ICT, Innovation and the E-Economy*

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1. Introduction

In the long run, our living standards depend on productivity growth. In turn, productivity growth depends on innovation. This makes innovation a critical concern for policymakers, managers and economists. Unfortunately, effectiveness of traditional innovative inputs appears to have grown weaker over time. While investments in R&D, the number of scientists, and scientific publications have all grown for over a century, productivity growth has not increased commensurately.

More recently, there has been a resurgence in productivity growth and this offers hope for the future of innovation. In particular, innovation in digital technologies has increased, creating a vibrate “e-economy”. This has affected both productivity and innovation in the rest of the economy as well.

Digital innovations drive productivity in three ways. First, they directly increase productivity through the simple mechanics of growth accounting. The quality-adjusted price of information and communication technologies (ICT) has dropped precipitously. Because the real quantity of computer power has grown even more rapidly, this price decline, when multiplied by the stable or growing expenditure share of ICT in GDP automatically generates a contribution to national productivity growth. For instance, in recent years, high tech has accounted for over 1/3 of the rise in productivity in the U.S. despite directly accounting for only about 5% of the inputs.

Second, digitization has spurred other innovations. In particular, firms have invested heavily in innovative management techniques, business models, work processes, and human resource practices which complement and amplify their ICT investments. These complementary organizational investments are typically several times larger than the direct investment in ICT and account for well over a trillion of dollars of intangible capital in American firms (Brynjolfsson, Hitt and Yang, 2002).[1]

Third, and perhaps most importantly, digitization is changing the way innovation itself is done. This is especially evident in information industries, but it is increasingly important in other areas of the economy as well. Over time, the benefits from increasing the rate of innovation will dwarf the benefits from any single innovation. However, the ways that ICT is transforming innovation are not yet well understood. Accordingly, I will devote more of my discussion to this aspect of digitization.

In this paper, I will first briefly highlight three important insights from research on innovation. I will then describe some evidence on how both the mean and dispersion of productivity growth has increased. Turning specifically to digitization, I will explain four ways that digitization is accelerating innovation: via measurement, experimentation, sharing and replication. These changes are especially evident in the Internet-based firms at the core of the e-economy, but are increasingly diffusing to firm in all sectors. In fact, they portent an long-term increase in the overall rate of innovation. Finally, I will provide some policy implications and conclude with some thoughts about future productivity growth.

2. Three Stylized Facts about Innovation

While the economic literature on innovation is vast – certainly too voluminous to summarize in this brief paper – three facts are important to keep in mind:

1. Although *inputs* to innovation, by almost every measure, have been rising significantly over the past century, *output*, as measured by the trend growth rate of multifactor productivity (MFP), has been flat.
2. There are dramatic differences among regions, industries and firms in their effectiveness at generating innovations.
3. The effect of an innovation on living standards depends on how much of the economy it affects.

a. Growing Innovation Inputs without Growing Productivity

Of these points, the first one is the cause for greatest concern. As shown in Figure 1, each R&D worker was associated with about seven times as much MFP growth in 1950 as in 2000. Other metrics show similar patterns (Jones, forthcoming; Azoulay and Jones, 2006).

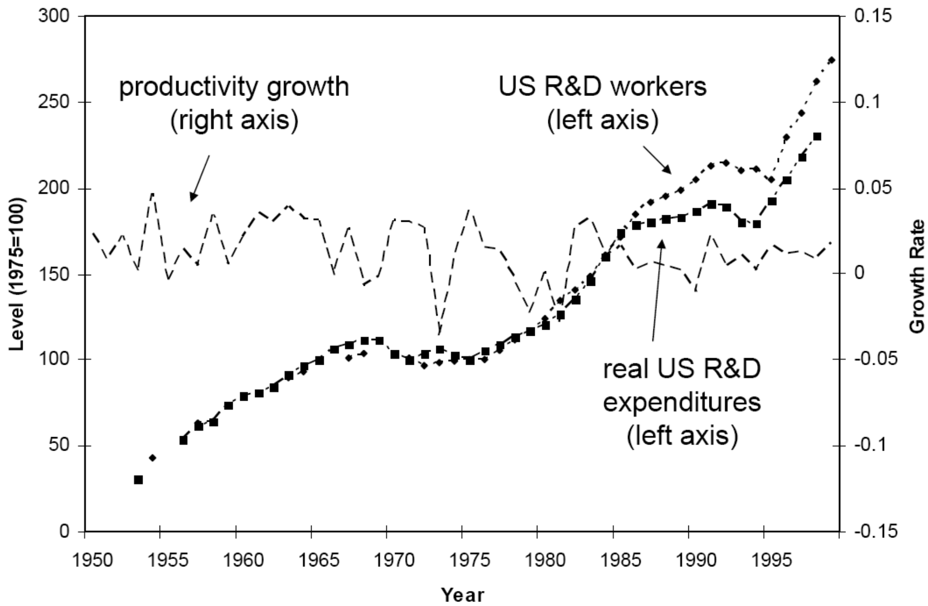

Figure 1: Higher R&D spending has not translated into higher productivity growth (*Source: Azoulay and Jones, 2006)*

Perhaps this discrepancy is merely an artifact of mismeasurement. After all, many of the sources of value in the modern economy are not reflected in the productivity statistics. Alternatively, it may be a real phenomenon. If we have "fished out" all the easy innovations, it requires more and more effort to get each incremental improvement in MFP. Let's look at each of these possibilities in turn.

