12 The digital revolution

Within living memory, the contribution of the state as sponsor of all the components of what came to be known as information and communications technology demonstrates the over-riding power of a political legitimate mission in the dynamics of the three-player game. World War II and the Cold War offered what even the Great Depression failed to provide: a rationale for state intervention both to direct the allocation of resources in the private sector and to take direct responsibility for creating new, previously unimaginable resources. As Marianna Mazzucato has reviewed at length, the legacy of this extended state engagement continues to inform the tools and toys that we have come to take for granted, including the Apple iPhone.[1]

Yet, during the fifteen years since the collapse of the great Internet Bubble, the relationship between the IT sector and the state has been reversed. Dependent on state support of research and procurement through its growth to maturity, the IT sector has now fostered a full-fledged digital revolution, comparable in scale and scope to the consequences of the railroads and of electrification. And the resulting transformation of economic and social and political life now confronts the market and regulatory structures of the legacy economy and redefines the responsibilities of the state. No longer solely functioning as collaborative partners with government in an extended process of invention and deployment, those at the forefront of the digital revolution are challenging the state at both micro and macro levels.

At the micro-level of individual firms addressing specific markets, the confrontation is deliberate. As always, the innovators are setting out to disrupt established markets and destroy the incumbents who occupy them: to do so, they must over-ride the ecosystem of state-sanctioned and enforced rules that co-evolved with the markets and without which the markets could not have functioned.[2] At the macro-level, digitalized automation has joined forces with IT-enabled globalization and financialization to drive the increasingly unequal distribution of income and wealth. Reciprocally if unwittingly, it shares ownership of the populist counter-movement that has emerged in contemporaneous consequence. At both levels, the dynamics of the

[1] M. Mazzucato, *The Entrepreneurial State* (London: Demos, 2011).

[2] For a detailed and informed analysis of the how difficult it is to tranform a "legacy industry" by introducing transformative technology, see W. B. Bonvillian and C. Weiss, *Technological Innovation in Legacy Sectors* (Oxford University Press, 2015)

three-player game have shifted to invite the question Tim O'Reilly asks in his new book: *WTF? What's the Future and Why It's Up to Us*.[3]

From Atoms to Bits to Atoms

The maturation of the IT Revolution is best measured by the radical, discontinuous decline in the cost of digitizing hitherto physical products and digitalizing hitherto physical processes into computer algorithms. The consequent reduction in cost goes beyond simple quantifaction of time and money. Perhaps most important, the need to "think like a computer" in order for a user to make the computer run a program has disappeared, as computing resources have become ever more abundant, enabling more and more software layers of abstraction to insulate users from the digital hardware by creating an ever more accessible environment.

The decline in such frictions not only benefits users. The combination of free, open source software and rentable cloud computing resources has also reduced the cost of developing digital services. These services now span an ever-growing range: from information discovery and retrieval through purchases of all manner of consumer goods to 3D-prototyping, by way of an array of two-sided marketplaces exemplified by Uber and Airbnb. In each case, work previously done by human beings in physical space has been transformed into coded instructions executed by a digital machine.

When a search is conducted on Google, the work of finding relevant information by consulting physical repositories of information, with or without the additional work of a librarian, has been replaced: atoms have become bits. When a consumer buys a book on Amazon, massive economies of scale are deployed to reduce the aggregate work previously distributed across multiple supply chains: atoms have become bits. When a designer uses a software program to specify the characteristics of a prototype for submission to a 3D printer, the work of hand-crafting a model has been replaced: atoms have come bits. When one of many customers requests transportation through Uber or overnight accommodation through Airbnb and the request is fulfilled by one of many possible suppliers, the work of physically matching demand and supply has been replaced: atoms have become bits.

To the extent that delivery of the service remains within the digital domain, consumption of the service is as free of *technological* friction as its development and deployment. And this friction-free mode of consumption is most likely to be available when the speed and ease of service delivery for the consumer is so much greater than the existing version that essentially it represents an entirely new service. Such is a Google search, for example, compared with visiting a library or the exchange of text messages versus

[3] T. O'Reilly, *WTF? What's the Future and Why It's Up to Us* (Harper Business, New York: 2017).

postcards or the enjoyment of digital entertainment. But these examples should suggest immediate caveats. The Great Fire Wall of China demonstrates that restrictions on digitally delivered services can be imposed by political authority. And, in order that consumption of digital entertainment be rendered as easy as touching a screen, years of litigation followed by years of negotiation were required.

The latter example demonstrates the fundamental point. To the extent that the digital service disrupts an existing service delivered through conventional means, its providers are bound to encounter frictions of all sorts. The return to the disrupters will be constrained by failure to recognize and negotiate these impediments: the extended battle between Google and book publishers over the protection of copyright is an example. To the extent that the service is delivered beyond the digital domain and "virtual space" becomes geographically local, bits are converted back to atoms and frictions are bound to exist. Purchased car rides and rented overnight beds, for example, have each accreted an eco-system of practices through generations, even centuries. And the frictions generated within each eco-system will be as disparate as is each local distribution of economic and political power and each local set of social and cultural norms.

These are the micro-consequences of digitalization:

Economic Frictions: Just because each local market is subject to the same disruptive competition does not mean that existing service providers will be displaced with equal ease. In relatively more concentrated markets, for example, oligopolistic service providers have more to lose and greater resources with which to resist. Moreover, companies like Uber and Airbnb enjoy the benefit of limited network externalities. The positive feedback between more drivers and more consumers of Uber services at the local level reaches across geographically specific markets only to the extent that consumers become habituated to using the same app in different localities. The drivers that comprise the supply side of the market are strictly localized.

