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Internet Innovations–Software *Is* Eating the World: Software-Defined Ecosystems and the Related Innovations Result in a Programmable Enterprise

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10.1 The Internet as a Driver for Innovations

The Internet has been the foundation for innovative changes in the use of computing, networking, and storage over the past decade. One major innovation, software-defined ecosystems,[1] has provided a platform for a series of innovations that would only have occurred if today's dramatically altered infrastructure—cloud computing infrastructure—was available to support them. These innovations have transformed how businesses operate, how software is developed, how we analyze data.

What drives these Internet innovations is a major structural change from the "Old IP" to the "New IP." The Old IP was the dominant Internet infrastructure from the early 1990s until recently. The "Old IP" is hardware-centric, with a rigid topology and architecture, innovation depended on proprietary but standards-based innovation. By contrast, the "New IP" is software-centric, fluid in topology and architecture, and capable of scaling clients and resources on demand.[2]

A basic innovation, software-defined infrastructure, lies at the heart of the "New IP," software-defined ecosystems. Facebook, Amazon, Netflix, and Alphabet (formerly Google) have built their operations on these ecosystems. The infrastructure they have built lets them benefit from the enormous growth of mobile video and data traffic. These firms have also commercialized business operations that underpin a vast expansion of social media and data analytics.

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10.2 Software-Defined Infrastructure: The Central Software Innovation

The Internet's key innovation is software-defined infrastructure. This innovation is the cornerstone of software-defined environments. In these environments, software not only replaces hardware (creating software-defined infrastructure) at the heart of computing, storage, and communications networks, but also becomes the platform and prime tool to develop new business processes, create new applications, and perform more complex data analysis.

This essay finds that contrary to strongly held views that the Internet's contribution to innovation, productivity, and growth ended years ago,[3] the adoption of software-defined environments has expanded the products, services, and markets that the economy supports. Thus, the expression, "software will eat the world,"[4] namely, that software will not only disrupt traditional industries, but also add significant efficiencies to existing industries, is not ill-considered. Through software-based innovations, the Internet will expand our economic base far beyond its current limits. It will promote job growth and improve productivity.

This will occur as innovations linked to software-defined environments change the way infrastructure functions. We begin by describing software-defined environments. We then explore how this fundamental innovation alters not only how we develop software, but also manage and analyze data and complex networks. These are the knock-on innovations that are tied to the core change, software-defined environments. These secondary innovations are central to recent advances in the economy. Without them businesses would find it impossible to manage production, optimize supply chains, or to operate real-time sensor networks for aircraft management, driverless vehicles, agricultural planting and harvesting, and wearable devices.

10.3 Software-Defined Environments: Controlling Today's Infrastructure

Software-defined environments are based upon software-defined infrastructure (SDI). This infrastructure relies upon software controls and instructions. It distinguishes today's infrastructure from that at the beginning of the Internet Age (1990–2000). SDI is a new "software platform." As such, it manages operational requirements that hardware once defined, i.e., software replaces the functions of physical equipment, such as servers, switches, load balancers, and intrusion detection devices.

When infrastructure shifts to being software-defined, software commands direct infrastructure to perform in a way that is more flexible, agile, scalable, and interoperable than was possible 15 years ago. If a group needs to test new software by scaling to a "business-wide operational level" involving access to tens of thousands of servers, this can be done in seconds because the software-defined environment can amass the required servers inside an enterprise or from the public cloud—from providers, such as Amazon AWS or Microsoft Azure—to do the testing in seconds instead of weeks or months.

10.4 The Move to OpenStack and APIs

The emergence of OpenStack and APIs has made it much easier for companies to transform their infrastructure and adopt software-defined ecosystems.

OpenStack is possible because of the open source model that many firms have decided to adopt. The open source movement began with the free release of the code for Netscape,[5] an early Internet browser over 25 years ago. Since open source software is free, it changes the economics of building software-defined infrastructure. Many firms, including Netflix, place their software on an Internet-based exchange named GitHub, where it is licensed for free use by others. AT&T has said it will increase the amount of open source software that it is using from 5% in 2015 to about 50% by 2020.[6]

Open source software encompasses a broader movement of technologists that is called OpenStack. OpenStack is "a free and open-source software platform for cloud computing …. The software platform consists of interrelated components that control hardware pools of processing, storage, and networking resources throughout a data center. Users either manage it through a web-based dashboard, through command-line tools, or through a RESTful API."[7]