i. Mismeasurement

The growth rate in MFP is derived from the national accounts. In turn, converting nominal GDP to real values depends on the price deflators. However, in an increasingly digital world, more and more goods are being delivered for free, earning them a weight of zero in the GDP statistics. A typical American teenager might spend the majority of his leisure time consuming services from Facebook, YouTube, and Twitter. Not only did none of these services exist a generation ago, but all of them are free. While improvements in the price and quality of broadband Internet service – delivering the bits – is reflected in the productivity statistics, the explosion in value of the content, including virtually all the millions of new sites on the World Wide Web, is not. In fact, industries like news and music appear to be shrinking, at least when measured by revenues, as they become more digital.[2]

Increased product variety is another change in the economy that is not fully reflected in the productivity statistics. While the typical physical bookstore has about 40,000 book titles, Amazon carries over three million, generating over a billion dollars of consumer surplus just from the increased choice (Brynjolfsson, Hu and Smith, 2003). In the broader economy, the number of trademarks and stock-keeping units (SKUs) has grown dramatically, and the welfare benefits of this variety are not fully reflected in the productivity numbers (Brynjolfsson, 1996). Mismeasurement may explain part of the productivity shortfall, but it is important to bear in mind that some output went unmeasured in earlier eras as well. For measurement to be the main explanation, it must be getting worse over time.

ii. Fishing Out

The more troubling explanation for the declining ratio of MFP growth to R&D investment is that we have begun fishing out the easy innovations. Ben Jones makes a compelling case that the "burden of knowledge" has grown: over time, there is more and more existing knowledge that must be learned before reaching the frontier, retarding the efficiency of innovators and forcing them to specialize more narrowly. This hypothesis has three testable implications. Over time, inventors are older at the time of their first innovation, they are less likely to switch fields, and, having specialized, they are more likely to work with collaborators, who may have complementary knowledge. Each of these implications appears to be true (figure 2, a, b and c).

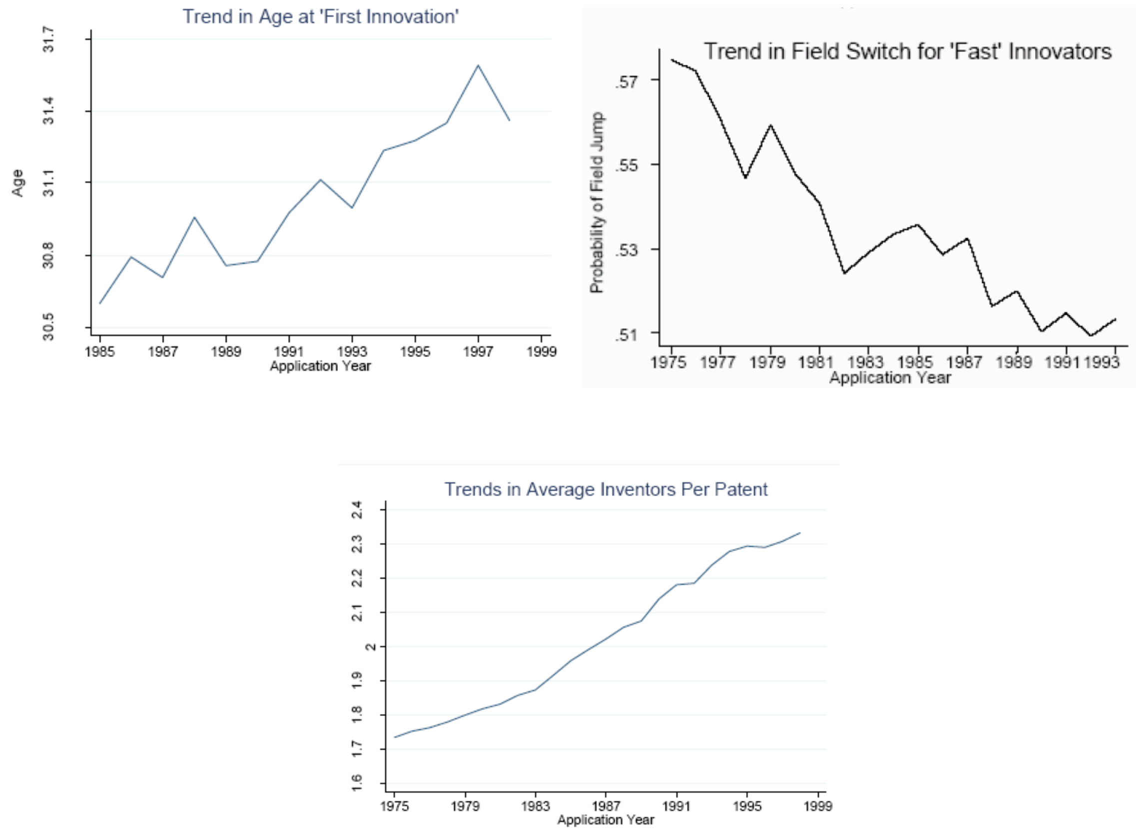

Figure 2a, b and c: Evidence that the Burden of Knowledge is Growing

Source: (Jones, forthcoming).

b. Unevenness in Innovative Activity

While the innovation output per dollar of R&D may be declining overall, there is enormous variability across regions, industries, firms and time periods. A small number of regions such as Silicon Valley produce a vastly disproportionate number of innovations. Some individual laboratories, like the one run by Eric Lander in Cambridge, Massachusetts, produce more patents each year than some entire nations, such as Sri Lanka. The pharmaceuticals, information technology, telecommunications and medical devices industries produce disruptive waves of innovation each decade, while other industries, like automobiles, produce a product that has not fundamentally changed in over half a century. This does not simply reflect differences in investment: in 2007, GM's R&D budget was the largest of any company in America and automobile companies accounted for three of the top four R&D spenders in the world (Hira and Ross, 2008).

