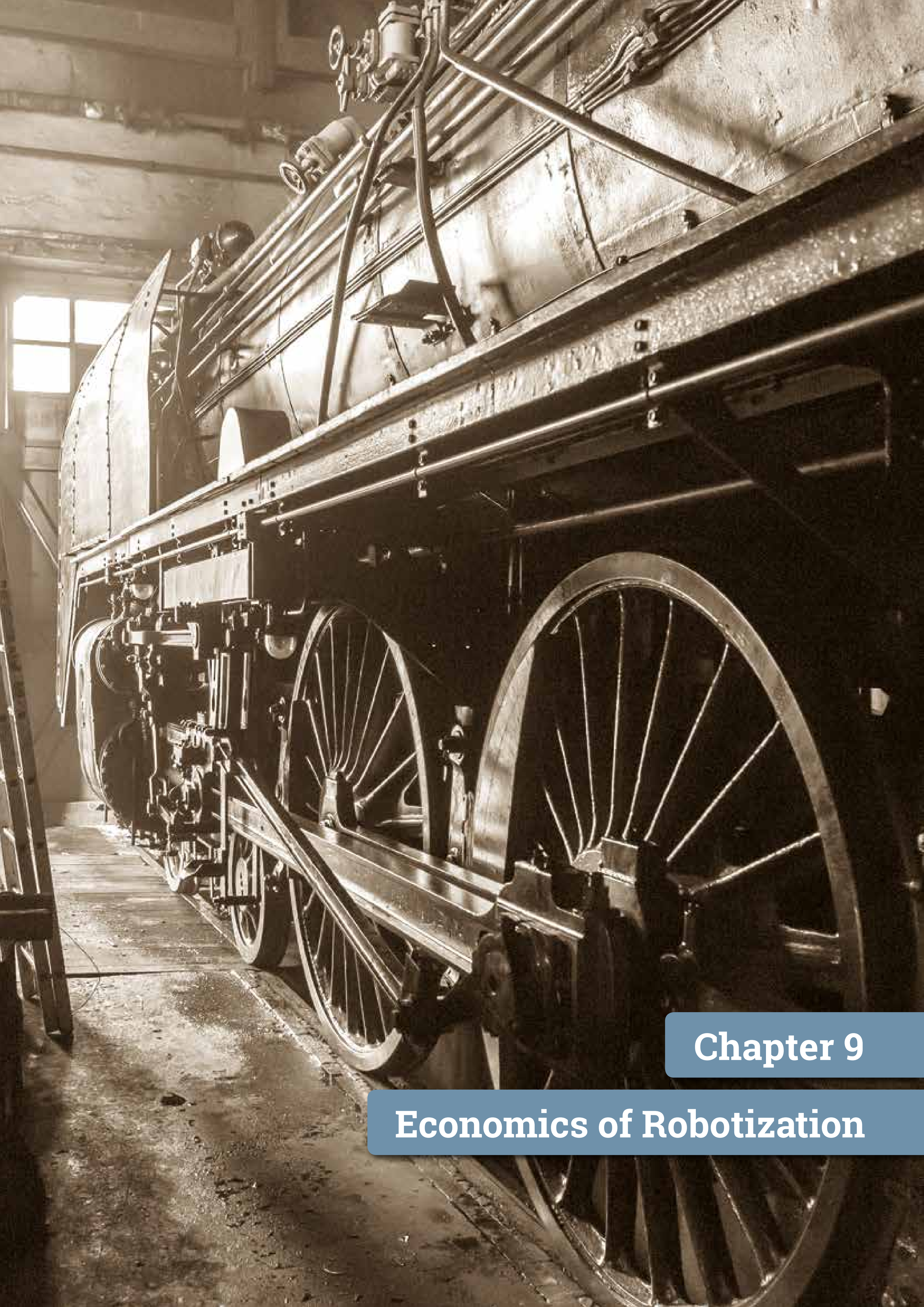


Chapter 9

Economics of Robotization

”

Based on my experience, and also what I have heard from others, it’s taking longer than we expected [to get a robotizised society], but at the same time, it’s going to have a larger impact than we expected. It’s more complicated and has a greater influence than we had expected. It alters the industry structures and cooperation models, it changes who is the leading player and who has power and influence.

(Dan, architect, affected stakeholder, WIPER)

◄ Robotization presents familiar struggles but also unprecedented challenges when compared with previous eras of industrialization (like the introduction of the steam engine).

9. Economics of Robotization

Motives of employers, impact on workers, and interventions by governments

You will find here

- Overview of elementary competitive forces driving robotization
- REELER's conceptual framework on structural change of the sectoral composition of economies
- Overview of simulation results of REELER's labor-economic computer model
- Overview of possible policy measures

You will acquire

- Awareness of how unfettered competition in capitalist economies drives rationalization and robotization
- Awareness of the effects of robotization beyond substitution and job loss
- Awareness of how the structure of the labor market, income distribution may change due to robotization
- Awareness of how policy measures may affect the labor economic impact of robotization

The last couple of years, inventions in artificial intelligence (A.I.), electromechanical actuators, batteries, etc. have made robots more nimble, smart, and versatile. With that, the number of applications of robots and the number of sectors thus actually using, or able to use, robots have increased. In fact, robotics (and artificial intelligence at its core) may well be a new **general-purpose technology** (Lipsey, Carlaw, & Bekar 2006) that will change the global economy and possibly society at large. Given that robots (and AI) are not only complementing but also replacing human labor, concerns are raised about the future of work both in popular media and academic literature (Brynjolfsson & McAfee 2011; Ford 2015; Frey & Osborne 2017). Robots may displace human labor at such a scale and at such a rate that mankind may converge to sustained mass-unemployment, it may be the 'end-of-work'. Recent figures show that the business-to-business sales of both industrial and service robots indeed is ramping up rapidly (International Federation of Robotics 2018).

General-purpose technology: *Technology with applications in many sectors, a major impact on economic growth, and transforming society. Examples are smelting of ore, writing, the steam engine, electricity, the computer, the internet.*

This chapter takes a comprehensive view on the economics of robotization. Section 9.1 elaborates on the rationales for firms to develop and apply robots, which are essentially common cost economics and strategic interests. Section 9.2 is concerned with the impact of robotization on individual workers in terms of employment, work availabilty, skill requirements, and income. Section 9.3 provides alternatives for the 'end-of-work' scenario and highlights how robotization also causes the emergence of complementary tasks, new occupations, and even new sectors. Section 9.4 provides policy interventions to regulate the adoption of robots and/or mitigate the impact.

Given the scope of these four interlocking topics (firm rationales, impact on workers, structural change, and policy interventions), complexity and actuality of the subject matter, and the ongoing academic discourse, this chapter is to be seen as an introduction to the topic. Although this chapter mostly addresses the *macro-level rationales and impact* of robotization, it is acknowledged that there are potentially far-reaching consequences for individuals. Where deemed illuminating, results from REELER case studies on *micro-level impact* of robotization on work have been included in the form of vignettes or quotations.

9.1 Firm rationales for robotization

> **Robotization:** *To convert for automated operation or production by robots or robot-like machines.*

The last couple of decades, **robotization** mostly took place in manufacturing sectors. As most manufacturing sectors are mature and have dominant designs for products and well-articulated demands, firms are generally engaged in fierce rivalry, often even across the globe. Following the standard strategic management framework of Porter (1979), firms thus have to cope with several competitive forces. Notably, if one firm succeeds in lowering production costs by adopting robots, direct competitors also look for cost advantages through production rationalization and robotization or, alternatively, soften competition by product differentiation, niche creation, alternative business models, etc. A more refined look is provided here. The competitive forces are also at work not only in sectors applying robots, but also in sectors involved in developing and building robots. Existing and newly entering robot developers and builders also look for new (commercially viable) applications of robots, means to lower the costs of robots they develop, or even innovative business models. A short description of the robotics sector is included in this chapter (*see also 2.0 Robot Beginnings* for a more detailed discussion of the rationales.)

9.1.1 Cost competitive pressures and production rationalization

There are multiple reasons why firms acquire robots (or *develop* them in-house) for application in their own production processes. Firstly, robots may be part of process innovation to increase the productivity, reduce dependency on human labor, lower unit costs (taking into account purchase, manufacturing, maintenance, and envelopment costs), differentiate products from those of competitors, etc. Note that robots may be part of a flexible production system allowing so-called mass-customization. Secondly, instead of changing firms' products or production processes, robots may (help to) provide *new* services and enhance services readily provided to customers that are complementary to the products. Thirdly, firms may seek to cement their reputation as technological frontrunners, being at the frontier of technological developments, etc. In this case, competitive advantages stem from marketing and 'window dressing' rather than actual competences or product features. Fourthly, a firm may have a subjective preference for technological solutions without (economic) justification.[1] Fifthly, for the (supposed) sake of workers or because robots may be more precise, can work in harsh conditions, and perform tasks deemed to be too dangeroues for humans (e.g. firefighting or bomb disposal).

