The Economic Perspective of Cloud Computing

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Abstract- **Cloud computing is an innovative, emerging and a novel phenomenon that paves the way for provisioning of infinitely scalable, re-usable, multi-purpose, flexible, cost-saving, efficient and customizable on-demand information technology services and products. The promise of cloud computing is to deliver all the functionality of existing information technology services (and in fact enable new functionalities that are hitherto infeasible) even as it dramatically reduces the upfront costs of computing that deter many organizations from deploying many cutting-edge IT services . All such promise has led to lofty expectations — Gartner Research expects cloud computing to be a $150 billion business by 2014, and according to AMI partners, small and medium businesses are expected to spend over $100 billion on cloud computing by 2014. One recent survey of six corporate data centers found that most of the servers were using just 10–30% of their available computing power, while desktop computers have an average capacity utilization of less than 5%.A recently conducted survey by Gartner Research indicated that about two-thirds of the average corporate IT staffing budget goes towards routine support and maintenance activities. In this article we will present the concept, strengths, weakness, oppurtuties, threats and research agenda of cloud computing from the economic perspective.**

Keywords: **Cloud computing, Virtualization, Software as a service, Platform as a service, Infrastructure as a service.**

I. INTRODUCTION

The future of computing lies in cloud computing, whose major goal is reducing the IT services' costs while increasing processing throughput and decreasing processing time, increasing reliability, availability and flexibility [1]. Cloud computing is a new paradigm where computing resources (from data storage to complete configurations of distributed systems) are made available (offered) over the Internet as scalable, on-demand (Web) services. Fig.1 shows a general view of clouds (and their resources) in relation to a client.

In cloud computing, the resources hosted within clouds can be anything: they could be database services, virtual servers (virtual machines), complete service workflows or complex configurations of distributed computing systems such as clusters. Regardless of their nature, all resources are provided via services to clients (users or software processes) by computers rented from the cloud (such as those offered by e.g., Amazon, Google, Microsoft), rather than by private systems. The services are provided on demand and clients only pay for the quantity of resources (data storage, computation, etc.) they use.

In addition to services and resources, cloud computing has providers of two forms: service providers and cloud providers. A cloud provider is the entity that offers and maintains a cloud and may offer internally developed services on the cloud. A service provider is an entity that creates and maintains services that are published in and ran on clouds. For example, a service provider may not have the capita to host its own services hence rents space on a cloud to reduce costs.

An analysis of products and services released by Microsoft [2], Amazon [3], Google [4] and Salesforce [5−7], the best known cloud service providers, shows that clouds fall into a number of categories: applications (Software as a Service−SaaS), platform (Platform as a Service−PaaS) and hardware (Infrastructure as a Service−IaaS).

In the SaaS category, there is delivery of use-specific services over the Internet (such as CRM software and email). The benefit of SaaS clouds is that clients only focus on the use of the software and do not have to worry about the cost and effort to keep software licenses current nor the handling of software updates. However, SaaS clouds are not without their risks. The decision on whether or not to deploy

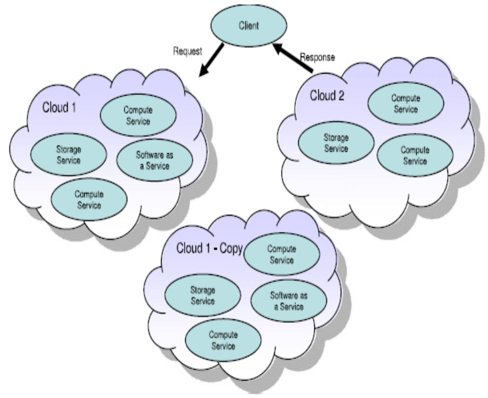

Fig.1. A single client vs. service provided by computing

PaaS clouds is clients are able to create their own required services and do not have to worry about provisioning and maintaining the hardware and software needed to run the services. On comparison, PaaS is like SaaS except clients are able to create software as well as use it.

While there is flexibility in what resources are provided, the underlying clouds are proprietary and specialized for internal uses. For example, while Amazon EC2 is the most commonly known IaaS cloud, how EC2 discovers and selects required resources from among their virtual servers (memory, CPU cycles, etc.) is not publicly known nor if such a function exists at all. There is also another issue: businesses experience problems when they wish to make services of their private clouds available.