This unevenness suggests that we may be able to draw lessons from the more innovative sectors of the economy. For instance, the Internet sector has experienced a wave of innovation, with companies like Google creating billions of dollars of shareholder value, and billions more in consumer surplus, with entirely new products and services in a relatively short period of time. While these companies often do have formal R&D budgets, employ scientists of various types, and may patent some of their inventions, many of their innovations do not follow this conventional path. They may innovate in business models, business processes, delivery methods and product features and these innovations may be developed by managers, engineers, or even customers, outside of any formal R&D budget and without any formal intellectual property (IP) protection.[3] More broadly, ICT has set in motion a collection of business innovations that are profoundly affecting industries from retailing, media and manufacturing to finance, transportation and consulting.

c. The Effect of Innovations on Living Standards Depend on Expenditure Shares

No matter how dramatically an innovation changes a good or service, its impact on GDP will be limited if that good or service is a small share of the economy. Furthermore, when an innovation leads to lower prices, then the share of the GDP devoted to that good or service will decline if the good is price inelastic. In turn, this will reduce the productivity benefits to the overall economy from further technological improvements for that good or service.

This fact is the source of "Baumol's disease" – sectors with high productivity growth often tend to shrink as a share of the economy (Baumol, 1967). However, there is no economic law that requires expenditure shares to always shrink as prices decline. When goods have price elasticity of demand greater than one, then price declines lead to a *growing* share of expenditure. Fortunately, this has historically been the case for ICT (Brynjolfsson, 1996) at least until recently. Thus, the relatively steady, exponential improvements of Moore's Law[4] have resulted in ever greater contributions to national productivity over time.

However, as long as an innovation only affects any one sector of the economy, it will have relatively limited effects on productivity. The greatest effects occur when the innovation can affect multiple sectors. This is why general-purpose technologies like the steam engine, electricity and today, ICT, can have a more revolutionary impact on living standards. In particular, when ICT is a catalyst for complementary co-inventions, its effects can be multiplied.

3. Productivity Growth and Dispersion

a. Productivity Growth

There is evidence that ICT-enabled innovations have collectively begun to increase the productivity growth rate in recent years. In the United States, productivity growth slowed down in the early 1970s and remained relatively low through the mid-1990s. It then experienced a resurgence, continuing through the past decade (Figure 3a and b). Interestingly, other industrialized nations have not experienced this productivity surge.

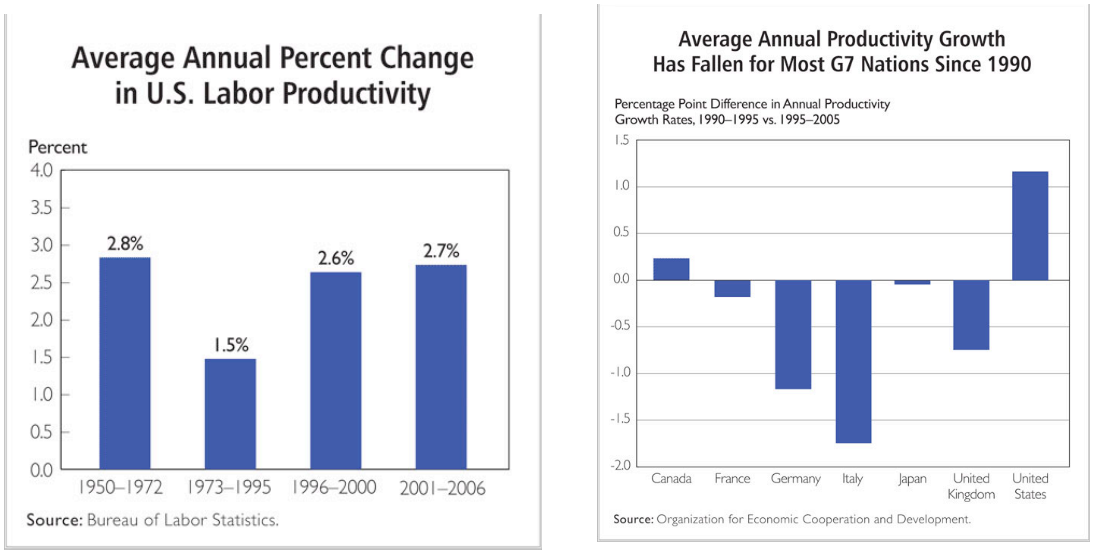

Figure 3a and b: Productivity Growth in the United States and other nations

The surge in U.S. productivity is correlated with increased investment in ICT. A careful growth accounting by Oliner, Sichel and Stiroh (2007) finds that ICT was a key factor in this resurgence. This is consistent with a similar analysis by Jorgenson and Stiroh (2004) who concluded that "A consensus has emerged that a large portion of the acceleration through 2000 can be traced to the sectors of the economy that produce information technology or use IT equipment and software most intensively."