APIs or Application Programming Interfaces let programmers interact with private and public OpenStack clouds. APIs are a set of techniques used "by computer programs to request services from the operating system, software libraries or any other service providers [are] running on the computer." By using APIs, developers can provide access to a proprietary software application. An API's code includes "requirements that govern how one application can communicate and interact with another. They also allow developers to access certain internal functions of a program."[8] More simply, APIs permit one software to interact with another. This lets developers in one firm create interfaces that can access software or developers in another organization to access an interface by using APIs.[9]

The real value of APIs is to make it possible for people and/or software—"automated service discovery"—to identify ways to manage other software and to automate business processes. While this is expected to happen in the future, the benefits of automating business processes are likely to be great. Thus, APIs might come to the fore more rapidly than expected.[10]

10.5 The Emergence of Continuous Software Delivery and DevOps: Creating Software Using Software

Agile software-defined environments have transformed how businesses design software. One innovation, "Continuous Service Delivery"[11] changes software development from a highly siloed series of processes—where every part in the software creation process took days to complete—to a new collaborative team structure. DevOps[12] is a complementary process change that accelerates software development by making processes more agile and lean. It also provides the basis for automating segments of the software development process, initially by using modular subparts of software or "microservices." Recent surveys show that many firms have already optimized this process and are able to deploy a new application or service in less than 15 minutes.[13]

10.6 Containers: An Innovation to Deploy and Manage Software and Data

A related innovation is containerization. Containers are a software-defined structure that is attached to servers that define applications and the environment in which they will operate, as well as the data they can use. This innovation has simplified the software development process so greatly that some firms are running hundreds of containers on a single server. With containers, resources behave as though they are part of a single, unified environment.

The main benefit of containers is to accelerate software implementation at different locations. Containers also create a pipeline for the distribution of new services. In addition, containers support building new software once and running it on different platforms.

10.7 Federating Data and Providing for Data Collection at the Edge of Networks ("Fog Computing")

Many firms are analyzing large databases. In the case of firms in several major industries, this has only been possible with the consolidation of data centers. So, Boeing, Ford, GM, UPS, and FedEx, as well as Netflix, Facebook, and other firms have created "big data" lakes they analyze by using sophisticated analytic tools.

For aerospace and auto firms, the analysis of "big data" streamlines the operations of suppliers around the globe. In other industries, firms, such as health-care providers are linking the analysis of "big data" genomic information to treatment outcomes. By doing so, they are transforming health care.

"Fog Computing" is the decentralization of infrastructure to support driverless cars and wearable devices. Today's software-defined ecosystems support this decentralization, where computing, storage, and networking, to support sensor networks, are relocated to the periphery of networks. This changes the architecture of infrastructure by relocating equipment and software to end points in data networks. This restructuring lets such peripheral centers collect data from planes, cars, and wearers of health devices collected transmissions close to their source and provides a way to evaluate them quickly.

10.8 Block Chains and More Secure Infrastructure

Block Chains[14] are "a public transaction ledger built in a network structure based on cryptographic principles so there does not need to be a centralized intermediary. Any kind of asset (art, car, home, financial contract) may be encoded into the blockchain and transacted, validated, or preserved in a much more efficient manner than at present including ideas, health data, financial assets, automobiles, and government documents."[15]

This innovation is important since it provides a way to insure the validity of a transaction in a network. Block chains can insure that data transmitted by sensor networks is valid because it meets the requirements encoded in the block chain.

10.9 The Impact of Recent Internet Innovations

Internet innovations have already had a dramatic impact on enterprise IT spending. They are expected to have an even greater impact in the future. RackSpace reports that in 2015, "68 percent of enterprises run less than a fifth of their application portfolio in the cloud; 55 percent of enterprises report that a significant portion of their existing application portfolio is not in cloud, but is built with cloud-friendly architectures."[16] This seems like slow progress. Nevertheless, Intel has estimated that by 2020, 65–85% of applications, nearly all of them, will be run on cloud infrastructure.[17]

Nomura Research[18] has confirmed these rapid changes. By 2014, many firms shifted IT consumption from traditional internal infrastructure—not based on cloud computing or software-defined infrastructure—to cloud-based infrastructure. Furthermore, by 2018, Nomura finds that spending on non-cloud-based internal infrastructure will drop to 40% of total enterprise IT consumption.[19]

Why is this happening? First, software-defined ecosystems use software, some of which is developed with Open Source and APIs, to create much less expensive and far more capable—scalable as well as interoperable—infrastructure. While these changes don't appear in US productivity data, they represent tremendous changes in the cost and ability of business to use ever more sophisticated computing, storage, and networking.