While vendors have concentrated their effort on the improvement of performance, resource consumption and scalability, other cloud characteristics have been neglected. Clients face difficult problems of resource discovery and automatic services selection; dynamic sharing toward efficient management of resources; QoS and reputation of providers and clients; fault tolerance; cloud security and ease of use have been neglected. For example, clients to IaaS clouds are heavily billion business by 2014, and according to AMI partners, small and medium businesses are expected to spend over $100 billion on cloud computing by 2014.
utilization of less than 5% [13]. Equally pertinent are the maintenance and service costs that have proved to

Fig.1. A single client vs. service provided by computing clouds.

Finally, the IaaS category allows for the provisioning of hardware resources so cloud clients can create various configurations of computer systems from servers to complete clusters. Clients to IaaS are able to host their own services and even complete software systems without having to worry about hardware costs. On comparison to PaaS and SaaS, clients are able to create and use software as well as create and use an underlying software infrastructure to make the software possible.

involved in configuration of virtual servers and the execution of their applications in the same manner as programmers did years ago when they used a Unix system [8, 9].

As computing becomes more pervasive within the organization, the increasing complexity of managing the whole infrastructure of disparate information architectures and distributed data and software has made computing more expensive than ever before to an organization [11]. The promise of cloud computing is to deliver all the functionality of existing information technology services (and in fact enable new functionalities that are hitherto infeasible) even as it dramatically reduces the upfront costs of computing that deter many organizations from deploying many cutting-edge IT services [12]. All such promise has led to lofty expectations — Gartner Research
Expects cloud computing to be a $150

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about two-thirds of the average corporate IT staffing budget goes towards routine support and maintenance activities [14], which does seem anachronistic in an

age of globalized and cutthroat competition — as the CEO of a cloud platform provider commented recently, "If you woke up this morning and read in

The Wall Street Journal that, say, Overstock.com has stopped using UPS and FedEx and the U.S. mail, and had bought fleets of trucks and started leasing airport hubs and delivering products themselves, you would say they were out of their minds. Why is that much more insane than a health care company spending $2 billion a year on information technology?" [15].

Cloud computing represents a convergence of two major trends in information technology — (a) IT efficiency, whereby the power of modern computers is utilized more efficiently through highly scalable hardware and software resources and (b) business agility, whereby IT can be used as a competitive tool through rapid deployment, parallel batch processing, use of compute-intensive business analytics and mobile interactive applications that respond in real time to user requirements [16]. The concept of IT efficiency also embraces the ideas encapsulated in green computing, since not only are the computing resources used more efficiently, but further, the computers can be physically located in geographical areas that have access to cheap electricity while their computing power can be accessed long distances away over the Internet. However, as the term business agility implies, cloud computing is not just about cheap computing — it is also about businesses being able to use computational tools that can be deployed and scaled rapidly, even as it reduces the need for huge upfront investments that characterize enterprise IT setups today.[1]

[1] An oft-cited example is that of The New York Times, which used 100 Amazon EC2 instances and a Hadoop application to process 4 TB of raw image TIFF data (stored on Amazon S3 servers) into 11 million finished PDF documents in the space of 24 h at a computational cost of about $240 (excluding the sunk bandwidth costs).

Fig. 2 shows a schematic of the cloud computing model. It shows how the computing resources in the cloud can be accessed from a variety of platforms through the Internet.