Furthermore, Stiroh (2002) found that industries that were heavier uses of ICT tended to be more productive. The correlation is also present at the level of individual firms. Companies that used more ICT tend to have higher levels of productivity and faster productivity growth than their industry competitors (Brynjolfsson and Hitt, 2003). Bloom, Sadun and Van Reenen (2007) found that American firms were particularly adept at implementing the management practices that maximized the value of ICT.

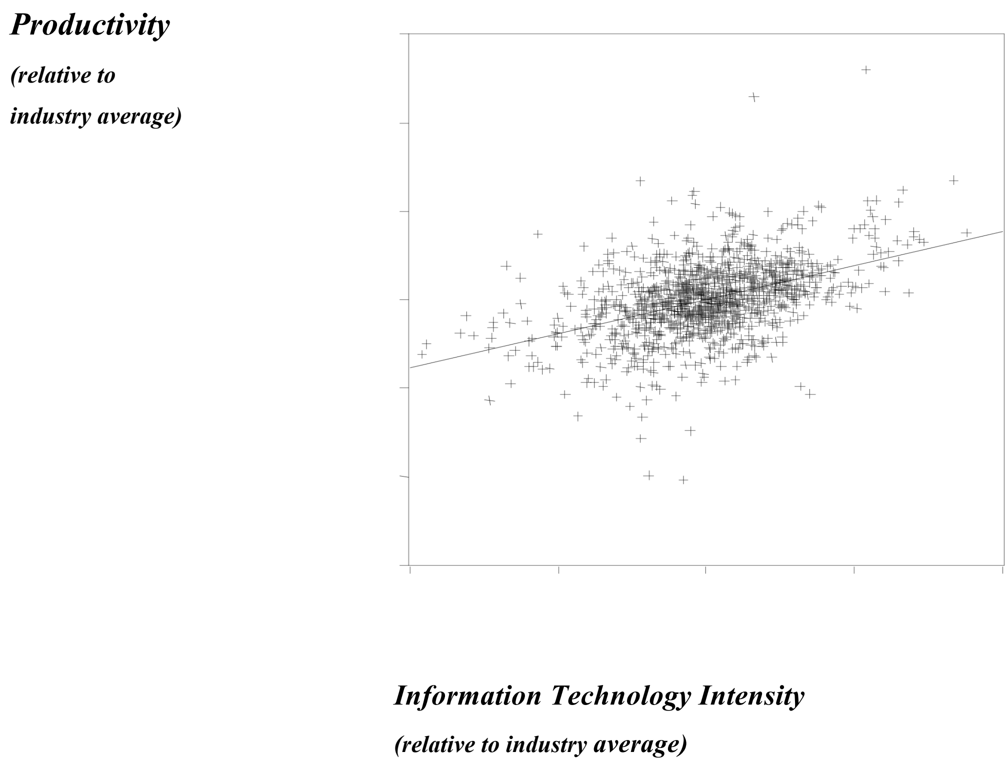

Figure 4: Productivity and ICT in large U.S. firms (Brynjolfsson and Hitt, 2000)

b. Productivity Dispersion

While productivity growth is strong evidence of innovation, Figure 4 also reveals a striking amount of variation in productivity across firms in the U.S. economy. This variation also says a lot about the diffusion of innovation across firms. As Gould (1996) noted, "Complex systems improve when the best performers play by the same rules over extended periods of time. As systems improve, they equilibrate and variation decreases." For instance, the rules and technology of baseball have remained largely unchanged for over a century. Figure 5 shows how the variation in baseball batting averages has declined during that period. This reflects the asymptotic limits of human performance and the elimination of ineffective techniques and training methods as better ones were adopted.

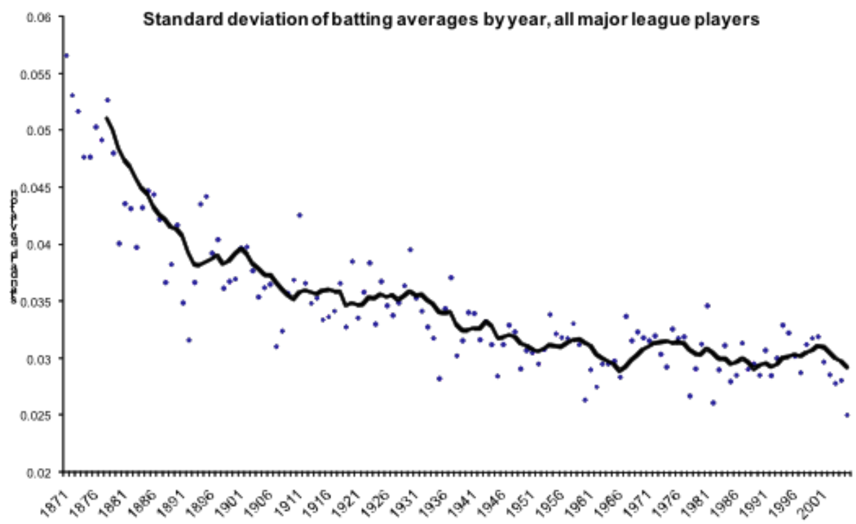

Figure 5: Decreasing Dispersion in Baseball Batting Averages since the 1870s

If there were no innovation in the technology and rules that govern production, distribution, and other aspects of business, one might also expect that variation in performance would decrease asymptotically over time, as existing innovations diffused and firms far from the frontier exited. Conversely, periods of faster innovation are likely to be reflected in increased dispersion in performance.

