Man versus Machine: Automation, Market Structure and Skills

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Abstract. The paper asks a simple question. If individuals demand products from the firms in the economy and supply their skills concomitantly to the firms, then why should there be skill gap in the society, i.e., mismatch between skills that individuals possess and firm's demand. After all, in a decentralised economy prices of various products and skill specific wages should adjust to ensure that there is match between demand and supply of skills. The paper suggests that there are three factors that keep skill gap alive. The first two are the web of dynamic complementarities in the way human beings acquire skills and the way they invent new technologies. The third factor is the lack of competition in the product market that accompanies period of accelerated technical change. The papers looks at the impact automation and globalisation has had in opening up the skill gap and suggest policies that would help close the skill gap. With accelerated changes in technology and concomitant social changes, it is ever so more important to have a learning environment that allows workers and citizens in the society to learn and adapt flexibly.

Keywords: Skill gap, Automation, Globalisation, Market structure

JEL Codes: D43, F15, J24, O33

Contents

1. Introduction

Predicting the future requires predicting the social equilibrium the society will find itself in the future. The postwar social equilibria was one where in response to the consumers' demand, the firms demanded the whole range of skills that workers in the society acquired, which in turn created a stable unimodal income distribution. The postwar economy thrived with the rise of the middle class, yet a thriving middle class may or may not survive the social equilibrium resulting in the computer age. The inequality was high before the war while mechanisation was refashioning production across the board and there are concerns that we may seems to headed in that way again with the advent of computer.[1]

The alternative apocalyptic yet entirely feasible future social equilibria is one where only the rich and the poor exist and both demand goods and services that require skills that only the rich and the poor possess, thus slowly eliminating the middle class and creating an highly unequal bimodal income distribution.[2]

Divergence from an established social equilibrium starts when there is a sufficiently large destabilising exogenous shock. The phenomenal advancement in computer power in 1940s and 1990s is the shock that the economy is currently adjusting to.[3] The length of time it takes to converge to the new equilibrium depends on three interlinked conceptual components of the economy. The first component is the consumer demand, i.e., how the consumers trade-off price with other product characteristics and the way in which consumer demand changes as their income changes. The second component is the nature of production at the firm level, i.e., how firms translate the consumer demand for goods and services into demand for skills possessed by workers. The third component is the supply of skills by the workers and its responsiveness to the demand for skills. This

[1] Temin (2017) makes the case US economy is transitioning from a one-sector economy to a two-sector economy.

[2] Equilibria where the rich (poor) exclusively demand goods and services that require skills only the rich (poor) possess is conceptually possible, though highly unlikely.

[3] Nordhaus (2007)

entails the process of skill formation and up-gradation and in the formal and informal settings in the society.

Consumption, production and skill formation are thus inextricably linked in a stable configuration in an social equilibrium. The stable post-war configuration for the developed economies may or may not persist in the future. A shock to any part of the system reverberates through the whole system. The adjustment lags in each of these interlinked components determine the transition process. The recursive nature of the social equilibrium is due to the fact that agents simultaneously play their part in both consumption and production and they obtain income for consumption in return for supplying skills to the firms. Thus, for instance, a shock to the consumers' income translates into a change in the composition of demand for goods and services, which may result in change in demand for skills, which in turn may have a second round impact on the consumers' demand and so on and so forth till the society converges to a new stable social equilbrium.

The paper starts by motivating the discussion with some stylised facts. Then it proceeds to discuss the production at the firm level, consumers' demand and the skill formation processes in detail. In doing so, it explains why takes a long time to for a society to converge to a new equilibrium with inequality rearing its ugly fangs after a technological shock like computer power or mechanisation before that. The paper then sets out policies that could help the society transition smoothly to its preferred social equilibria.

1.1. **Stylised Facts: Looking back.**

- *Computer power*[4] *has increased phenomenally over the last century and a half.* Nordhaus (2007) estimates that since 1850 the computer performance has improved by a factor of between 1.7 trillion and 76 trillion. The pace of improvement sharply

[4]Defined as computations per second and cost per computation.

accelerated after 1945 and the most rapid pace of improvement took place during 1945—1955 and 1985—1995.

- *The supply for workers with a particular type of skill tend to have long term trends.* In the US, the proportion of college educated workers in the total labour force has been consistently growing over the 1915–2005 period.[5] Similarly, the proportion of graduates in UK labour force has been rising since 1990s.[6] In 18th and 19th century England, there was a surge in the supply of unskilled workers as demand for more skilled artisans declined.[7]
- *Since the 1980s the richer developed countries have seen polarisation of jobs*, where there is a rapid growth in both well paid high-skill (professional, managerial) jobs and low-skill (personal services) jobs with a substantially reduced share of employment for the middle-skill (manufacturing, routine office) jobs.[8] *A similar job–polarisation had occurred in US manufacturing during 1850–1910 period as mechanisation replaced the artisans.*[9]
- *Wage contingent on education has a less stable trend and varies across countries and time periods reflecting the trends in demand and supply of skills.* The US college wage premium has periodically increased and decreased over this period 1915–2005 period.[10] Wage inequality in UK has risen significantly since the late 1970s with evidence of increasing college wage premium.[11] Conversely, the German wage structure across the board have been relatively stable since the 1980s.[12]

[5] Goldin and Katz (2007)

[6] Lindley and Machin (2013)

[7] Mokyr (1990)

[8] See Goos and Manning (2007) for UK, Autor et al. (2006) for USA, Spitz-Oener (2006) Dustmann et al. (2009) for Germany, Goos et al. (2009) for European Union, and Ikenaga (2009) for Japanese.