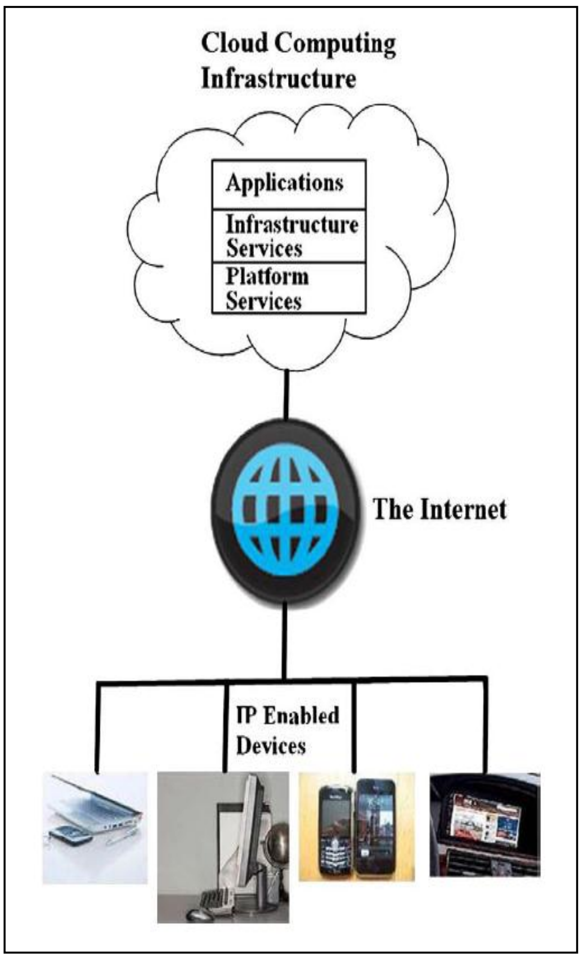

Fig.2. Cloud computing infrastructure.

II. THE KEY ADVANTAGES OF COUD COMPUTING

Cloud computing offers the following key advantages:

1. It dramatically lowers the cost of entry for smaller firms trying to benefit from compute-intensive business analytics that were hitherto available only to the largest of corporations. These computational exercises typically involve large amounts of computing power for relatively short amounts of time,[2] and cloud computing makes such dynamic provisioning of resources possible. Cloud computing also represents a huge opportunity to many third-world countries that have been so far left behind in the IT revolution —some cloud computing providers are using the advantages of a cloud platform to enable IT services in countries that would have traditionally lacked the resources for widespread deployment of IT services.

2. It can provide an almost immediate access to hardware resources, with no upfront capital investments for users, leading to a faster time to market in many businesses. Treating IT as an operational expense (in industry-speak, employing an 'Op-ex' as opposed to a 'Cap-ex' model) also helps in dramatically reducing the upfront costs in corporate computing. For example, many of the promising new Internet startups like 37 Signals, Jungle Disk, Gigavox, SmugMug and others were realized with investments in information technology that are orders of magnitude lesser than that required

just a few years ago. The cloud becomes an adaptive infrastructure that can be shared by different end users, each of whom might use it in very different ways. The users are completely separated from each other, and the flexibility of the infrastructure allows for computing loads to be balanced on the fly as more users join the system (the process of setting up the infrastructure has become so standardized that adding computing capacity has become almost as simple as adding building blocks to an existing grid). The beauty of the arrangement is that as the number of users goes up, the demand load on the system gets more balanced in a stochastic sense, even as its economies of scale expand.

3. Cloud computing can lower IT barriers to innovation, as can be witnessed from the many promising startups, from the ubiquitous online applications such as Facebook and Youtube to the more focused applications like TripIt (for managing one's travel) or Mint (for managing one's personal finances).

4. Cloud computing makes it easier for enterprises to scale their services – which are increasingly reliant on accurate information – according to client demand. Since the computing resources are managed through software, they can be deployed very fast as new requirements arise. In fact, the goal of cloud computing is to scale resources up or down dynamically through software APIs depending on client load with minimal service provider interaction [17].

5. Cloud computing also makes possible new classes of applications and delivers services that were not possible before. Examples include (a) mobile interactive applications that are location-, environment- and context-aware and that respond in real time to information provided by human users, nonhuman sensors (e.g. humidity and stress sensors within a shipping container) or even from independent information services (e.g. worldwide weather data)[3]; (b) parallel batch processing, that allows users to take advantage of huge amounts of processing power to analyze terabytes of data for relatively small periods of time, while programming abstractions like Google's MapReduce or its open source counterpart Hadoop makes the complex process of parallel execution of an application over hundreds of servers transparent to programmers; (c) business analytics that can use the vast amount of computer resources to understand customers, buying habits, supply chains and so on from voluminous amounts of data; and (d) extensions of compute-intensive desktop applications that can offload the data crunching to the cloud leaving only the rendering of the processed data at the front-end, with the availability of network bandwidth reducing the latency involved.

[2] Amazon recently announced availability of specialized Cluster GPU instances for its EC2 services for high performance computing (HPC) and data intensive applications.

[3] Perhaps one of the most striking and innovative uses of the cloud can be witnessed at the MIT Media Labs' SixthSense technologies, a set of wearable sensors that augments the physical world with information from the cloud, and lets people use natural hand gestures to interact with that information.