Thus, the innovations identified here are having a real effect on the economy. When firms have used this new software-defined infrastructure that permits them to implement far more mathematically sophisticated data analysis, they are saving billions of dollars by optimizing supply chains[20] and other service operations. In some cases, as at Boeing, they are expanding the scale of production[21] far beyond what was possible with traditional infrastructure.

Thus, the new infrastructure innovations described here are already having significant impacts on profits and return on assets. In the future, driverless cars and wearable devices will depend on the software-defined infrastructure described here and open vast new opportunities to expand how our economy uses computing, networking, and storage.

10.9.1 As Enterprises Adopt Cloud Computing, the Firm Changes to a "Programmable Enterprise"[22]

One illustration of how the innovations cited above are changing the economy is the shift in the way the firm operates. I call this new change a shift to the "programmable enterprise." I have chosen this phrase because the innovations in infrastructure changes mean that a firm's competitiveness and dynamism are now defined more by how it adopts the innovations enumerated in the previous sections.

We argue here that changes in technology based on the virtualization of computing and networking will transform the business world into one where software and services play a dominant role. This will change the jobs people perform and mean that most jobs will require more technical skills. These changes will occur very rapidly and traditional training mechanisms very likely will be unable to adjust to them.

The "programmable enterprise" differs from traditional firms. It is shaped by three main trends: cloud computing; handling big data; and managing sensor ecosystems that are part of the Internet of Things. New types of jobs will result from these trends. Some illustrations are: continuous service delivery jobs where employees become skilled generalists and part of DevOps teams, data analytics teams, and jobs related to sensor ecosystems.

Programmable firms have new, open, extensible, and interoperable computing and communications architectures. These businesses expect to survive based upon their ability to create new services and applications based on this new architecture. As illustrated by the MetLife case, the analysis of big data will be at the heart of "programmable enterprises."

The programmable firm represents not only talented and very skilled people, but also substantial numbers of managerial, support, and marketing employees. It is highly "people-centered" because its central purpose is connecting people and responding to their needs.

We recently estimated based on spending for cloud services that spending on cloud services (cloud computing, data analysis, and the Internet of Things) will contribute $1.7 trillion in new spending, add 3 trillion to GDP, and create about 8 million jobs for the US economy by 2025. This would add about 1.5% per year to GDP and about 0.5% per year to employment growth.[23]

10.9.2 The "Programmable Enterprise"—The Motor Promoting Dramatic Job Change

Three trends are shaping the evolution of firms:

1. The adoption of cloud computing and a shift of applications to a cloud environment.
2. Developing the ability to deal with big data because of the need to run real-time analytics and to link operational tools and processes to applications.[24] In part, this responds to much greater use of mobile applications.

3. Moving into sensor ecosystems and Internet of Things. This dominates retailing, firms with a web presence, such as eBay and Twitter, and firms that maintain and control equipment or services, including driverless cars. This trend will affect health care, but not until many operational and data privacy issues are resolved.

As a result, "programmable firms" are *distinguished by the new*, *open*, *extensible*, *and interoperable computing and communications architecture they have deployed and continue to expand*.

Rather than being "creative," these businesses expect to survive based upon their ability to create new services and applications for customers and suppliers. The innovative architecture—possible only with the help of refinements to virtualization and cloud computing over the last 3–5 years, turns functions and processes that had once been impossible and time-consuming to create into a key characteristic of "programmable firms." It provides them with the ability to operate new ecosystems, especially a series of functions driven by huge amounts of data analysis. These functions provide firms with the ability to develop software platforms that support innovative services of substantial value. They also offer paths to improve the value offered by such services in the future.

To illustrate this with a case, MetLife is one of the firms that has moved rapidly to establish itself as a provider of services, going beyond being a firm that merely sells insurance. It focused much of its transformation on its ability to gather large amounts of data on policyholders, not only characteristics of individuals holding policies, but also data on the places they live, the health care in their community, climate, and other dimensions.

With tools that come from the latest generation of big data analysis, MetLife created a wall for all its policyholders and their recent transactions. Using the wall, a MetLife employee can respond to a policyholder's call and see an entire window of recent interactions with the company, based upon sophisticated data management tools and links. This provides timely and comprehensive service without the usual delays.