[9] Bairoch et al. (1988), Habakkuk (1962), Katz and Margo (2013)

[10] The US college wage premium decreased over the 1915–1950 and 1970–1980 period and increased over the 1950–1970 and 1980–2005 period (Goldin and Katz, 2007).

[11] Machin (2010), Lindley and Machin (2016).

[12] Prasad (2004), Spitz-Oener (2006).

- *Firms in the developed countries differ significantly in their size and productivity and worker's wage is largely determined by kind of firm they work for.*[13] There is assortative matching between worker characteristics and firm characteristics.

2. Canonical Production Model

A firm produces goods and services by combining a set of factor inputs. To illustrate the idea, let's take an simple example where a firm requires just two inputs, low-skilled and high-skilled workers, to produce a good.

2.1. **Substitutability and Complementarity.** If the firm could use either high or low skilled workers without affecting the production process, then the two types of workers would be *perfect substitutes*. In this case, the firm would just employ one type of worker, the cheaper type. If the production process requires that the high and low skilled workers are used in a fixed proportion, then the two types of workers are *perfect complements*.

Firms in the real world combine a number of inputs to produce their output. What matters is the way in which these inputs relate to each other, i.e., are they substitutes or complements. The relationship between inputs spans the whole continuum between perfect substitutes and perfect complements. The more substitutable the inputs are, the less the distinction between them matters and their usage is determined solely by their relative cost. For instance, if the high and low skill workers were perfectly substitutable, then we could lump the two types together into once input category of "labour". This also illustrates the hazard of lumping together input categories that are complementary.

The three broad category of inputs firms use are human capital, physical capital and technology. Technology encompasses all the ideas about how the physical and human capital can be used to produce the output.

If an entrepreneur wanted to set up a coffee shop on the high street, she would need a set of ideas about how she can combine workers and physical capital to produce coffee

[13] Song et al. (2015), Mueller et al. (2015), Barth et al. (2014) Abowd et al. (1999), Card et al. (2013), Faggio et al. (2010).

that caters to consumers' taste. She may have a range of ideas to choose from. For instance, the entrepreneur could use low-skilled workers with highly automated coffee machines or high-skilled baristas with high quality grinders and espresso machines. Thus, the demand for technology, human and physical capital are inextricably linked and determined simultaneously and continuously at the firm level.

To extrapolate to the aggregate economy level, the consumers demand a certain type of goods. The firm could potentially choose from the range of available technologies. Thus, the firm level demand for technology and physical and human capital is determined simultaneously taking their respective costs into account. Firms' demand for inputs is thus merely a reflection of the consumers' demand and ideas.

2.2. **The college wage premium puzzle.** College wage premium or wages of college graduates relative to high school graduates in the US decreased steadily and then increased steadily over the last century in spite of steady increase in proportion of workers with college degrees over that period.[14] Katz and Murphy (1992) suggest that technological progress drove the demand for college educated workers due to its complementarity and outstripped the supply of college educated workers leading to rising college wage premium.

The problem is that this explanation takes the process of technological progress as exogenously given. Acemoglu (1998) suggests that a sudden increase in supply of a particular type of input leads to a temporary drop in its relative price, which in turn spurs innovators to develop technologies that complement this particular input.[15] According to this explanation, technological progress biased towards college educated workers since 1950s may actually be a response to the steady increase in supply of college educated workers in the US.

[14]Autor et al. (2008) document the rise in both the College wage premium and the difference in weekly pay for those at the 90th and 10th percentiles of the wage distribution over the 1963–2005 period in the US.

[15]The college wage premium is thus determined by extent to which college educated and high schools graduates are substitutable after the firms have taken their complementarity with the latest technologies into account.

Similarly, Habakkuk (1962), Bairoch and Braider (1991) and Mokyr (1990) document the increase in supply of unskilled workers in the 18th and 19th centuries leading to development of technology that was biased in favour of unskilled workers. Over this period, the artisanal shop was replaced by the factory and subsequently by interchangeable parts and assembly line and the demand for workers shifted in favour of the unskilled workers.[16]

2.3. **O-ring theory of Complementarities.** If factor inputs have strong complementarities in the production process, each input has an significant impact on the output. This ideas is best illustrated by O-ring theory, named after an extremely inexpensive yet extremely critical component that cracked and led to the Challenger shuttle disaster in 1986.