Regulatory Frictions: Market imperfections are more resistant to competitive disruption when they have been embedded in regulations. And, of course, such regulations may raise the stakes by allowing incumbent suppliers to capture rents, as licensed taxi suppliers do. But by no means are all such regulations the result of greedy rent-seekers co-opting the political process for their own advantage. There are evident social benefits that explain why taxi drivers should be specially licensed and required to carry more insurance and why hotel operators should be required to meet fire regulations.

Cultural Frictions: A prime example is represented by the extreme range of responses to Uber's penetration of different local markets reflected in the extent to which it is subject to regulatory restrictions, up to and including outright bans. Taxi drivers in San Francisco are not the same as "black cab"

drivers in London, as Uber has discovered the hard way.[4] Of course, Uber's internal cultural frictions have fed back to undermine its own disruptive mission.

In addition to the idiosyncratic frictions that each disrupter encounters in each of its target markets, there are two more general types of confrontation between the frontier firms of the digital economy and the state. The first includes the issues that typically arise with monopolies but that are even more acute when what is monopolized is the platform to which buyers and sellers have little choice but to converge. The signal example is the European Commission's decision to fine Google €2.42 billion "for abusing dominance as a search engine by giving an illegal advantage to another Google product, its comparison shopping service."[5]

The second source of confrontation with the state remains only potential in the fragmented jurisdictions of the American fderal state but is becoming salient in Europe. This is the legal status of people whose livelihoods are dependent upon the digital platform companies which, in turn, deal with them as independent contractors.[6] Again, the libertarian ethos of Silicon Valley treats the availability of "gig economy" employment as a one-dimensional increase in freedom of contract. But the terms of that contract are entirely within the control of Uber or Deliveroo or Task Rabbit, and those terms exclude such standard employee benefits as workman's compensation for injury on the job.[7] Access to available alternatives – the "outside option" that confers some iota of counter-vailing power – also varies across geographical and politica space.[8] The gig economy, like traditional sources of "cadual" employment such as construction and fruit-picking, provides gainful employment to those trying to enter the market economy. But note: exactly the same kind of software that enables on-the-fly scheduling of drivers is used for scheduling minimum wage shifts at legacy economy employers working on "zero-hour [of guaranteed employment] contracts". It is not difficult to view the digitally enabled gig economy as the instantiation of Marx's vision of the

---

[4] See, for example, J. Kollewe and G. Topham, "Uber apologises after London ban and admists "we got things, wrong,"*The Guardian*, September 25, 2017, available at https://www.theguardian.com/business/2017/sep/25/uber-tfl-concerns-vows-keep-operating-london-licence

[5] European Commision, "Antitrust: Commission Fines Google €2.42 billion for abusing dominance as search engine by giving illegal advantage to own comparison shopping service," 27 June 2017, available at http://europa.eu/rapid/press-release_IP-17-1784_en.htm

[6] See E, Mulvaney, "States Take on Battle Over Regulating the Gig Economy," *The National Law Journal*, April 27, 2010, available at http://www.nationallawjournal.com/id=1202784752208/States-Take-On-Battle-Over-Regulating-the-Gig-Economy?slreturn=20170903104417

[7] L. Alderman, "Europe's On-Demand Economy Draws Complaints. And Regulators." *New York Times*, October 1, 2017, available at https://www.nytimes.com/2017/10/01/business/uber-economy-europe.html?smprod=nytcore-ipad&smid=nytcoreL. Aldse-ipad-share&_r=0

[8] For the premier explication of this problematic phenomenon, see Albert Hirschman, *Exit, Voice and Loyalty*, (Cambridge MA, Harvard University Press: 1970).

"reserve army of labor," available on command by capitalists as a commodified resource.

Once again, the European Commission has taken the lead in exploring the legal and regulatory ramifications of this dimension of the digital economy:

> The Commission is starting a consultation of social partners to define possible new rules in this area. Rights and obligations associated to social protection have been developed over time primarily for workers employed on standard contracts, whereas these have been insufficiently developed for people in self-employment and non-standard employment.
> Today's more flexible working arrangements provide new job opportunities especially for the young but can potentially give rise to new precariousness and inequalities. The Commission wants to explore ways of providing as many people as possible with social security cover, including self-employed and gig-economy workers. In practice, these people should also be able to build up rights against contributions.[9]

Thus, speed bumps are encountered on the way to the fully digital future, speed bumps that represent history asserting itself. This is where the technically brilliant and innovative founders of the digital services are at a serious disadvantage. It is understandable that those who know they are inventing the future should have minimal, if any, concern for understanding what has gone before. Taking seriously the historical evolution of taxi or hotel regulations may appear as irrelevant to a digital disrupter as would mastering the Ptolemaic model of the universe to a 21st century cosmologist. But ignoring them may carry very large costs.

Multi-billion dollar valuations of "Unicorn" digital service providers with no stated intention (and limited likelihood) of achieving profitability in the foreseeable future have become common, rationalized by the potential to dominate an incalculably large market. But these valuations eventually will require rationalization in the traditional terms that I mastered almost fifty years ago, through calculation of net present value by discounting expected future cash flows. In this model, the rate at which those future cash flows are discounted and the time over which they are discounted matter as much as the magnitude of the future cash flows themselves.

Any incremental uncertainty in this calculus expresses itself in a higher discount rate, reducing the net present value of the same future cash flow. Any extension of the time over which future cash flows will be realized also expresses itself in a lower net present value. The existence of frictions when bits are turned back into atoms necessarily adds uncertainty and delays realization. And the consequences are cumulative: the higher the discount rate the greater the cost of delay. Thus, $10 to be received 3 years hence is worth $6.58 today at 15% and only $5.79 at 20%. If it is not expected to be

[9] See "Access to Social Protection," European Commission: Employment, Social Affairs & Inclusion, available at http://ec.europa.eu/social/main.jsp?catId=1312&langId=en

received for one additional year, at 15% the present value drops to $5.72 and at 20% to $4.82. Of course, this fine calculation of net present value is profoundly misleading. Valuing ventures at the frontier involves layers of uncertainty which are overcome, in the first instance (if they are overcome at all), only by that collective willed suspension of disbelief expressed as a "bubble."