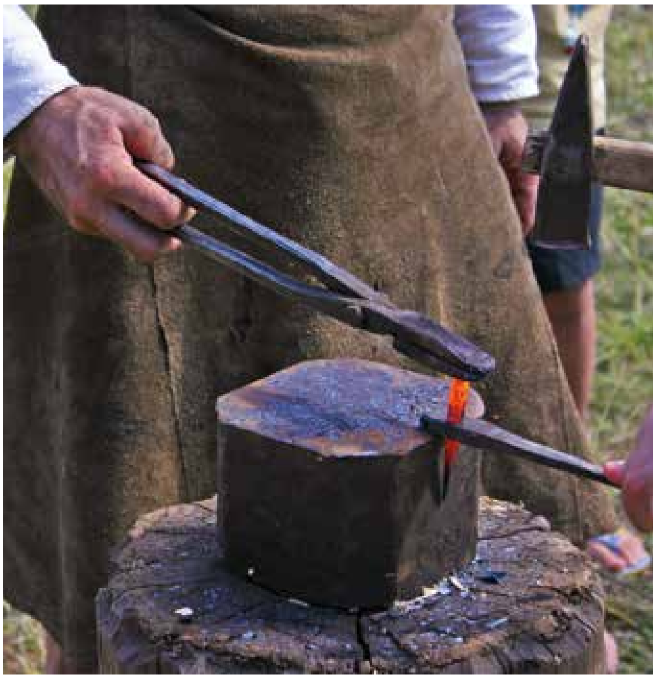
At present, and notably for industrial robots, firms seem to buy robots for the first reason, i.e. robotization is part of process innovation and **rationalization of production**.[2] Arguably, this takes place primarily in relatively mature industries. After all, during the inception phase of the industry lifecycle (Jovanovic & MacDonald 1994; Klepper 1997), entrepreneurial firms enter the young industry and mostly seek to develop new products and place their products in the market. Generally, the variety of product technologies is high, firms are still frequently innovating their products, and demand and production volumes are low. As there is considerable uncertainty about the popularity of products and demand is not well-articulated, firms are not sure whether they will even survive the 'product shake-out' and are hence reluctant to invest in production equipment [3] such as robots. After the product shake-out and emergence of a dominant design, a relatively small number of firms is still active in the industry and there is a substantial market demand for their products. As customers' preferences for certain product features are now more articulated, product innovations become mostly incremental. Given that the variety of and technological differences of products are relatively low, firms are mostly engaged in encroaching upon competitors' market shares through price competition, gaining access to (geographically) new markets, marketing, etc. Moreover, given that products are similar in the mainstream market segment, customers will go for cheaper options. This forces firms to engage in price competition, lowering prices, rationalizing production to lower costs, or rather face a decline in market share, financial losses, and ultimately bankruptcy. So, upscaling production, progressive rationalization of manufacturing processes, and designing an integrated process of production steps may be required not to be 'weeded out'. In short, competitive forces have firms first attend to product innovation to survive the product shake-out and then attend to process innovation to survive price competition. Sometimes, the cost advantages of using production equipment over human labor are so great that rationalization of production and further mechanization becomes an obvious choice, as in the

> **Production rationalization:** *Increasing the efficiency of an existing production process by changing the division of labor, redefining production steps, and introducing alternative production technology (such as robots).*

1 Terms associated with this are 'technological solutionism' (Morozov 2013) and 'techno-chauvinism' (Broussard 2018).

2 The fabled example is that of a pin factory in which workers specialize in particular production steps (thus become more dexterous), have no task switching costs (such as time to take different tools), and separate tasks requiring highly skilled and generally highly paid workers from tasks requiring less skilled workers that can be paid a lower wage. The concept of division of labor is mostly associated with Adam Smith (primarily for economic growth). However, it is particularly Charles Babbage further rationalizing the organization of factories. See the extensive historical, conceptual discussion of the concept in Groenewegen (2008). For the original work see Babbage (2009[1832]).

3 Note that advanced production equipment (such as robots) or complementary services (provided by robots) may add a competitive edge to certain products and thus increase chances for firms to survive the 'shake-out' at the end of the inception phase. To our knowledge there is no literature on this though.



Rationalization is exemplified by the mechanization of nail production in the 20th century, where an expert blacksmith could produce 2300 nails per day, compared to a machine at 250 nails per minute.

case of the mechanization of nail making. Prior to mechanization, nails for woodwork and carpentry were made manually by blacksmiths. An expert blacksmith, who had never done anything apart from making nails, would be able to produce at most 2300 nails *per day*. And it was a tiring and dull activity. In the early 20th century, machines were introduced that manufactured nails from iron wire at a rate of 250 nails *per minute*.

So, from the lifecycle perspective, firms in mature industries seeking to produce mainstream products are forced to engage in production rationalization, process innovation, and considering robotization. Even in industries that are mature for decades (e.g. automotive), firms may well be urged to further deepen automation due to market particularities (e.g. changes in customer demand), competitive circumstances (e.g. competitors offering equivalent products at lower prices), strategic decisions (e.g. differentiation or diversification of product portfolio), changes in laws and regulation pertaining to wages, working conditions, etc., technological (dis) integration within the value chain (e.g. suppliers or customers calling for synchronization of production, reaping benefits of progressive division of labor), and the advent of new management scientific methods (e.g. rise of Fordism).

Note that, in the sector of application, from a competitive point-of-view, firms mostly introduce robots to increase productivity (lower unit costs, higher efficiency). Of course, this does not mean all robots increase productivity. This section started with providing a few other reasons for adoption of robots: window dressing as tech savvy firm, technology solutionism, reducing labor dependency, for the sake of workers, etc. Moreover, robots may allow provision of complementary services, manufacturing higher quality products, work in harsh conditions, etc. Even if the total cost of ownership of robots exceeds the cost of labor, robots are introduced if they are believed to yield a 'sufficiently higher' productivity and thereby lower unit costs, or whenever robots yield more competitive products or services (e.g. in terms of quality) and thereby a 'sufficiently higher' revenue. As such, there are situations in which robotization is a trade-off. Table 1 shows the rationality of robotization when the operational performance in terms of unit costs is pitted against another performance characteristic.

Even in cases when substitution is economically rational, there may be reasons not to adopt robots, e.g. envelopment (changing physical space to facilitate/accomodate the operations of the robot) is not possible, there is worker resistance, it violates certain laws, etc. Resistance, regulations, etc. may have to do with the destruction of jobs, deterioration of working conditions, changes in the task set or valuation of skills, etc. These topics are discussed in the next sections and in *10.0 Meaningful Work*.

Given the role of wages and total cost of ownership, there is a close relationship of the economic rationales of robotization and offshoring production to low wage countries. For firms producing mainstream products and not differentiating their products, price competition forces firms to reduce first pro-

Table 9.1. Rationality of robotization in a two-dimensional performance framework.

		Operational performance of robot compared to human worker	
		Less productive/ slower. Higher cost per unit product.	More productive/ faster. Lower cost per unit product.
Additional performance characteristics	(Yet) inferior solution (e.g. inaccurate, requires envelopment, ample labor, underdeveloped, etc.)	Technology solutionism? Window dressing?	Trade-off
	Superior solution (e.g. precision, complementary service, operates in harsh conditions, resolves labor shortage, preferred by customers)	Trade-off	Substitution is economically rational

duction costs and subsequently labor costs in both cases. As such, European firms in competitive manufacturing sectors seem to be faced with two alternatives: either lowering unit costs by offshoring production to low wage countries or by robotization of production, as mentioned by a robot developer participating in the REELER research.

> *The need of higher productivity is a reality for different sectors. So, this increase of productivity and the cost of the human operator is higher, in particular in Europe. So, there is not the choice of the robot versus the operator: It's no work in Europe versus having the work in Europe.*
>
> (Emilia, director of research and innovation, robot maker, COOP)

For monopolists, firms serving niches, or firms enjoying strong scale or scope advantages, this may be yet somewhat of a rhetoric, but the cost economic and strategic management arguments reveal that robotization may thus 'save' European jobs. In the past, many manufacturing jobs were offshored (and often also outsourced) to low-wage countries such as China. Increasing wage levels in these countries and mounting logistic costs already drove de-offshoring/ reshoring tendencies. Now, with increasing sophistication of robots and a drop of prices of robots, reverse-offshoring production activities becomes economically attractive. So, robots may make it viable to onshore production again. However, instead of using labor intensive manufacturing jobs, the jobs are done by high-tech robots and require high-skilled employees. A touted example is that Adidas de-offshored the production of trainers (The Economist 2017) from China to Germany

9.1.2 Rationales for robot research, development and production

This section only provides a brief view of the robotics sectors. Extrapolating the sales figures on robots of the International Federation of Robotics reported earlier in this chapter, the outlook for firms conducting research into, developing, and building robots (and robotic parts) is favorable. However, the robotics sector is multifaceted and diverse. So far, the lion's share of sales is still industrial robots (e.g. automotive, manufacturing, warehousing) and these robots are technologically rather mature and produced by large, established firms. However, currently, the sector is experiencing a swarm-in of many (small) entrepreneurs engaged in research, development, and sometimes already commercial sales of robots in sectors such as agriculture (e.g. milking robots, harvesting robots, precision farming), healthcare (e.g. surgery), construction (e.g. brick laying), maritime (e.g. pipe line inspection), etc. Moreover, the robotics sector is characterized by a rich set of knowledge institutes conducting mostly research and building early prototypes often in collaboration with entrepreneurs or on component technology with large established firms.

In general, the developments in the sectors of production equipment builders (such as robots) directly affect the sectors applying that equipment. While traversing their own industry lifecycle, many robot developers are engaged in product innovation, looking for new applications for robots and opening up new niches/ sectors, rationalizing their own production, and reaping scale advantages (e.g. by standardizing, modularizing, introducing commonalities across robots). Clearly, for reasons outlined before, firms in sectors applying robots are likely to have to respond to innovations in the robotics sector or even actively collaborate with robot firms to pre-empt competitors in their own sector. Indeed, robot developers may thus trigger 'deepening automation' in firms in 'robot-applying sectors', while competitive moves of firms applying robots may trigger new robot developments.