III. CORE TECHNOLOGICAL CONCEPTS AND TERMINOLOGY

While the evolution of cloud computing will take several years or even a decade to fully unfold, the three core technologies that will enable it – virtualization, multitenancy and Web services – are rapidly taking shape.

Virtualization is the technology that hides the physical characteristics of a computing platform from the users, instead presenting an abstract, emulated computing platform [18]. This emulated computing platform for all practical purposes behaves like an independent system, but unlike a physical system, can be configured on demand, and maintained and replicated very easily. The computing infrastructure is much better utilized, leading to lower upfront and operational costs (one side benefit of virtualization is the savings in real estate for the data centers).

A related concept is that of multitenancy, whereby a single instance of an application software serves multiple clients. This allows better utilization of a system's resources (in terms of memory and processing overhead), the requirements of which could otherwise be considerable if the software instance had to be duplicated for each individual client.

A Web service is defined by the W3C as "a software system designed to support interoperable machine-to-machine interaction over a network" [19]. The definition encompasses many different systems, but in common usage the term refers to clients and servers that communicate over the HTTP protocol used on the Web. Web services help standardize the interfaces between applications, making it easier for a software client (e.g. a web browser) to access server applications over a network.

A public cloud is characterized as being available from a third party service provider via the

Internet, and is a cost-effective way to deploy IT solutions, especially for small or medium sized businesses. Google Apps is a prominent example of a public cloud that is used by many organizations of all sizes. A private cloud offers many of the benefits of a public cloud computing environment, such as being elastic and service based, but is managed within an organization. Private clouds provide greater control over the cloud infrastructure, and are often suitable for larger installations. A private cloud can actually be handled by a third-party provider, e.g. the upcoming Government Cloud product from Google that will be certified under the Federal Information Security Management Act (FISMA) to store both applications and data of government agencies in a completely segregated environment, both logically and physically. A community cloud is controlled and used by a group of organizations that have shared interests, such as specific security requirements or a common mission. The United States federal government is one of the biggest users of a community cloud: built on Terremark's Enterprise cloud platform, it has allowed the government to rapidly deploy very specific applications such as Forms.gov (for all federal forms) to the topical Cars.gov (for the so-called 'Cash for Clunkers' program) and Flu.gov, all of which are all linked to the U.S. government's official web portal USA.gov. In October 2010, The U.S. General Services Administration selected Enomaly to provide cloud based IaaS to federal, state and local governments through the government's cloud-based services storefront, Apps.gov. as a Finally, a hybrid cloud is a combination of a public and private cloud — typically, non-critical information is outsourced to the public cloud, while business-critical services and data are kept within the control of the organization.

IV. CLOUD COMPUTING-A SWOT ANALTSIS

A. Strengths

The ability to scale up services at a very short notice obviates the need for underutilized servers in anticipation of peak demand. When an organization has unanticipated usage spikes in computing above its internally installed capacity, it has the ability to request more computing resources on the fly. Cloud computing offers organizations the ability to effectively use time distributed computing resources. One example is that of an internet photo website Smugmug. The company has relatively stable computing workloads throughout the year; however during the months of December and January the required resources spike to five times the usual workload. Cloud computing allows the company to meet the excess requirements during the two months without incurring the costs of hosting a traditional infrastructure for the rest of the year.

In 2000, over 45% of capital equipment budget was spent on IT, however on average only 6% of the server capacity is utilized. Assuming a 3-year lifespan of a server, the infrastructure and energy costs alone exceed the purchase price of a server. Cloud computing leads to reduced infrastructure costs and energy savings as well reduced upgrades and maintenance costs. Economies of scale for datacenters cost savings can lead to a 5- to 7-time reduction in the total cost of computing [20].

One of the components of maintenance costs is the management of technology, which is potentially made much simpler by using a cloud computing service. Preset configuration of servers and virtual machines can be put in place with appropriate applications, security, and data. (With so much of personal computing moving to virtual servers or to the cloud, it is perhaps no wonder that the market for enterprise servers is expected to double by 2013 [21].) This allows for a more secure environment with the company having better control of the resources on their network. Cloud computing services allow an organization to control when, where, and how employees have access to the organization's computer systems, all managed over a simple web-based interface (for example, Amazon Web Services (AWS) can be managed easily through the AWS Management Console). Employees like the arrangement too, since they are able to make full use of the company's computer systems using less powerful devices such as a smartphone or a netbook.