Here, the point is this: the Unicorn Bubble is not only threatened, as every bubble is, by the marks to reality when the privately valued shares are subject to trading in liquid markets plus the inevitable increase in the supply of wannabe Unicorns. It is also threatened by cumulative evidence that realization of the incalculable returns from digitizing the economy of atoms is subject to impediments that are literally mundane, the frictions of the economic, political and cultural world that exists and has existed and will exist.

The most successful digital disrupters have come to recognize this. To achieve their potential growth and ultimate profitability depends on taking these impediments seriously and learning how to address them effectively. Unfortunately for those who believe we have entered a libertarian golden age, freed by digital technology from traditional constraints on market behavior, firms successful in disrupting the old physical economy will need to have as a core competency the ability to manage the political and cultural elements of the eco-systems in which they operate, as well as the purely economic ones.

The technological revolutions that transform the market economy inevitably generate political spillovers. The transcontinental railroads, exercising their control of the cost of access for western farmers, spawned the populist movement in late nineteenth century America.[10] Electrification, in turn, engendered fierce debate over private versus public ownership and control of the new, essential resource: Pennsylvania Power and Light's triumph over Governor Gifford Pinchot's proposed state-owned "Giant Power" in the 1920s was countered by FDR's creation of the Tennessee Valley Authority a decade later.[11]

Our contemporary disrupters would do well to consider the history of the American telephone industry, which passed through a stormy and destructively competitive maturation, characterized by fierce contention with local, state and federal authorities, until in 1913 Theodore Vail negotiated the settlement that ratified ATT's unique place in the American political economy. Vail's successful reading of the contending interests and forces - cultural and political as well as economic - established "Ma Bell" as

---

[10] For a spirited account of the waste and corruption that accompanied the building and mismanagement of the transcontinentals, see R. White, *Railroaded: The Transcontinentals and the Making of Modern America* (New York NY: W. W. Norton, 2011), pp. 331-2 and 371-2 for discussion of the populist political response.

[11] T. P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore MD: The Johns Hopkins University Press, 1983), chapter 12.

the universal service provider and ATT's Bell Labs as a distinctively powerful engine of innovation for some 75 years.[12]

Today's valuations of Uber and Airbnb and many another Unicorn are not based on their proprietary technology. These valuations reflect the possibility of establishing a "natural monopoly" in markets of enormous scale with consequent monopoly profits, based on a business model and network externalities not unlike that of ATT in telephony. As was the case with ATT, establishment and maintenance of such monopolies will depend on earning the tolerance of the stakeholders in the relevant eco-system. In short, the longer term, sustainable value of those disrupters that succeed in closing the loop from atoms to bits and back to atoms will depend as much on successful application of lessons from the humanities (history, moral philosophy and literature) and the social sciences (the political economy and sociology of markets) as to mastery of the STEM disciplines. To the extent that they choose to share those profits in ways broadly deemed fair, there will be less pressure for the state to mandate the redistribution.

In the meantime, however, the idea that the digital revolution has a further and deeply transformative way to run has been challenged head on. That challenge needs to be taken seriously, not least because it opens the door to consideration of the "productivity puzzle": the apparent secular slow down in the growth of productivity across the developed world. Addressing the productivity puzzle, in turn, illuminates the macro-consequences of digitalization.

Is Economic Growth Over?

The most prominent academic challenger has been Robert Gordon of Northwestern University, a distinguished economic historian whose work in macroeconomics and studies of long-term economic growth have properly earned him high regard. So his recent exercise in speculative future history, which asks whether economic growth in the United States has come to an end, has attracted much favorable attention. But a basic flaw in Gordon's argument is immediately obvious.[13]

Gordon distinguishes three Industrial Revolutions that have driven economic growth and improved living standards since the eighteenth century: IR #1 ("steam, railroads"), whose defining inventions date from 1750-1830; IR #2 ("electricity, internal combustion engine, running water,

---

[12] See Robert MacDougall, *The People's Network: The Political Economy of the Telephone in the Gilded Age* (University of Pennsylvania Press, 2013).

[13] Gordon's original statement of his thesis was presented in R. J. Gordon, "Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds?" National Bureau of Economic Research Working paper 18315, August 2012. His comprehensive restatement in the context of an extended evaluation of American economic growth over the past 150 years was published as *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War* (Princeton University Press, 2016).

indoor toilets, communications, entertainment, chemicals, petroleum"), whose defining inventions date from 1870-1900; and IR #3 ("computers, the web, mobile phones"), dating from 1960. The core of his article and subsequent book contrasts the transformational impact of IR #1 and, especially, IR #2 on per capita GDP and the quality of life with the relatively trivial consequences of IR #3.