Let's take the stylised example of movie production to illustrate the O-ring theory. If the objective is to make a movie of exceptional quality because the potential audience does not trade-off price and quality, then every worker and equipment is critical. Producing a good movie requires a producer, a director, actors and cinematographer working with a variety of equipment. For a high quality movie, each aspect is critical. An error by just one of the workers could be fatal and the discerning viewers would shun the movie for other high quality movies. The example of designing a major building, developing software programmes or designing a car have similar properties and could be similarly used to illustrate the O-ring theory.

In the O-ring theory, the objective of the firms is to produce products of a particular quality due to either market competition or other external constraints. Producing the final output requires a number of separate processes, each carried out by a separate worker.[17] If highly skilled workers are less likely to make an error and the quality of the final product is the probability that it is not faulty, then each worker's skill level

[16]Mokyr (1990), James and Skinner (1985), Hounshell (1985).

[17]This is true in both the framework whether they are a number of workers working together to produce something or whether they is one worker performing a large number of consecutive tasks.

has an impact on the quality of the final product. If follows that the contribution that a new worker makes in the production process is determined by skills of the rest of the workers. A very small drop in the average skill level in the firm will lead to a very large drop in quality. If workers are paid their marginal contribution, then their wage is determined by the skill level of the rest of the workers in the firm. We can generalise this to say that in production process where quality is crucial, each factor input is critical and firms will employ workers whose skills are beyond reproach.

With time, production processes are getting more and more drawn out and complicated. Quality products that are produced through intensive use of non-rival factor inputs can be supplied at reasonable prices in large markets. It is important to remember this process is ultimately driven by product market competition and the consumers' quality price trade-off.[18] Consumers are willing to pay for quality unwittingly set off a chain of events where the O-ring type production processes dominate and only workers with skills beyond reproach are employed and paid high wages in line with their marginal contribution. Conversely, in a economy where workers are unwilling to pay for quality, the O-ring type production process will not survive. Thus, in choosing between buying a cup of coffee from an expensive independent coffee shop, a mid-priced global chainstore or a cheap local greasy spoon cafe, the consumers unwittingly set off a chain of event that ultimately determine their own job prospects.

3. Technology and the Product Market

> "... as always and everywhere, invention is the mother of necessity."
>
> — Veblen (1914, p. 314)

Technology constantly evolves through inventions to augment the productive capacity of the firms and the factor inputs they use. Mokyr (1990) draws a distinction between

[18] Individually and collectively through the regulations that government of the day puts in place.

macro and micro innovations. *Macro innovations* like steam engine, electricity and computers introduce radical changes and bring wide sweeping changes in the way the production takes places in the society. *Micro innovations* are more frequent and bring about small changes by introducing newer variety, improving the quality or simply reducing the costs of existing products. Figures 1 shows the sequence of macro and micro inventions that led to the development and commercialisation of mechanical and computing power. The inventions range from ones that overcome technological obstacles, create things that are entirely novel or come up with social innovations that make products commercially viable. There is a large body of work in this area that argues that macro innovations occur serendipitously, while micro innovations respond to incentives provided by the economic and social environment.[19]

We examine below the role consumers play in spurring the research firms to innovate. Grossman and Helpman (1991b, 1991a) have modelled the product space as a two-dimensional space from which consumers pick the products they want to consume. The horizontal product differentiation represents the variety of different kinds of products available.[20] The vertical product differentiation is in terms of quality, i.e., where better quality products are located up the quality ladder. Most micro innovations either expand the product space or reduce the cost of production. The consumers choose their consumption goods over this two-dimensional space in accordance to their preferences. They may also buy a new product that is a new variety or of higher quality if the price is sufficiently low. Firms thus get their incentive for micro innovation from the consumers.

Firms produce goods using broadly two types of factor inputs, rival and non-rival inputs. A *rival input*, if it is being used by one entity at one place, it cannot be simultaneously used elsewhere. Conversely, a non-rival input, once it exists, can be used simultaneously at numerous locations by numerous entities. Physical capital and labour

[19] Rosenberg (1976) and Ceruzzi (2003) argue that macro innovations are exogenous and not in response to the opportunities. Griliches (1957), Schmookler (1966), Griliches and Schmookler (1963), Mokyr (1990), Newell et al. (1998) and Popp (2002) give example of micro innovations responding to opportunities.

[20] The horizontal dimension would include cars, clothes, food, houses, laptops, MP3 players, smartphones etc.

