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Learning from history: how innovation transformed our world and will be essential in the future

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I. Introduction: Why learning from history is essential to understand and engage with transformative innovation today[1]

Innovation is the most important fact about the modern world, but one of the least well understood. It is the reason most people today live lives of prosperity and wisdom compared with their ancestors, the overwhelming cause of the great enrichment of the past few centuries, the simple explanation of why the incidence of extreme poverty is in global freefall for the first time in history: from 50 per cent of the world population to 9 per cent in my lifetime.

Matt Ridley, "How innovation works"

The Scientific Revolution has not been a revolution of knowledge. It has been above all a revolution of ignorance. The great discovery that launched the Scientific Revolution was the discovery that humans do not know the answers to their most important questions.

Yuval Noah Harari, "Sapiens"

This paper serves to inform the discussion about shaping new approaches to and frameworks for innovation policy by highlighting a range of important features of how innovation and transformation throughout history. The issues and perspectives covered in the paper are far from comprehensive and are intended to inform and spur discussion as well as to stress the rich learnings from successes and failures in the past to address the challenges and opportunities for sustainable development and beyond.

Innovation has driven the transformations in the past and now, from the rise of civilization over the industrial revolution to the green and digital transformation we are working on today. Transformative innovation is a perspective that puts societal, economic, and environmental transformation into focus and looks at the kind of invention, innovation, and social norms and values that underpin it. Such transformative innovation has been at the centre of the overwhelming enrichment the world has seen over the past two centuries.

[1] The history of transformative innovation is too vast to give justice to in a short paper. We are portraying only a select few features and angles among many. The aim of this paper is to contribute to the discussion of transformative innovation policy and spur debate.

It is equally essential to attaining and possibly exceeding the Sustainable Development Goals (SDGs), including enabling and accelerating green and digital transitions. As the 2023 report shows[2], despite substantial progress on poverty reduction and health, progress on half of all targets is insufficient and, on 30%, has stalled or gone into reverse – especially in the wake of Covid-19 restrictions and outbreaks of armed conflicts in several parts of the world and the UNECE region. Particularly urgent is the ambition radically to reduce anthropogenic greenhouse gas emissions (SDG 13) – while also ensuring affordable and clean energy, especially for the least developed countries (SDG 4). The latter in particular face urgency (given the ambition to move to net-zero emissions by 2050), and cross-border externalities.

Transformative innovation has helped us overcome challenges in the past; and can in the future. Targeted, mission-oriented policies and investment into basic and applied research into a full range of potential ways to harness energy could bring us energy sources that are not only emissions-free, but also more reliable, affordable, and sustainable across the board. Providing primary health care for all at a cost affordable even for the poorest is eminently possible with innovation in a range of ways of driving down the cost and broadening coverage. However, this also requires rethinking innovation and a range of other policies. This paper aims to pinpoint some of the important lessons from the history of transformative innovation to feed into a broader discussion of what transformative innovation policy within an SDG perspective could look like.

Throughout all of human history, we have gained little understanding of innovation in history – and myths and misconceptions about it. This has led to a range of mistakes by entrepreneurs and, later, policymakers. In fact, up until the "Great Enrichment" (TGE) started two centuries ago in Great Britain, we have resisted innovation, including clearly superior ideas, across the board, be it because of myopia, potential job losses for individuals or even the end of work, or an overall fear of the new and unexpected. And even nowadays, we see suspicion of innovation in public attitudes, costly regulation, rent seeking, and unintended, negative side effects of the patent system (e.g., patent thickets). This concern is particularly intense in concerns around AI and the singularity, the end of jobs (especially for the low-skilled), inequality, and the urgent energy transition.

These are all valid concerns. But it is also innovation that has been and will be essential for progressing towards the Sustainable Development Goals, development, and green and digital transformation in the long term. Nobel laureate Bill Nordhaus estimates that humankind could be as much as 960 times better off than two centuries ago because of innovation. This is because of all the factors that GDP and inflation estimates fail to capture: benefits such as new and, within a decade, affordable products and services, a three-fold increase in life expectancy, antibiotics, anesthesia, fast travel, clean air, near ubiquitous internet access, and social networking, to name a few. In other words, a social return.

If history shows us anything, it is that human ingenuity can solve all kinds of problems, including affordable, scalable energy generation technologies and creating new and, mostly, better jobs to replace the ones that will be lost in the process. This calls for optimism, but not complacency, about how it can serve us ahead – to reach the SDGs, to catalyse the green and digital transition, and to continue the trajectory of great enrichment to the benefit of all. That is why a nuanced understanding of how innovation has worked, works today, and will work in the coming decades is even more important, especially for understanding how public policy can play a productive role in supporting the innovative dynamism that has catapulted us to where we are today and could work for us as well or better in the future.

Enhancing that understanding to guide innovation for sustainable development, including the green and digital transition, today and in the future, is the core intent of this paper. A central insight is that innovation is almost impossible to predict: throughout history, we have been wrong, often erring on the side of doom and gloom. This holds especially for predicting transformation: as the examples of electrification and digitalisation clearly show, putting potential to use can take decades, with many false starts and mistakes along the way. Another insight is that technology and invention are mostly not the driving forces: ideas for putting them to use, grit, and persuasion brought us railways and electricity – the technology itself had already been around for over a century and required only marginal improvements. A final insight is serendipity: innovation policy should not aim at supporting specific solutions but rather broad experimentation with ideas and continuous learning, aware that most will fail but that we have to try out all kinds of activities to find the ones that can create momentum and demonstration effects that can lead to positive transformation.

After a background section on the scope and persistence of the Great Enrichment that started after the first industrial revolution, the next section will explore selected, often overlooked or at first glance counterintuitive,

[2] The Sustainable Development Goals Report: Special edition. United Nations, 2023.

features of transformative innovation. After that, we have collated examples of prevailing myths and misconceptions.

The Great Enrichment: how the world became 960 times richer after millenia of stagnation and can continue in the future.

Understanding innovation today and in the near future calls for the close study of history
Paul David, 1975, p. 16

This, in the words of economic historian Deirdre McCloskey, the "Great Enrichment" was unprecedented not only in its scope, but in its tenacity. Previous growth spurts in history typically fizzled out in a few decades, whereas the Great Enrichment has continued despite numerous setbacks and devastating wars. In fact, the post-war years in Europe almost doubled growth rates for what the French call "les trente glorieuses". Figure 1 shows this stark trend on human development measures.

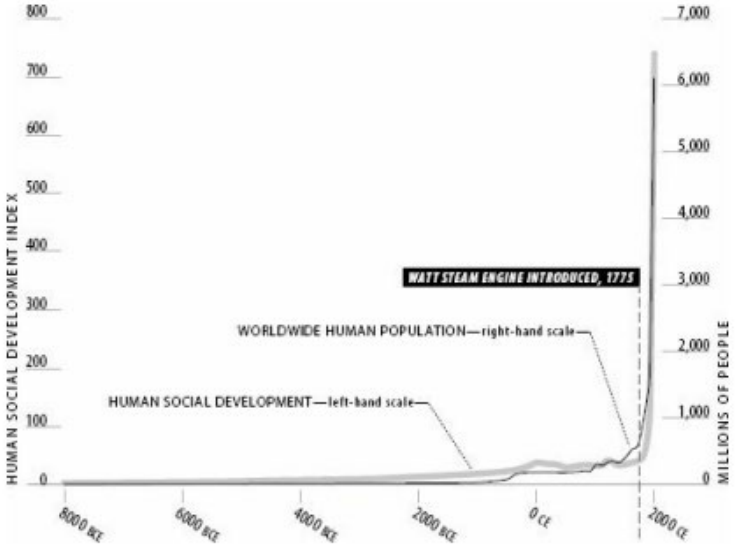

Figure 1: Human social development over the past millenia[3]

Why? That is the question that this paper will try to review, as briefly as possible for such a complex subject, and draw essential and perhaps for many surprising and illuminating lessons from it to help us understand and enable transformative innovation in modern times.