The vulnerability of Gordon's argument is his shortened time horizon for IR #3. Consider the following four sentences:

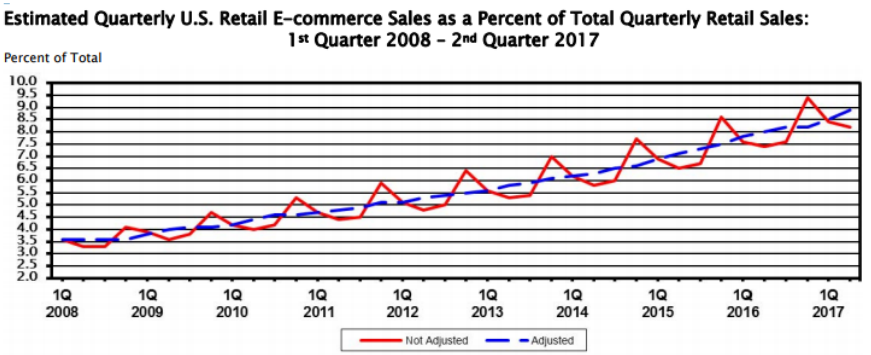
> Both the first two revolutions required about 100 years for their full effects to percolate through the economy.
> At a minimum, it took 150 years for IR #1 to have its full range of effects.
> The inventions of IR #2 were so important that they took a full 100 years to have their main effect.
> …[T]he productivity benefits of IR #3 evaporated after only eight years, compared to the 81 years (1891-1972) for the benefits of IR #2 to have their full impact…

The last sentence is crucial: Gordon cuts off IR #3 circa 2005 – that is, 45 years from its onset, but less than half the time allowed for IR #1 and IR #2 to run their respective courses. To take a salient example from the prior industrial revolutions, this as if the impact of the railroads on the US economy were to be measured as of 1873, 45 years after construction began on America's first line, the Baltimore & Ohio. But in 1873, the retailer Montgomery Ward was just a year old, and the first Sears Roebuck catalogue was still 15 years away. Together, these companies invented mail order as the "killer app" of the railroad age - the "railroad services" business model, as Brad Delong characterized it - creating a continental market for consumer goods, with all of the economies of scale and scope and the reconfiguration of economic geography that followed.

Or, to take another example, what if we terminated measurement of the economic impact of electrification only 45 years after the construction in 1882 of the first generating plant, Thomas Edison's Pearl Street Station? At that point, America's manufacturing industries were just discovering the benefits of flexible production processes, which distributed electric power and unit drive motors made possible, while America's home-appliance industry was in its infancy.

Gordon asserts that "the era of computers replacing human labor was largely over" during the past decade. Innovation in information and communications technology (ICT) focused first on electronic commerce, "itself largely completed by 2005." After that, "labor-saving innovation" took a back seat to "a succession of entertainment and communication devices that do the same things as we could do before, but now in smaller and more convenient packages." In thus truncating and trivializing the ongoing ICT revolution, Gordon misses two fundamental processes. First,

and most evident, the rise of e-commerce is far from over. In the US, the most advanced country in this respect, e-commerce has just reached 9% of total retail spending and is continuing to grow at double-digit rates, a multiple of the growth of total retail.

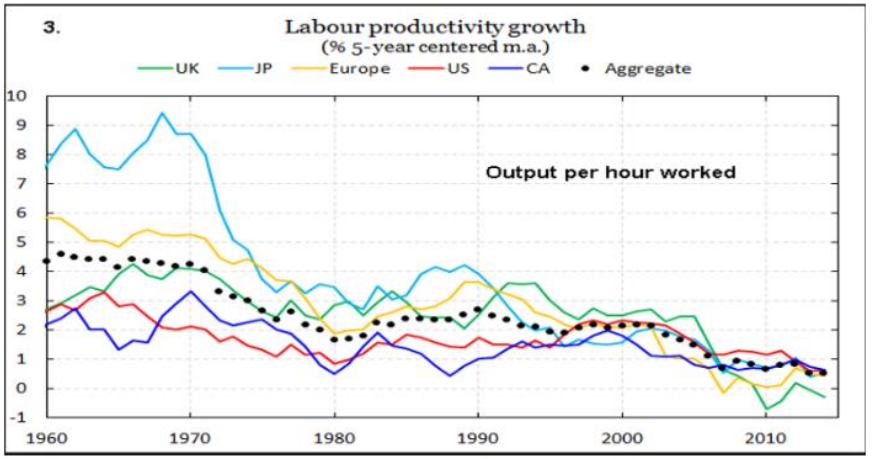


(Source: "Quarterly Retail E-Commerce Sales, 2nd Quarter 2017," U. S> Census Bureau News, August 17, 2017, available at https://www.census.gov/retail/mrts/www/data/pdf/ec_current.pdf.)

At the same time, something much more significant is happening beneath the economic surface. From the early days of the computer revolution, as discussed in chapter 2, researchers and popularizers envisioned "artificial intelligence" as the ultimate killer app (literally, in the case of the computer HAL in the film *2001: A Space Odyssey*). Decades of frustration are now yielding to success: the application of sophisticated statistical techniques to the accelerating accumulation of unprecedented quantities of Big Data that the Internet simultaneously generates and captures. In turn, the success of the leaders of the digital revolution in transforming data into information and information into meaning and meaning into economic value is generating macro effects that only begin with the competitive advantage thereby gained.

Which Productivity Puzzle?

Gordon is quite correct to call out the evident slowdown in the growth of productivity: over the past 30 years, with the exception of the uptick during the years of the great Dotcom/Internet Bubble of the late 1990s, productivity growth has slowed markedly.



Gavyn Davis, "Is Economic Growth Permanently Lower?" available at https://www.ft.com/content/3822867f-85bf-33a2-85a5-4a40974d7d9e

Post-war reconstruction, especially of the devastated economies of western Europe and Japan, was responsible for a rate of growth in productivity that was unsustainable. But renewed slowdown in average productivity growth across the advanced economies is evident through the twenty-first century to date.

One mode of response to Gordon and to the data has been to focus on the potential mismeasurement of output in the increasingly digitalized economy, since any such shortfall would automatically reduce the measured rate of growth in productivity. Thus, MIT's Erik Brynjolfsson and Joohee Oh, note:

> Over the past decade, there has been an explosion of digital services on the Internet, from Google and Wikipedia to Facebook and YouTube. However, the value of these innovations is difficult to quantify, because consumers pay nothing to use them.[14]

But their estimate of the missing output is only $30 billion, not a rounding error in a $18 trillion economy.