So what do the data show?

Since the mid-1990s, the gap between leaders and laggards has grown overall in the U.S. economy. For instance, the interquartile range or IQR (the difference between the firm at the 75th percentile and the firm at the 25th percentile) in gross profit margin held steady at about 20 percentage points throughout the 1960s, 1970s and 1980s, but in the mid-1990s it started to increase substantially and by 2006 it was nearly 35 percentage points (Brynjofsson, McAfee and Zhu, 2009). This increase in performance spread coincides with the surge in the overall productivity growth rate of the U.S. economy starting in 1995, and has continued through boom and recession. These results are consistent with the idea that there was a broad based innovation or cluster of innovations, a “rules change", in the mid-1990s. This gave some firms a competitive advantage over others and increased the overall rate of technological progress.

The increase in performance spread has not occurred equally in all industries. Those with relatively higher levels of R&D spending tend to have slightly greater dispersion in these metrics. This is consistent with the idea that innovation increases performance heterogeneity. However, since the mid-1990s, ICT intensity has been a much stronger correlate of performance spread. The IQR for gross profit margin roughly doubled in the 31 industries with the highest ICT intensity while it was largely unchanged in the 31 industries where ICT intensity was below the median (Figure 6). Other performance metrics show a similar pattern, including EBIDTA margin, Return on Assets, Return on Equity, Tobin's Q, and the ratio of market value to revenue.

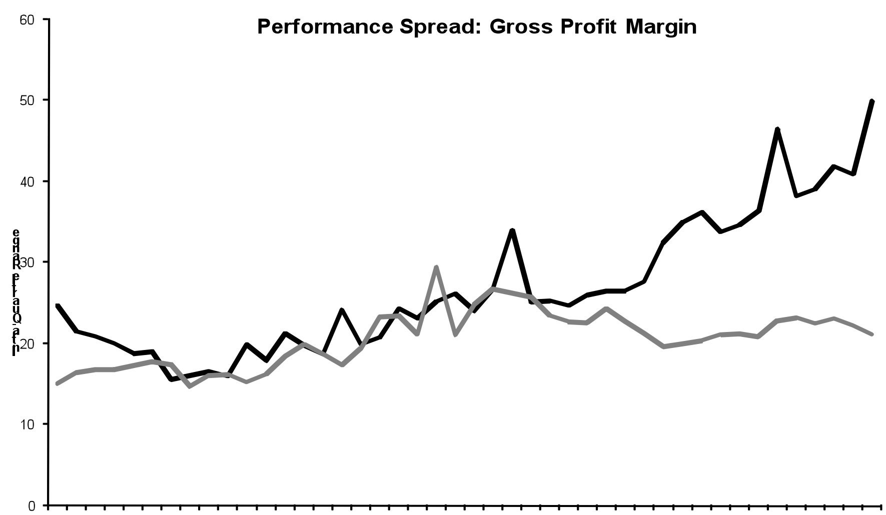

Figure 6: Increasing Dispersion in Business Performance in ICT Using Industries (Brynjolfsson, McAfee and Zhu, 2009)

Thus, whatever the underlying drivers are behind the increase in both productivity growth and the dispersion of performance, they appear to be strongly correlated with the use of ICT.

4. How Digitization is Transforming Innovation

While the exponential improvements in the power of digital technologies have been remarkably consistent for over 40 years, the absolute magnitudes of the increases are, of course, much larger in recent years. For instance, the number of bits stored digitally has doubled roughly every 18 months. Thus, the number of digital bits newly stored in the past 1.5 years is as great as the digital storage from all previous years combined. Meanwhile, networking and software has become much more pervasive. The widespread use of the Internet by consumers and businesses since the mid-1990 is a particularly visible example, but the adoption of enterprise information technology by most major corporations is probably even more important for productivity and business innovation.

There's a long tradition in economics of modeling both markets and organizations as information processors (e.g. Hayek, 1945; Sah and Stiglitz, 1986). As a result, it would be surprising if the large drop in the cost of digital information processing did not have significant effects on business model and business process innovation, and indeed, on the organization of innovative activities themselves.

The increasing digitization of economic activities has made possible four important trends, each of which has significant implications for innovation:

- Improved real-time, fine-grained measurement of business activities,
- Faster and cheaper business experimentation,
- More widespread and easier sharing of observations and ideas,
- The ability to replicate process and product innovations with greater speed and fidelity.

While these are certainly not the only ways that digitization is affecting innovation, they are each important in a significant and growing number of firms. In the next four subsections, I will briefly describe each of these trends, and then discuss how they complement each other to accelerate innovation.

a. <u>Measure</u>: Digitization makes it possible to measure activities in real-time and with great precision

Historically, revolutions in measurement have engendered revolutions in innovation. For instance, when Anton van Leeuwenhoek developed of an improved microscope and documented the existence of tiny "animalcules" in water droplets and human blood, it provided the foundation for the germ theory of disease and eventually a host of medicines and treatments.

Today, businesses have begun gathering extremely detailed data on their activities and customer relationships. This is particularly evident in the e-economy, where clickstream data give precisely targeted and real-time insights into consumer behavior. Anyone with access to a web browser can get summaries of billions of keyword searches, and this information is highly predictive of present and future economic activity, such as housing purchases and prices (Wu and Brynjolfsson, 2009). Mobile phones, automobiles, factory automation systems and other devices are routinely instrumented to generate streams of data on their activities, making possible an emerging field of "reality mining" to analyze this information (Pentland, 2008). Manufacturers and retailers use RFID tags to deliver terabits of data on inventories and supplier interactions and then feed this information into analytical models to optimize and reinvent their business processes.