But this is not just an easier way to respond to inquiries. It indicates that new technologies, such as Hadoop together with tools, such as MongoDB[25] are providing new ways to employ data analytics to obtain insights into many firms' big data lakes.

In addition, because of its command over big data, MetLife can do what other firms, such as Netflix already do.[26] It can see what groups of users like to do when they call for policy information. It can offer them different bundles of services or policies and see what works and what does not. It can evaluate what is going amiss when policyholders or customers terminate their policies and try to correct the flaws. It can also analyze the behavior of specific populations of policyholders or groups within the population.

This indicates that the analysis of big data and creation of new services will be at the heart of "programmable enterprises." It also indicates that what is new about these companies is:

1. A *unique architecture* in their enterprise computing and networking, based broadly upon open systems and standards, with easy "end-to-end" connectivity.[27] This architecture facilitates resource sharing and agile creation of new services.
2. Their ability to analyze and manage enormous amounts of data.
3. The ability to create new services based upon the innovative architecture and data analytics.
4. The development of *software and services platforms* within the organization and outside of it to distribute and manage existing, emerging, and future services.

Building on these innovative capabilities, the "programmable firm" represents not only talented and very skilled people, but also substantial numbers of managerial, support, and marketing employees. These employees are probably going to account for 30–60%[28] of a "programmable firm." The engineering and research, operations, IT and IS staff will account for about 40–70% of employees, with the higher share being true for startups.

In addition, through secondary impacts, the employment in these firms might provide jobs in related areas that also have substantial multiplier impacts of their own. Prof. Enrico Moretti[29] has estimated that Silicon Valley firms create a disproportionate number of legal and engineering jobs as well as many personal service jobs.

Thus, the jobs created by new "programmable firms" are likely to include more than just IT jobs. In their secondary or multiplier impacts, these firms are also more likely to support the creation of a wide range of jobs largely outside of information technology.

The new architecture for business does several things that will affect jobs and the pattern of employment:

1. It creates new jobs, such as DevOps positions that combine software design, software testing, and software deployment. This is an example of a "Hybrid" job, but it also indicates that the new jobs in the emerging economy will be far more skilled than previously. Rather than providing tasks, new jobs will demand skills.

2. It provides a way for services to create new value in the economy. The new economy is not likely to be a guild economy where the central focus is "liberating value."[30] Rather, it is innovating to create new services on top of the new computing and networking architecture, largely by exploiting new software platforms that can provide new functions for the economy.
3. Software and services become the defining features of the new economy. This means that productivity gains are based upon improvements in the efficiency in the use of resources and processes that can be controlled and managed by software.

Companies can be overwhelmed by the number of transactions they must manage and the constant demand for new applications and services due to the glut of mobile communications and a rapid rise in data flows. To respond, some firms have developed rapid action teams to make their firms more productive and responsive.

This permits such firms not only to derive important advantages from the new software-defined infrastructure that supports accelerating product and service development, but also to create work teams or groups that meld skills that had formerly been isolated to perform specific tasks. So, these firms are terminating jobs, such as software developers or quality assurance employees. The new positions they are filling in teams or squads have superseded the old occupations. The new occupational designation for these employees is not clear, nor are the tasks clearly defined. Team and squad members may be called platform team engineers but this is not true of all cases where such positions exist.

These changes in the workforce are part of an experiment in agility that has begun over the past 5 years. As the use of virtualized infrastructure with software-defined networking, cloud computing, and containers becomes more widespread, it is providing firms with a chance not only to speed the creation of new products and services, but also to emphasize creativity and teamwork above task work.

The new types of jobs that will arise from these trends are:

1. Programming jobs and support for "continuous service delivery" and the creation of microservices. These positions usually merge old technology competencies, so a "platform engineer" may need to know about DevOps (software programming), networks, and storage. In some cases, positions that formerly required only business knowledge, like a data center manager may need to be more technical and know how to work "hands-on" with Hadoop.