Interestingly, some robotics companies actually have the explicit goal of making robots that are cheaper than humans for their customers:

> *So, the idea of the company is actually to create robotics that are accessible. So, it's not as expensive as people - I mean, it's still not going to be cheap yet, but it is acceptable and it's affordable and more companies can employ robots.*
>
> (Felix, CEO advisor, robot maker, WAREHOUSE)

Given the increasing competition and maturation of the industrial robotics sector, some industrial robotics firms specialize in subsystems (e.g. grippers, sensors, actuators), others in specific applications (e.g. painting, welding, assembly, cutting, packaging, SCARA material handling), while yet others differentiate by offering modularized designs or rather customization. Arguably, successful improvement of robot features (e.g. refined sensors, actuators), a lower unit price of robots (e.g. due to upscaling of production), enhanced functionality (e.g. tailored to sector specific applications), and alternative business models (e.g. renting or leasing robots)[4] will speed up the adoption of robots in existing and new sectors. So, the increasing competition drives product innovation, differentiation, upscaling, etc. in the robot making sectors, which in turn drives process innovation in the applying sectors.

Given the many promises on process innovation in the applying sectors, the EU funds quite a few robotics projects. In fact, REELER's analysis of the CORDIS database reveals

4 See for instance the company Smart Robotics in Best, The Netherlands: https://www.smart-robotics.nl/

that across close to 600 robotics research projects in the 7th and 8th Framework combined, more than 1500 institutes and firms received more than €25k, more than 250 institutes and firms received more than €1M, and more than 25 institutes and firms received more than €10M in funding. The biggest receivers consist of major research institutes such as Fraunhofer, DLR, DFKI, and Max Planck Institute in Germany, the IIT and LFCA in Italy, the INRIA, CNRS, CEA in France, etc. These are followed by major universities and colleges such as the SSSA and UPisa in Italy, TUM and KIT in Germany, ETH Zürich, the Imperial and University College in England, the three technical universities in The Netherlands, etc. to name just a few. The financed projects range from early stage (low Technology Readiness Level) projects with a variety of applications (e.g. in agriculture, rehabilitation, home appliances, surgery, firefighting, maintenance), fundamental research on topics like swarms, communication protocols, nanorobots, etc., or refinement of existing components such as grippers or sensors.

In several of the REELER cases, it was found that robots are sometimes expected to be neither better, nor cheaper than humans but are developed anyway. Firms involved may have been motivated by technological deterministic or techno-chauvinistic points of view , and because there was risk capital and public funding available for robot development. The rationale of funding organizations may thus be to gain technological expertise, build a collective knowledge base, establish an innovation network for future projects, establish technology transfer, develop early prototypes to extend, and ultimately cascade into additional developments that are expected to be economically viable or contribute to society.

9.2 Impact on workers

Over the past centuries, there have been several waves of innovations that enhanced the productivity of laborers. Generally, processes of mechanization, automation, and computerization increased the agricultural yield per farmer per acre, the number of products produced per worker per hour, the value added per worker per task, etc. As mentioned in *10.0 Meaningful Work*, there are several potential effects for individual workers in workplaces adopting the productivity-enhancing, labor saving technologies. Firstly, higher productivity per worker means that fewer workers are needed for the same output. Redundant workers may be laid off or see their wages are lowered. Secondly, with the introduction of technology, the sets of tasks executed by workers may change, e.g. may become reduced to residual tasks necessary to keep the machines running or may change to require differ task to install, program, and maintain machines. As production and service tasks change and/ or new ones are introduced to reap complementarities with the robots adopted, the remaining jobs are expected to change qualitatively. Thirdly, given the change in task sets and required skills, the wage of workers may change: workers with scarce, advanced skills in high demand will generally have higher wages than workers with basic skills and/or in low demand. Fourthly, newly unemployed may look for jobs in the same sector or (may be forced to) look for jobs in other sector(s) that may require different skills. This underlines the importance for education or training-on-the-job in reskilling (*see also 10.0 Meaningful Work*).

9.2.1 History: a reason for optimism?

Illustratively, when steam-powered weaving looms and other ‘frames’ were introduced in factories in the early 19th century, British craftsmen, weavers, and textile workers thoughtfully [5] protested against mechanization of their work, the destruction of jobs, changes in skills required and tasks to be performed, and the wages paid. Figure 9.1 shows that, over the past 170 years, the unemployment rate remained relatively low, real consumption wages increased, and the hours worked decreased. So, superficially, and disregarding external costs such as environmental pollution, the impact of mechanization and progressive industrialization may have had mostly positive effects.

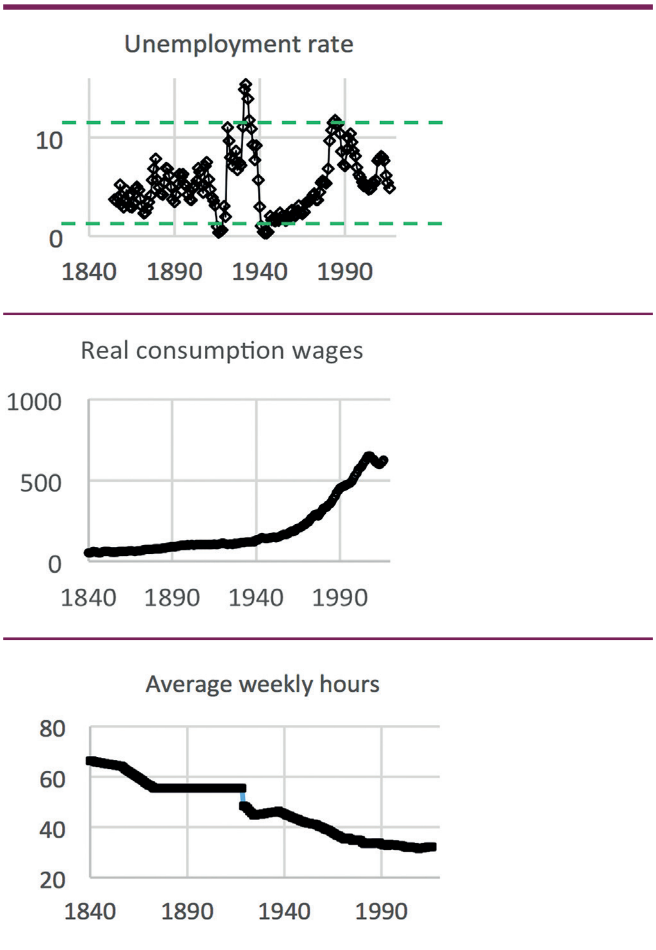


Figure 9.1. Unemployment rate, real consumption wages, and average weekly hours worked in Great Britain over the years 1840–2016. Source: Bank of England, Millennium of Data v3, dataset A48, A50, and A54. (Data visualization by Ben Vermeulen)

5 In the historian Frank Peel’s entertaining account of the Yorkshire Luddite movement, however, the mere loss of jobs seemed to be the prime reason for the uprising and the ‘degradation’ of the highly skillful workers finishing cloth (‘cropping’) the secondary reason. See: Peel (1888).

Robotization may affect professional pride, the care and sense of ownership tied to the product of one's labor. (Photo by Kate Davis)

While there were fears that steam-powered machines would replace labor, cause mass unemployment, and have people live at subsistence levels, these figures suggest that the negative outlook was unwarranted --at least in the long run. Why would it be different in the case of robots? (Mokyr, Vickers, & Ziebarth 2015). In this chapter, we discuss various scenarios on the development of employment and analyze how countervailing forces, structural chance, policy interventions, and education may contribute to sustaining high levels of employment.

However, although ultimately the industrial revolution brought prosperity to many, the living conditions of factory workers in the 19th century were poor. Indeed, throughout that century, there were repeated calls for social and economic reforms, not least by Marx and Engels. Not before the 20th century did living standard improve substantially, particularly in Western countries. Nevertheless, even now, the Western countries still have 'working poor' and society is facing further stratifications with a growing 'precariat' living in uncertainty and near subsistence levels (Standing 2014). Robots and AI are expected to have a potentially tremendous impact on employment, also on a global scale. Moreover, like before, there are economic forces that may increase income inequality and stratify society, both within nations, but also across the globe.

While the previous section revealed how the competitive forces in capitalist economies drive production rationalization and robotization, and this may (again) cause stratification, inequality, etc., it is important to note that progressive robotization is not inevitable. Further, technological development may still be regulated, and certain adverse effects of adoption of robots may possibly be mitigated politically, for instance, through a robot tax, universal basic income, etc. That said, if mass-robotization does indeed occur and mankind ends up in a situation with mass-unemployment, yet other political and economic reforms may (again) be needed to redistribute wealth, tax capital goods, re-educate and upskill the unemployed, and safeguard the well-being of citizens in general. However, arguably, contemporary economies are quite different from those in the early 19th century.