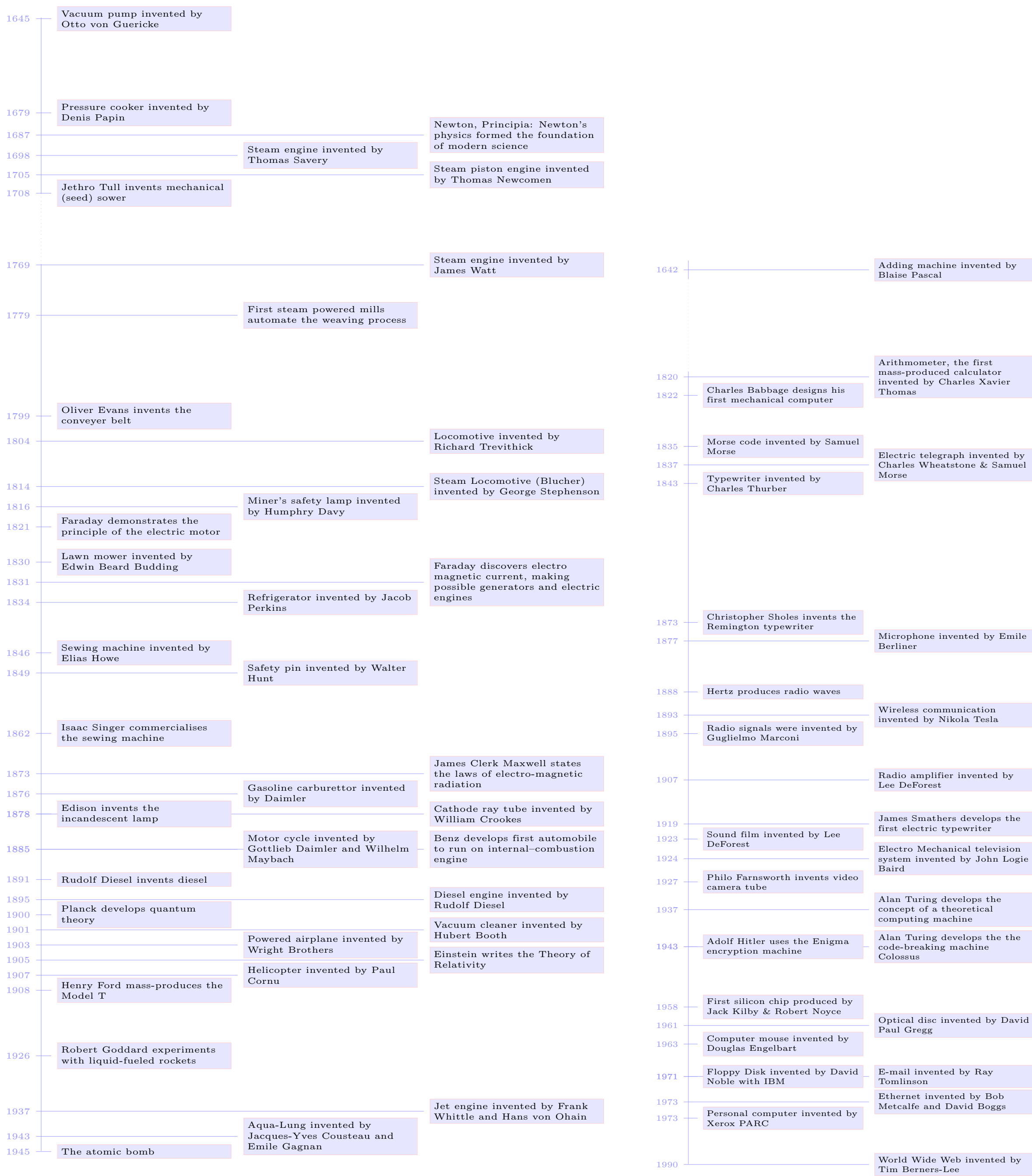

FIGURE 1. Timeline of inventions that led to development of mechanical power (left) and computing power (right).

are examples of rival inputs. An innovative idea, technological innovation and organisational design are examples of non-rival inputs.[21]

[21]Other equally important examples of non-rival inputs are social capital, the prevalent culture in the society and public goods like roads and electricity.

If a good is produced using a combination of rival and non-rival inputs, each additional unit of output requires increased use of rival factor inputs. Conversely, the non-rival input has to be created only once and once created, can be used ad infinitum. Ideas that help produce new product variety or a higher quality version of an existing product are examples of non-rival input.[22]

The innovators get their incentive to develop new ideas for a product that is a new variety or higher quality of a pre-existing product if the consumers are willing to pay a price that covers the cost of developing the products. The innovative ideas could be about how to solve a certain logistics problem or about finding a reliable supplier. These ideas have a way of diffusing amongst proximate interlinked firms and reduce the cost of innovation if firms spatially agglomerate.[23] This is why firms that intensively use non-rival inputs have tendency to agglomerate. Good examples are Silicon Valley for software, City of London for banking and Oxford and Cambridge for educational institutions.

A macro innovation does not immediately get incorporated into the firms' production processes. This is because they tend of be abstract ideas without an obvious path to commercialisation. For example, Newton's Principia or Alan Turing's theoretical computing machine (Figure 1). A macro innovation does however encourage a cascade of micro innovations that operationalise and commercialise the macro innovation for its use in the various industries. It takes time and there is a large time lag between the macro innovation and its impact on the firms' production processes. This is why even though the first spurt in computer power took place during 1945-1955, we associate the computer age with a much latter time period (Nordhaus, 2007). This is also why authors like Griliches (1957), Griliches and Schmookler (1963), Schmookler (1966), Rosenberg (1976), Mokyr

[22]It thus follows that if a particular skill type worker suddenly becomes relatively abundant driving down its relative cost, it gives the firms incentive to develop ideas for using it more intensively in the production process.

