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# SIZING UP THE GLOBAL MOBILE APPS MARKET

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Industry Study Commissioned by Getjar

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## Executive Summary

Mobile applications (apps) have been around since the late nineties and the apps stores have been available for a quite some time as well. Operators have been offering content and applications on their appstores for most of the last decade. But it wasn't until the launch of Apple Appstore that the appsworld started to blossom in earnest. First, it fundamentally changed the revenue model in favor of the developers which has become the current defacto standard (70/30) in the mobile apps business. Second, it brought more developers into the ecosystem as it fostered the notion of focusing on just 1-2 platforms rather than the entire device ecosystem to be relevant. Third, the time-to-market equation changed for developers so that they can get the application from conception to market in a fraction of a time of what was possible in the past. Finally, the importance of a seamless end-to-end user experience to increase usage and monetization became a core principle in the mobile apps space.

While Apple has played a significant role in reenergizing the mobile apps space by bringing more consumers and developers into the ecosystem, there is significant activity outside the iPhone or smartphones space that is often not discussed. The purpose of this research study is to take a holistic look at the mobile apps space across all platforms and on a global basis to get a sense of the size of the mobile apps market and the direction it is headed.

The overall mobile apps downloads are expected to increase from over 7 billion in 2009 to almost 50 billion by 2012 growing at the rate of 92% CAGR. The revenue from mobile apps which includes both paid downloads and revenue from advertising and virtual goods is expected to increase from \$4.1 billion in 2009 to \$17.5 billion by 2012 at the rate of 62% CAGR. Though ondeck (operator managed) mobile apps sales exceeded those from offdeck in 2009, by 2012, offdeck is expected to hold the lion share of the mobile apps revenue.

The dynamics of the app market are quite different in emerging nations where to effectively monetize the significant app momentum (app downloads/active user and growth rates in some of these countries exceed those from the western markets, irrespective of the device type), creative strategies are needed to attract new consumers and different business models will be required to make the regional ecosystems viable.

Overall, by enhancing discovery, improving user experience, dropping price barriers, and increasing developer revenue share, the apps ecosystem can continue to prosper. The paper presents the results of the study in more detail as well discusses the future of mobile apps and how the app economy is likely to evolve.

## The Mobile Apps Explosion

The overall global subscriptions base is expected to exceed 5 billion by the end of 2010 (figure 1) with over 27% of them being data subscribers (messaging not included) meaning that they are either actively downloading content and apps and/or actively browsing the web. In the next three years, the data penetration is expected to reach 45% with North America leading the way with almost 60% of its base as active data subscriptions. The advent of apps helped fuel the growth in data subscribers as the availability of flat free pricing attracted users to upgrade and try out new applications. In the US, almost all smartphones and many featurephones are now required to have a data subscription.

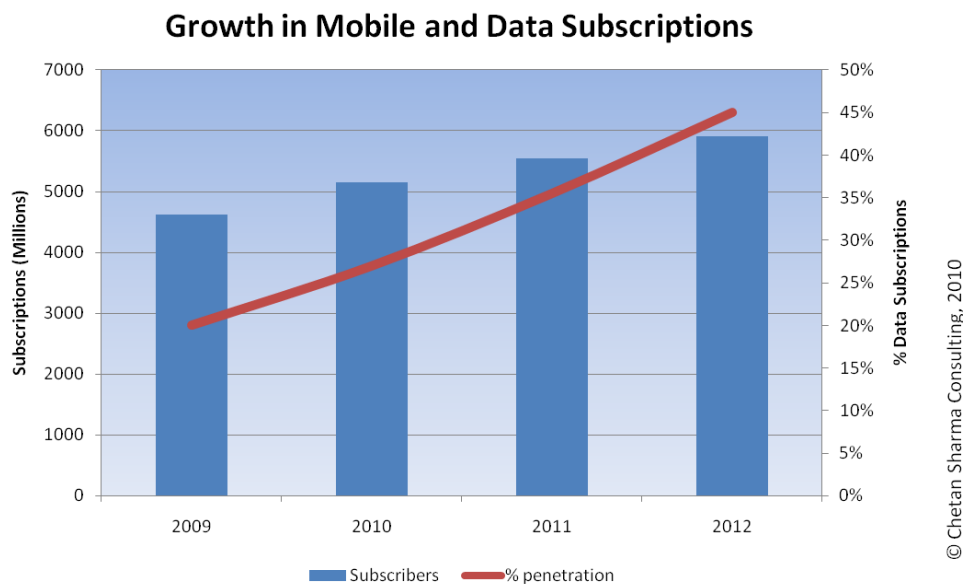


Figure 1. Growth in Mobile and Data Subscribers

The year 2009 saw an explosion of the Appstores. Non-carrier appstores jumped from a mere 8 to 38 last year (figure 2). Almost all OEMs, big or small, have launched their own appstores. Additionally, many vertically focused, or country specific, or platform specific appstores are trying to take advantage of the gold rush.<sup>1</sup> This dynamic evolution is fueled by thousands of new developers who are developing for specific platforms.

The shift from the old revenue share model where developers used to get as little as 10% of the revenue to a 70% share of the revenues has made the whole mobile apps ecosystem attractive for developers. Also, the development and the go-to-market costs have come down significantly, especially for the developers who want to focus on just 1 or 2 platforms. Even though the fragmentation of platforms remains a significant problem, developers don't have to port applications to devices that will have little to zero ROI.