9.2.2 Susceptibility to robotization

Much of the popular debate focuses on which jobs will be robotized and what happens with the *total rate of employment*. As discussed before, there are various reasons for further rationalization of production processes and robotization of certain production steps. Following straightforward economic rationales, firms' separate tasks requiring highly skilled, highly paid workers from tasks requiring less skilled workers that can be paid less. Until recently, the labor economic literature concerned with technological change argued that particularly *low-skill jobs* would be at risk of mechanization, automation, and now robotization. Nowadays, though, it is argued that technological substitution primarily occurs for *routinized tasks* in stationary, predictable environments. Arguably not by coincidence, robots were first introduced in Fordist factories in which time-and-motion-studies had already organized work in short-cyclic, repetitive tasks: they could easily be executed by robots. Recent studies revealed that such routinized tasks are typically found in middle-skilled jobs (Autor, Levy, & Murnane 2003; Ford 2015). Jobs which require refined perception and physical dexterity, creative intelligence/ improvisation, or social intelligence, regardless of whether they are low-skilled or not, are less at risk of replacement (Brynjolfsson, & McAfee 2011; Deming 2015; Frey & Osborne 2017). Hence, one could argue that robots (and AI) will take over routinized tasks, while tasks requiring essential human qualities are left to humans (*see section 9.2.3*).As robots become increasingly nimble, learn to handle more complex tasks, and can cope with more dynamic environments, more and more tasks will become susceptible to robotization.

9.2.3 Qualitative transformations and labor mobility

Apart from the debate on the total rate of employment, the Luddite uprising already illustrated that people, do not just work to make a living, but seek to engage in meaningful activities, which requires and values their skills. For that reason, we do not only discuss how robots affect the rate of employment, but also the *types of jobs* and notably the *tasks* subsequently performed by humans and the *skills* required.

> **Qualitative transformation:** *A notion underlining that not only 'having a job' matters when thinking of the impact of robotization on employment, but also the type of work, the skills required, and the job satisfaction.*

A popular rhetoric in favor of robotization is that robots ultimately do the work deemed dull, dirty, and dangerous, which was supposedly ungratifying to begin with (Kaplan 2015). Thus, workers relieved by robotization may then focus, willingly and happily, on meaningful, gratifying work requiring supposedly distinctly human qualities such as emotional and social intelligence, creativity, and physical dexterity (e.g. Deming 2015; Brynjolfsson & McAfee 2011). The argument is that robots effectively 'rehumanize' work for people, and, implicitly, that mankind should rejoice in the coming of robots. This 'rehumanization argument' is nicely illustrated in the quotation of one of the interviewed stakeholders:

> **Rehumanization argument:** *Line of reasoning arguing in favor of progressive robotization because robots can and may take over dull, dirty, and dangerous work deemed ungratifying and thus free up humans that can then focus on work requiring supposedly distinctly human qualities. Robotization thus facilitates rehumanizing work of people to do supposedly gratifying, meaningful work rather than supposedly ungratifying, meaningless rationalized production activities.*

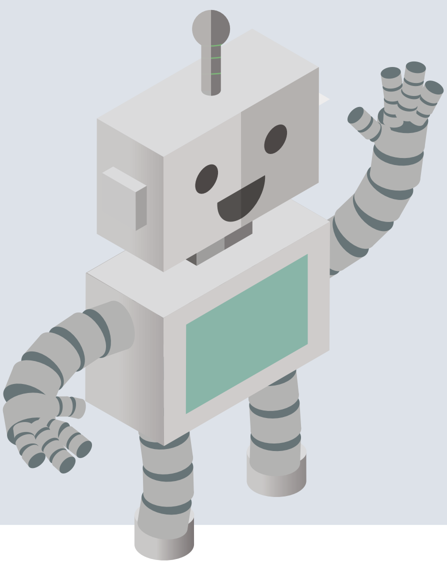
> *It's great that machines do a lot of the hard work we had to do in the past, but if we liberate a lot of people from that work, we should use these creativities, energy, this time, for other things; there are a lot of things to do in the social way, help people, manage the environment and reflect about that.*
>
> (Emanuel, exhibition coordinator, affected stakeholder, BUDDY)

Robots may be adopted out of necessity if there are no workers to do supposedly dull, dirty, and dangerous work (*see section 9.1.1*). Robots may also be adopted to cope with regulations on working conditions that protect people from doing particular dirty or dangerous work (e.g. lifting very heavy elements), or highly repetitive and dull work (e.g. extremely short cyclic work) (*section 10.3. in Meaningful Work* for a counter-perspective involving post hoc explanation of relief of workers). Indeed, the introduction of robots may resolve labor shortages in production, which may itself be caused by poor working conditions, low wages, legal complications, etc. Though robotization of such jobs and tasks are often seen as relieving the worker, robotization need not be the only solution, just as assumed dull or repetitive tasks may not be perceived that way by the workers.

While robots may take over some jobs entirely, it is more likely that robots perform certain tasks, and that workers get an altered set of tasks. Indeed, the introduction of robots in the workplace may have a great impact on the tasks executed and skills required – see the story from the field "A construction robot" below. It may well be that workers get new tasks assigned that are complementary to the tasks of robots. These tasks may be more complex and require upskilling, but this is not necessarily so. On the other hand, the introduction of robots (and the rationalization of production possibly required for robotization) may also make the tasks less complex, more repetitive, even more dangerous (and unintentionally countering the rationale for introducing them in the first place). Think for instance of skilled masons at construction sites that became operators feeding bricks to robots, who perform their old tasks. In this case, robotization may actually introduce rather than eliminate repetitive tasks.

STORY FROM THE FIELD:
A construction robot

In WIPER one of the robots aim to change the work for people at construction sites. Before the introduction of the robot, two or three workers used to coordinate to install heavy doors in commercial spaces, but now the task of lifting is taken over by the WIPER robot (a prototype still under development). The shift from multiple workers lifting and adjusting the doors to a robot lifting the doors and one worker manipulating the robot has required changes in the workers' skills, their rhythm of work, and their collegial relations. Instead of laboring together with his colleagues, now one man or woman can manipulate the door using a controller attached to the robot. Previously the workers felt a sense of pride when installing doors that swing perfectly into place. Now, the robot acts as a mediating device between the worker and the completed task, which has affected the workers' professional pride. On the other hand, the robot also demands new skills of the workers. The construction workers had to learn to steer the equipment and smoothly position the door using the robot. For new operators, the robot can perform rather shakily, which can be unnerving when handling for instance large glass doors. But the workers who received hands-on training became confident enough to try installing some doors with the assistive device, whereas those who'd only seen a demonstration and received a training guide abandoned the tests with the robot. Thus, a robot can significantly alter existing tasks and demands for skills both positively and negatively.



(Based on interviews from the WIPER case)

Even if robotization would change human work to consist of tasks requiring qualities currently cosidered to be uniqely human (e.g. sociality and creativity), this is not necessarily desirable from the perspective of the individual worker. Indeed, an interesting finding in the REELER project is that robot developers, firms applying robots in production, policymakers, labor economists, etc. suffer what is dubbed a 'human quality - meaning fallacy': this is the (possibly) mistaken belief that people *want to* do complex work requiring social skills, creativity, physical dexterity, or general intelligence. However, the REELER data shows examples of people, affected stakeholders, who do not dislike their low-skilled, repetitive, or physical work (*see section 10.4. in Meaningful Work*). As such, the reasoning that robotization of dull or repetitive tasks is universally desirable or that workers prefer to do (what some might consider) more meaningful work is fallacious. While the repetitiveness of assembling tasks may be dull to some, it has a 'pleasant meditative' effect speeding up the passing of working hours to others. While working on a cattle farm is considered dirty by some, it may actually be an enjoyable job to others. And while cleaning windows of skyscrapers is considered dangerous by some, it is exciting to others. Even physically straining work may be considered desirable by some, for instance because such work helps develop a muscular physique (see the SPECTRUS case, for example). Moreover, working a desk job and sitting in a chair all day, doing complex work, or having to do social work may be disliked or considered tiresome by some.

Quality – meaning fallacy: *The (possibly) mistaken belief that jobs requiring more human qualities (notably social skills, creativity, intellect) are considered more meaningful or desirable to or more appreciated by workers.*

A related question is whether there will be enough of these supposedly meaningful jobs? And, given the wider dispersion of automation and robotization, will job creation keep up with increasing rates of job elimination, and will we be able to educate people fast enough to fill new vacancies? (Goldin & Katz 2008; Acemoglu & Restrepo 2018a). These topics are discussed in more detail in *section 9.3*.

9.2.4 Income inequality and geographical division

A primary concern of mechanization, automation, robotization, etc. is that it widens the gap between the rich and poor. Given that routinized tasks are more prone to be taken over by robots, certain jobs are more likely to be affected and possibly vanish completely. Due to predispositions and personal aptitudes, those newly unemployed may struggle to re- or upskill to compete with an increasing pool of low- and middle-skilled unemployed competing for scarce low-skill jobs, which in turn would depress wages. Or, if they succeed in re- or upskilling, they may face an increasing pool of well-educated unemployed workers competing for increasingly scarce high-skill jobs. So, due to limited geographical and labor mobility as well as increasing competition for jobs, we may see an increasing class of people grappling for a low income. This may drive progressive stratification of society into the classes (e.g. Standing 2014; 2011) 'precariat', 'technical middle class', 'elite', etc. A related perspective is that particularly *middle*-skill, white-collar jobs with routinized tasks are subject to robotization. Consequently, there is polarization of the labor market, with a growing gap between a small group of highly paid, highly skilled workers and a big group of workers with low-paid, low-skill jobs (Autor, Katz, & Kearney 2006; Goos & Manning 2007; Goos, Manning, & Salomons 2009). So, robotization may stratify societies, i.e. may create classes of people with different wages and opportunities, purely based on different capabilities, existing skills, and education.