Much of this information is generated as a costless byproduct of computerization, and sits unused, at least initially. A few years after installing a large enterprise resource planning system, it is common for companies to purchase a "business intelligence" module to try to make use of the flood of data that they now have on their operations. The aim is to identify patterns in the data and to generate and test hypotheses about potential business innovations. This is creating a shift from intuitive management to more numbers-driven decision-making. As a Microsoft researcher memorably put it, objective, fine-grained data are replacing HiPPOs (Highest Paid Person's Opinions) as the basis for decision-making at more and more companies (Kohavi, Henne and Sommerfield, 2007). For instance, Enologix has used this approach to help Gallo vineyards accurately predict the wine ratings that Robert Parker would give to various new wines, UPS has mined data on truck delivery times to develop a new routing method and Match.com as even developed new algorithms for matching men and women for dates (Davenport, 2007). For each innovation, analysts drawing on detailed measurement have supplanted human experts who used more tacit knowledge and intuition.

b. *Experiment: Digitization makes it possible to run business experiments much more cheaply and frequently*

Examining data that has been generated as a byproduct of regular operations and interactions can yield insights that drive innovation. However, it typically takes controlled experiments to determine causality. Historically, experimentation has been difficult for businesses to do outside of the laboratory because of cost, speed and convenience. While scientific thinking has been dominated by the experimental approach for nearly 400 years, an era of exceptional scientific progress, it is only relatively recently that experiments have begun to become more widespread as a tool for business innovation.

The change has been most sweeping in "born-digital" companies like Amazon and Google. A central part of Amazon's research strategy is a program of "A-B" experiments where it develops two versions of its website and offers them to matched samples of customers. Using this method, Amazon might test a new recommendation engine for books, a new service feature, a different check out process, or simply a different layout or design. Because of the large number of customer interactions it processes, Amazon sometimes gets sufficient data within just a few hours to detect a statistically significant difference between the two hypothesized solutions.[5] This ability to rapidly test ideas fundamentally changes the company's mindset and approach to innovation. Rather than agonize for months over a choice, or model hypothetical scenarios, the company simply asks the customers and get an answer in real time. Ideas that might have taken months or even years to develop and assess can now be quickly and cheaply prototyped and tested, vastly increasing the clockspeed of the innovation process.

The scale of business experimentation at some firms is prodigious. According to Hal Varian, Google runs on the order of 200-300 experiments per day, as they test new products and services, new algorithms and alternative designs. An iterative review process aggregates findings and frequently leads to further rounds of more targeted experimentation.

At the same time, Google's competitors, partners, customers and third party consultants are doing their own experiments, creating a complex, interacting ecosystem that demands continuous innovation. While Google currently dominates the market for web search, it is unlikely that it would have any market share at all if it still relied on the original, unmodified PageRank algorithm that Larry Page and Sergey Brin developed in 1998.

Greg Linden, who led one set of experiments at Amazon, describes the emerging experimentation philosophy succinctly:

> "To find high impact experiments, you need to try a lot of things. Genius is born from a thousand failures. In each failed test, you learn something that helps you find something that will work. Constant, continuous, ubiquitous experimentation is the most important thing." (Brynjolfsson and Schrage, 2009).

These words echo the approach of innovators since Thomas Edison, but ICT has made it possible to apply it to a much broader class of business challenges and significantly compress the "hypothesis-to-experiment" cycle time.

While web-based companies have been particularly aggressive in using business experiments to drive innovation, digital platforms have brought this approach to other industries. For instance, Harrah's transformed itself from a 2nd tier casino company to the industry leader in large part because of the culture of experimentation that CEO Gary Loveman introduced. When Loveman, an economics PhD from MIT and former Harvard Business School professor, arrived at Harrah's, he found that it was already gathering a great deal of data about its customer interactions via its existing information systems and programs such as its Total Rewards loyalty card. However, it wasn't using these data systematically to develop improved processes, products and services. When Loveman became the CEO of Harrah's, he developed strategies to continually tests new promotions, price points, services, workflow, employee incentive plans and casino layouts using controlled experiments.

Widespread business experimentation has required a fundamental change in the corporate culture. As Loveman puts it "There are two things that will get you fired from Harrah's: stealing from the company, or running an experiment without a properly designed control group" (Brynjolfsson and Schrage, 2009). Meanwhile, many of Loveman's competitors have been slower to make this transition, allowing Harrah's to gain market share. Loveman does not believe that the gaming industry is uniquely suited to this approach – it can and has occurred in many other industries. For instance, leading firms in retailing (e.g. Zara's, Tesco's, Wal-Mart), consumer finance (e.g. Capital One, Fidelity), and hospitality (e.g. Marriott) have also adopted a more aggressive strategy of business experimentation.

c. *Share: Digitization makes it possible to share observations, insights and innovations more widely and easily*

The Internet and other recent improvements in communications have had a significant effect on scientific and business collaboration. For example, there has been an increasing trend in collaboration among scholars in distance attributable to the decreased communication cost (e.g. Griffith, Lee and Van Reenen, 2007; Jones, Wuchty, and Uzzi, 2008; Rosenblat and Mobius, 2004).