Explaining the Great Enrichment – the standard answers do not suffice…

Historians and economists, try as they might, struggle to find solace in the standard explanation. Not only in capital accumulation, or adding capital (machinery, steam, and electric power, but also in human capital – skills, know-how, and an enabling culture) to produce more - Nordhaus estimates that at most capital accumulation contributed 15% of the total. Nor in expanding trade – even in Great Britain, trade as a percentage of GDP was a few percent, and, before the steamer, transport costs and risks, both human and financial, were prohibitive. Nor in emerging features of healthy capitalism and markets: in Great Britain, property rights were secured in the Bill of Rights a century and a half before, London had taken over from Amsterdam as the center of world finance, and

[3] Figure is from Erik Brynjolfsson and Andrew McAfee, The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies. Norton: 2012.

regulation was mild or non-existent for centuries. Nor in free trade: in fact, up until the toppling of the Corn Laws, Great Britain had a highly protected economy – more so than France.

The importance of institutions came to the fore with the emergence of the institutionalist school, but the institutions that were around were often harmful rather than enabling: judicial corruption was rife, property rights enforcement was lax (the enclosures and railway construction required massive, poorly compensated expropriation). Nor did the government have much of a positive role: the public sector stood for just 5% of GDP, mostly spent on defence, the small police force, and salaries.

Nor did colonialism and slavery: economic historians (McCloskey, Mokyr, Landes) broadly agree that colonialism was a net cost more driven by prestige, the fruits of one-sided trade diminishing fast as we found other resources close by; and slavery was not only inhumane, but as Thomas Sowell and others calculate, it became increasingly costly as it held back efficient production requiring skill and motivation not likely to emerge by force. Nor was it Dickensian exploitation: while living standards were atrocious for the working class in the cities for at least the first 50 years, poverty in the countryside was much worse – and, starting around 1850, wages grew at double-digit rates because of scarcity, pushing many workers into the middle class and setting off the first mass consumer boom in history a decade later. TGE happened, rather, because workers became better off and more engaged, and some of them became entrepreneurs in their own right. Nor did scientific insights have an impact until much later; in fact, it was the gradual improvement of the steam engine that triggered the field of thermodynamics, not the other way around.

Neither was it scientific progress and invention. Despite the scientific revolution, science remained largely an unpaid hobby of the curious and wealthy (McCloskey) – only in the late 19th century, based in large part on impetus from educational reformist Alexander von Humboldt in Germany, did we see formal training or well-equipped laboratories emerge, let alone the paid profession of a scientist. In fact, few inventions were based on a scientific understanding of the underlying physics, and many inventions waited for centuries, if not millennia, to be of little use only to be picked up again by avid entrepreneurs during the early phases of TGE.

II. Learning from the Great Enrichment: how innovation works

If you look at history, innovation doesn't come just from giving people incentives; it comes from creating environments where their ideas can connect.

Steven Johnson (born 1968), Science author

The liberal idea, or modern liberal equality of permission… was the spring in the machine of growth.

Deirdre McCloskey

Looking at the turn of the human spirit in England by political life; seeing the Englishmen… inspired by the sense that he can do anything…. whether nature has scooped out ports for him or given him coal or iron

Alexis de Toqueville[4]

You can imagine the Great Enrichment without the Renaissance, the Reformation, or the (Glorious, scientific, French, American, Enlightenment) Revolutions… But you cannot imagine it without the Revaluation.

Deirdre McCloskey, Bourgeois Dignity

Inventors are the elect of the human race.

The London Times, April 22, 1826

Intensive growth, or doing more with less, prevailed after centuries of sluggish, extensive growth – heaping more capital without otherwise doing things differently. The difference is increased total factor productivity (TFP), which Nordhaus estimates made up at least 85% of growth, while capital accumulation alone accounts for a maximum of 15%. This is the result of innovation, much of which, with time, turned out to be transformative. But the past two centuries also teach us much about how innovation works. Above all, it was a bottom-up phenomenon – millions of people tinkering, mostly out of sheer pleasure and interest, and coming up with and trying out all kinds of ideas, including the crazy. On a massive scale.

Hundreds of books try to suss out how innovation works, looking at history. The following contains a selection of those that are among the most important, surprising, and relevant to innovation and innovation policy today. We will first review some of the central features of the cultural switch towards modernism that enabled innovative dynamism to take place. In a second section, we will look at overall features of how innovation works – then and now.

[4] Toqueville, Alex de. 1835. Voyages en Angleterre et en Irlande.

Feature 1: Social and cultural change matters: dropping the dishonour tax.

As most economic historians note clearly, the Enlightenment, the scientific revolution, and even the first industrial revolution could have, but did not, create sustained growth and innovation rather than just invention. It was stuck in the struggle between traditionalism and liberalism. Only with the swift change to a liberal, modern order were the Promethean forces of the entire population unleashed – although the struggle remained, at least until the social revolts of the 1848 revolution.

Despite the Enlightenment and the French revolution, society was still conservative. A world where, as the icon of British Romanticism with the telling name Wordsworth stated, was perhaps the most famous poem of the era, "The world is too much with us": "Getting and spending, we lay waste our powers" – where entrepreneurial pursuit and the rise of the bourgeoisie emulating noble birth faced disdain. But in the early 19th century, McCloskey, Mokyr and others point out based on meticulous research, society changed from that of the heroines of Jane Austen, dignified in adhering to manners and morals, to that of Jane Eyre, a woman refusing to adhere to societal expectations, consistently asserting her autonomy.

Most importantly, commerce and entrepreneurship became tolerated, at times even sources of dignity – only a generation after being the opposite, despised by the upper classes as greedy and devoid of decorum. Don Boudreaux, for instance, talks about removing the "dishonour tax" on commerce and entrepreneurship that stifled such activities for centuries5. The growing bourgeoisie asserted itself, the top hat emblematic of social climbing. But more broadly, these changes unleashed massive energy among the illiterate working classes as well: in fact, most famous entrepreneurs of the age came from poor backgrounds with little if no education, and some, like Stephenson, the hero behind the railways, were completely illiterate. Innovation, from tinkering to new technologies, was a near universal obsession. It was out of that steam pot that the good ideas that stand for at least 85% of the growth came from as noted above. It was our first knowledge economy on a broad scale. And it has persisted until now, far from being new. In a generation, Great Britain had turned from a rigid class society to one of broad opportunities; from suspicion to celebration if not obsession with ideas and future potential; From mercantilism and protectionism to a culture where the Corn Laws came to symbolise reaction and preservation of landed privilege. Within a century, most of Western Europe followed suit: first Belgium, then France, then reunified Germany, and, with remarkable speed and a strong liberal tradition, Scandinavia.

Feature 2: Ideas and incremental process innovation, not technology, are the driving forces of transformation.

There's a way to do it better. Find it.

Thomas Edison (1847 - 1931), Inventor

Exploration is the engine that drives innovation. Innovation drives economic growth. So let's all go exploring.

Edith Widder

Few ideas work on the first try. Iteration is key to innovation.

Sebastian Thrun

History is speckled with examples showing that inventions and new technology, even obviously useful ones, fail to lead to market-tested innovation and transformation – or take decades to come to fruition. What matters is coming up with and, through entrepreneurship, trying out a range of ideas to realize their potential – ideas about how to use them, how to persuade potential customers, how to bring about changes in habits, and how to create a sustainable model. The steam engine, invented in the 17th century, was made useful to provide energy much more broadly by Watts a century later, and it took another half-century for steamships to replace sails, reducing shipping costs and times radically.

One frequent misconception is about the genius of Thomas Edison as an inventor who gave us the light bulb. In fact, that is not where his contribution to transformative innovation lies. The technology and potential were well

[5] D. Bourdreaux, Deirdre McCloskey and economists ideas about ideas. Liberty fund blog, July, 2014.

in reach: at least twelve parallel inventions of other ways to make a lightbulb emerged around that time – some of them clearly superior to what Edison's engineers came up with.

Edison's contribution to transformation, and his genius, was in coming up with and trying out ideas, as well as his nous for persuasion and entrepreneurship. Ideas for process and market creation through demand and infrastructure. Convinced of the potential not only of the lightbulb but also of household electricity more broadly, Edison went about the challenge of digging up streets and laying wires from his steam-powered generation plant across several neighbourhoods – an initiative that was to prove by far the most transformational: building hard infrastructure. He then turned to persuasion, giving out lightbulbs and electricity connections for free in the hope that the word would spread. It worked and did spread, although, as noted later, it would take another five decades before his dream of electricity fully replacing steam would come to fruition through decades of persuasion and ubiquitous process innovation to rearrange pretty much everything to move from steam to electricity at scale.