These stratifying and polarizing forces also work across the globe. Given differences in the sectoral and occupational composition of economies, the impact of robotization may greatly differ across nations and effectively exacerbate the 'North-South divide'. Concretely, robots may be developed and built in the "North" countries and (also) applied in "South" countries. While widely varying, developing economies ("South") may be affected by robotization in several ways. Firstly, the capability to arrange technology transfer and absorb new technology may be limited due to an as of yet limited knowledge base. As such, developing economies may miss out on potential benefits of researching, developing, and building robot technology. Secondly, as the developing economy's labor force that is part of a global production network is possibly employed in labour-intensive manufacturing or routinized service industry, those workers are (1) at risk of becoming unemployed due to rationalization and robotization or even reverse-offshoring of production, or (2) facing wage reductions in competition with robot technology that becomes cheaper. Thirdly, if reverse-offshoring were to take place, production networks are dissolved, which also severs reverse knowledge sourcing channels. And particularly these ties in production networks were considered important channels for technology transfer (*see e.g. Ernst 2002*).

Taking robot patents as indicator of their locations,[6] REELER research revealed that firms in the robot making sectors are located in countries such as the U.S.A., Japan, China, South Korea, and Germany. However, sectors *applying* robots may be located in other, even peripheral countries. In the case of Europe, several North-Western countries may develop and build robots that, when applied, destroy jobs in Southern and Eastern countries. Thus, robotization may counteract the European Union's goal of inclusive growth. Such an emerging geographical disparity is well-conceivable for several sectors – not least agriculture. In agriculture, however, the introduction of robots may in fact increase productivity in the more advanced production systems rather than in less advanced production systems.

Inclusive growth: *A central policy objective of the European Union emphasizing that all classes of society across all nations should benefit from economic growth.*

6 European Patent Office patents, excluding WO and EP patents.

STORY FROM THE FIELD:
Agricultural robots

REELER's anthropologists made a case study of agricultural robots. One of these agriculture robots was cooperatively developed by a number of institutes and companies mostly in north-western Europe. The robot is being developed for and tested in specific areas in these countries. However, REELER's researchers conducted interviews in wider Europe to explore the potential impact of that robot on more distantly affected stakeholders, like growers in Spain and Italy, and farm lobbyists in the United Kingdom.

In Italy and Spain, the areas used for farming have different sizes and growing conditions than in Western or Northern Europe. In western parts of Europe, the plots are often large and flat with crops arranged linearly along raised berms, with lower, wide, flat swales between the rows – creating a more predictable map and a more easily navigable environment for a robot to maneuver between the planted areas. Today, these farms are coordinated and managed almost like industries, with collective harvesting and packing arrangements, and relying on labor from the eastern parts of Europe and other immigrant workers. In the southern parts of Europe, we find more small family owned farms on plots that are anything but flat and straight – where the crops are planted in contours over hills and around the occasional tree or rocky outcrop. The field's layout and the growing and harvesting methods are much less predictable than in the large, flat farms to the north. Such farms are incompatible with precision farming in a robotic future.

If agricultural robots increase productivity or efficiency significantly in Northern Europe, Southern European farms may struggle to compete with the crop prices in the North. These developments might also affect migration patterns, as fieldworkers and growers in the Southern parts of Europe and in North Africa may find themselves without jobs. There are unrelated fears in the UK, as Brexit has already led to migrant workers leaving the UK. Large emigration of European migrant workers could leave a labor deficit in agriculture, followed by increasing wages, and thereby food prices. Robots may then be called in to solve the labor crisis, though not without substantial changes in how agriculture is performed. This shows links between robotization and broader societal issues, such as food security, migration, and labor mobility.

9.3 Structural change

The previous sections discussed firms' motives for and activities in production rationalization as well as entrepreneurial robot development including the impact thereof on workers in terms of employment, tasks performed, income, and skills required. At an aggregated level, this brings about a shake-out of firms and job destruction in sectors relying on 'old' technology gradually being robotized, as well as a swarm-in of entrepreneurs and job creation in sectors engaged in 'new' technology, including robots. So, the development of employment, income, and skills takes place within and across different types of sectors. Here, this notion is extended in a multi-sectoral perspective.

9.3.1 Multi-sectoral perspective on the impact of robotization

Arguably, the scientific 'end-of-work' literature, with such prominent proponents as Brynjolfsson and McAfee (2011), Ford (2015) and Frey and Osborne (2017), and some strands of popular media have a narrow focus on the *loss of jobs due to substitution*.

Countervailing force: *An economic mechanism in which the introduc-tion of robots creates work and thus compensates the destruction of work.*

Although firms in some sectors are indeed mostly *applying* robots to increase productivity and reduce required labor and the technological advancement of robots do expand the range of sectors in which robots are (potentially) applied, there also are sectors in which the technological change actually *creates new jobs* (see, e.g., *Hughes 2017; Nathan & Ahmed 2018) or transforms the task content of jobs*. Additionally, there are (indirect) effects on wages, disposable income, and thereby consumption, with consequences for product demand and thereby employment in other (types of) sectors. As such, there is a range of countervailing forces aimed at compensating job loss due to robotization. In short, the main direct 'countervailing factor' concerns increases in demand for skilled labor to build robots, labor demand for complementary skills required to use robots, and increasing demand for labor due to a decrease in product costs caused by robots (for further reading, see e.g. Vivarelli 2007; Autor 2015; Acemoglu & Restrepo 2018b; Vivarelli 2014). Different countervailing forces are at work in different types of sectors. The 'countervailing forces' are cast in a structural change framework based on *different types* of sectors (*see Vermeulen et al. 2018 and Annex 1*).[7]

7 see responsiblerobotics.eu/annex-1

Structural change literature (Baumol 1967; Echevarria 1997; Ngai & Pissarides 2007) studies the evolution of the composition of an economy in terms of sectors, occupations, and (types of) work, notably featuring increasing variety in the sectoral composition and output (Pasinetti 1981; Saviotti & Pyka 2004; 2008). Over the last two centuries, technological change drove the migration of labor from the agricultural sector to manufacturing sectors and later from manufacturing to service sectors (Leontief 1982; Ginzberg 1982). One of the REELER studies (Vermeulen, Kesselhut, Pyka, & Saviotti 2018) proposes a classification of sectors based on the impact of technological change (here: robotization) on demand for labor in certain occupations. For one, there is a definite increase in labor demand in sectors making robots. Think of all the people researching, developing, designing, and building robots as well as implementing these robots in other sectors. Moreover, in the *applying* sectors in which firms buy and apply robots, these robots often do not outright replace workers, but takes over certain tasks. New and complementary tasks that emerge with the introduction of robots are, for instance, programming, controlling, and maintenance of robots, as well as reorganizing production and services. In addition, sectors *complementing* the applying and making sectors (such as the education & training sector, consulting sectors, the legal support sector, etc.) see a transformation in the activities, as people need to be (re)educated to either research, develop, and design robots in (potentially new) production & service environments. Similarly, people need to be (re)educated to (also) use robots instead of tools used previously, and possibly program and maintain these robots.

Structural change: *An economic core concept on how the composition of an economy evolves over time in terms of sectors and occupations, often due to cascading effects of development and application of new technologies.*

On top of the creation and elimation of jobs, as well as changing tasks of occupations, the *income* of people changes. With a foreseen increase in demand for robots, demand for workers in the *making* sectors becomes high, and firms compete for robot developers, such that wages may well increase. In the *applying* sectors, some workers may be replaced by robots and thus become unemployed. These workers may not be able to upskill and may end in low-skill jobs with lower wages or may have to rely on social benefit schemes. In fact, in *competitive* applying sectors, rationalization and robotization may be sought to reduce reliance on skilled workers, which could depress wages. The *complementing* sectors will see a decrease in demand for teachers, trainers, lawyers, production engineers, consultants, etc. specialized in the old technology now being replaced with robots. However, the demand for teachers, lawyers, engineers, consultants etc. with an expertise in robotics is expected to rise, peaking during the transition, and then plateauing at the lower level in the long run enough to replenish natural employment turnover. Moreover, particularly those that are experts in robotics may get higher wages (Vermeulen, Kesselhut, Pyka, & Saviotti 2018; see also Annex 1)[8]. In addition to making, applying, and complementing sectors, there are *competing* sectors, in which firms make technologically different products but that provide services rivalling those in the applying sectors, e.g. the railway sector is competing with road transport of people and goods. Clearly, application of robots in one of these sectors may strengthen the competitive position of firms vis-à-vis firms in these competing sectors due to higher productivity, lower prices, lower dependency on labor, etc. Consequently, the competing sector may see a decrease in product demand, employment, and wages. That said, firms in these competing sectors may respond by investing in research and development to catch-up or even leapfrog. Note that even among the sectors applying robots, there may be sectors competing for the same demand, which probably intensifies rationalization and robotization on the one hand and investments in research & development of new products and production processes on the other hand.

All else being equal, a change in the number of workers employed and the wages they receive across all (types of) sectors reflects in the total disposable income. Part of this income is spent in *spill over* sectors, e.g. on vacations, recreation, sports, entertainment, personal care, lifestyle, luxury goods & services, etc. As such, changes in employment and income are amplified by the effects on the spill over sectors. On top of the developments within and across existing sectors, new sectors will emerge.