<sup>1</sup> Obviously, not all appstore initiatives will succeed. Some will morph while others will whittle away with time

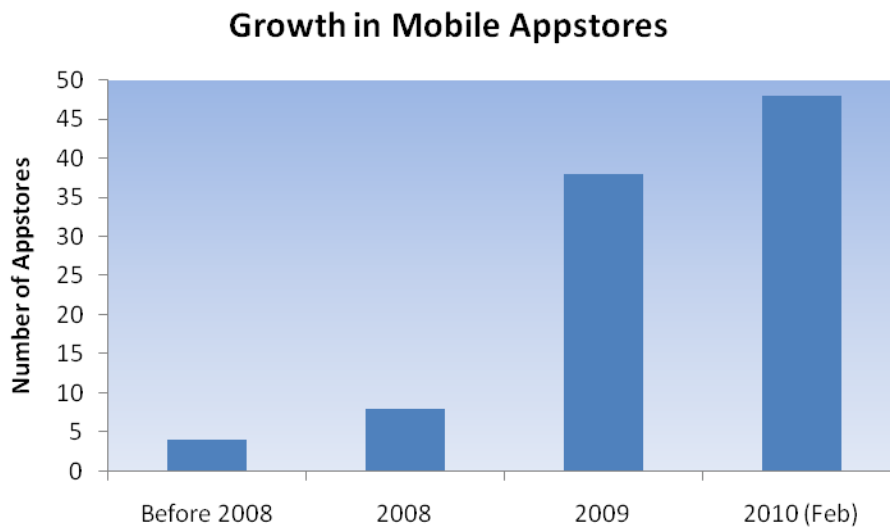


Figure 2. Growth in Mobile Appstores<sup>2</sup>

The explosion in mobile apps has come about by the troika of three specific trends that have empowered consumers to become appfanatics. First, the devices have become more powerful with up to 1-2 GHz processors. Second the wireless networks are delivering consistently high bandwidths and better user experiences with 3G+ deployment. Finally, the creativity of developers has blossomed with access to native APIs, richness of the platforms, ease of development, and the favorable revenue sharing terms.

Additionally, many in the ecosystem including operators are pursuing an on-device storefront strategy to make the user experience of search, discovery, and fulfillment better.<sup>3</sup>

The app marketing done by Apple and others has raised the level of exposure to the consumers who want to try out new apps and spend discretionary money on new apps. The mobile advertising ecosystem has also become more robust to provide developers with an added avenue to monetize their applications. Many developers like Tapulous and mig33 see apps as a way to build fiercely loyal communities of millions of users and once the user base gets scale, it can be used to sell other digital and virtual goods to start a new revenue stream. The creative elements in mobile advertising has seen a significant improvement on platforms such as the iPhone and Android and made the ads more engaging for the consumer and rewarding for the advertisers.

<sup>2</sup> Source: WIP Connector [http://www.wipconnector.com/download/appstore\\_compare\\_Feb10.pdf](http://www.wipconnector.com/download/appstore_compare_Feb10.pdf), Chetan Sharma Consulting

<sup>3</sup> Compared to the WAP based storefronts

## Methodology

The goal of this research study was to quantify the global mobile apps market. To build an effective framework for analysis, we built a ground-up model that took into account how the overall apps consumption is evolving across all dimensions - ondeck (offered on carrier deck), offdeck (outside the carrier deck though they still might play a role like in billing or marketing), smartphones, featurephones, paid, free, and advertising based (including virtual goods) apps revenue.

The detailed methodology map is outline in figure 3. The model focused on apps consumption by five major regions: North America, Europe, South America, Asia, and Middle East and Africa. We first estimated the total number of smartphone and featurephone users in each of these regions, then looked at the active data subscribers on these devices who are actively downloading mobile apps (there are active data users who don't actively download mobile apps on a monthly basis so the actual population of subscribers who download apps on a monthly basis is smaller than the overall active data subscribers). Then, we estimated the number of apps download/user/month by smartphone and featurephone platforms respectively.

Then, for each of the platforms (smartphone and featurephone), we calculated the the percentage split between the downloads that were happening ondeck vs. offdeck. It should be noted that in certain instances, the line between ondeck and offdeck is blurring with some of the offdeck providers providing white label services (operator branded) to the operators through the operator/OEM deck (e.g. Handmark, Getjar, Cellmania) and in other instances, OEM appstores are available with operator billing (e.g. RIM, Nokia). For the purposes of this study, we defined ondeck purely as an appstore that is created and operated by the carriers.

Later, the paid and advertising funded revenue models were analyzed (virtual goods revenue were estimated in the advertising funded revenue stream). Based on this analysis, there were 8 separate revenue streams.

		Smartphones		Featurephones	
		Offdeck	Ondeck	Offdeck	Ondeck
Smartphones	Paid	1	2		
	Free	3	4		
Featurephones	Paid			5	6
	Free			7	8

The results from these 8 streams were aggregated to arrive at the global mobile apps market size. The model was also tested top-down by comparing the numbers from some of the major operators (ondeck) and OEMs (offdeck) to ensure that the numbers match-up.

The data for the year 2009 came from over 20 players active in the global mobile apps ecosystem which included operators, OEMs, analytics players, measurement companies,

content providers and publishers, off deck storefronts, mobile advertising players, application developers, and aggregators. The forecasts are based on growth rates experienced by various players combined with the estimates from Chetan Sharma Consulting. We will be discussing the aggregate numbers in this paper.

We didn't include any new form factor devices for app downloads like the iPad or the Telematics platform or the digital camera, etc.<sup>4</sup> Applications on such set of devices will start to grow later this year.

### ***Smartphones vs. Featurephones***

The classification of devices into buckets has been a long standing debate in the industry. In the early days, the division was easy as the form factor, functionality, OS, and capabilities of smartphones was quite distinct from the featurephones which used to have limited processing power, smaller screens, and were primarily for voice and messaging. However, over the last 12-18 months, the edges between the categories have blurred significantly.