The real transformation came about from something much more pedestrian: small changes in processes along the value chain that not only yield improvements but, most importantly, create new markets by tapping into the huge potential of the financially constrained mass market, including the poorest. In fact, tweaks as simple and, in hindsight, obvious as consolidating railway schedules and setting up a system for joint pricing and ticketing could transform society – in this case, turning railway travel from a daunting, often expensive hassle of exploring different routes, buying tickets from half a dozen transport service providers, and often missing connections, to a convenient, affordable service that dominated transportation for almost a century.

Feature 3: Small-scale, often unpaid, tinkering and experimentation create a large pool of ideas – the innovation commons.

We are very innovative in bits, not so much with atoms.

Peter Thiel

There's a way to do it better. Find it.and give me a common old garden device, and I will… find you an innovative version of it.

Thomas Edison (1847 - 1931), Diffuser more than inventor

Exploration is the engine that drives innovation. Innovation drives economic growth. So let's all go exploring.

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Few ideas work on the first try. Iteration is key to innovation.

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A common notion is that is that innovation needs big money, brilliant ideas, and cutting-edge technology supported by great corporate or government structures – or dynamic start-ups and the astonishingly successful unicorns. It is true in some cases, most markedly in pharmaceutical research of the traditional type, defence, expensive hardware, and utility-type business models. And sometimes we need conceptual breakthroughs – not only in technology, such as quantum computing, but in society, values, and behaviour. Sharing your house or getting on trains or using the first phones required thinking about how society worked in different ways.

But the history of TGE shows largely no driving role for science until almost a century after it had started. With a few exceptions, invention was about marginal improvement or recombination of existing technologies and ideas that had been around for centuries – railways and steam power had been used since the 17th century in mining; electricity generation for over a century, before diffusing. Rather, it was driven by entrepreneurs who took up and tried out ideas from a vast pool of possibilities that emerged: what Potts calls the "innovation commons".

Tinkering

How did this vast pool form so suddenly? It happened through radical changes in culture and attitudes that, within a generation, went from strict adherence to rigid social norms and class differences, to a society where optimism and celebration of entrepreneurship pervaded society. This encouraged what historian Joel Mokyr terms tinkering. Tinkering with all kinds of ideas, including improbable or ostensibly crazy ones, and minor improvements – spurring innovation that has been, in many ways haphazard. Some, like Ridley, believes it remains a driving force – and that large corporations and government mostly do not have the agility and flexibility to encourage it. But most breakthroughs towards broad transformation come about without directionality or even intent. That is the kind of activity most in need of support but that often fall foul of criteria for support of innovation by being

unexpected, such as robots in nursing homes or applying branding and quality control and international expansion of childcare services (both initially opposed, eventually embraced).

In the early 1800s, as Arthur Diamond notes in his book "Openness to creative destruction", industrialisation still broadly meant small workshops in individual houses and sheds, constantly repairing, customising, perfecting them – efforts that often, and in an increasingly encouraging social environment, led them to come up with ideas for new tools.

This kind of tinkering, or intense, curiosity driven playing with ways to solve a particular problem, or one that comes up in the process, or one that does not exist yet, or experimenting with ideas, differs in scale but not much in kind from the processes of enthusiastic tinkering, long processes of trial and almost inevitable error, continuous learning from failures and from others in their strive to "get on", that led to most transformative innovation in the 19th century and even today. It is not much different from tinkering with different ways to code software, to have robots try out hundreds of tasks to find the ones it can do well, or from the unseen but ubiquitous tinkering going on to perfect scientific instruments, bicycles, and windsurfing boards6.

Learning from trial and error – without grand plans or set ambitions

Apart from tinkering, cultural change and the dropping of the "dishonour task" on entrepreneurship enabled another important source of practical, recombinant knowledge and discovery of potential ideas: more systematic trial and error. At the extreme, we can think of how many pharmaceutical compounds came about: through systematic creation of thousands of similar compounds and then go through a process to find out, step by step, which would have potential and for what disease – often with little clue beforehand (in fact, much medical knowledge still relies on the near certainty of patterns in large amounts of data, rather than an understanding of the exact mechanisms through which medication works).

Mostly, however, trial and error are slightly less ambitious – but the principle remains the same. Famously, Brunelesschi, in trying to find out how to build a relatively modest dome, discovered a technique that could withstand the pressure of a dome double the size – which he then built.

In fact, everything in the environment – technology, customers, competition, other inventions, changes in taste, obsolescence of tastes or fashions, scientific discoveries, social media memes – changes so rapidly and unpredictably, that even trying to see a year or two in the future is a long shot. The successful entrepreneur, Christensen counsels, rejects deliberate long-term goals and planning and pursues a vague, emergent strategy of looking for opportunities, improvising, and exploring and testing ideas that may lie way beyond the original intent.

Learning by doing and discovering what people mean and want can be years of persistent, patient work

Many people fail to appreciate the complexity and slow pace of the current transition because they confuse technology with invention, and relevant skills with educational attainment. A new technology typically requires much more than an invention to be designed, built, installed, operated, and maintained. Initially, much of this new technical knowledge develops slowly because it is learned through experience, not in the classroom. Throughout history, workers have acquired their technical knowledge through a combination of formal training and experience. They gained much of their important technical knowledge on the job through "learning by doing." Formal and informal experimentation, aided by informal communication with others, allowed workers to acquire new skills and knowledge of technology. This allowed, throughout history, factory workers with little or no schooling to gain skills and command middle-class pay.

This is equally important today, even for work with frontier technologies and science. The reason we could see technology everywhere except in productivity figures is simple: the idea and the technology dwarf in importance compared to the challenge of defining how systems should work in detail and of office workers spending months to learn and to use the system productively – just like the large scale mechanisation in the past faced the overwhelming constraint of the time it took for workers to change their habits and learn how to operate in a new environment.

And perhaps most importantly: a tolerance for the bizarre and crazy.

[6] Examples and spirit borrowed from Eric Hippel, 2005.

Feature 4: Most innovation is the result of serendipity: not pure luck, but almost.

It is an iron rule of history that what looks inevitable in hindsight was far from obvious at the time.

Yuval Noah Harari. "Sapiens."

Most innovation consists of the non-random retention of designs

Matt Ridley, "Why innovation matters"

There were no automotive experts at the turn of the century, only inventors and entrepreneurs following their hunches and enthusiasms and trying to convince potential car owners to buy their product. Given this situation, once the gasoline engine gained ascendancy, steamers and electrics were either forgotten or viewed as missteps along the road to automotive progress.

George Basalla[7]

If you're not failing every now and again, it's a sign you're not doing anything very innovative.

Woody Allen (born 1935), Director, writer, actor, and comedian

Innovation is more likely to come from a person who sits down and does the same thing every single day until they become an expert than from a person who sits down once because they feel inspired.

Stacy Caprio

If I have a thousand ideas and only one turns out to be good, I am satisfied.

Alfred Nobel (1833 – 1896) Chemist, engineer, and inventor

Innovation- any new idea- by definition will not be accepted at first. It takes repeated attempts, endless demonstrations, monotonous rehearsals before innovation can be accepted and internalized by an organization. This requires courageous patience.

Warren Bennis (1925 – 2014), Scholar and organizational consultant

As innovation involves tinkering, experimentation, and learning the results are often serendipitous – in terms of what is invented how and when. Even, as many example shows, improvements that must have been obvious way before they came about, are the result of a range of serendipitous circumstances.

Serendipity means a bit more than just luck

The classic example of serendipity, perhaps one that stretches credulity a bit but illustrates the point, is how Charles Goodyear came across vulcanised rubber. Coming from extreme poverty but energised, perhaps, by the dynamism and opportunity optimism of his era, he developed an obsession with improving rubber, a promising material that turned out to be of limited use because of some of its feature – sticky when hot and brittle when cold. Relentlessly tinkering with additives, processing steps, or coverings that would cure these defects, he once accidentally spilled a mixture of rubber, sulphur, and lead on a hot stove. Upon discovering it later, he found it to be nonsticky and pliable. What came to be vulcanised rubber, born from alertness and serendipity, became another transformational invention that made bicycles and automobiles much more comfortable than before, allowing them to boom as a result.