The structural revisions and additions to classifications such as the International Standard Industry Classification (ISIC) or the Nomenclature statistique des activités économiques dans la Communauté européenne (NACE) reveal changes in the sectoral composition. However, the institutes behind these classifications only occasionally revise the classifications: the last ISIC revision (rev.4) dates from 2008 and the last NACE revision (rev.2) dates from 2006. The biggest change in both classifications at the time was the addition of a section on 'Information and communication', with notably computer programming (including the development of webpages), computer consultancy, service activities (such as webhosting, streaming services, data processing, etc.). Tellingly, these standards refer to robots only in the context of manufacturing for tasks such as lifting and handling in production lines, but not yet in healthcare services, transport & logistics, agriculture, defence, space, maintenance, etc. Many of the currently emerging sectors do not yet have distinct names or clear outlines. Arguably, entrepreneurial activities are likely to revolve around (1) emerging technologies such as data science, artificial intelligence, quantum computing, block chain, internet-of-things, etc.,[9] (2) intangible technology and based on concepts and information content such as e-commerce, social media, computer games, (3) data-driven decision and research support such as fin-tech, drug discovery, etc. and, (4)

8 see responsiblerobotics.eu/annex-1

9 See the World Economic Forum report "Future of Jobs 2018".

advanced applications of robot technology in sectors mentioned before (transport, agriculture, healthcare, etc.). Under these circumstances, all the jobs in these emerging sectors are newly created and would 'mop up' unemployed workers from readily existing sectors. That said, not all positions in these newly emerging sector can be immediately fulfilled because they require new skills, knowledge, etc. and labour mobility is limited (for a more detailed account, see section 9.3.2). Furthermore, it is unlikely that the majority of newly unemployed, previously working in the applying sector, will find new jobs immediately following their termination.

Table 9.2 provides a comprehensive overview of the effects of robotization, both in terms of employment and income specified for the different types of sectors.

Table 9.2. The sector-occupation matrix specifying how the introduction of robotics affects the number of jobs for the impact-specific types of sectors and (types of) occupations. This is developed in Vermeulen et al. (2018), see Annex 1 Methods and Methodology (responsiblerobotics.eu/annex-1). Note that there are also unrelated sectors that are not or only highly indirectly affected.

		Type of sector				
		'Making'	'Applying'	'Complementing'	'Competing'	'Spill over receiving'
Change in occupations	EXISTING	+ Increase in demand for robotic technology and deepening automation of older 'vintages' of existing production equipment + Increase in demand for upstream component suppliers, and downstream service suppliers	– Pure substitution of workers by robots + Increase in demand due to lower prices caused by increase of productivity of manufacturing + Exploitation of complementarities by adding new tasks or even (specialized) jobs (e.g. maintenance of robots)	– Loss of jobs pertaining to old technology and jobs now replaced by robots (e.g. teachers in vocational studies welding, painting) + Increase of jobs pertaining to robots, to occupations transforming and reaping complementarities (e.g. trainers for maintenance of robots)	– Decrease of employment and income due to weaker competitive position, relatively higher price, lower demand + Increase of employment in R&D for improvements to catch-up or leapfrog (including possibly robotic add-ons)	+ Increase in employment and disposable income in making sector +/– In- or decrease in employment and disposable income in applying, competing, and complementary sectors + Increase in employment and disposable income for higher skilled workers in applying sectors
	EMERGING	+ R&D, innovation, and entrepreneurial activities further exploring & extending robotics + New high-skill and high-paid jobs, notably for exploitation of emerging robotic technology	+ Resources freed up to put to use in creating new products/ services + New applications facilitated by using robotics in production & services. + New occupations due to new ways of organizing, communication, new social processes, etc.	+ For new occupations and new technology	+ Increase in employment in R&D, innovation, exploration & exploitation of new technology competing with robotics	+ Increase in employment and disposable income in newly created occupations in all sectors

9.3.2 Labor mobility & vacancy chains

In the multi-sectoral perspective on structural change, labor mobility is paramount in sustaining (or regaining) high levels of employment. After all, workers need to be able to acquire skills complementary to working with robots in the applying sectors, or workers laid off may need to re- or upskilled to find work elsewhere in the same or another (applying) sector. Moreover, in the making sectors, there is an increasing demand for robot developers and builders. For jobs in the emerging sectors, workers need to acquire advanced skills to produce new (types of) products, provide new (types of) services, etc. (although, of course, also low- and middle-skill jobs are required in these sectors). Moreover, firms might not be able to find skilled and willing workers locally and hence may decide to either relocate activities, offer training on the job, increase wages to attract talent from elsewhere, etc.

Labor mobility: *The ability to take up other jobs (possibly but not necessarily requiring other skills), which may, but need not, be in another geographical location.*

In addition to ethnographic studies, REELER has also conducted a study (Vermeulen, Pyka, & Saviotti (forthcoming), and Annex 1)[10] involving an agent-based computer simulation model with firm agents and worker-consumer agents. It was developed to study the evolution of a multi-sectoral, multi-occupational labor market subject to robotization and the moderating effects of several policy interventions proposed in literature. At the core of this model are two interlocking processes driving labor allocation: (1) the competition of firms for skilled workers, which drives wage increases, and (2) the switching of workers to jobs with 'sufficiently higher' wages, i.e. in which the wage gap exceeds a positive threshold. Hereby, a 'market matching process' recursively allocates the most suitably skilled workers to the highest paid vacancies until all vacancies are filled or no workers are unemployed anymore. The workers subsequently spend disposable income on consumption in the economy itself. This basic model reproduces empirically observed wage-price spirals. In addition, there are two independent processes that affect the number of jobs: (1) robotization drives productivity increases, thereby price drops and the laying off of redundant employees (job destruction) across all sectors, and (2) at an exogenous rate, new sectors emerge in which new firms offer new products that (by experimental control may or may not) substitute products offered in already existing sectors.

Unlike the conceptual model of structural change presented in the previous section, the operational simulation model requires assumptions about the job switching propensity of workers as well as the constraints on labor migration in terms of skill gaps accepted by firms. From experiments with this 'admissible skill gap', it is found that the rate at which upskilling is possible moderates the rate of recovery of employment whenever robotization destroys jobs. In fact, this model reveals a phenomenon which was dubbed a 'vacancy chain'. Similar to how hermit crabs swap to bigger shells, employees swap to (better paying) jobs requiring higher skills, thus leaving a vacancy for lower skilled workers to fill, including both job hoppers and the unemployed. Such vacancy chains emerge under a persistent creation of new jobs in new sectors requiring higher skills and sufficient labor mobility (i.e. sufficiently high rate of upskilling). Particularly when the gap in skills is (too) large, initially, suitable workers are scarce, and the offered wages increase.

Vacancy chain: *An economic phenomenon (observed in one of our computer simulation models) in which workers move to better paying jobs by upskilling, thus leaving vacancies filled by others with lower skills.*

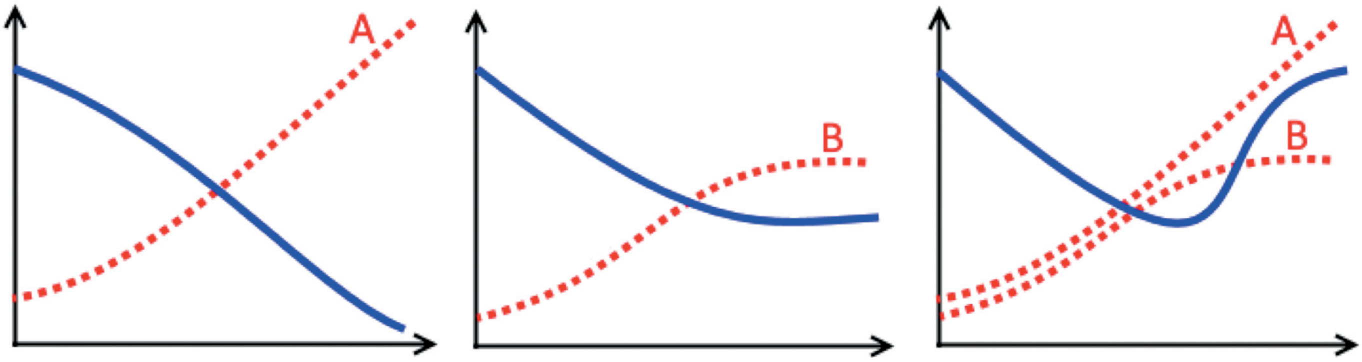
10 see responsiblerobotics.eu/annex-1

The model findings underline the importance of labor mobility and sector creation. However, for analytical purposes, this simulation model has been left highly stylized. Both the mechanisms for upskilling and radical innovation are not modelled. In reality countries differ in the amount of schooling paid for, institutional arrangements for education, labor market regulations, innovation policies in place, etc. In spite of this, one of the policy interventions proposed here is exactly to enhance mobility and stimulate innovation.

9.3.3 Scenarios

By and large, there are three scenarios pertaining to what robotization may do to total employment (*also see Figure 9.2*). Firstly, there is the *end-of-work* scenario in which robots ultimately do all the work and most people have no job at all. In a structural change perspective, this means that robots and AI will become so advanced that any job is almost instantaneously taken over. This would include jobs with technological complementarities, newly created ones in emerging sectors, and even jobs in robot-making sectors. Given that robots are currently far from this level of versatility, but rather designed for specific tasks, the diffusion and adoption is expected to occur gradually. However, note that once robots start designing & making robots, development may well accelerate. Secondly, there is the *structurally* lower scenario in which robots and humans each do part of the work. It is well conceivable that people take care of inherently human tasks, while robots do the tedious or intensive work. Moreover, it may also that work hours decrease across the board. A more refined discussion on tasks and skills (left) for humans is found in section 9.2.3.