While no one will confuse the current version of Apple's iPhone or Google's Nexus One to be featurephone or conversely a Motorola Razr or Nokia 2720 to be a smartphone, it is the middle category that is becoming more difficult to separate out.<sup>5</sup> Consider devices like the Samsung Instinct<sup>6</sup> which is a 3G device with capabilities for video, applications, emails, and with up to 8 GB, it can't be confused for a featurephone, yet, since it is a Java phone, some might categorize it as a featurephone based on the platform.

Similarly, INQ1 by INQ Mobile the first social mobile device is based on BREW - hardly considered a smartphone platform yet its mobile data usage is higher than even the iPhone.<sup>7</sup> Similarly, Japan's largest mobile operator NTT DoCoMo reaped the benefits of mobile data services without the introduction of smartphones in any meaningful way, it was more due to the deeply integrated services that were in tune with the culture of content consumption as well as lucrative 91%/9% revenue split in favor of the developers and publishers that encouraged them to participate and invest in the ecosystem.

We are clearly seeing a middle category emerge that provides functionality of a smartphone in the form factor of a featurephone.<sup>8</sup> For the purposes of this paper, we included devices with large screen form factor, virtual or physical qwerty keyboard, application download and streaming capabilities in the smartphone category.

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<sup>4</sup> However, we did include downloads on the iPods in our model

<sup>5</sup> Even the smartphone category is splintering into two camps - superphones which are devices like the iPhone, Androids, and Pre and the remaining devices without a full browser and higher processor class as smartphones

<sup>6</sup> <http://www.samsungmobileusa.com/Instinct.aspx>

<sup>7</sup> <http://bit.ly/1PBx4G>

<sup>8</sup> See "The Untapped Mobile Data Opportunity," Chetan Sharma, for more discussion on this subject <http://chetansharma.com/untappedmobiledataopportunity.htm>

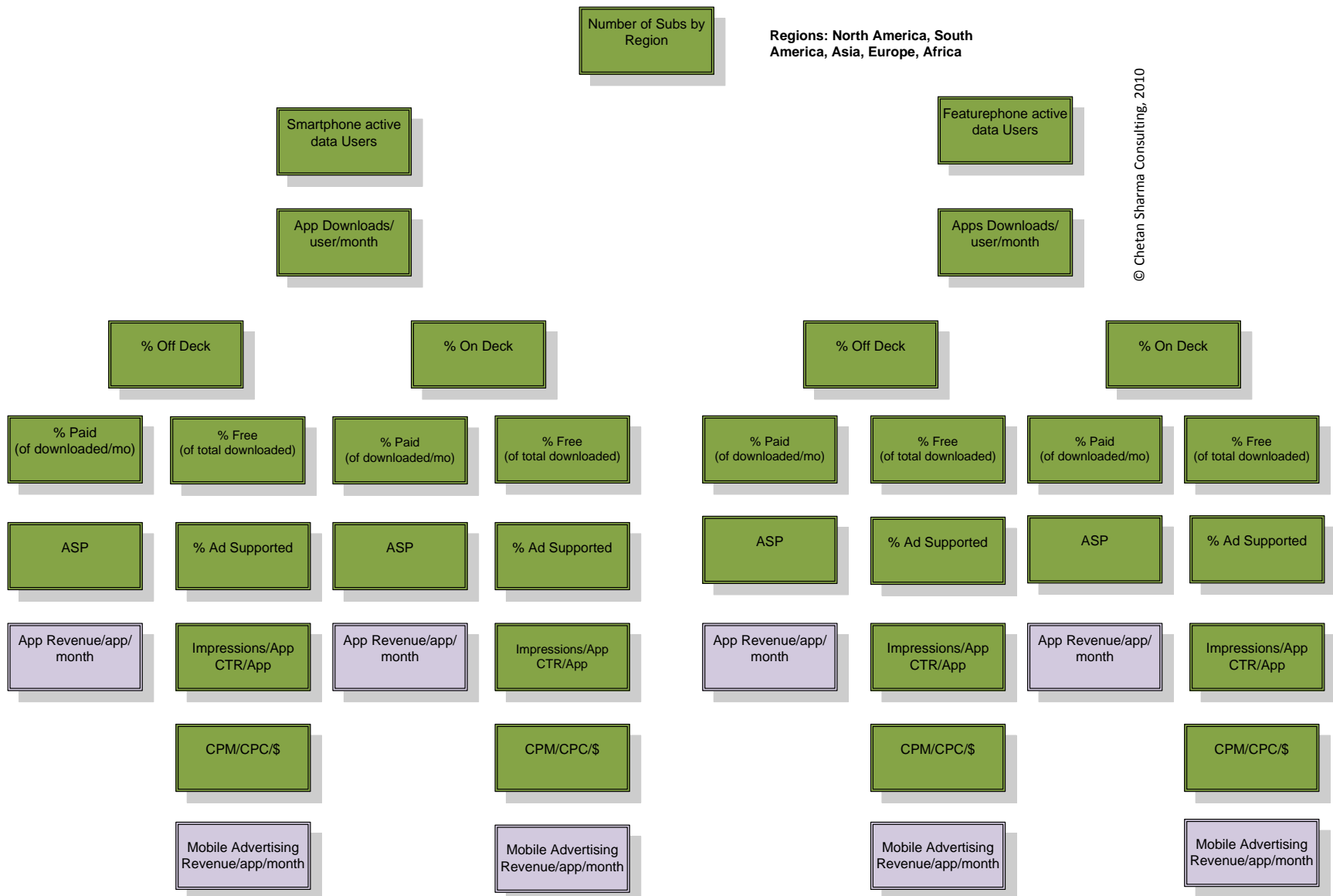


Figure 3. Mobile Apps Market Sizing Methodology Map



## Mobile Apps Market

The dynamics of the global apps market vary by region. In North America and Western Europe where smartphone penetration exceeds 25% and 3G penetration is above 40% (as of 2009), the total number of downloads on smartphones is significantly higher than those on the featurephones. Thus, despite the lower penetration, the revenue generated is more than revenues generated from featurephone downloads. One of the reasons is the high number of active data users on smartphones compared to featurephones. In China and India, featurephones rule and as such the downloads and apps revenue are relatively higher from such devices. Figure 4 shows the distribution of devices in various regions by devices type.

