiencies, defaults and interference occur because of inadequate policy design, and it is as important as designing an auction if the goal is realising the mechanism in real world.

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