2. Data analytics teams that must perform rapid analyses and set up data visualization and reports on trends and new directions. This requires higher level competency with new database tools, such as Hadoop and Apache. It also requires lower level jobs to assemble and manage the data and translate the analysis into understandable discussions or reports.
3. Jobs from sensor ecosystems will expand due to several requirements. First, the building and deployment of ecosystem infrastructure, particularly computing, storage, and networking at the edge of large enterprise or public networks. These ecosystems will most likely evolve through several stages, so the building will not end in the first phase of building but require several stages of rebuilding to add more capabilities. Second, data analysts and managers to support the retailing, web, and maintenance firms that will be big early users. Major areas of expansion will be data analytics (extending big data analytics mentioned above), computer security, and software developers.

10.10 Conclusions

This chapter identifies Internet innovations made possible by the emergence of software-defined infrastructure. Most of these are based upon the fact that software is driving innovation in the way we use infrastructure and how we develop new services and applications.

Without understanding the central role of software in innovations, it would be easy to conclude that the Internet has not contributed to recent innovations in the US and global economies and will not contribute to future growth. Given the wide range of innovations identified here, that would be an unfair oversimplification.

While it is almost impossible to find the impact of these innovations in current data, they are creating a new generation of infrastructure and services that is likely to have as dramatic an impact on the economy as the early ascent of the Internet.

We also argue that changes in technology based on virtualization will dramatically change the types of jobs people perform. These changes will occur very rapidly and traditional training mechanisms will be unable to adjust. This will open new categories of jobs for people that lack formal degrees. Employers like Microsoft[31] are already moving people to the types of jobs that will be needed in this new economy and providing them with new skills to function effectively.

Notes

1. We use the phrase software-defined ecosystems as a synonym for the "New IP" and the Internet of Things. Some groups believe that the innovation described here is a precursor for much broader changes in the future. The 2nd International Workshop on Software-Defined Ecosystems (BigSystem 2015) notes: "With the emerging technology breakthrough in computing, networking, and storage, the boundary of systems is undergoing fundamental change and is expected to logically disappear. It is the time to rethink system design and management without boundaries toward software-defined ecosystems, i.e., the BigSystem. The basic principles of software-defined mechanisms and policies have witnessed great success in clouds and networking. We are expecting broader, deeper, and greater evolution of these concepts and technologies, and a confluence toward holistic *software-defined ecosystems*." [emphasis added] Association for Computing Machinery, Portland, Oregon, June 15–19, 2015, http://bigsystem.ece.ufl.edu/2015/.
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12. "DevOps is a new term emerging from the collision of two major related trends. The first was also called "agile system administration" or "agile operations"; it sprang from applying newer Agile and Lean approaches to

operations work. The second is a much-expanded understanding of the value of collaboration between development and operations staff throughout all stages of the development lifecycle when creating and operating a service, and how important operations has become in our increasingly service-oriented world." "What Is DevOps?" http://theagileadmin.com/what-is-devops/.

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23. Cohen, Robert, "Enterprise Spending on Cloud Services Will Expand US GDP, Jobs and Tech Spending. A New Forecast Predicts the US Economy will gain nearly 3 Trillion Dollars in GDP and 8 Million new Jobs from 2015 to 2025." Economic Strategy Institute, http://www.econstrat.org/research/the-new-ip-and-the-internet-of-things/638-cloud-services-till-expand-us-gdp-jobs-and-tech-spending.

24. Anderson, Chris (2008), "The End of Theory Will the Data Deluge Makes the Scientific Method Obsolete?" *Edge: The Third Culture*, June 30, https://www.edge.org/3rd_culture/anderson08/anderson08_index.html. Anderson argues that scientific methods based upon "grand theories" are not likely to survive the emergence of big data. He says of the petabyte world that "It calls for an entirely different approach, one that requires us to lose the tether of data as something that can be visualized in its totality. It forces us to view data mathematically first and establish a context for it later." I would argue that we are likely to find new and innovative methods to analyze and visualize big data and I am not sure I would agree with Anderson's conclusion. I think with new mathematical and visualization techniques, we may continue to be able to visualize data in its entirety.
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26. Adrian Cockcroft of Battery Ventures, formerly at Netflix, personal discussion with the author at the Open Network Users Group (ONUG), Columbia University, May 2015.
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30. This essay offers a different perspective from the one by Geoffrey Moore, "Developing Middle Class Jobs in a Digital Economy," Conference presentation, Columbia University, Columbia Institute for Tele-Information, New York, NY, "The Internet's Effect on Employment," June 5, 2015. This essay proposes that the economy is moving to a new stage where computing and communications architectures alter the economy. Central to this change is the view that new value creation will no longer be dependent on creating value-adding niches along existing value chains.
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