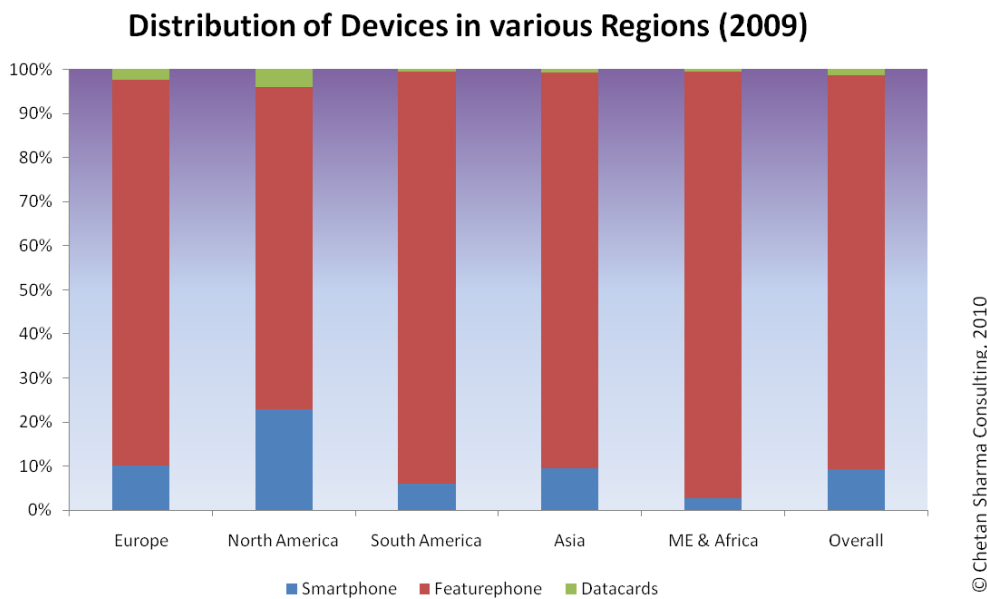


Figure 4. Distribution of Devices in various Regions (2009)

In 2009, the total number of apps downloads (global) were approximately 7 billion with Asia leading the way with 37% of the global downloads. By 2012, the total number of apps downloads are expected to grow at 92% CAGR to almost 50 billion downloads per year (figure 5). This is in part due to increasing number of featurephone users becoming active app users and due to the increase in the number of apps downloads/user/month across the board.

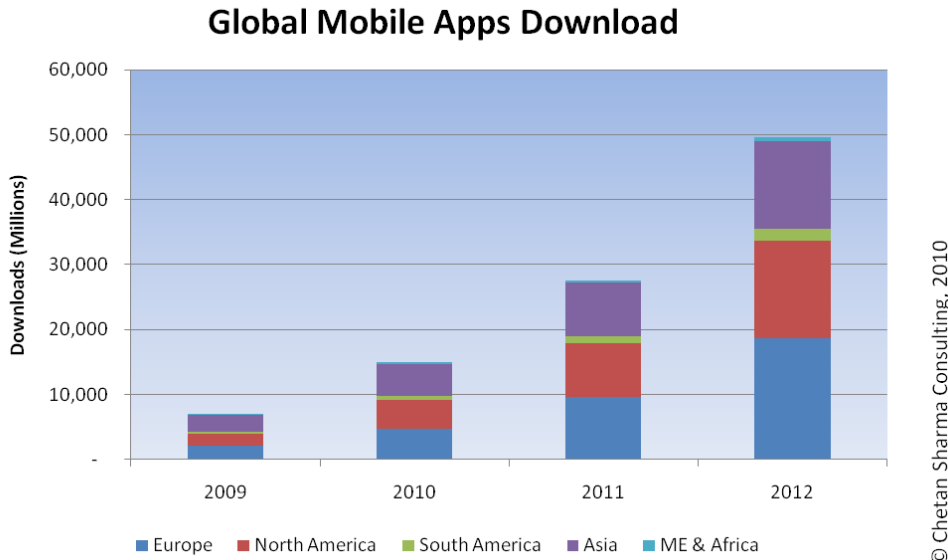


Figure 5. Global Mobile Apps Download Forecast

The corresponding revenue figures for 2009 were over \$4.1 billion growing 62% CAGR to \$17.5 billion by 2012 (figure 6). While Asia had the highest percentage of the download share, North America had the highest share of the apps revenue accounting for over 50% of the total revenue.