[23]Using a US scientist-level dataset within chemistry over the period 1991 – 2012, Catalini et al. (2016) find that after Southwest Airlines enters a new route, scientific collaboration increases by 50%.

(1990), Newell et al. (1998), Popp (2002) and Ceruzzi (2003) argue that, even through micro innovations are driven by commercial interest, macro innovations are not.

Further, there is a market size effect due to the fact that the cost of coming up with a new idea is upfront fixed cost. Innovators thus have a greater incentive of develop technologies that can capture a larger consumer base as this allows the cost of developing the new idea to be spread over a larger number of units produced.

Thus, *micro innovations are determined by consumers' willingness to pay for an innovative product, the size of the market and the spatial location of interlinked firms.* As we saw in Section 2.2, *micro innovations also respond to the relative abundance of factor inputs and is likely to develop technology that is complementary to the abundant and inexpensive factors inputs*.

3.1. **Market Dominance.**

> "ten years of competition and 90 years of oligopoly"
>
> — Alfred Chandler quoted in Wooldridge (2016)

Commercialising a macro innovations through micro innovation can be extremely costly and requires investment with a long gestation period. Micro innovations are difficult to produce. Their production requires a high degree of complementarity between factor inputs like highly skilled workers and specialised physical capital. Laszlo Bock, veteran of senior human resources role at Goolge and General Electric, illustrates the critical role complementarities play in micro innovation oriented super firms when he argues that a top-notch engineer "is worth 300 times more than an average engineer."[24]

The critical complementarities can be achieved within a large super firm with O-ring type production process or within spatially agglomerated industries. The super firms and the spatially agglomerated industries bear the cost of micro innovations and, if they succeed, dominate the market for the new product. Google and Microsoft are current examples of super firms (Wooldridge, 2016). General Electric, Ford and General Motors are examples of super firms from a century ago (Lamoreaux et al., 1988). Silicon Valley,

[24] Wooldridge (2016)

Hollywood, Akron rubber industry and City of London are good example of spatially agglomerated firms dominating the industry (Krugman, 2009).

It is useful to analyse large super firms and spatial agglomeration is critical for cutting edge long gestation micro innovation.

- Micro innovations are non-rival inputs with quality as its most important attribute. This creates a "winner takes all" market for micro-innovation.
- The first reason is that the production process for micro innovation has increasing returns to scale. This is because micro innovations are non-rival inputs and require long gestation up front fixed investment. The investment could either by pecuniary investment or non-pecuniary "sweat-equity" investment. Firms that make large investment early on capture the market. The ex-ante investment is increasing in both expected size of the market market and market share the firm can acquire within it.
- Second reasons the process of producing innovation is extremely uncertain. Outsourcing a certain part of the development process is difficult because of moral hazard and unforeseen contingencies. The literature on incomplete contract argues that firms should produce things in-house when complete contracts are difficult to sign.[25]
- The third reason is the externalities or knowledge spillovers in production process of micro innovation. These knowledge spillovers are better captured either within a large super firm or within spatial agglomerations.

difficult to outsource small co sign explicit contracts in it is difficult to sign contracts over innovation process.

[25] Grossman and Hart (1986) and Hart and Moore (1990)

4. Job Polarisation and the Task Approach

A string of papers have documented the phenomenon of *job polarisation*, the emerging bimodal distribution of jobs, across the developed world since early 1980s.[26] With job polarisation, the share of professionals and managers at one end and low-paid personal service workers jobs at the other end has increased and the share of middle-pay manufacturing and routine office workers has decreased.

In the canonical model (Section 2) labour, capital and ideas are combined in a production process to produce output, i.e., good and services. Different types of labour and capital could either be substitutes or complements in this process. In the canonical model a factor input's identity is synonymous with what it does or the service it provides in the production process. This is not a bad approximation in a static framework where capital and labour do exactly what they do over time. In reality, the boundary of what labour and capital can do is pliable with technological advancement and changing factor costs. Either human or machines can dispense a boarding passes for a flight, make the line calls in a tennis match or sell a soda can.

The two main explanations for job-polarisation are the routinisation and offshoring hypothesis. These both follow from the new "task approach", which take a more detailed approach to production than the canonical model.

4.1. Task Approach.

> "We can know more than we can tell ..." — Polanyi (1966)

The "*task approac*h" draws a useful distinction between tasks the workers perform and skills they posses.[27] A *task* is a unit of work activity that produces output. *Skill* is worker's inalienable stock of capabilities for performing various tasks.[28] Workers apply

[26]This phenomenon is documented for US by Autor et al. (2006), Autor et al. (2008), Autor and Dorn (2013), UK by Goos and Manning (2007), Germany by Spitz-Oener (2006) and Dustmann et al. (2009) and Europe by Goos et al. (2009), Goos et al. (2014), Michaels et al. (2014).