Sharing has also increased within firms, using relational databases, knowledge management systems, intranets, email networks, wikis and a variety of other tools. This has increased the speed with which new findings and insights propagate throughout the firm. The way firms are working to optimize the flow ideas and information, ideas and collaboration can be compared to the way assembly lines optimized the flow of physical products through factories a century ago (Varian, 2008).

Today, the components being combined are made of bits, rather than atoms, which makes it possible to replicate them perfectly and nearly costlessly, and to transport them worldwide almost instantly. Because the process of innovation often relies heavily on the combination and recombination of previous innovations (Weitzman, 1998), the broader and deeper pool of ideas and individuals that an innovator can draw on, the more opportunities there are for innovation. As a result, improved sharing has important implications for not just the level of innovation, but also the rate of growth of innovation.

d. *Replicate: Digitization makes it possible to scale up innovations with greater speed and fidelity*

The fourth trend is the ability to scale up innovations rapidly and with unprecedented fidelity. Again, the e-economy leads the way. When Amazon improves its website, the innovation is almost instantaneously replicated in hundreds of millions of its “stores” worldwide – the computer screens of its customers. Similarly, innovations in other digital products like software, music, video and websites can be rapidly replicated and delivered.

The result has been a more Schumpeterian form of competition in these industries, in the sense that new firms are born and quickly supplant the incumbents, resulting in “creative destruction” and renewal. Consider software. Firms that develop better software applications can rapidly grow to dominate the industry, or even create entirely new sectors. At the same time, their dominance is far from assured, with many industry leaders losing their position, or even failing altogether, when competitors or new entrants develop a superior product, or when the dominant platform changes from mainframes, to minicomputers, to personal computers, to the Internet and beyond. The high productivity levels and productivity growth rates of software firms are also consequences of easy replication of innovations.[6]

Today, technology is increasingly making it easier replicate not just innovative digital products, but also innovative business processes. For instance, when CVS developed an improved prescription drug ordering process for its pharmacies, it embedded the process in an enterprise IT system. Because the process was tightly coupled with technology, CVS could assure that each clerk and pharmacist would adhere to the new process precisely as it had been designed, increasing overall customer satisfaction scores from 86 to 91. More importantly, the innovation could be rapidly rolled out to over 4000 physical locations across the country. In effect, the economic impact of this one process innovation was multiplied by 4000-fold because it was embedded in technology. This is a marked contrast to the slow and error-prone paper-based or training-oriented procedures that were used for propagating processes a decade ago. (McAfee and Brynjolfsson, 2008)

Enterprise resource planning (ERP) systems such as those sold by SAP and Oracle since the mid-1990s have made process replication possible in other industries and for many types of large and mid-sized firms. The geographic reach of enterprise software has been greatly increased by the Internet, which freed companies from having to construct private networks to remote locations. This combination represents a quantum leap forward in firms' abilities to replicate business process innovations widely, rapidly and with high fidelity.

e. An Emerging Sequence – Experiment, Measure, Share and Replicate – is a new kind of R&D

Important as the trends of experimentation, measurement, sharing and replication are when used separately, their impact is amplified when they are used together. While passive data gathering can be useful, measurement is far more valuable when coupled with conscious, active experimentation and sharing of insights. Likewise, the value of undertaking the experiments themselves is proportionately greater if the organization can capitalize on those experiments in more locations and at greater scale.

In combination, these practices constitute a new kind of "R&D" that draws on the strengths of ICT to speed innovation. As flexible, scalable ICT infrastructure makes this approach more widely feasible, the main bottleneck becomes the ability to ask the right questions so that the experiment, measure, share and replicate paradigm can help answer them. This requires both an understanding of business needs and experimental design concepts.

5. Implications for Policymakers

As the nature of innovation changes, so to should the institutions and policies that we use to foster innovation.

a. Incentives

One of the first policy levers considered by most economists for affecting the pace of innovation is incentives. Patents and other forms of intellectual property rights are enshrined in the constitution in order "to promote the progress of Science and useful Arts." However, stronger IP protection does not necessarily lead to more innovation. Davis (2001) and others have argued that existing forms of IP are not well suited for digital goods and services, and innovations in business processes also appear to be a poor fit. In part, this is because the combinatorial innovation approach common in building digital innovations can be severely hampered when IP law restricts use of the components. Innovations in other fields such as biotech also build heavily on previous contributions. As a result, Williams (2009) found that that the IP rights that Celera obtained when it sequenced parts of the human genome retarded subsequent innovation by as much as 30%, compared to similar sequences which were placed in the public domain. In some cases, open source projects such as Wikipedia and Linux have been unexpectedly successful. This suggests that institutions that harness non-financial motivations, such as those described by Maslow (1943) may be important.

b. Education

Greater investment in education is another common policy recommendation and nothing in the measure, experiment, share and scale paradigm reduces its importance. However, it does put a premium on creativity and the ability to frame questions that are both relevant to the business and amenable to rigorous experimental design and analysis, often using statistical techniques. Education that is overly narrow, however, deep, may be less effective in such an environment. Furthermore, if competition becomes more Schumpeterian, firms with a skilled workforce that is flexible enough to quickly adapt to changes will get higher returns on their innovations. Such firms can therefore be expected to invest more in innovation in the first place.