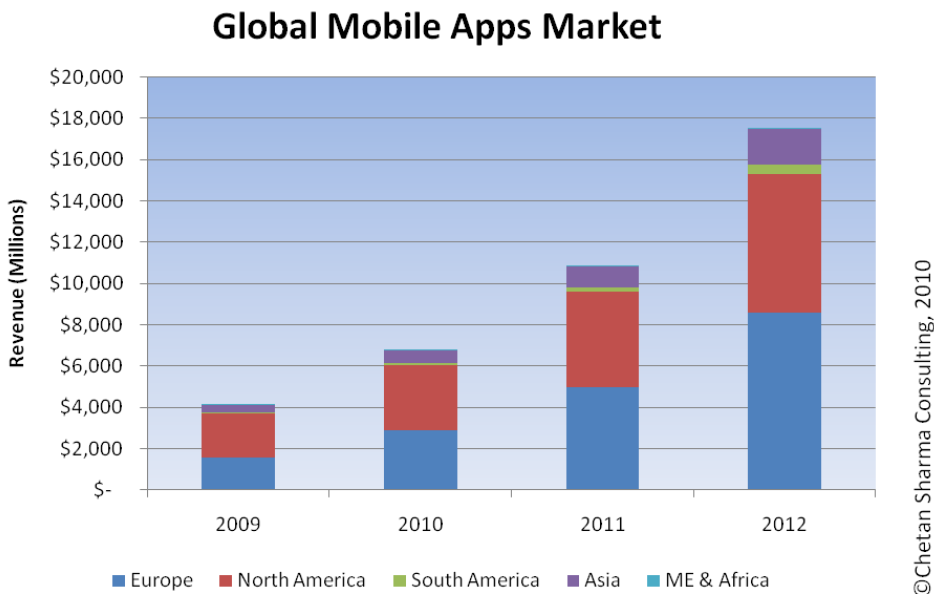


Figure6. Global Mobile Apps Market Revenue Forecast

If we look at the revenue from the perspective of ondeck vs. offdeck and paid vs. advertising (figure 7), ondeck paid had the biggest share of the pie followed by offdeck

paid. Advertising based revenue accounted for about 12% of the overall revenue though by 2012, advertising is expected to generate 28% of the app revenue.

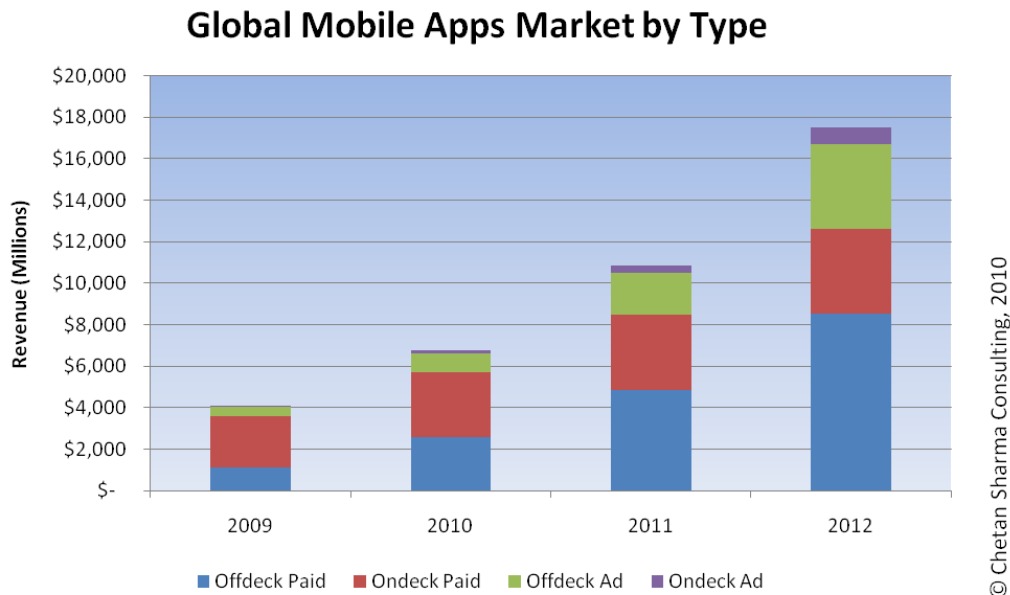


Figure 7. Global Mobile Apps Market Revenue by Type

Operators still have a larger share of the apps revenue for a couple of reasons a) the ASP on an operator deck is almost twice the offdeck average and b) featurephones still make up the bulk of the global market device base. However, the balance has been gradually shifting in favor the offdeck ecosystem.

While the growth in the mobile apps market will continue to astound many, one should keep things in perspective. Overall, the global mobile services (operator reported service revenues) revenue exceeded \$861 billion in 2009 with approximately \$220 billion coming from data services (including messaging).<sup>9</sup> So, even though the mobile apps revenue is growing at a fast pace, it represents a relatively small percentage (albeit growing) of the overall data revenues in the ecosystem.

## Business Models - Distribution of App Revenue

The business models for apps have evolved over time. Initially, the focus was entirely on the paid downloads or the subscription based models that bundled other forms of content like the ringtones and pictures with applications.<sup>10</sup> However, over the last 3-4 years, advertising based models have become both popular and successful with developers and the app ecosystem. In fact, for some developers, the advertising revenue on some platforms (like Android) is bigger than the revenues generated from the paid

<sup>9</sup> Source: Chetan Sharma Consulting, 2009 Global Mobile Data Market Update, 2010

<sup>10</sup> Ringtones and graphics are not included in our definition of applications

downloads.<sup>11</sup> Some mobile players have focused on building loyal and vibrant communities which creates an audience for selling/up-selling/cross-selling virtual, digital, and even physical goods

The main forms of monetization for apps are:

1. Paid
  - a. Subscription
  - b. In-app
2. Advertising
  - a. Impression-based
  - b. Performance-based
  - c. Promotion
3. Virtual Goods
4. Up-selling/cross-selling other goods
5. Hybrid

For the purposes of this paper, we focused on two broad categories of paid and advertising.<sup>12</sup> In 2009, advertising contributed almost 12% to the overall apps revenue. This share is expected to more than double by 2012 to almost 28%. In some of the developing regions, advertising will account for more than 50% of the apps revenue by 2012.

If we break down the revenue by featurephone/smartphone and ondeck/offdeck, in 2009, featurephone ondeck paid apps revenue had the biggest market share with 35% followed by smartphone ondeck and offdeck paid apps revenue streams respectively.

### ***Average Selling Price (ASP)***

The price range of applications in various stores can vary from \$0.99 to \$999. However, if we look at the average selling price of only the downloaded apps, the paid ASP in 2009 was approximately \$1.9 and the advertising revenue generated from the free applications was approximately \$0.09/user/app/year (figure 8).