B. Weaknesses

There are many issues that need to be resolved before cloud computing can be accepted as a viable choice in business computing. As pointed out in the previous section, organizations will be justifiably wary of the loss of physical control of the data that is put on the cloud. Hitherto, providers have been unable to guarantee the location of a company's information on specified set of servers in a specified location. However, cloud computing service providers are rapidly adopting measures to handle this issue. For example, Amazon Web Services recently announced the Amazon Virtual Private Cloud that allows a business to connect its existing infrastructure to a set of isolated AWS compute resources via a VPN connection. To satisfy the

European Union data regulations, AWS now allows for companies to deploy its SimpleDB structured storage physically within the EU region. The Government Cloud product from Google that we alluded to earlier is also a response to allay concerns from government entities over the location of their data.

Large organizations will also be wary of entrusting mission-critical applications to a cloud computing paradigm where providers cannot commit to the high quality of service and availability guarantees that are demanded in such environments. For example, Amazon Web Services Service Level Agreement (SLA) currently commits to an annual uptime percentage of 99.95% over the trailing 365 days, which might be enough for most small- and medium-sized organizations, but will be deemed insufficient for mission-critical applications for large organizations. Even though many in-house IT services often fail to live up to such uptime standards, such failures are not held up for media scrutiny, unlike the much-publicized failures of prominent cloud computing service providers.

C. Opportunities

One of the significant opportunities of cloud computing lies in its potential to help developing countries reap the benefits of information technology without the significant upfront investments that have stymied past efforts. In fact, cloud computing might do to computing in developing countries what mobile phones did to communications — allow the governments and local firms to benefit from the effective use of information technology. A recent survey by the Forrester Group indicates that SaaS is a priority for 74% of Chinese firms, with 29% planning to pilot SaaS projects in the next 12 months. In contrast, the survey found that a majority of European or American firms is interested but have no plans to pursue SaaS [22]. An impressive example of the power of cloud computing in developing countries comes from Ethiopia, where the government has commissioned the cloud computing provider FullArmor to remotely manage 250,000 laptops with teachers throughout the country. The laptops will contain sensitive teacher and student data, and information like syllabi and class material will be managed centrally. In order to prevent security breaches, if a laptop drifts outside a virtual "fence", its contents can be remotely 'wiped' (i.e. made unusable) through cloud-based interfaces. Much like developing countries, small businesses represent another huge opportunity for cloud computing. All of a sudden, small businesses can exploit high-end applications like ERP software or business analytics that were hitherto unavailable to them. While it can be argued that some of the more involved features of such applications might not be available on their cloud-based counterparts, such omissions will matter very little for their intended customers [23].

Mashups represent another opportunity in cloud computing. In web development, a mashup is a web page or application that combines data or functionality from two or more external sources to create a new service in originally unintended ways. An example of a mashup is the use of cartographic data to add location information to real estate data, thereby creating a new and distinct Web service that was not originally provided by either source. The new type of mashup that we are beginning to see combines different cloud computing services and integrates them into a single service or application. Amazon's GrepTheWeb is a good example for cloud computing service compositions within the domain of a single provider.

In an age where businesses are looking to burnish their 'green' credentials, cloud computing appeals to large IT infrastructures that want to reduce their carbon footprint. According to a Forrester survey, over 41 percent of people in the IT departments believe energy efficiency and equipment recycling are important factors that need to be considered. In the same survey, 65 percent believed reduction of energy related operating costs as the driving factor for implementing Green IT [24]. Moving to the cloud will allow organizations to not only reduce their IT infrastructure, but, since it is much cheaper to transport computing services than energy, it will also represent a smarter use of energy.

In his much-heralded book, The Innovator's Dilemma, Clayton Christensen pointed to disruptive technologies as innovations that upset the existing order of things in a particular industry [25]. Such disruptive technologies are usually lower-functionality innovations that appeal to customers who are not served by the current industry, but which quickly leapfrog the market incumbents in terms of functionality, innovation and price to upend the latter. Cloud computing today shows all the characteristics of a disruptive technology. We believe that many of the innovative services that will be developed on the cloud – such as the education applications being developed for Ethiopian schools – will soon make many cloud computing applications functionally richer than their in-house counterparts.