Recently, Philippe Aghion, a leading economist of innovation and his colleagues have identified what appears to be a substantially larger source of under-measurement of productivity in the over-statement of inflation. Aghion and colleagues examine the process through which the U.S. Bureau of Labor Statistics accounts for the price of new products and services in their inflation indices by using the prices of already existing "comparable" offerings. Since new additions to output are most likely to be sold at lower prices, the result is to over-state inflation and to under-state growth of real output and, consequently, productivity. The understatement of productivity growth captured by Aghion amounts to 0.5 percentage points

[14] E. Brynjolfsson and J. Oh, "The Attention Economy: Measuring the Value of Free Goods on the Internet," available at http://ide.mit.edu/research-projects/attention-economy-measuring-value-free-goods-internet

of the 1.75 point decline in the rate of real economic growth and productivity between 1996–2005 and 2006–2013.[15]

In the UK, Diane Coyle of the University of Manchester has been playing a lead role with the Office of National Statistics and its supporting Economic Statistics Centre of Excellence in the effort to understand the impact of digitalization on reported productivity relative to the underlying technological and economic reality. Coyle identifies three sets of issues. One is the increased scope and pace of quality improvement in digital goods that exceeds the conventional "hedonic" techniques for correcting price indices. A second concerns the "production boundary" between "monetised activities," counted in GDP at their exchange value and "online activities undertaken by the household sector…which are not in GDP."[16] A third reflects "the development of new digitally-enabled business models" that result in "an activity included in measured GDP…being progressively substituted by activities that are not included."[17] A prime example is the purchase of cloud computing services as an intermediate good, netted from GDP, which substitutes for the previous purchase of computer hardware and software counted as investment in GDP. One detailed analysis of this large and fast growing phenomenon suggests that alone it would account for a missing 0.1 percent of growth in GDP and Productivity.[18] Ongoing research sponsored by the British Office of National Statistics suggests that a much larger adjustment may be required to reflect the extraordinary increase in the performance of data communication networks, whose cost per bit fell by as much as 90 percent between 2010 and 2015.

Chad Syverson of the University of Chicago recently challenged the "mismeasurement hypothesis," to account for the "missing $3 trillion" of US output that would have been generated if productivity growth had stayed on track:

> My evaluation focuses on four pieces of evidence that pose challenges for mismeasurement-based explanations for the productivity slowdown that the US economy has been experiencing since 2004. Two patterns—the size of the slowdown across countries is uncorrelated with the information and communications technology intensities of those countries' economies, and the GDI–GDP gap began opening before the slowdown and in any case reflects capital income growth—are flatly inconsistent with the implications of the mismeasurement hypothesis. Two others—the modest size of the existing

[15] P. Aghion, A. Bergeaud, T. Boppart, P. J. Klenow and H. Lu, "Missing Growth from Creative Destruction," July 2017, Federal Reserve Bank of San Francisco working paper 2017-04, available http://www.frbsf.org/economic-research/files/wp2017-04.pdf

[16] D. Coyle, "Do-it-yourself digital: the production boundary and the productivity puzzle," ESCoE Discussion Paper 2017-01, June 2017, p. 5, available at https://www.research.manchester.ac.uk/portal/en/publications/doityourself-digital(22599b9c-aea8-41cd-94d7-4bcd0b5bec23).html

[17] Ibid.

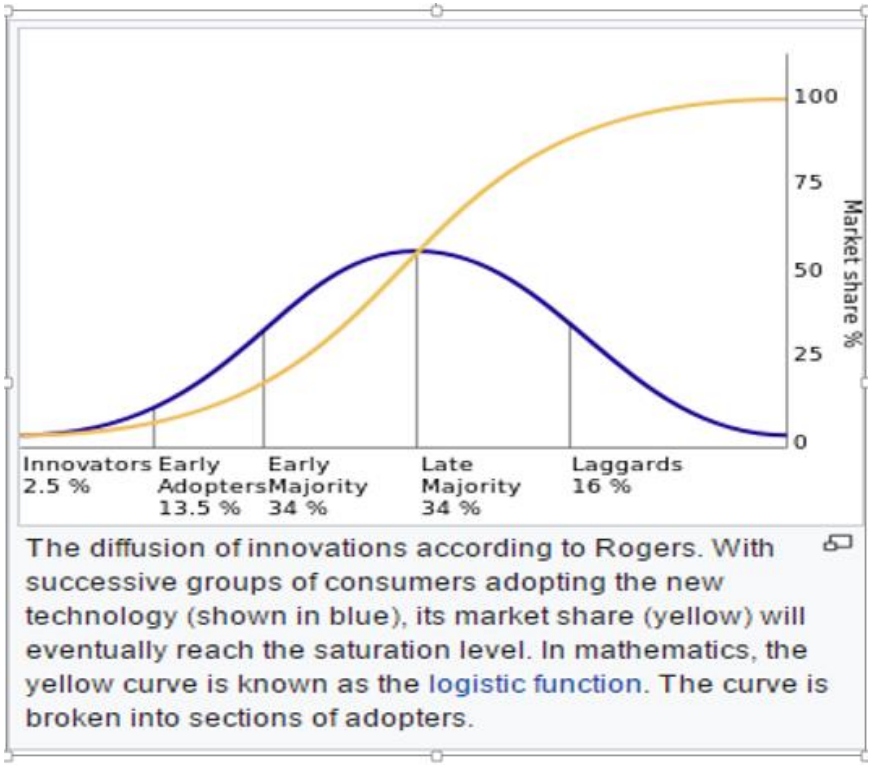
[18] D. Byrne, C. Corrado and D. Sichel, "The Rise of Coud Computing, Minding your P's and Q's," available at https://bea.gov/about/pdf/acm/2017/the-rise-of-cloud-computing-minding-your-ps-and-qs.pdf .