Though advertising revenues per user per application doesn't equate to ASP of the app, for the purposes of this paper, we are looking at the advertising revenue that can be generated by each free downloaded application/user/month. As always, there is pressure on the ASP and as the number of the apps consumed per user increases, we are likely to see the paid ASP decline by 29% in three years while the advertising revenue/app is likely to stay relatively flat. The improvement in targeting and creative elements will make mobile advertising more attractive and engaging thus negating the

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<sup>11</sup> In part, this also has to do with inefficient billing methods that often discourage consumers to complete the paid transaction

<sup>12</sup> Virtual goods were included in the advertising calculations. It is a new phenomenon and relatively speaking is still small compared to the overall apps or advertising in-apps revenue

pressure on CPMs/CPCs. Additionally, we are likely to see new measurement metrics emerge in mobile advertising that will help in monetizing the free apps a bit better.

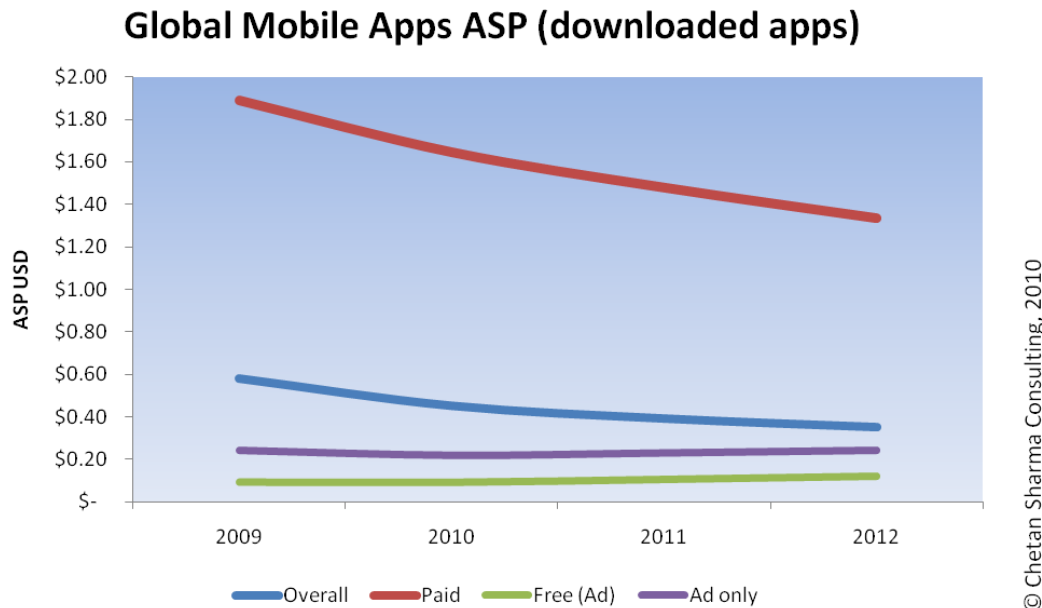


Figure 8. Global Apps Average Selling Price for Downloaded Applications

We are also likely to see the increase in the sales of virtual goods and redemption of the coupons and promotions. The various channels of mobile advertising like the web, messaging, video, search, display are going to work more tightly together to make the mobile advertising experience for the consumer and brand better.

### ***Business models in Emerging Markets***

There are significant differences in ASP by regions. North America has the highest overall ASP with \$1.09 followed by Europe with other regions below \$0.20 (figure 9). It is evident that the business models required for the emerging markets will be quite different than the western markets as the market economics and dynamics are quite different. Most consumers are on prepaid so more data plan choices are needed to convert subscribers into data users. Then, given the propensity to pay, mobile advertising will play a more significant role in the app economy in countries like Indonesia, Brazil, India, and China. As seen in the western markets, providing a bucket based or an unlimited data offering takes away the fear factor from the consumers and data usage including app downloads jumps significantly.

For the emerging markets, it is a volumes game. While the ASPs will be smaller, if an overall strategy is executed well, the volume of data usage and app downloads can make up for the smaller per unit revenues (either from paid downloads or advertising). Indeed, the data shows that despite these markets being featurephone heavy,

application downloads in emerging markets can actually exceed downloads on smartphones in western markets.