Thirdly, there is the *rebound* scenario in which robots will gradually take over tasks, possibly even rapidly, but new jobs emerge which cannot be done by robots immediately and which will employ the human workforce. In this case, the level of unemployment returns to a 'regular' rate of frictional unemployment. Also note that a structural transformation with a rise of (employment in) quaternary sectors (some of which are headed under 'spillover') contributes to a rebound. Both in the rebound and in the structurally lower scenario, education moderates the pace of technological progress. However, in the rebound scenario, people can reskill and catch up faster than technology can progress.



End-of-work: progressive substitution of capital for labor and countervailing forces are too weak to compensate for job loss.

Structurally lower: capital for labor substitution tapers off, but countervailing forces do not create enough jobs.

Rebound: whether capital for labor substitution continues (A) or tapers off (B), employment rebounds to former levels due to countervailing forces

Figure 9.2. Three scenarios on the development of employment subject to the introduction of robots (see Vermeulen et al. 2018). The continuous line is the level of employment, the dashed lines are two scenarios on the degree of robotization (or, in general: capital intensity of work). (Data visualizations by Ben Vermeulen; see also Annex 1: responsiblerobotics.eu/annex-1).

9.3.4 Education and labor mobility

For the end-of-work scenario to occur, either one of the following two conditions is to be met. Firstly, the job destroying potential of technology through substitution exceeds the job creating potential of technology (through complementarities (MacCrory et al. 2014) and other countervailing forces). Or, secondly, the rate at which humans can be reeducated and retrained for new employment is lower than the rate of technological advancement (Brynjolfsson & McAfee 2011). Moreover, whenever the mobility of workers increases, the dynamic efficiency of adjusting to shifts in labor demand also increases. Consequently, the peak in technological unemployment is also reduced. So, education is a prominent moderator of the labor economic impact of robotization and offers an instrument to policymakers.

First and foremost, education is pacing robotization itself. Robots developers of specialized components (AI, machine learning, battery technology, etc.) are required to be educated and their skills and knowledge needs to be kept up to date (e.g. by training-on-the-job, attending conferences, following micro-masters). Moreover, with the introduction of robots, task requirements in existing, applying and complementary sectors change. Consequently, adoption requires reskilling of the existing labor force.

Secondly, people, who lose their jobs, need to be retrained for other jobs. As the creation and emergence of new sectors and thereby new jobs are contingent upon innovative and entrepreneurial activities, the migration of labor from old to these sprouting sectors is to be facilitated. So, technological progress and job creation in new sectors and hence absorption of workers that became redundant in older sectors stagnate, if education institutations are unable to forsee, which skills will be required in the new economy.

Note that the gradual transition of the labor force due to workers retiring with outdated skills and influx of young workers trained in currently required skills may be too slow. As such, workers have to acquire new skills during their working life (Peters 2017) and are to be (re)trained (possibly multiple times) during their career. However, as illustrated in *10.0 Meaningful Work*, REELER research into affected stakeholders shows that some people end up in their jobs, because they only have an elementary education, are illiterate or dyslexic, or their life circumstances have restricted their choices. There may be practical obstacles for these people to engage in training or studying outside of their job. See the quotation below from REELER's empirical data:

> *Interviewer: "You don't think you could reconcile work with school?"*
>
> *Veronica: "No, because I'm living alone, I don't have anyone to help me. I live alone with my daughter and when I'm working, she's in school, when I leave work, she leaves the school, then I have to go get her and stay at home with her."*
>
> (Veronica, cleaning staff, affected stakeholder, SPECTRUS)

Considering that robots are now gradually diffusing into service sectors that offer work to people who have had limited education and have limited opportunities, the educational system may need to be revised to also offer opportunities for reskilling to these people.

9.3.5 Graduality of robotization

Regardless of whether robotization will ultimately replace

most of the human labor force or not, it is expected to be a gradual process for various reasons. Firstly, sectors and occupations differ substantially in the ease with which robots can replace labor. After all, the elasticity of substitution (i.e., the degree to which factors can be substitute for one another in the production function)[11] depends on the complexity of tasks at hand, socio-technological features of the production (or service) process, etc. This in turn affects the price of the robots to develop. Given the substantial wage and robot price differentials of sectors (and occupations), firms in the various sectors will adopt robots at different points in time. Indeed, while robots are used already for decades in Fordist factories, robots are only now gradually entering services (Decker, Fischer & Ott 2017).

Secondly, firms in the robot making sectors typically first build robots to do repetitive and physically easy tasks, to be deployed in sectors in which wages are relatively high and jobs cannot be easily offshored. Only with the advancement of robotic technologies, notably electromechanical actuators, sensors, processing power, and artificial intelligence, can robots be expected to take over more complex tasks. However, whether these technologies are developed depends on the market viability and notably the wages in the apply sectors. This in turn is moderated by the labor mobility, labor competition, etc. As such, the faster robots destroy jobs, the faster developing more advanced robots becomes financially unviable.

Thirdly, robotization is by no means inevitable. Whenever labor mobility is limited and unemployment rates rise, governments may well intervene to moderate the pace, e.g. using robot taxes, wage moderation, etc.

9.4 Policy interventions

As outlined above, the progressive adoption of robots, if occurring, might have several fundamental consequences in terms of employment, income, and opportunities. However, so far, the role of governments has not been explicitly considered. Governments have several instruments at their disposal to regulate the adoption of robots and/or mitigate their impact thereof. In a report containing recommendations to the Commission on Civil Law Rules on Robotics, the Committee on Legal Affairs writes *"the development of robotics and AI may result in a large part of the work now done by humans being taken over by robots, so raising concerns about the future of employment and the viability of social security systems if the current basis of taxation is maintained, creating the potential for increased inequality in the distribution of wealth and influence"* (European Parliament 2016).

Progressive robotization may upset the labor market by challenging the sustainability of the current social safety net. The Committee recommends considering the introduction of "corporate reporting requirements on the extent and proportion of the contribution of robotics and AI to the economic results of a company for the purpose of taxation and social security contributions." This alludes to a 'robot tax'. However, the Committee continues and states that *"a general basic income should be seriously considered"*. Moreover, the Committee recommends "start monitoring job trends more closely, with a special focus on the creation and loss of jobs in the different fields/areas of qualification in order to know in which fields jobs are being created and those in which jobs are being destroyed as a result of the increased use of robots." So, there seem to be three main types of interventions: impose a tax on robots/ robotization, provide an unconditional income, and catering to the shifts in labor demand. Below the three types of policy interventions are discussed in detail (also see Vermeulen, Kesselhut, Pyka, & Saviotti 2018).

9.4.1 Robot tax

Whenever robotization eliminates more jobs than it creates structurally – directly or indirectly – it may be commendable to regulate rates of adoption. A 'robot tax' (Abbott & Bogenschneider 2018; Guerreiro, Rebelo, & Teles 2017) is a general notion concerning taxation of either the ownership of a robot or value created by (application of) a robot. There are three main ideas behind robot tax.

First and foremost, the idea is that taxation of robots is a disincentive for labor substitution. Indeed, imposing a tax, and thus making robots more expensive to buy and/or use, makes robots less attractive as a substitution for human labor, and would thus curb, mitigate, slow down, or stall robotization, albeit from the cost economic perspective described in section 9.1.1. Note that tax systems in most countries do tax labor but not robots, which contributes to the substitution of labor by robots.

Secondly, in the popular debate, the tax revenue is earmarked (hypothecated) to combat (supposedly adverse) effects of robotization by redistributing wealth, close the income gap, provide an unemployment benefit particularly for those displaced, compensate those that are directly affected, etc. (Gasteiger & Prettner 2017). An earmarked tax[12] is allocating the revenue from a single source to a single public service (generally within a multi-tax, multi-service fiscal unit). Arguably, introducing an earmarked robot tax seems impractical. Collecting taxes from the robot owners (say, for instance, manufacturing firms), on the one hand, and immediately providing particular services such as direct monetary compensation, training, etc., on the other hand, may impose a consid-

11 The notion of elasticity of substitution was originally introduced by John Hicks in 1932. It expresses the degree to which factors can be substitute for one another in the production function. Generalization of the ratio formula to multiple dimension is involved, see Blackorby & Russell (1989). Prominent evolutionary economists have criticized the notion of production functions as over-formalization, see e.g., Foster & Wild (1999) and Foster (2005).

12 A seminal, formal treatise on earmarked taxes can be found in Buchanan 1963.

erable administrative burden. Moreover, there are reasons to question the possibility of computing the optimal level of taxation,[13] the right amount of compensation, etc. Arguably, economies are rarely ever in equilibrium, and economic actors, including governments, are boundedly rational (Simon 1972), imperfect informed, struggling with combinatorial complexity, etc. Clearly, using a generic capital input tax in combination with a general unemployment benefit does not impose new, specific administrative burdens and most legal units already have public institutes in place for this (e.g. municipal employment agency).

Thirdly, the robot tax revenue may be used to (contribute to) create employment opportunities, enhance labor mobility through training and education, etc. Arguably, the upward mobility of the unemployed both between occupations within and between sectors (*see sections 7.2.3 and 7.3.4*) may be limited: these workers may have been laid off because they struggle with acquiring skills required for jobs in demand (particularly in the newly emerging sectors), may lack the aptitude, may not be motivated (e.g. close to retirement), etc. The latter topic is discussed more generally in the context of the 'dynamic efficiency' policy.