literature's estimates of surplus from internet-linked products and the large implied missing growth rates of digital technology industries that the mismeasurementhypothesis would entail—show the quantitative hurdles the hypothesis must clear to account for a substantial share of what is an enormous amount of measured output lost to the slowdown (around $9,300 per person per year).[19]

Critical scrutiny of the data must not obscure recognition of the broad and continuing shift in the competitive position of the leading developed economies relative to the emergent ones, led by China. Between 1995 and 2015, the global share of "gross value added" – output less intermediate goods and services – of the G-7 countries declined from about 65 percent to about 50 percent, while the share of the next sixteen economies has increased from about 15 to 25 percent. In manufacturing, "the great convergence" is much more extreme: the G-7's share has fallen from two-thirds to less than one-half, while the share of the next sixteen has risen again from about 15 percent to almost 40 percent.[20] As relatively high-productivity manufacturing employment declines, the sectoral shift to relatively low-productivity services would of itself result in a reduction in overall productivity, a fall temporally covered up by the extreme increase in the reported productivity of the financial sector until the Global Financial Crisis.[21]

All of this observation and analysis concerns the rate of growth of ***average*** productivity. With respect to income and wealth, we have learned from the late Anthony Atkinson[22] and Thomas Piketty[23] to look through the averages and evaluate the distribution. In this case, the focus on average growth in productivity across the whole economy misses the point. The transformational economic impact of technology does not come as one uniform wavefront. In 1962, Everett Rogers analyzed the "diffusion of technologies" as a process that he mapped to the logistics curve that begins slowly, accelerates to a peak rate of growth and then slows down as the market space becomes saturated

[19] C, Syverson, "Challenges to Mismeasurement Explanations for the US Productivity Slowdown," *Journal of Economic Perspectives*, 31:2, Spring 2017, pp. 182-3.
[20] See, R. Baldwin, *The Great Convergence: Information Technology and the New Globalization* (Cambridge MA, Harvard University Press: 2016), chapter 3.
[21] I owe this insight to Lord (David) Sainsbury.
[22] A. Atkinson, *Inequality: What Can Be Done?* (Harvard University Press, Cambridge MA, 2015)
[23] T. Piketty, *Capital in the Twenty First Century* (Harvard University Press, Cambridge MA, 2014)



The diffusion of innovations according to Rogers. With successive groups of consumers adopting the new technology (shown in blue), its market share (yellow) will eventually reach the saturation level. In mathematics, the yellow curve is known as the logistic function. The curve is broken into sections of adopters.

https://en.wikipedia.org/wiki/Diffusion_of_innovations

Almost thirty years ago, the great historian of technology Paul David called out an historical analogy between the observable economic consequences of electrification and the contemporary "productivity paradox" famously encapsulated by Robert Solow of MIT: "We see the computers everywhere but in the productivity statistics."[24] As David wrote:

> Certainly, the transformation of industrial processes by the new electric power technology was a long-deThe layed and far from automatic business. It did not acquire real momentum in the United States until after 1914-17, when regional utility rates for electricity were lowered substantially…and central station generating capacity came to predominate over generating capacity in isolated industrial plants.[25]

Realization of potential productivity gains from the electrification of manufacturing were also delayed by the pre-existing infrastructure: the belts and pulleys required to deliver power whether from water wheels or setam engines to fixed groups of machines. "In 1900," David wrote, "contemporary

[24] P. A. David, "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox," *American Economic Review*, May 1990, p. 355.
[25] Ibid., pp. 356-7.

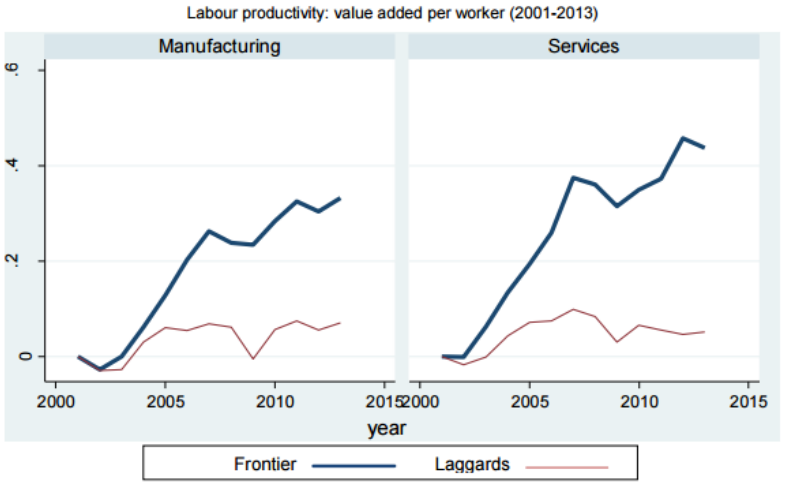
observers well might have remarked that the electric dynamos were to be seen "everywhere but in the productivity statistics."[26]

Only when "unit drive" motors enabling lower cost, flexible manufacturing plants were widely disseminated did in factories to which the regional grids, funded by the speculative boom of the later 1920s, delivered the electrical equivalent of power from the cloud did manufacturing productivity take off. Alexander Field has mobilized evidence to suggest that the greatest measured increase in US total factor productivity occurred during the Great Depression, when industrial laggards took advantage of the proven benefits of electrification and when public investment in road building enabled major improvements in transportation and distribution.[27] IR #2 was not over in 1933, fifty years after Edision turned on the world's first central power station on Pearl Street in New York City. And far from IR #3 being over today, the acceleration of eCommerce, the universality of social media, the deployment of increasingly functional robots, and—above all—the mining of ever bigger data by machine learning algorithms all offer evidence that, 50 years on, we are barely half done.

The best versus the rest

[26] Ibid., p. 356.
[27] A. J. Field, *A Great Leap Forward: 1930s Depression and US Economic Growth* (New Haven, CT: Yale University Press, 2011), pp. 19–41.