More than luck, serendipity requires a willingness to travel to interesting places, alertness, an ability to notice and remember the dissonant and unexpected, and the effort to think about how the unexpected could be used. As Louis Pasteur lectured in 1854: "chance favours the prepared mind". The Goodyear example may be (a bit too) straightforward, but most serendipitous discoveries require more thought and effort. Petroski points to Spencer Silver, who, in trying different mixtures at random to fin strong glue, discovered a mixture whose adhesive effect was very light. Far from obvious, it took three years, presumably the thought and effort of Silver and his colleague Arthur Fray, to come up with the idea of the now universal Post-it notes.

Befuddling serendipity, take 1: sliced bread

Bread had been around for millennia. For millennia, people had to slice it themselves. For centuries, slicing it with machines had been fully possible with just a bit of tinkering. Yet it first occurred long after it was possible and obviously useful: in 1928. Why then? And why, of all places, in a small town in the middle of Missouri?

In fact, many people had made sliced bread machines. But the most successful inventor who made the final improvements was Otto Rohwedder, an optician and then a jeweller who, driven by the dynamism of the time, perhaps decided to build a bread slicer. But bakeries were not interested, for a very simple reason: automatic packaging that prevents the slices from going stale. He did not know how, and no one was interested – except for

[7] George Basalla, The Evolution of Technology (Cambridge University Press, 2002).

a small bakery in Chillicother, Missouri—that, through serendipity and perhaps in an act of final desperation, Rohwedder walked in to. The rest is history.

Befuddling serendipity, take 2: wheeled luggage

Other anecdotes are instructive. Ridley talked of the late arrival of wheeled luggage. We had luggage. We had wheels. Why did it take until the mid-1970s before we could buy such an obviously useful container? In fact, Bernard Sadow of a baggage-making company had tried. In 1972, he applied for a patent for taking four castors off the wardrobe and screwing them onto his suitcase. But when he took his prototype to retailers, he was summarily rejected. Why add to the cost and the weight? Why not use a trolly or a porter? Only a few years later did Macy's pick it up, and a decade later it had become standard. In fact, he was not the only one; Ridley has listed at least five related patents since 1925. So why?

Air travel was not ready. Airports were small, customers wealthy enough to hire porters, staircases abounded, and wheels could break up them. That changed when air travel was liberalised: after the 1970s, air travel in the US became widely available and airports grew – the time was right.

Feature 5: The transformative effect of innovation takes decades or more to come to fruition: the case of digitisation and electrification.

Any sufficiently advanced technology is indistinguishable from magic."
Arthur C. Clark

We have written above about the improbability and unpredictability of innovation several times. Yet we have also outlined in this paper a range of unexpected features and misconceptions that appear to hold true with striking regularity. This applies in particular to the transformative effect of innovation around general-purpose technologies such as steam power, electricity, aviation, and digitalisation. These are the basis for a range of secondary transformations (depending on the exact definition), such as railways, factory automation, household appliances, smart phones, and AI, and their effects underpinned the Great Transformation and, arguably, the rise of civilisation overall.

Sometimes history repeats itself with spooky precision. Remember the productivity paradox?

You can see the computer age everywhere but in the productivity statistics
Robert Solow[8]

What Snow (1966) called "the biggest technological revolution men have known", delivered computing power in the US and saw orders of magnitude of investment and computing power in the following three decades. Computers were all around. But productivity had stagnated. It was as if Americans were no more productive with personal computers than they used to be with mechanical typewriters and calculators 30 years ago. Most shared Snow's befuddlement.

A brief look at history tells us why. General-purpose technologies in particular take time, complementary technologies, consumers, standards, entrepreneurs, experimentation, acceptance, overcoming hurdles, continuous improvement, and adaptation – before they are finally able to bring about the transformation that underpinned the initial hype half a century earlier. Since mainframe computers in the late 1940s (or, some claim, the invention of the computer by Charles Babbage in 1840), it took half a century for it to make a dent in productivity figures. The timeline is strikingly different from that of the spread of electricity once it had become both feasible and clearly superior to steam power.

Eerily so:

[8] Robert Solow. We had better watch out, NYT book review. Jul 12 1987

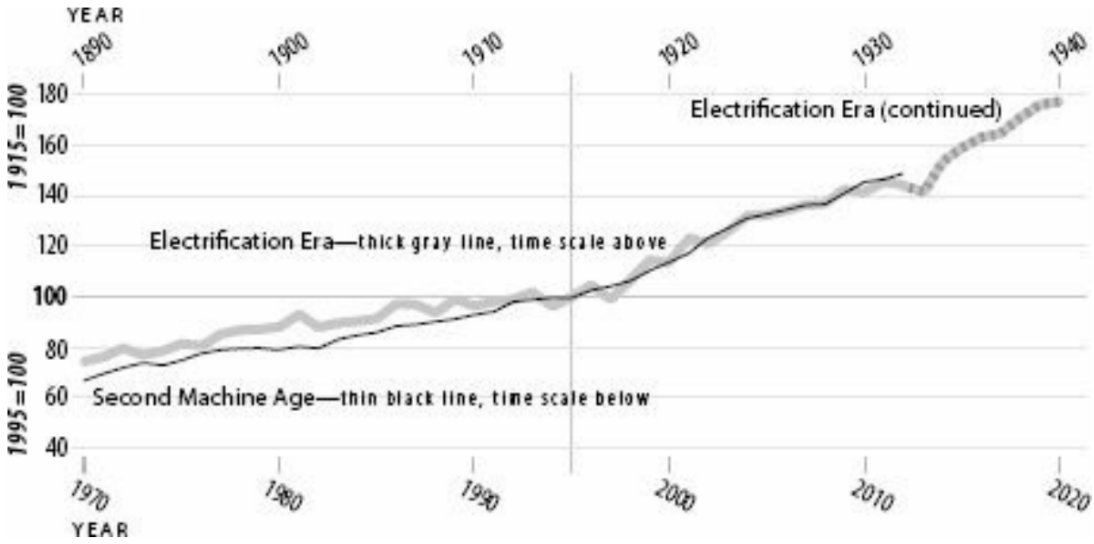

Figure 22: Labour productivity and the rise of electricity and IT: a comparison (Brynj/McAffee 2012)

To understand exactly how astonishing these parallels were and how similar they are to the trajectory of most general-purpose technologies (telephones, railways, autonomous vehicles, and perhaps AI), or GPTs, is essential to understanding how transformation works.

Feature 6: Innovation drives decoupling and environmental sustainability by creating more value with less resources.

> *Innovation… is a process of constantly discovering ways of rearranging the world into forms…. That happen to be useful. And innovation is potentially infinite because…. It can always find ways to do the same and new things more quickly and for less energy (or resources)*
>
> *Matt Ridley, How innovation works*
>
> *...man, far from being the overlord of all creation, is himself part of nature…. Man's future welfare and even his survival depend on his learning to live in harmony with these forces.*
>
> *Rachel Carson, Essay on the biological sciences*

Almost all innovation involves doing more with less. More and better products and services, larger markets that are affordable to the poor, and more value with fewer natural resources, capital, labour, other inputs. The Great Enrichment itself would probably not have happened had not the preceding agricultural revolution, which was driven by necessity in the densely populated Netherlands and then England, been able to produce much more using the same or less land and a fraction of labourers who could then provide the manpower for industrial development. This trend has grown exponentially. Figure 3 shows US corn acreage now yielding more than 18 times more corn per cultivated acre than a century ago.

Few expected this. Alfred Marshall, the leading 19th-century economist, points to the distressing conclusion that growth and technological progress always lead to more from more. This all changed around fifty years ago, the time when overpopulation seemed unmanageable, there was alarm over Global Cooling and the end of oil, and there was the prospect of all kinds of resources becoming more and more scarce as mines drained and the economy and population kept growing. As figure 3 depicts, right about then the opposite happened. The economy and population continued to grow, but resource use started to fall – decoupling that continues to this day.