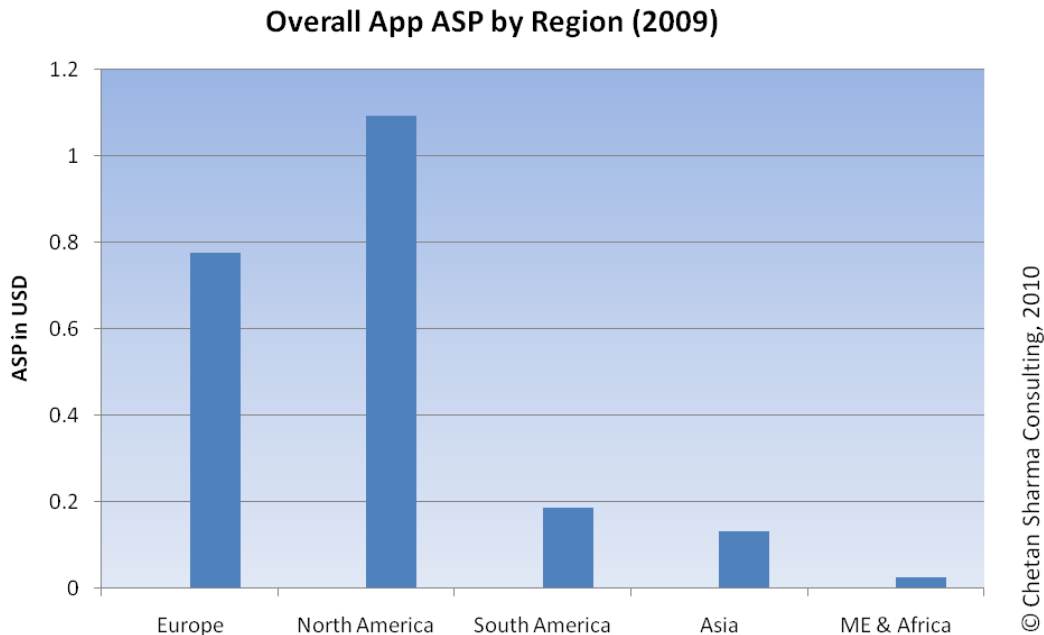


Figure 9. Overall App ASP by Region

## Mobile Apps vs. Mobile Web - Impact on Evolution and Revenues

There is a lot of discussion and debate in the industry on the topic of Mobile Apps vs. Mobile Web in the industry. As we have seen in the past, three critical factors will determine how this plays out over the next few years:

1. Penetration of HTML5+ browsers on mobile
2. Difference between the native OS support and browser access to the same APIs
3. Implementation differences between various browsers

As things stand in early 2010, there are pros and cons to both approaches and as such it is not an either/or situation but rather the decision is based on the type of the applications. Developers will choose native vs. browser direction for their apps based on the business and technical goals for their apps. Today, native provides much richer functionality and access to capability and as such much richer experience than a browser does. For example, the recent Winter Olympics app by AT&T (figure 10) combines different elements of image, text, news feeds, social networking, video, and in-app advertising in a seamless fashion. To accomplish that in the browser will be difficult. The user experience won't match the performance of a native app. This issue is even more pronounced for highly interactive games from companies like EA, Gameloft, Glu, and others.

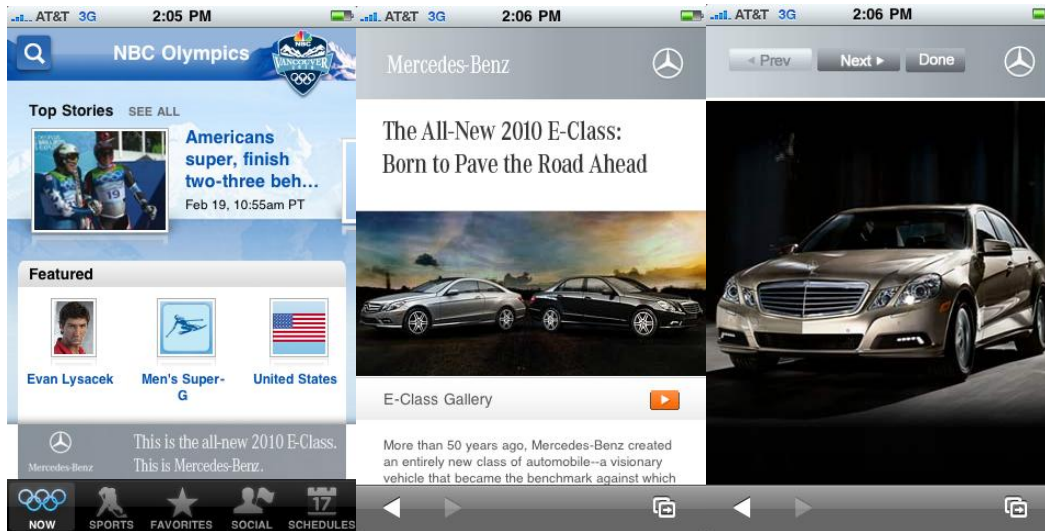


Figure 10. AT&T's Winter Olympics Application for the Vancouver 2010 Games

On the other hand, the fragmentation issue in mobile only gets worse with each year with new devices, different implementations and operating systems, the cost of rolling out an app across multiple devices around the world can increase exponentially.<sup>13</sup> As such, the browser provides the prospect of being the great unifier so you can truly design once and run everywhere (where the browser is available). For the simple apps that are less interactive and require less multimedia capability, like the popular social networking and news/weather apps, browser provides the perfect avenue to maximize impact with least amount of development.

However, when considering a global market, one needs to be mindful of the rate at which HTML5+ browsers will penetrate the market (or in other words what's the "effective reach"). While things might move relatively quickly in the western markets, in many of the developing markets, the penetration of devices with HTML5+ browsers (and fast broadband mobile networks) will only increase gradually over the course of this decade. As such, the HTML5+ browser reach will be limited, so developers will weigh against the technical and business requirements of the applications with cost to build such applications and how that fits in with their business strategy and revenue goals. Some might decide to build both versions with web version for some markets and native apps for the others. Browser won't be the great unifier that some hope for anytime soon.<sup>14</sup>

<sup>13</sup> Another aspect that plays into the decision is that developers no longer worry about supporting apps on devices that don't have a big base, so they generally focus on only the platforms and devices with maximum reach and ignore the others.

<sup>14</sup> We have been down this road before with J2ME, Flashlite, Android, etc. While in theory, browser can be deployed across multiple OSs and device platforms, reality is often quite different as the implementation cycles will vary for different OSs and in different markets. The mobile ecosystem is just more complex than the PC one.



While there is hope that browser will have same access to APIs that any native apps does, native support is generally always ahead of the browser support and the leading developers looking for an edge in user experience are likely to go native. For some it is a matter of semantics. For example, many web shortcuts or URLs are available as app icons which primarily link to a website. A good percentage of the downloads for the most popular social networking app - Facebook is via an app icon that can be downloaded as an app.

Finally, it is a misconception that there won't be fragmentation in the implementation of the mobile browsers by OEMs. There will always be differences due to the primal urge to differentiate and as such developers can expect to have these differences in the future though the fragmentation in browsers is only marginal to that created by the native OSs.