In fact, the right question is: where are we in the diffusion of digital technologies? To this question, the Organization for Economic Cooperation and Development ("OECD") has provided an answer based on masses of relevant evidence. Two summary charts deliver the central message of the OECD's working paper, appropriately titled "The Best versus the Rest."[28]



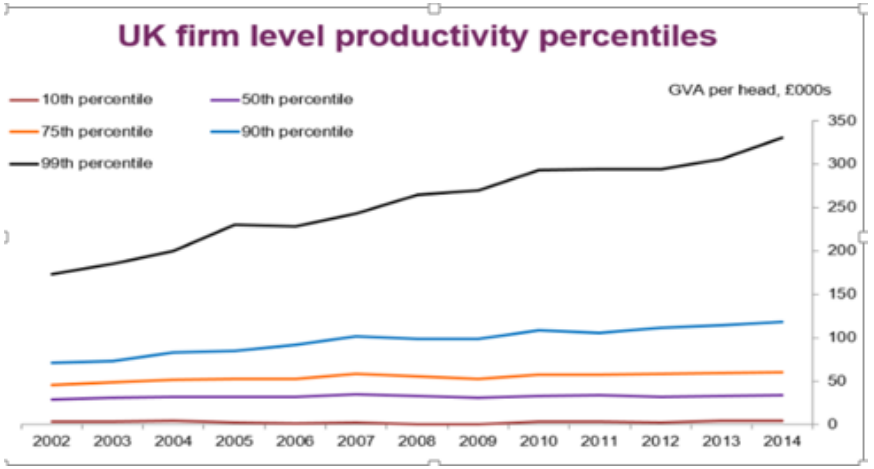
Notes: the global frontier is measured by the average of log labour productivity for the top 5% of companies with the highest productivity levels within each 2-digit industry. Laggards capture the average log productivity of all the other firms. Unweighted averages across 2-digit industries are shown for manufacturing and services, normalized to 0 in the starting year. The time period is 2001-2013. The vertical axes represent log-differences from the starting year: for instance, the frontier in manufacturing has a value of about 0.3 in the final year, which corresponds to approximately 30% higher in productivity in 2013 compared to 2001. Services refer to non-financial business sector services. See details in Section 3.3.

Source: Authors' calculations based on the recent update of the OECD-Orbis productivity database (Gal, 2013).

Since the end of the Dotcom/Internet Bubble, across the developed world, the "best" 5% of firms in terms of productivity have maintained historic trend growth in productivity both in manufacturing and service industries, while average productivity of the laggards has stagnated.

Andy Haldane, Chief Economist of the Bank of England, found the same phenomenon when he analyzed the labor productivity of no less than 30,000 British firms over roughly the same period:

[28] D. Andrews, Criscuolo C., and P. N. Gal, "The Best versus the Rest: the Global Productivity Slowdown, Divergence across Firms and the Role of Public Policy," OECD, December 2016, available at http://www.oecd-ilibrary.org/economics/the-best-versus-the-rest_63629cc9-en;jsessionid=9ag8ukcclm7fb.x-oecd-live-03



So the crucial, follow-on question becomes: why are the best so much better than the rest? Let's look first at why the Rest lag. The history of electrification suggests one possible explanation. Before electricity supply was standardized and widely distributed, manufacturing firms needed to install and manage their own generators and motors. Skilled electrical engineers were required to turn frontier invention into useful work. So it has been in the Age of ICT from the first deployment of computers and so it remains for those who do yet have broadband access to "the Cloud." Firms that want the benefits of computing have had to hire their own IT Departments and manage computer operations and application development and deployment. So the first hypothesis is that access to cloud computing through "real" broadband internet (say, 100 megabits per second) will virtualize the underlying technology even as the grid did with electricity.

Of course, unlike electricity, taking advantage of internet access to basic processing and storage services is not enough. What broadly characterizes the Best is their development and deployment of ways to mine and monetize the data that their business activities generate. And the leader in cloud computing, Amazon Web Services, is responding:

> Amazon Web Services provides a broad range of services to help you build and deploy big data analytics applications quickly and easily. AWS gives you fast access to flexible and low cost IT resources, so you can rapidly scale virtually any big data application including data warehousing, clickstream analytics, fraud detection, recommendation engines, event-driven ETL, serverless computing, and internet-of-things processing. With AWS you don't need to make large upfront investments in time and money to build and maintain infrastructure. Instead, you can provision exactly the right type and size of resources you need to power big data analytics applications. You can access as many resources as you need, almost instantly, and only pay for what you use.[29]

[29] https://aws.amazon.com/big-data/

While AWS and its followers, notably Microsoft Azure and Google Cloud, will be helping the Rest to use analytics to refine their business offering and improve their operational efficiency—with benefit to productivity—the Best, the very BEST that is, will stay ahead. For, at the frontier, the Digital Revolution is delivering a new dynamic source of self-sustaining competitive advantage.

No less than a dozen years ago, with characteristic foresight, Tim O'Reilly recognized that the driving source of value in IT was once again shifting. Over the decade from roughly 1985, value shifted from hardware to software as computers themselves were commoditized. This was the technological and economic and investment transition that I and my colleagues at Warburg Pincus exploited through BEA and OpenVision/VERITAS. Now, some thirty years later, value is shifting again: this time, from software to data.[30]

Data generates business value to the extent that it is mined to extract meaningful and actionable information. This is the sharp end of the machine learning juggernaut, where the development of new computational processes generally known as "deep learning" neural networks are doing just that. Practitioners at the frontier, like Yann Lecun of NYU and Facebook, are at pains to counter the renewed hype over Artificial Intelligence that these real achievements have generated. In particular, the systems are brittle in the extreme: trained on a dataset initially curated by humans, a machine learning algorithm that masters identification of dogs will fail utterly in determining what an image of a cat represents. But behind the hype and likely to survive its frustration, machine learning techniques are transforming the economics of production, distribution and consumption.