[27]The "task approach" has been developed in Autor et al. (2003), Acemoglu and Autor (2011) and David et al. (2013).

[28]A masseur may use her massaging and interpersonal abilities to accomplish the task of massaging a client. A accountant uses his numeracy skills and problem solving skills to do the accounts. A physicist

their skills to task in exchange for wages. The skill – task distinction becomes critical if either technological changes or shift in market prices necessitate reassignment of skills to tasks.

Automating a task requires it be codified to a point where a relatively inflexible machine can perform the task semi-autonomously in a predictable environment. When a task is unfamiliar or poses unforeseen obstacles, human workers can improvise drawing on their knowledge and problem solving skills.

In line with the principle of comparative advantage, through the process of optimisation the factor input with the lowest economic cost is assigned the task in the production process. The economic cost reflect both the technological feasibility and the opportunity costs. Nissan Motors uses robots extensively in producing cars in Japan. It uses robots parsimoniously in India because labour in India is relatively inexpensive.[29] Similarly, how extensively Amazon uses kiva robots to move the shelves in its warehouses in a particular location depends on the cost of labour relative to the cost of automation.

In developing the task framework, Autor et al. (2003) suggest the following categorisation of tasks based on whether they can be codified. The *routine tasks* have routine procedures that require precise execution of repetitive physical and mental operation in an unchanging environment and be potentially codified. The tasks that are non-routine can be further divided into two categories. The *abstract tasks* require problem solving abilities, intuition, creativity and persuasion. The *manual tasks* require situational adaptability, visual and language recognition and in-person interaction. Routine tasks are repetitive and require both cognitive and non-cognitive routine skills. Abstract and manuals tasks are both unpredictable with the former requiring cognitive skills and the latter requiring non-cognitive skills. Blinder et al. (2009) has suggested "offshorability" as another task dimension that overlaps routinisation. *Offshorability* are tasks that can be relocated to a remote location without substantially degrading the quality of the output.

her intimate knowledge of physics and mathematical abilities to write a research paper. These skills are acquired through formal training and honed with the experience.

[29] Fackler (2008)

Table 1. Routine Task Intensity Index and Offshorablity of European Occupations

Occupations ranked by mean European wage	Routine Task Intensity Index	Offshorability	Employment Share in 1993	% change 1993 – 2010
High-paying occupations	*-0.72*	*-0.12*	*31.67*	*5.62*
Corporate managers	-0.75	-0.32	5.65	0.59
Physical, mathematical, and engineering professionals	-0.82	1.05	2.93	1.36
Life science and health professionals	-1.00	-0.76	2.01	0.57
Other professionals	-0.73	0.21	2.79	1.38
Managers of small enterprises	-1.52	-0.63	4.16	0.17
Physical, mathematical, and engineering associate professionals	-0.40	-0.12	4.44	0.21
Other associate professionals	-0.44	0.10	7.24	0.79
Life science and health associate professionals	-0.33	-0.75	2.45	0.55
Middling occupations	*0.69*	*0.24*	*46.75*	*-9.27*
Stationary plant and related operators	0.32	1.59	1.70	-0.25
Metal, machinery, and related trade work	0.46	-0.45	8.78	-2.08
Drivers and mobile plant operators	-1.50	-1.00	5.03	-0.48
Office clerks	2.24	0.40	10.60	-2.06
Precision, handicraft, craft printing, and related trade workers	1.59	1.66	1.45	-0.54
Extraction and building trades workers	-0.19	-0.93	1.45	-0.54
Customer service clerks	1.41	-0.25	7.35	-0.64
Machine operators and assemblers	0.49	2.35	2.13	0.06
Other craft and related trade workers	1.24	1.15	5.99	-1.63
Low-paying occupations	-0.08	-0.84	*21.56*	*3.65*
Labourers in mining, construction, manufacturing, and transport	0.45	-0.66	4.26	-0.55
Personal and protective service workers	-0.60	-0.94	6.86	2.36
Models, salespersons, and demonstrators	0.05	-0.89	6.06	-0.11
Sales and service elementary occupations	0.03	-0.81	4.38	1.95

Table reproduced from Goos et al. (2014, p. 2512). Occupations are ordered by their mean wage across the 16 European countries across all years. The Routine Task Index in column 2 is based on the five original DOT task measures in Autor et al. (2003). The offshorability measure in column 3 is taken from Blinder and Krueger (2013) and is based on professional coders' assessment of the ease with which an occupation could potentially be offshored.

Goos et al. (2014) document the pan-European job-polarisation with a dataset that covers 16 Western Europe Countries over the period 1983 – 2010. They look at the importance of routinisation and offshoring and find that routinisation has player a more important role than offshoring in job-polarisation.