c. Infrastructure

The benefits of combinatorial innovation are amplified the more distinct components there are to combine. However, the infrastructure that makes such interaction and sharing possible has characteristics of a public good, and there may be underinvestment if it is not subsidized or publicly provided. The American interstate highway system, the Internet and the human genome project are all examples of government-supported infrastructure that foster innovation by facilitating interconnections.

d. Immigration policy

While the global Internet makes it easy to almost instantly transmit gigabytes of data almost anywhere in the world, this does not mean that geography has become irrelevant to innovation. On the contrary, it remains highly uneven, with some areas innovating disproportionately. Innovators benefit from being physically near other innovators so that they can more easily share the types of tacit knowledge and understanding that are difficult or impossible to distill into explicit instructions. Rather than diminishing returns to scientific concentration, the pay-off to each participant often grows with greater concentration, accounting for innovation clusters. Flexible immigration policy can help assure that more of these clusters emerge.

e. Flexibility

The waves of "creative destruction" that characterize the increasingly Schumpeterian competition and innovation in the economy lead to the rapid scaling up and ramping down of businesses. This requires flexible institutions, labor force and regulatory policies. Antitrust in the e-economy should be less concerned with static market shares and more concerned with potential lock-in or inertia that prevent innovators from supplanting incumbents.

f. Rent dissipation vs. Value Creation

Not all innovations have equal social value. An innovation that redistributes a dollar of rents does not benefit society as much as an innovation that creates a dollar of new value. In the United States many of the technology investments, and many of the top students, been devoted to innovating in activities like pricing and bargaining where the private benefits often come largely at the expense of other parties, rather than science and engineering innovations, where the spillovers are often positive. Policies that enrich or favor the rent-redistributing components of some industries may exacerbate this trend. Philippon and Reshef (2009) found that rents account for 30% to 50% of the wage differentials between employees in finance compared to engineering since the late 1990s. This has attracted talented individuals from other sectors to the financial sectors.[7]

6. Conclusion

Information technology holds promise for increasing the rate of innovation. However, fulfilling this promise will require a transformation by both companies and policymakers that has barely begun. Success in this transition should begin with a clearer understanding of what digitization can do and what it is working in leading firms and sectors.

The explosive improvements in computers and related technologies can raise productivity growth three ways: directly through technological progress in computers and communications goods, indirectly by catalyzing co-inventions in management and organization, and most recently, by transforming the innovation process itself.

Because innovation ultimately depends on the creation of knowledge, information technology has a unique role in augmenting, if not automating, creativity and discovery. Companies that successfully use technology to improve their measurement, experimentation, sharing and replicating of innovation will be in a position to outcompete their rivals, and gain a growing share of the economic landscape.

The increase in productivity growth since 1995 is a promising sign. Even more tantalizing is the increase in the performance spread among companies, especially those in ICT intensive sectors. A large performance spread is *prima facie* evidence that the frontier of practice is far ahead of the mean, and thus an optimistic sign for future productivity growth. Indeed, it suggest that firms that are currently behind the frontier, whether in the U.S., Europe, or elsewhere, have great potential benefits ahead of them even if they simply match the current leaders. By many measures, we have a more innovative society than ever before.

Looking to the future, the recent sharp decline in business investment and in particular ICT investment is cause for concern, especially if it inhibits complementary investments. However, it is likely that most businesses are still very far from fully exploiting all the potential complements to 1990s technology, let alone the current ICT capabilities, so there's still room for continued innovation. Even if Moore's Law stopped tomorrow (and it has no signs of slowing down), there are potentially decade's worth of innovation possible just from wringing out the potential of today's ICT.

In some ways, the current downturn contains seeds of hope. Historically, recessions have been a stimulus for innovation and restructuring. The 1930s had more major product innovations than any other decade since the 1850s (Kleinknecht, 1987). A majority of Fortune 500 companies were founded during economic downturns (Stangler, 2009). Similarly, some companies are using today's challenging economic environment as a rationale for making tough changes that would have been conceptually or politically difficult when they were more profitable. If these changes create more innovative nations and further raise productivity growth, the so-called "Great Recession" may eventually become known as the "Great Restructuring" instead.

7. References

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8. Endnotes

[1] See also Brynjolfsson and Hitt (2000), Bresnahan, Brynjolfsson and Hitt (2002), Bartel, Ichinowski and Shaw (2007) and Bloom, Sadun and Van Reenen (2007).

[2] Between 2004 and 2008, music industry revenues from physical shipments and digital downloads shrank from $12.34 billion to $7.39 billion.

[3] As a result, these types of innovation may not be well captured by traditional metrics of innovation such as patents and other forms of intellectual property, R&D spending, and counts of scientists or their publications, exacerbating the mismeasurement problem discussed above. For instance, most organizational and process innovations are not developed by scientists via the

traditional R&D process and are never patented. Similarly, there have been a plethora of important human resource innovations that measurably affect productivity (Gant, Ichniowski, and Shaw, 2003).

[4] The doubling of transistors per chip approximately every 18 months is known as Moore's Law, although the term is also applied to similar improvements in other dimensions of ICT such as storage and communications.

[5] Jeff Wilke, Head of North American Retail, Amazon.com, personal communication.

[6] For instance, Gandal (1994) and Brynjolfsson and Kemerer (1996) found that the quality-adjusted improvements in spreadsheet software were 10% or more per year.

[7] According to Goldin and Katz (2008), Harvard graduates worked in finance earned almost 3 times more than their peers, even controlling for their undergraduate performance.