Given the above, we are likely to see both worlds (native and web) coexist for a long time to come. Depending on the needs of the applications and business models, both models will stay in place for the foreseeable future. The dominance of one over another will largely depend on the device capabilities and reach in any given region.

In fact, a larger focus should be on app search and discovery, quality of content, end-to-end user experience, zero billing friction, developer ecosystem and how to make developers more profitable and successful. These issues are important to tackle to keep the app economy vibrant and healthy. Operators and OEMs can play a crucial role by opening up the network and device APIs and building a fair and sustainable business models that help the smaller developers. For example, in some Asian countries, the operators still get 40-70% of the app revenue. Smaller developers who don't have the scale of billions of downloads will find it hard to survive in such an economic climate.

Additionally, data plans should be attractive enough to fit the needs of the subscriber, for example, Bharti Airtel introduced daily, 3 day, monthly data packs with varying data caps so that users can pick the plans per their needs. One should segment the user base granularly and design data packs that fits the needs of each of these segments. Such strategies enable quicker adoption especially in countries where mobile is the primary vehicle for Internet access.

### ***Apps to go where no app has gone before***

Connectivity breeds apps. It is a given that as consumer electronic devices become wirelessly connected, consumers are looking to download apps on those platforms. Apps download on the iPod have been every bit of a success as they have been on the iPhone. Similarly, we will see a significant uptick in the apps for devices such as the iPad, telematics platforms in vehicles, digital cameras, navigation devices, picture frames, weight scales, and the list goes on and on. These apps will entertain and amuse consumers, analyze data on the devices, connect users with content and friends, and will interconnect various end-points in the pervasive mobile ecosystem in a much more profound manner.



## Conclusions

Over the course of the last two years, thousands of new developers have entered the app ecosystem. With the capability to design better user experiences and a more lucrative business model, developers have been designing apps for literally every possible scenario. From highly interactive games that only used to run on consoles to simple news or weather look up apps, there is practically an app for every scenario from bar exams to simulated libation consumption.

The app ecosystem itself is adjusting across multiple dimensions of regions, offdeck/ondeck, device type, and paid/advertising/virtual goods. The growth in the quality of the mobile advertising has opened up new revenue streams for developers. More accurate analytics, control over pricing, and generally a shorter time-to-market capability is providing developers to have a better understanding of how users react to apps, features, and pricing and enables developers to adjust their strategies accordingly.

As the number of active data subscribers across the planet continues to grow and as new forms of consumer electronics devices come online, we will continue to see the proliferation of apps in many directions.

## Acknowledgements

A project of this scope and nature can't be completed without the assistance from several players in the ecosystem. Over 20 companies from around the globe shared their data to help us build the model. These companies included store front providers, operators, OEMs, analytics companies, content providers, off deck providers, and aggregators. Our thanks to Motally, Smaato, Nexage, Getjar, Ringleader Digital, Playscreen, and the remaining companies who requested to stay anonymous, for assistance with the data that helped build the model for this paper.

## Disclaimer

This industry study was commissioned by Getjar.

The opinions expressed in this white paper are those of Chetan Sharma Consulting. Getjar commissioned the study but Chetan Sharma Consulting did all the research and writing for the paper. Getjar did provide unfettered access to its appstore data to be considered for analysis along with several other sources.

## About Chetan Sharma Consulting

Chetan Sharma Consulting is one of the most respected management consulting and strategic advisory firm in the mobile industry. We are focused on evolving trends, emerging challenges and opportunities, new business models and technology advances that will take our mobile communications industry to the next level. Our expertise is in developing innovation-driven product and IP strategy. Our clients range from small startups with disruptive ideas to multinational conglomerates looking for an edge. We assist major brands formulate winning, profitable, and sustainable strategies.

Please visit us at [www.chetansharma.com](http://www.chetansharma.com)

## About the Author

Chetan Sharma is President of Chetan Sharma Consulting and is one of the leading strategists in the mobile industry. Executives from wireless companies around the world seek his accurate predictions, independent insights, and actionable recommendations. He has served as an advisor to senior executive management of several Fortune 100 companies in the wireless space and is probably the only industry strategist who has advised each of the top 6 global mobile data operators. Some of his clients include NTT DoCoMo, Disney, KTF, China Mobile, Toyota, Comcast, Motorola, FedEx, Sony, Samsung, Alcatel Lucent, KDDI, Virgin Mobile, Sprint Nextel, Skype, AT&T Wireless, Reuters, Juniper, Qualcomm, Converse, Motricity, Reliance Infocomm, SAP, Merrill Lynch, American Express, and Hewlett-Packard.

Chetan is the author or co-author of five best-selling books on wireless including *Mobile Advertising: Supercharge your brand in the exploding wireless market* and *Wireless Broadband: Conflict and Convergence*. His books have been adopted in several corporate training programs and university courses at NYU, Stanford, and Tokyo University. His research work is widely quoted in the industry. Chetan is interviewed frequently by leading international media publications such as *Time* magazine, *New York Times*, *Wall Street Journal*, *Business Week*, *Japan Media Review*, *Mobile Communications International*, and *GigaOM*, and has appeared on NPR, WBBN, and CNBC as a wireless data technology expert.

Chetan is an advisor to CEOs and CTOs of some of the leading wireless technology companies on product strategy and Intellectual Property (IP) development, and serves on the advisory board of several companies. He is also one of the most sought after IP strategist and expert witness in the wireless industry and has worked on and testified in some of the most important cases in the industry such as Qualcomm vs. Broadcom, Samsung vs. Ericsson, Sprint vs. Verizon, and Upaid vs. Satyam. Chetan is a senior member of IEEE, IEEE Communications Society, and IEEE Computers Society. Chetan has Master of Science degree in Electrical Engineering from Kansas State University and Bachelor of Science degree from the Indian Institute of Technology, Roorkee.