Table 2. Routinisation and Offshorability in Occupations

Occupations	Non-Routine Occupations	Routine Occupations
Low-offshorability	*High Paying occupations* Corporate managers Life science and health professionals Managers of small enterprises Physical, mathematical, and engineering associate professionals Life science and health associate professionals *Middling Occupations* Drivers and mobile plant operators Extraction and building trades workers *Low-paying occupations* Personal and protective service workers	*Middling Occupations* Metal, machinery, and related trade work Customer service clerks *Low-paying occupations* Labourers in mining, construction, manufacturing, and transport Models, salespersons, and demonstrators Sales and service elementary occupations
High-offshorablity	*High Paying occupations* Physical, mathematical, and engineering professionals Other professionals Other associate professionals	*Middling Occupations* Stationary plant and related operators Office clerks Precision, handicraft, craft printing, and related trade workers Machine operators and assemblers Other craft and related trade workers

The occupations are classified on the basis of their Routine Task Index (RTI) and offshorability measure in Goos et al. (2014, p. 2512), which is reproduced in Table 1. Non-routine occupations have a negative RTI and Routine Occupations have a positive RTI. Low-offshorability and High-offshorability have a negative and positive score on the offshorability measure respectively. Managers of small enterprises is the most non-routine job and office clerks is the most routine job. Drivers and mobile plant operators and least offshorable jobs and machine operators and assemblers are the most offshorable jobs.

As we can see in Table 2, the most precarious jobs for a European countries are the middling occupations because they routine and easy to offshore. Low paying jobs are relatively safe due low offshorability. High paying jobs are exclusively non-routine jobs spanning that span the full range of offshorability.

5. Human Capital Formation

Accounting for the full impact a teacher has on the pupil is extremely difficult. A number of paper show that teacher's impact on test scores, though easy to measure, can be very misleading.[30] The real challenge is to isolate the effect of quality of teachers on lifetime income and outcomes.

[30] Jacob et al. (2003), Jacob (2005) and Neal and Schanzenbach (2010) document the adverse consequences of incentivising teachers through students' test scores.

Chetty et al. (2014b) examine the long-term impact of the quality of teacher during grade 3–8 on the lifetime income of the pupils by using school and tax records for more than one million children in the US.[31] Teachers quality is measured by their value added score[32] or the effect a given teacher has on pupils' test scores.

Chetty et al. (2014b) find that replacing a teacher from bottom 5% value added teacher with an average value added teacher would increase the lifetime incomes of students' in that classroom by approximately $250,000 per classroom. Further, students assigned to high value added teachers were more likely to attend college, earn high salaries and less likely to have children as teenagers. This suggests that there are a pattern of complementarities in the human capital formation process that leads to a multiplier effect initiated by a increase in teacher quality in school.

A reasonable skill formation function would be one where educational achievement of the pupil is determined by her or his individual level characteristics, number of years of spent in school, quality of the school, the characteristics of the parents and the supplemental help they provide the pupil (Glewwe and Kremer, 2006). Implicitly embedded in this framework is the strong assumption that schooling at various are substitutes, i.e., improving the quality of schooling in early or later years would have the same impact on the realised educational achievement of the pupil.

Based on two decades of empirical evidence on remediation, Cunha and Heckman (2007) suggest that skill formation process is a multi-stage process. Individuals posses a vector of skills at each age. These abilities are multiple in nature and range from pure cognitive abilities (for example IQ) to non-cognitive skills (patience, self control and temperament).

Inputs or investment at each stage produces output of skill, which in turn becomes the input for skill formation for the next stage. There are distinct channels through which

[31]School records are from urban US school district covering the 1989–2009 period. This is linked with the US tax data over the period 1996–2011.

[32]Chetty et al. (2014a) develop a new methodology that eliminates the bias value added may have on proxying for the quality of the teacher.

skills formed in different stages are interlinked. Skills produced at one stage augment the skills attained at a latter stage. This is called *self-productivity* channel. Further, skills produced at one stage raise the productivity of investment into skills at a latter stage. This is called *dynamic-complementarity*.[33] Thus, levels of skill investments at different ages are synergistic and bolster each other.

Together, self-productivity and dynamic-complementarity gives us a multiplier effect through web of complementariness where a small investment in the early stage has a very large impact on life outcomes. This explain why Chetty et al. (2014b) finds such large effect of teacher quality on the life outcomes of the students. Rather surprisingly they find that improvements in English teacher quality has a much larger impact than improvements in math teacher quality. This highlights both the impact of non-cognitive skills in the overall skill formation process and the labour market outcomes.

Carl Wieman, the Nobel Prize winning Physicist has spent the last few years working on undergraduate science education. In Wieman (2017), he says the following

> Research has established that people do not develop true understanding of a complex subject such as science by listening passively to explanations. True understanding comes only when students actively construct their own understanding via a process of mentally building on their prior thinking and knowledge through effortful study.