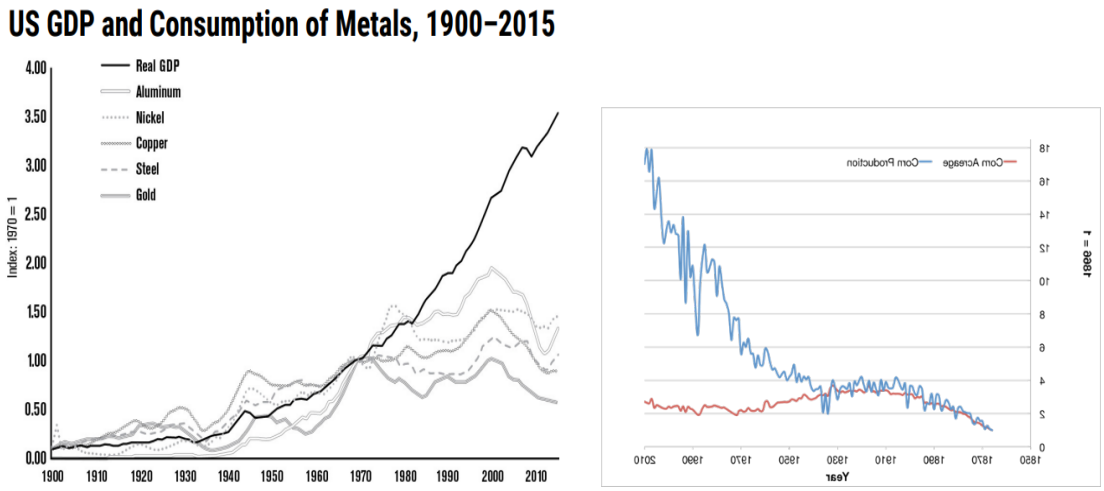

Figure 3:3 Decoupling - corn acreage versus production 1850 – 2012

Similar decoupling of growth from resource use abounds: particulate pollution, energy use per unit of output, and energy efficiency – though on average, several areas lag far behind. Environmental scientist Jesse Ausubel, puzzled by this trend change, looked at the use of the 100 most important mineable commodities and found the same correlation between growth and use until around 1970. But then, in his 2015 essay "The return of nature: how technology liberates the environment", he found that the world was not only using fewer resources per dollar of output but in total, despite the world population doubling from 3.7 to 8 billion and the world economy skyrocketing from $3.4 trillion to $85.3 trillion in the same period. As Ausubel writes, "of the 100 commodities, we found that 36 had peaked in absolute use... Another 53 have decoupled from economic growth and stagnated. Almost all of them now seem poised to fall".

Because of digitalisation, we may now have reached what Chris Goodall calls "Peak stuff" in a 2018 paper9: "(The world) began to reduce its consumption of physical resources in the early 1990s).This conclusion applies to a wide variety of physical goods, for example, water, building materials, and paper…. Both the weight of goods… and the amounts finally ending up as waste (are falling)".

But at the same time, we are consuming more – perhaps as much as 40 times more than in 1970, based on GDP figures. One of the reasons is that we are more efficient at building and producing things. Companies have strong incentives to use fewer inputs of any kind.

The main reason, however, is the rise of services, which now make up over half of the economy (and perhaps 90% of value, as many are free). And not services in general, but services that are either completely new or replace physical goods. In 2014, historian Steve Cichon bought a stack of newspapers from 1991 and saw an ad from the electronics retailer Radio Shack that struck him: out of the 16 gadgets advertised, 13 have disappeared and reappeared on his smart phone: a calculator, camcorder, alarm clock, telephone, tape recorder, and camera. It is easy to think of more that have disappeared: GPS devices, compass, barometer, maps, restaurant guides, most newspapers, movie rentals, airline tickets, travel agents, shopping lists, weighty mail order catalogues, most physical books, and enormous long-distance phone bills. And it was equally easy to think of many other services unimaginable back then, such as free video calls. This trend might well continue in the emerging platform economy. Mike Munger, one of many, estimates that over 90% of the goods we owe could be replaced by on-demand services, from car rides (with AVs), over a drill for hanging a picture, a high-end barbecue set for the one time you throw a party that year, and online, sensor-based medical services from near or afar.

The vibrant, continuous, incremental, recombinant, process, market-creating innovation has large potential to take us even further towards the end of ownership altogether. What we can access as a service, we do not need to own.

[9] Chris Goodall, Peak stuff: has the world had its fill of things? Pictet blog, 2018.

Feature 7: Innovation is recombinant – ideas, old and new, coming together.

The iPhone is made on a global scale, and it blends computers, the Internet, communications, and artificial intelligence in one blockbuster, game-changing innovation. It reflects so many of the things that our contemporary world is good at - indeed, great at.

Tyler Cowen

Imagination is not only the uniquely human capacity to envision that which is not, and therefore the fount of all invention and innovation. In its arguably most transformative and revelatory capacity, it is the power to that enables us to empathize with humans whose experiences we have never shared.

J.K Rowling

It is our habit of trade, idea-sharing and specialization that has created the collective brain which set human living standards on a rising trend. This holds out hope that the human race will prosper mightily in the years ahead — because ideas are having sex with each other as never before.

Matt Ridley

But an innovation, to grow organically from within, has to be based on an intact tradition, so our idea is to bring together musicians who represent all these traditions, in workshops, festivals, and concerts, to see how we can connect with each other in music.

Yo-Yo Ma

When people congratulated Newton on discovering and accounting for the effect of gravity, revolutionising math and science across the board, he responded that he did not deserve the credit: he was "standing on the shoulders of giants." In other words, he would not have been able to do what he did without relying on an immense wealth of previous ideas and discoveries.

That is how innovation functions. It does not come out of the blue but relies on a wide range of ideas, scientific insights, and existing technologies that can be combined to create enormous value. As Matt Ridley puts it, "Innovation is about ideas having sex".

In fact, the ideas and technologies are often old ones that are rediscovered and put to use. Fibre optic technology, for instance, revolutionised telecommunications in the 1980s – but it was Graham Bell who developed and tested it a full century earlier in his failed attempt to transmit images as well as voice over long distances: the "photophone". The reason the technology did not take off in the 1980s was simply that a range of other ideas and technologies, especially demand for increasing connectivity, were needed to put it into practice: computing, near ubiquitous telecommunication infrastructure, tweaks to enable scalable production, and the like.

In fact, almost every seemingly grand idea can be divided into an infinite series of smaller, previously known ideas. There is no singular magic moment of transformative innovation; instead, there are many smaller insights accumulated over time. The Internet required nearly 40 years of innovations in electronics, networking, and packet-switching software before it even approximated the system Tim Berners-Lee used to create the World Wide Web. The refrigerator, the laser, and the dishwasher were disasters for decades before enough of the cultural and technological barriers were eliminated through various insights, transforming the products into true business innovations. Big thoughts are fun to romanticize, but it is many small insights coming together that bring big ideas into the world.

Feature 8: Innovation overwhelmingly benefits the poor.

Finally, and often forgotten, is that innovation overwhelmingly benefits the poor. The data are indisputable: within two centuries, poverty has dropped from near universal to affecting 8% of the world's population, despite there being 8 times as many of us as then (Figure 4). World average life expectancy alone has risen from 28 years at the start of the industrial revolution (1770) to 72 years in 2021 during the COVID pandemic, and well over 80 in Japan and other leading countries in that same year.

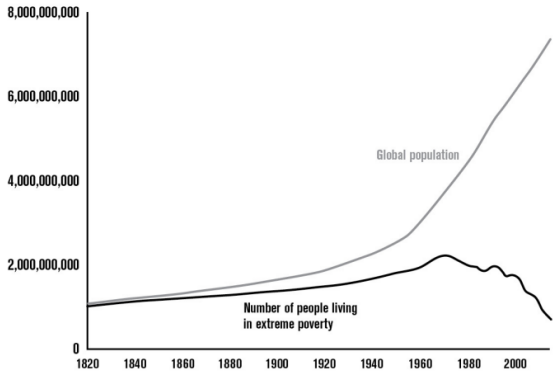

Figure 4: Population and extreme poverty of the world, 1820-2015 (World development indicators)

Not only by creating opportunities for entrepreneurship and employment and, by competition, eventually radically driving up wages and allowing unskilled workers a living standard unimaginable to their grandparents, but by driving down prices and making previous luxuries affordable within often less than a decade – creating entire new markets. The Great Enrichment was driven by demand, and to create such demand, innovators had to expand consumer markets to include the poor and create a series of consumer booms that reached almost everyone. Within a decade or so, luxury products tend to become affordable – think of clothes, silk stockings, motorised transportation, and smart phones, a luxury status item in 2007 that, ten years later, became available for less than 50 dollars in poor countries in Africa – equipped with ten times of the processing power. And the value of internet search, social media, and the sharing economy is available to almost all, as the last gaps in access are closing fast.