The more data, the better the algorithms. And the better the algorithms, the better the quality of service offered by Amazon, Facebook or Google and the other frontier firms. This is the positive feedback law of machine learning. Previous sources of market power have been conventional economies of scale and scope, augmented by patents (Xerox), network externalities (IBM) and government regulations and franchises (ATT). All of these still matter, of course, in the age of the internet. But machine learning as a source of competitive advantage adds another, technological driver whereby those whose offerings—for whatever initial reason —achieve market leadership are endowed with an amplifying ability continuously to improve their relative market position.

So here is the double, paradoxical hypothesis that arises from considering the right question about the Productivity Puzzle. The second half of the Digital Revolution (Gordon's IR #3) will see the productivity of the Rest rise. But even as average productivity emerges from its slump, the Best will continue to maintain, perhaps widen further, their already enormous lead. The immediate

[30] See "What is Web 2.0? Blogging and the Wisddom of Crows," available at http://www.oreilly.com/pub/a/web2/archive/what-is-web-20.html?page=3

impact is on the markets that these firms increasingly dominate. These companies function as platforms enabling two-sided markets, the participants in which generate positive feedback increasing progressively the attractivesness of the platform for each other. And as participation increases, they become ever more attractive sites for others to gain access to potential customers: hence the dominant share of Google and Facebook in online advertising. Whereas Amazon and Uber and Facebook generate revenues directly from paying customers attracted to their marketplaces, Google and Facebook make money by attracting advertisers. As the saying goes: if the service is free, you are the product.[31]

This new source of competitive advantage and market monopolization has also attracted regulatory response, again most notably in Europe. Much of the data that is the new source of value is generated through voluntary transactions of individuals with the aggregators. But much of it is also generated through the continuous monitoring of users by those aggregators, such as geo-location data. So economic and political questions immediately arise over ownership and responsibility. The European Union's General Data Protection Regulation is a comprehensive effort to construct a framework in which data can be legally collected, processed and used, with the intent of protecting the privacy rights of individuals. Applicable from April 25, 2018, its fairness and effectiveness will only be demonstrated in use.[32]

More broadly, the rise of the platform superstars has consequences at the level of the macro-economy, with most particular respect to increased inequality and the decline in labor's share relative to profits. David Autor of MIT and his colleagues "established the following facts" through an intensive and extensive empirical investigation that defines the emergence of "superstar firms" so successful that they materially alter the aggregate distribution of income between capital and labor:

> (i) there has been a rise in sales concentration within four-digit industries across the vast bulk of the U.S. private sector; (ii) industries with larger increases in product market concentration have experienced larger declines in the labor share; (iii) the fall in the labor share is largely due to the reallocation of sales between firms rather than a general fall in the labor share within incumbent firms; (iv) the reallocation-driven fall in the labor share is most pronounced in precisely the industries which had the largest increase in sales concentration; and (v) these patterns are also present in firm- and industry-level datasets from other OECD countries.[33]

---

[31] For an incisive analysis of the economic consequenes of internet platforms, see M. Kenney and J. Zysman, "The Rise of the Platform Economy," *Issues in Science and Technology*, vol. XXXII, Issue No. 3, Spring 2016 available at http://issues.org/32-3/the-rise-of-the-platform-economy/

[32] https://gdpr-info.eu/. For a stimulating, historically informed evaluation of the new transparency driven by the digital revolution, see B. Harcourt, *Exposed: Desire and Disobedience in the Digital Age* (Cambridge MA, Harvard University Press, 2015).

[33] D. Autor, Dorn D., Katz, L.F., Patterson, C., and Van Reenen, J., "The Fall of the Labor Share and the Rise of the Superstar Firms," MIT Working Paper, May 2, 2017, available at https://economics.mit.edu/files/12979.

In a recent Harvard Business Review cover story, Nick Bloom has summarized his complementary findings on the role of *inter*-firm differentials as a primary source of increased income inequality: they are to be "attributed to three factors: the rise of outsourcing, the adoption of IT, and the cumulative effect of winner-take-most competition."[34] But all three causes reduce to one. It is the maturation of IT into the digitalization of economic activities and relationships that both enables outsourcing and drives the superior productivity and wage-paying capacity of the winners who are taking most of the markets in which they compete.

Beyond the economic consequences of digitalization and their direct spillovers into the political arena, a new front in confrontation with the state has been opened for the digital media companies, much as they may seek to evade it. It concerns the problematic integrity of the underlying political process on which the authority of the state rests. There is, of course, a long history of the use and abuse of the power of the press for political ends: from the first contested presidential election of 1800, distinguished by the vituperous falsehoods of the partisan press, through William Randolph Hearst's asserted responsibility for the Spanish-American War to the role of Fox News in the polarization of politics over the past twenty years. But digital media has a unique power of simultaneous polarization and amplification through its narrow-casting focus and its friction-free response and distribution. The sheer volume of digital communications renders the task of filtering and validating what is posted technically impossible in the limit. In the evolving aftermath of the 2016 election, however, those responsible economically for these new channels may expect to be held responsible politically for the content they disseminate.

And so the IT revolution, sponsored by the state and funded by speculation, feeds back not only to transform the market economy. It also conditions the political dynamics that shape the capacity of the state to offset and balance the coordination failures and self-destructive outcomes of markets operating under conditions of radical uncertainty. Thus, it contributes to the reconfiguration of the three-player game, whose dark side we now get to consider.

[34] N. Bloom, "Corporations in the Age of Inequality, available at https://hbr.org/cover-story/2017/03/corporations-in-the-age-of-inequality.