D. Threats

One of the biggest threats to cloud computing is the possibility of backlash from entrenched incumbents. While we believe that many forward-looking organizations will see cloud computing as an opportunity to migrate to better computing practices that open up exciting opportunities for the in-house IT staff, there will probably be many other IT departments will view it as a threat to their corporate IT culture (in terms of data security, IT audit policies, etc.) or just in terms of job security. Although small businesses have been quick to adapt and even welcome cloud computing, larger corporate customers have voiced a plethora of concerns about handing over their operations to another company. Another legitimate concern has centered on cloud providers going bankrupt, especially in a shrinking economy. Yet another concern is security — in an ongoing survey conducted by the research firm IDC, almost 75 percent of IT executives and CIOs report that security is their primary concern, followed by performance and reliability [26]. The cloud computing industry continues to make rapid strides in all these areas, but it will still be interesting to see how all these threats play out over the next few years in this nascent industry.

Several concerns have centered on the lack of standards. The cloud has been described as "a trap" by GNU creator and Free Software Foundation founder Richard Stallman — one where companies like Google will force customers into locked, proprietary systems that will gradually cost more and more over time. It is therefore encouraging to note that the International Organization for Standardization's (ISO) technical committee for information technology has just announced the formation of a new Subcommittee on Distributed Application Platforms and Services (DAPS) that includes working a Study Group for standardization of cloud computing, with the goal of pursuing "active liaison and collaboration with all appropriate bodies…to ensure the development and deployment of interoperable distributed application platform and services standards in relevant areas." More informally, industry professionals have coalesced to form several bodies like the Open Web Foundation (formed in 2008) that promote the development and protection of open, non-proprietary specifications for web technologies. Anticipating the backlash against proprietary cloud computing platforms, cloud computing providers are also proactively promoting standards. The recent formation of EuroCloud (in 2009), backed by more than 30 leading cloud computing vendors, to promote the development of standards in cloud computing across the EU that coordinate with local issues at the national level of individual countries is a welcome step. Even individual providers have promoted standards — for example, Google has formed the Data Liberation Front, an engineering team within Google whose goal is to make it easier for users to move their data in and out of Google products [27]; and Microsoft has recently filed a patent for a method that promises to streamline the process of moving from one cloud to another, and in many cases completely automate the process [28].

Perhaps the biggest factor that will impede the adoption of the cloud computing paradigm is regulation at the local, national, and international level. Regulation can range from data privacy and data access to audit requirements and data location requirements. When corporate data are moved to the cloud, regulations such as Sarbanes- Oxley and the Health and Human Services Health Insurance Portability and Accountability Act (HIPAA) with their defined requirements for physical data audit will come into play. Such and other requirements at the local, national and international level (e.g. many nations have laws requiring SaaS providers to keep customer data and copyrighted material within national boundaries) might negate many the benefits of cloud computing [29].

V. A SUGGESTED RESEARCH AGENDA

The research agenda in cloud computing can be divided into six categories: (1) Cloud computing economics; (3) Cloud computing and IT strategy/policy issues (including security); (4) Technology adoption and implementation issues; (5) Cloud computing and green IT; and (6) Regulatory issues.

VI. CONCLUSION

Cloud computing is here to stay. The specific roadmap for the technology might be still unclear, but the fundamental economic and business forces that shape the computing industry point to a logical conclusion: many computing applications are general-purpose in nature, and therefore offer tremendous economies of scale if their supply can be consolidated. While the researchers and practitioners in the computer science community are making rapid strides in realizing this conclusion in technological terms, we believe that an equally important discussion needs to start from a economic perspective. Unlike some of the previous waves in computing, cloud computing also demands a thoughtful and coordinated response from governmental agencies, and we have listed down some of the key issues in this respect.

The famous physicist Niels Bohr once said, "Prediction is very difficult, especially about the future." The fluid and uncertain environment that surrounds cloud computing – be it in terms of the technology, its adoption, the industry structure or the regulatory regime that will eventually need to be in place – makes such an exercise that much more difficult. We however hope that our attempt to look at the phenomenon through a economic perspective reduces some of the uncertainty surrounding the phenomenon, and more importantly jumpstarts the discussions on the various issues that we have identified.

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