Perhaps the most striking example comes from William Nordhaus, who estimates the actual enrichment to be not 20, not 100, but at least 960 orders of magnitude. In his 1997 paper "Do real output and real wage measures capture reality?", he noted that if inflation is any guide, light should cost 13 times more per head since 1800. But inflation does not cover improvement – radical improvement. He illustrates this by measuring how long an average labourer would have to work to pay for one lumen hour. In 1800, light was a rare, inconvenient luxury: 60 hours of labour would give you an hour of flickering candlelight. Today, those same 60 hours could keep a room lit for 51 years – at a much better quality and with no need to steep candles or change oil.

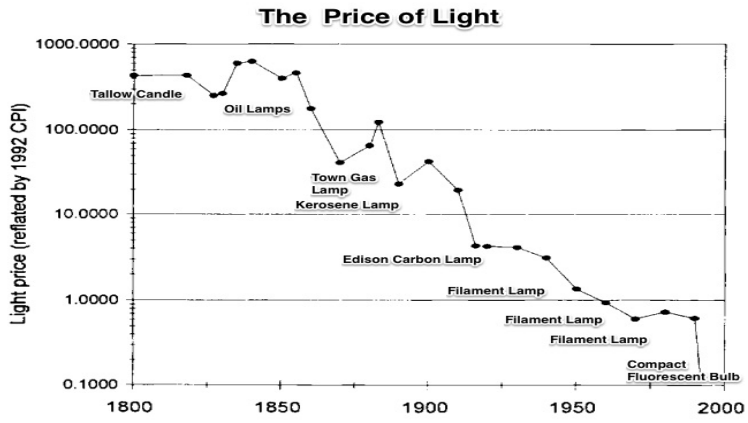

Figure 55: The amazing drop in the price and jump in quality of light

III. Myths and misconceptions about how innovation and innovation policy works

Although we know how important it is to growth, poverty reduction, and almost any area of sustainable development, we also understand little more than the broad strokes and often fail to draw lessons from both what

the recent and distant tell us about how innovation works and how transformations take place. Not only in GPT trajectories, such as electricity and computing, but the parallels of half a century or more of laying the groundwork, coming up with the idea, competing with others, testing it, and rolling it out – yes even the economic and political circumstances – are striking. So why, for instance, could we be so optimistic about the first .com boom, less than a decade after the World Wide Web came onto the scene and the internet became available to the public, that the obvious potential of the internet would materialize so fast? Almost all technologies have gone through similar so-called Amara hype cycles, where a technology and ideas for using it cause initial enthusiasm, which then drops into disillusionment at some point and slowly reawakens again to eventually bring about benefits, often going far beyond what we had initially imagined. The same most probably applies to promising technologies today, such as AI and autonomous vehicles: overall, the technology is only the basis; what matters is trying out ideas for using it to see what works and what does not, and most importantly, learn.

More importantly, however, is that human beings like to think in intuitive, memorable, attractive, and simplifying ways. The genius of Thomas Edison rather than the long history of putting electricity and lighting to broad, affordable use and the dozens of simultaneous, often better innovations – in fact, as an inventor, he was not notable, but as an innovator, trying out ideas for using inventions, he played an essential role. The courage of Jane Eyre as a feminist icon, rather than the broader societal shift to the dynamic but disorienting and risky get-together mentality that she has fallen prey to and demonstrates, her gender being just one obstacle among many that now could be overcome, especially poverty and ignoble birth.

For innovation policy purposes, however, such stories can be misleading and often counterproductive. The first step to effective intervention is making sure these myths are popped and that people understand innovation better to know what they want to enable and support. Or, the only way for innovation policy to be effective is to innovate itself. Innovate in the tinkering, modest, low-tech, recursive, evaluative, failure-embracing, direction-changing, customer understanding, and opportunity-spotting sense. The goal is simple: to enhance dynamic innovation overall and to make sure, at the micro level, that more people try out more promising ideas than they otherwise would. Most will fail, some will succeed, and some will be part of the many elements of a transformational innovation.

Myth 1: Transformative innovation based on grand ideas and cutting-edge technology convince and diffuse quickly by offering better ways of doing things.

Truth: Most ideas are modest and often ostensibly peculiar in the beginning, and the technology has often been around for years, if not centuries. Transformation occurs gradually over decades – and we only realise it afterwards.

The most important of my discoveries have been suggested to me by my failures

Humphry Davy

I have not failed 6,000 times (to find the right filament material); I have found 10,000 ways that do not work.

Thomas Edison

If at first the idea is not absurd, then there is no hope for it.

Albert Einstein (1879 – 1955), Mathematician

Confusion is a word we have invented for an order that is not yet understood.

Turning an idea into function is the (part of innovation) that takes up most of the time and involves the hardest work

Mihaly Csikszentmihalyi

The greatest shortcoming of the human race is our inability to understand the exponential function. — Albert A. BartlettHenry Miller (1891 – 1980), Writer

The value of an idea lies in the using of it.

Thomas Edison (1847 – 1931), Inventor

This misconception comes up open and is, in a way, the result of lacking awareness of one of the most important features of most innovations: gradualism, incrementalism, path-dependency, and, in short, tinkering. It was taken for granted by Marx and upheld as a foundational principle in the work of the dazzling Joseph Schumpeter, whose iconic entrepreneur used discoveries outside the economy, that is, science and technology, to develop an idea and go through the grueling process of raising capital, starting a company, developing a project – or, as he says, "to get the job done".

Phelps baptises this myth of scientism, and it is one that flies in the face of almost all evidence. It implies that innovation is predictable, its likelihood is knowable, and that once science has figured something out, we only need an expert entrepreneur and a veteran banker to turn it into an innovation. It is hard to think of an example of an innovation that fits this pattern even today, and yet scientism reigns supreme: countries still engage in exercises like innovation and technology forecasting, despite a 2,000-year track record of almost always being wrong.

Rather, most historical evidence – and perhaps even contemporary observations – shows that innovative dynamism may at times benefit from advances in science, but that the link between prosperity and science is weak compared to the importance of attitudes, beliefs, and a culture that protects and inspires individuality, imagination, understanding, success as much as failure, and self-expression.

Myth 2: If you build a better mousetrap, they will come: superior technology is destined to win out.

Truth: More often than most throughout history, clearly superior technology has been rejected outright or replaced by inferior alternatives. Grit, persuasion, and serendipity are much more important.

Surely what is obviously better will prevail…?

Another common misconception is that having a tested idea that would constitute an unequivocal improvement over existing solutions is not only necessary but often a sufficient condition for its success. While the stylised assumptions about the fully rational self-interest of homo economicus is the butt of much mockery even among its guardians of neoclassical economists (a small sacrifice for the unadulterated pleasure of reducing the infinite complexity of the economy to equations and growth predictions with plenty of decimals after the comma), we still find it hard to conceive why anyone would prefer walking to taking a train; polluting expensive candles with kerosene and electric lighting; and toxic pollution from indoor dung-fired fire pits rather than electric stoves. Surely, the logic goes, firms or consumers are offered a new technology solution, evaluate it, and if it, in the neoclassical sense of competition, is cheaper than the alternatives or, in the Schumpeterian sense, replaces the existing solution with one that increases productivity and hence profits, they will buy it; otherwise, they will not.

….yet apparently, they rarely do – and only after a long process

Yet most innovations that have vastly improved our lives did not emerge through a clean process of objective, utility-maximizing, rational selection. GPTs, like we illustrate in our comparison of the trajectory of computing and electricity, take decades to penetrate the economy and a few more to bring tangible net benefits. They require a range of complementary factors, creating a multitude of chicken and egg dilemmas: no lightbulbs without electric production and wiring; no electricity without a critical mass of electrical appliances it could power; telephones are useless until all the people you want to speak to have one. They face accidental and more often deliberate obstacles designed to protect the interests behind existing inferior technologies – the catalytic converter shutting out Japanese competition and outlawing innovation in emissions reduction for over a decade to benefit US car makers and reduce the pressure to reduce harm.