This could potentially explain dynamic complementarities in the Cunha and Heckman (2007) framework. A student that did not fully understand a basic concepts taught earlier is greatly burdened cognitively by the process of trying to recall that concept and apply it to the concept they are learning now. Hence, they find it difficult to fully concentrate and grasp the concept they are being taught now. A student who has truly understood the basic concept is cognitively unburdened and thus is able to build on the previously

[33] Cunha et al. (2006), Heckman (2008).

learning concept to further their understanding of the concept they are learning currently. In a conveyor belt method of learning[34], learning a particular concept in the time frame allocated to it is extremely critical. If the student misses learning that concept in that time frame, then there is no time to get back to it and understand it fully. A conveyor belt learning timeline, the task of learning a concept becomes complementary to the task of learning another concept due to the strict sequencing of the learning process. Given that there is no flexibility for students to go back and learn the concepts they missed, the impact of missing a early concept can have rather large consequences further down the line.

Going back to the Glewwe and Kremer (2006) framework, it is important to work out the relationship between school quality or teacher's effort and the parents or external input. Conceptually, the two could be substitutes or complements. If teacher quality improves, the parents could either put more effort to school the child or alternatively just get complacent. Since data on parents is not easy to obtain, a lot of work in this area is suffers from the omitted variable bias where all the impact on educational achievement is attributed to school or teachers and the parents efforts are ignored. Michelle Obama repeated interaction over a three year period with pupils of a London school led a substantially higher GCSE scores (Burgess, 2016). This underlines the importance of accounting for parents input or external input is an study of skill formation.

Another way to think about the skill formation process is any set of conceptual gaps should not be left behind. A conceptual gap at an early stage can have a huge impact on latter life. A small discouraging remark or a bad performance in an early stage test can have disproportionately large consequences.

We could alternatively think that the role of a teacher is akin to the role of a GP. One of diagnosing the problem a young students may have and curing it by helping the student overcome the conceptual gap. Parents who posses high human capital are likely

[34]A conveyor belt method of teaching is one where the course material is taught in a particular sequence and not subject to any flexibility.

to find this conceptual gap and fill it before it has an adverse impact on the pupil. Thus, having teachers skilled at diagnosing the problem is especially important for children with parents who are not equipped to fill these gaps.

In this framework, the tests are diagnostic tools. The implication that follows from the discussion on the task framework is that the comparative advantages humans have vis-a-vis the computers is the range of non-routine skills. A schooling system that appreciates the multistage learning process and complementarities between various skills and develops the full range of skills is essential. Steve Jobs made this point very eloquently in the following quote.

> "It is in Apple's DNA that technology alone is not enough —- it's technology married with liberal arts, married with the humanities, that yields us the results that make our heart sing ... One of the greatest achievements at Pixar was that we brought these two cultures together and got them working side by side." — Steve Jobs' 2003 remark quoted in Lehrer (2011)

Large public schooling systems develop their own metric for evaluating the efficacy of their teachers. The institutional response is to often centrally devise a curriculum and require teachers to follow a very regimented regime. This is akin to asking a teacher to accomplish a "routine task". The development of skills amongst the pupils is a strongly "non-routine task" that require both cognitive and non-cognitive skills. Non-routine skills cannot be developed through routine tasks.

The multi-stage skill formation suggests that there are critical periods for development of cognitive and non-cognitive skills. Once this period is missed, then remediation is expensive. To create a flexible labour force that able to move from sector to sector and is able to acquire skills as and when they need, a strong base of range of skills acquired and honed in early part of the life is extremely important.

> "Life cycle skill formation is dynamic in nature. Skill begets skill; motivation begets motivation. Motivation cross-fosters skill and skill cross-fosters motivation." — Heckman (2008)

Learning a skill later in life is going to be more difficult if a person has a conceptual gap that have never been filled. This conceptual gaps over the years would have turned into a phobia. Standard course that deliver material in a routine way does not help at all.

One way to address this problem would be to apply the diagnostic approach to teaching and learning. What this requires is diagnosis by someone who skilled at pinning down exactly the conceptual gap and then giving the student the tools to fill this gap. The best example of this is the approach is in the practice of medicine. In medicine, the doctor diagnoses the problem and prescribes a treatment and the patient then is left to apply that treatment to themselves.

What Cunha and Heckman (2007) and Chetty et al. (2014b) tell us is that small conceptual gap early on has a big impact later on. This is in the context of a "conveyor belt" learning environment where learning has a very strict sequence and once a student misses their opportunity to acquire a concept, it is very difficult to get back to it. In a more flexible learning environment, each student would learn at their own pace and the educators are simply the ones that visualise the potential of a student, diagnose their conceptual gap and provide the students with tools for self-learning. With accelerated changes in technology and concomitant social changes, it is ever so more important to have a learning environment that allows workers and citizens in the society to learn and adapt flexibly.

6. Conclusion

The paper has looked at how automation and globalisation has disruptive and has led to the mismatch between the skills individuals possess and the skills that firms demand. The task approach is the best way to understand how automation and globalisation is changing the nature of work. The market structure of the industry is crucial because firms in a non-competitive industry can use their market power to resist the consumer's demand for a certain kind of tasks through goods. This create the mismatch of skills in the economy. The paper also looks at the education system that would be best suited to producing flexible skills that can easily move across tasks and reduce the mismatch of skills. The policy implication is that market power and early education are the best tools that can ensure that workforce of country smoothly deals with the challenges of automation and globalisation.

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