In fact, many argue that the notion of market-tested technological decisions is the exception rather than the rule. As the section on resistance to innovation explores further, a brief look at history makes this clear: it is hard to find examples of technologies winning primacy based on utility considerations alone. Social, ecclesiastical, political, mythical, and conflict-related factors were at least as important.

This factor might be one of the most important ones: when novel ideas are first proposed, people think they will not work because if they did, they would have thought of them themselves. Similarly, the reaction of students in my generation when coaxed to switch from electronic typewriters to computers to write papers was one of bafflement; they only seemed more complicated without adding any extra value. Discovering that extra value not only took time but required changes to our habits – writing papers with the ability to save and revise them repeatedly was a completely different process altogether from the forethought, conscientiousness, and inflexibility required to type a paper out and print it to hand in in one go. The technology was clearly superior in theory. But

it would take us a year or two to feel it. Mokyr claims that in the past, today's reluctance often took the form of outright resistance, working fully outside the normal economic process10.

The process of adoption of ideas, technologies, and standards is long, complex, and has more to do with politics and skills of persuasion and chance than objective utility

Precisely because these obstacles are frequent, if not systematic, the distinction between economic and political reasoning is misleading. Adopting new ways of doing things, even without new-fangled technology, was and is the subject of long debates, conflicts, and considerations far beyond the question of utility. The entrepreneurship of trying out a wide range of ideas to find what works, or the 99% of innovation that is perspiration, is, in Mokyrs view, to a significant extent a challenge of persuasion, rhetoric, and political nous. That is much more important than scientific insights or inventions, and it has been throughout history.

This might explain, for instance, why some economies have embraced nuclear power, GMOs, standard railway gauges, and the metric system (assuming for the sake of argument that they all represent choices clearly better than the alternatives) and others have not. It certainly explains why the highly unintuitive QWERTY key board layouts, presumably doubling the time needed to learn typing, prevail over intuitive ones, or why English, with its quirks, enormous vocabulary, and legacy spellings that sometimes bear no relation at all to the actual pronunciation, won out over the positivist project of a fully regular, rational, artificial language, Esperanto (admittedly based on Romance languages and not standalone logic).

Understanding this context is essential to make public support as effective and catalytic as possible

These constraints may be overstated – at any rate, innovation is an obstacle course for sure, but the obstacles have not stood in the way of the Great Enrichment to a significant extent. But a fuller understanding of the political economy of transformative innovation is essential, especially for government support to be effective and catalytic. At any rate, if the uptake and spread of innovation are the results of a process of Hegelian dialectic rather than messy, random evolution and the poorly understood process of speciation, they will, most of the time, prove misleading.

Myth 3: The Eureka moment: Innovation comes from brilliant, sudden insights by geniuses

Truth: We like storytelling, and many 19th innovations are swept in memorable stories. But almost all of these are false or misleading.

> *There seems to be this almost innate desire to tell stories about innovation in terms of eureka moments. For some reason, we just want to ... condense them to these moments of sudden clarity, where a light bulb pops over someone's head and they ... suddenly see the world differently. The apple falls from the tree — and they have a theory of gravity — whatever the trigger is. But when you actually go back and look at it ... in the historical record of innovation, eureka moments are the exception and not the rule. Almost always, there is a very long incubation period that goes into a breakthrough idea.*
>
> *Steven Johnson, Where Goods Ideas Come From*

We have a strong predilection for striking narratives that simplify the complex nature of phenomena and exaggerate turning points, such as Eureka moments. This has led to a range of myths – a grand example of which is the often-told story of Isaac Newton and his discovery of gravity. In a story constructed and popularised a century later by Voltaire11, Newton was sitting under an apple tree when an apple fell upon his head – prompting, out of nowhere, the epiphany of the idea of gravity.

This glosses over what innovation is about. Almost all new ideas leading to transformative innovation involve dozens of contributors, tinkering, persistent work, heaps of failures, and sacrifice, rather than the illusory notion of great insights appearing at once, fortuitously, and unpredictably in the head of a single person. In fact, most

[10] For some historical detail, see Joel Mokyr, "Progress and Inertia in Technological Change," in Capitalism in Context: Essays in honor of R.M. Hartwell, edited by John James and Mark Thomas. University of Chicago Press, 1994, pp. 230-54.
[11] Voltaire, Essay on the civil war in France, 1927.

insights are relatively modest tweaks drawing from a long legacy of thinkers who have gone before. Newton himself, in a 1675 letter in his harried correspondence with his pathbreaking peer, Robert Hook, admitted that "if I have seen further (than others), it is by standing on the shoulders of giants."[12]

We also, equally misleadingly, attribute incidents of post-facto transformative innovation to the myth of the lone genius or inventor. In fact, the opposite is true in almost all cases: even the heroes we celebrate, such as James Watt and the steam engine (see box X) and Edison's light bulb (see box Xi), turn out to have contributed mere improvements or ideas for commercialisation to technologies that already existed and had many alternatives at the time, many of which might have been better than the one that prevailed.

This misconception is as widespread now as in ancient Greece: crucial developments such as the invention of the World Wide Web have little to do with Eureka moments, but rather with accretion of insights, tinkering, and pure chance. Had Tim Berners Lee[13] not invented it, it is almost certain someone else might have come up with the same idea, though probably with different technologies and protocols. Stories like this surround almost all the technology and all the leading technology companies today, and are often invented, as the story of Ebay arising from a desire to trade PEZ dispensers[14], has one. They, just like good PR, are much more satisfying than the truth and indicate that we prefer what we want to believe to be true and resist facts that confound us or undermine the comfort we seek in our convictions.

Scott Berkun cites Gordon Gould, the inventor of the laser, on his own epiphany: "In the middle of one Saturday night…the whole thing…suddenly popped into my head and I saw how to build the laser…but that flash of insight required the 20 years of work I had done in physics and optics to put all of the bricks of that invention in there. Any major innovation or insight can be seen in this way. It's simply the final piece of a complex puzzle falling into place".

Myth 4. We can predict innovation through forecasting and analysis

Truth: Throughout history, almost all predictions turned out false – even in the short term. But scanning the horizon continuously is important to find opportunities.

This telephone (cannot) be seriously considered as a means of communication. (it) is inherently of no value
Western Union memo, 1876

We do not (need the telephone). We have plenty of messenger boys

Sir William Preece, Chief Engineer, British post office, 1876

When the Paris Exhibition closes, electric light will close with it and no more will be heard of it

Erasmus Wilson, Oxford University, 1878

"Radio has no future. (Airplanes) are impossible. X-rays will prove to be a hoax" Lord Kelvin, 1899

"Everything that can be invented has been invented" Charles Duell, head of US Patent Office, 1899

The reasonable man adapts himself to the world; the unreasonable one persists in trying to adapt the world to himself. Therefore all progress depends on the unreasonable man."

George Bernard Shaw (1856-1950), Playwright

The best way to predict the future is to invent it first.

Alan Kay

Economies are inherently unpredictable. They are the outcome of human conversations yet to be had.

Friedrich Hayek

Given a sufficient lapse in time, any substantial innovation will resemble magic. In a lecture, Rodney Brooks imagines Newton traveling forward to our time, where he receives an iPhone. Even a genius who began our understanding of colour and how it works will stare at the screen, click and see apps and videos pop up, receive a video call, and see nothing but magic. Even if much can be explained with his own insights in Principia Mathematica, he would have no idea how it all could work otherwise.

[12] Newton, Isaac. Letter from Sir Isaac Newton to Robert Hooke. Historical society of Pennsylvania. https://discover.hsp.org/Record/dc-9792/Description#tabnav
[13] Tim Berners-Lee, Weaving the Web (HarperCollins, 1999).
[14] Adam Cohen, The Perfect Store: Inside eBay (Back Bay Books, 2003).

The same effect, though less pronounced, haunts us today – a central feature of almost all innovation is that they are enhanced forms of improbability. An equally misguided notion, also touted by several otherwise insightful analysts, is what Arthur Smith calls inevitabilism. Innovation is inevitable; the entrepreneur's job is that which Schumpeter envisaged: to take patently promising ideas and put them into practice with little risk. This is arguably the case here and there, such as with the light bulb, the internet, and the steam revolution, which relied on recombinant or incremental improvement of existing potential. Any deeper look into examples of innovations and the obstacles, twists, and turns they faced; or the number of inventions that failed but turned out to be useful for other purposes; or the ones that, like the Goodyear tire material that Goodyear spilled a vial of resin on to and found that it made the rubber much sturdier, came about by pure chance.

That is why almost all attempts and predicting, let alone planning, innovations are much more likely to err than to be right. A recent example is the report from the 2005 meeting of the World Summit on the Information Society. Gathering leading experts from around the world to produce a 500-page tome outlining what will come was as solid a try as we could muster. Yet most predictions failed, and, strikingly, not one of the experts noted the transformative changes that lurked just around the corner: social media, smart phones, and cloud computing.

Technology is predictable only in retrospect and not at all in prospect. In 1800 and now, we have scores of future scenarios that we can be pretty sure will not play out. Ridley cites Ken Olsen, chairman of the Digital Equipment Corporation, a hugely successful minicomputer pioneer, referring to machines the size of large desks, replacing mainframes as large as rooms. Yet at the World Future Society meeting in 1977, the same year that Apple II hit the market, he reportedly said "there is no reason anyone would want a computer in their home".

The myth of methodology, in short form, is the belief that a playbook exists for innovation and removes risk from the process of finding new ideas. It's the same wish that fuels secret lusts for time-saving gadgets, for strong opiates without addiction, for tasty but low-fat meals, and for guaranteed success on five-day diets. Bringing together ideas, technologies, needs, desires, predispositions, and skills—all involve tangles and networks that are just as badly guided by start-up text books as policies are guided by so-called "best practices", a legacy of Monnet, Stalin, and Kosygin.

Myth 5: Society welcomes innovation

Truth: Throughout history and today, we have been wary, scornful, and sometimes alarmed by innovation – and many measures intended to enable innovation have the opposite effects.

"When the winds of change blow, some people build walls and others build windmills."

Unknown, An ancient Chinese proverb

"If I had asked the public what they wanted, they would have said a faster horse."

Henry Ford (1863 – 1947), Founder of Ford Motor Company

The paradox of innovation is this: CEO's often complain about lack of innovation, while workers often say leaders are hostile to new ideas.

Patrick Dixon. Building a Better Business (2005) p 137.

But the sun itself, however beneficent, generally, was less kind to Coketown than hard frost, and rarely looked intently into any of its closer regions without engendering more death than life. So does the eye of Heaven itself become an evil eye, when incapable or sordid hands are interposed between it and the thing it looks upon to bless."

— Charles Dickens, Hard Times

Innovation is moving at a scarify fast pace.

Bill Gates

The nature of an innovation is that it will arise at a fringe where it can afford to become prevalent enough to establish its usefulness without being overwhelmed by the inertia of the orthodox system.

Kevin Kelly

"Rail travel at high speeds is not possible because passengers, unable to breathe, would die of asphyxia"
Dionysus Larder, UNC, 1830

Even among those who proclaim their full support and excitement for innovation, they barely mask the puzzling but well-established fact that, despite all the lip service, innovation has been, is, and will be strikingly unpopular. Overcoming this resistance can take years or decades of hard work with uncertain outcomes.

A leading thinker on disruptive innovation, Joseph Schumpeter, stressed in his work that the critical role of the entrepreneur is not only to come up with and try out ideas but also to handle the long process of overcoming resistance. Any innovation represents a departure from established practices or consumption habits, creating resistance by peers, incumbent businesses, the government, and society at large. Deviation from norms elicits astonishment and fear, which in turn put pressure on or roadblocks ahead of those that seek to bring new ideas to market, all the way to "social ostracism, … physical prevention or... direct attack".

Jared Diamond in "Guns, Germs, and Steel (2009)", called the neolithic revolution and the birth of settlement and agriculture the worst mistakes in history. The important point is that no innovation, no matter how beneficial, is devoid of any downsides and, at any rate, can avert fierce criticism. Throughout history, the force of status quo has impeded progress and prevented transformative innovation.

In fact, almost all transformative ideas faced rejection and strong resistance – even when the ideas were, at least in retrospect, obviously superior. A typical example, cited by Scott Berkun in his book "The Myths of Innovation,", is that of Graham Bell's telephone. After having come up with the idea of the telephone and tried it out repeatedly, Western Union, the leading communications company in the world, dismissed Bell's pitch summarily as a useless toy – why on earth would a telephone be better than the telegraph or simple letters? We laughed as much as at Einstein's theory of relativity, Copernicus idea of heliocentricity, and Darwin's theory of evolution. Nobel laureate Paul Lauterbur, the coinventor of magnetic resonance imaging, famously said, "You can write the entire history of science in the last 50 years in terms of papers rejected" by science journals.

This predilection for the status quo and fear from the new, well established in vast psychological research, is at least as important and instructive as innovation and technological progress itself. Today, some may not recognise the immense scope of the Great Enrichment, and some would even point to its downsides, most agree that technology, or more precisely the experimentation with ideas to create value (often, but far from always by using technology in a broad sense), is the main source of the progress, growth, and by historical standards minute poverty rates we enjoy today. But throughout history, with remarkable consistency lasting to our days, innovation has been held back by fear and cultural anxiety. Since ancient times, literature has portrayed technology as alien, incomprehensible, powerful and threatening and at risk of running out of control and take over our lives (such as the AI singularity today, which may seem new but is merely an application of culture, history, and psychology applied to yet another innovation.

IV. Conclusion and some policy implications

The history of transformative innovation is too vast to give justice to in a short paper. However, in the context of the innovation and transformation we need to meet the SDGs and to ensure human flourishing continues more broadly, the insights covered and beyond are highly instructive in shaping a new approach to and perspective for the role of UNECE governments. Innovation policy 3.0, transformative innovation policy, and mission-orientation are important frameworks, but they should not fall into the trap of what Lant Pritchett calls "isomorphic mimicry" – changing labels and proceeding de facto as before. For that reason, UNECE proposes a set of transformative innovation policy principles that capture essential aspect of the rethink needed.

- **Support new activities** – Existing sectors and activities do not merit support. What matters are those that are new to the economy, the sector, or context and have strong potential for creating positive spill overs. For instance, the risk involved in the research, development, and scaling of better energy sources, such as thorium molten salt reactors or producing CO2 neutral oil from algae may be too daunting for individual entrepreneurs to take on, but we only need a few such ventures to succeed to demonstrate the viability of an essential element of the energy transition. Innovation policy should target such ventures clearly.
- **Make sure that targeted support plays a catalytic role** – support should enable entrepreneurs to try out ideas that would be too risky without it.
- **Base decisions on potential social return**. Innovation policy instruments should support projects that are important for progress and create social return well in excess of potential private return. This requires clear performance metrics used for continuous monitoring, revision, and evaluation – failure to meet this metrics should trigger a revision of the decision and, if warranted, discontinuation.

- **Ensure systematic learning and embrace failures** as learning opportunities. Innovation policy cannot be evaluated based on subsequent success of recipients of support – in fact such an approach will inevitably lead to funds flowing to less risky and hence less innovative projects.
- **Innovation policies and institutions have to be innovative as well** – trying out different ways of supporting innovation and evaluate them carefully to see what works and learning from what does not is essential.
- **Stop what is not working** – the most important principle of all. Monitor how projects and instruments are working, evaluate, learn from mistakes, and stop whatever falls short of the intent and try something else.

As history shows us, we need a new perspective and a new approach to innovation policy. At the core of the approach should be the two main things that the political economy and public choice schools of thought yield: the knowledge problem (we cannot predict the future) and the incentives problem (political influence and institutional structure). We need to move away from the instinct of planning and prediction and focus on specific solutions, whether it be ways to harness energy or regulate AI, before we even know whether our misgivings will play out or what other potential or risks may come up along the way. And we need to move towards a broad view of innovation policy as a process of continuous discovery and learning. A view that puts the ambition to enable and catalyse broad experimentation with all kinds of ways to create societal value through sustainable (in as many ways as possible, but financial sustainability of the business model is essential in all cases) activities. The first person to demonstrate the viability of business process outsourcing in the Philippines or ICT service exports in Armenia and Belarus triggered massive transformation and whole new growing dynamic sectors of the economy. Let us find and encourage as many of those as we can.