9.4.2 Universal basic income

A 'universal basic income' (or: 'unconditional basic income') is a regular income to any member of society regardless of wage, other sources of income, employment status, intentions, etc., and without further obligations. It supposedly buffers against poverty and guarantees access to resources to sustaining a certain standard of living (Colombino 2015; Parijs 1995; 2018; Parijs & Vanderborght 2017; Standing 2017). Moreover, from an innovation economic perspective, the individuals receiving universal basic income may pursue (entrepreneurial) dreams at limited risk. So, the basic income may stimulate entrepreneurial activity, innovation, and the creation of new sectors. However, there is a wide range of economic concerns about the viability of the universal basic income. Concerns covers, among others, sourcing, costs, and effects such as inflation and lower participation (*see e.g. Clark & Kavanagh 1996*), lower real income for the (voluntarily) unemployed (cf. Groot & Peeters 1997), or rather higher wages (*see e.g. Levin-Waldman, 2018*), as well as practical issues to consider (De Wispelaere & Stirton, 2012).[14]

13 For an advanced, albeit equilibrium model on the optimal taxation of robots, see: Thuemmel 2018.

14 There are concerns about sourcing, costs, and effects such as inflation and lower participation (see e.g. Clark & Kavanagh, 1996), lower real income for the (voluntarily) unemployed (cf. Groot & Peeters, 1997), or rather higher wages (see e.g. Levin-Waldman, 2018), as well as practical issues to consider (De Wispelaere & Stirton, 2012). With that, it remains to be seen whether it truly ensures a certain standard of living and safeguards demand for goods and services. There is a wide range of effects foreseen, including changes in the hours actually worked, an increase of and shift in consumption (products and services) and investments, ability to study, etc.

Moreover, also from the perspective of workers, it is not necessarily desirable. Across REELER cases, affected stakeholders were asked about their perspective on universal basic income, explained to them as a governmental intervention that would keep them from falling into the poverty that might follow if they were to lose their jobs to robots. Among hotel cleaners in Portugal, what became clear is that 'avoidance of poverty' is not the only reason people go to work:

> *Interviewer: "Universal Basic Income is an unemployment subsidy. Imagine that a robot came to work in your place and you had to go home but you received lifelong unemployment subsidy."*
>
> *Frida: "But it doesn't compensate. It's not about the money."*
>
> (Frida, hotel cleaning staff, affected stakeholder in SPECTRUS)

The question of universal basic income also emerged among other affected stakeholder types in other cases. The German labor unions are generally not in favor of universal basic income; they seek to create meaningful work and workplaces for citizens that ensure them an income and a 'good life', and they fear that a universal basic income will cause greater social inequality. Another affected stakeholder, Marc, is more open to the idea, though he thinks it is doomed to fail in Germany because of a strong work ethic and identity tied to work:

> *But I do not think it will prevail here in Germany. In Germany, I would rather say that people can also distinguish themselves by their work, because they also identify strongly with the work they are doing. And accordingly, you want to be able to differ within certain salaries, like performance for money or money for performance.*
>
> (Marc, university researcher, affected stakeholder, COBOT)

Both affected stakeholders and robot developers across cases in REELER expressed that their work was important to them because of the satisfaction, pride or fulfillment it gives them.

I mean, I think there are a lot of craftsmen who like to deliver a result, and if they can deliver a larger result per day, I think they would feel good about that. But there is also the issue of professional pride. And if we are to talk ethics, I think there are lot of craftsmen that would be affected if they are placed in the secondary position.

(Dan, development consultant, affected stakeholder in WIPER)

STORY FROM THE FIELD:

Poverty versus colleagues

Veronica is a cleaning staff in Portugal – she works 4 days a week and earns 400 EUR per month. Her boss has never made her a contract and does not want to. He pays Veronica and the other workers by the end of the day each time they clean. Veronica works 9 to 6 with a one-hour lunch, but often has to work in the lunch hour. She cleans private vacation rentals for residents who rent the houses from Veronica's boss, who is also the owner of the vacation houses. Veronica's schedule can be very tight on time because she must do everything in the house (sweep, wash, fold towels) and there are too many clients. She explained to a REELER researcher that she cannot stop for a little while even when she is very tired. After a 4-day work cycle, Veronica rest for three days. On the first day she rests the whole day because she is physically exhausted. On the second and third days, however, she wants to do something because she grows tired of being at home. She is done resting and wants to go out and do something, she explains. Despite the tough working conditions, Veronica still wants to work even if she were to get some money from a Universal Basic Income. Though she hates her boss and gets worn out from the work, what keeps her going is her colleagues. She works with three other women and a man who drives them from one area to the next where they clean a few houses. They stick together, chat in the van, and have a lot of fun even as they work.

(Based on an interview with Veronica, cleaning staff, affected stakeholder, SPECTRUS)

To preserve the meaningful work life, considerations of collegiality, identity, and other work values must accompany any serious consideration of Universal Basic Income (*see 10.0 Meaningful Work*).

9.4.3 Dynamic efficiency & innovation policy

Dynamic efficiency & innovation policy: *An economic growth policy, proposed to facilitate creation of and efficient reallocation of labor across occupations and sectors.*

An alternative to providing a disincentive for and mitigating the effects of robotization is a policy intervention in the spirit of Schumpeter: to have unfettered competition that creates new technological opportunities and new labour-intensive jobs, and notably renders efficient structural change. To facilitate a quick and adequate rebound to high levels of employment without high peaks in technological unemployment, the 'dynamic efficiency' and 'labor generating ability' of an economic system is to be enhanced, notably by stimulating the emergence of new sectors (without harming existing sectors) and facilitating labor migration such that new opportunities are indeed reaped. However, also this policy instrument is not a panacea.

A necessary (but not sufficient) condition for structural change to occur is that entrepreneurial activity creates new jobs and there is sufficient upward labor migration (European Commission 2007; Forge, Blackman, Bogdanowicz, & Desruelle 2010). To make structural change sustainable in terms of high employment rate, wage development, and income equality, those becoming unemployed because of robotization, new labor market entrants, and also people planning on traversing the vacancy chain should have access to training and education. To this end, educational institutes need to keep pace with technological developments. That said, as became clear from affected stakeholder interviews, the current educational approaches may not be adequate (*see 7.0 on Learning in Practice*), considering that many people working in the service sector to be affected by robotization do not have an education to build upon or are hampered by practicalities such as being single parent.

Moreover, some argue that labor market flexibilization (i.e. making it easier to lay off workers and offer temporary contracts) increases the propensity to hire workers and thus help resolving unemployment and enhances mobility in the direction of new technological opportunities. This flexibilization requires revising institutional arrangements and labor market regulations such as dismissal protection, social security system, and education offered (Kattenbach et al. 2014).[15] However, empirical findings of Barbieri & Scherer and Eichhorst & Kaiser reveal that although flexibilization reduces unemployment, workers in many of the (new) jobs have

15 For the reference work on the varieties of capitalism approach, see: Hall & Soskice 2001.

temporary contracts with limited outlook on regular, steady employment. In fact, deregulation facilitated the replacement of secure, unionized labor with precarious, cheaper labor thus effectively harming career prospects and wage mobility (Barbieri & Scherer 2009; Eichhorst & Kaiser 2006). So, just deregulation and flexibilization of the labor market seems too inadequate and undermine social cohesion and sustainability.

At a first glance, adverse effects of robotization such as wage stagnation, inequality, and a high rate of unemployment are combatted by increasing dynamic efficiency (including labor market flexibilization) and stimulating innovation to promote creation of labor-intensive jobs in newly emerging sectors. However, the current educational system and labor market mechanisms need to be revised diligently such as not to exacerbate the (socio-)economic effects of robotization.

9.4.4 A refined look on policy interventions

The REELER agent-based computer model of the labor market (*see section 9.3.2 and Annex 1*)[16] is used to study the effects of the aforementioned three policy interventions on the intricate interplay of the labor market (in terms of employment rate, wages, labor mobility between occupations and sectors) and the product market (at which employer-firms and worker-consumers interact). Simulations reveal that particular policy interventions have different effects when there is labor surplus (high levels of unemployment) and when there is labor scarcity (high labor demand/ many vacancies).

In case of substantial labor mobility, labor surplus causes wage stagnation (and hence a drop in disposable income, decline in consumption, etc.), which invites entrepreneurial activity and thereby the creation of new sectors with new jobs that are -prior to rationalization- labor intensive. This restores high labor utilization rates and hence renewed wage competition. Robotization would exacerbate unemployment and prolong wage stagnation. In this case, it is commendable to have a policy mix with (i) robot taxation to disincentive robotization, a (ii) universal basic income to stimulate product and labor demand, and (iii) stimulation of innovative activities to create new sectors and education to enhance labor mobility and thus mop up the unemployed.

In contrast, in case of labor scarcity, possibly caused by limited labor mobility, wages escalate. This induces technological substitution/ robotization and slows down sector emergence. This then reduces wage competition and labor utilization. Here, robotization does free up labor, but, importantly, also resolves labor shortages, reduces vacancies, and softens (fierce) wage competition. In this case, a universal basic income exacerbates labor shortages, robot tax sustains fierce wage competition, and new sectors increase labor demand, such that these policy interventions are actually discommended.

This simulation model thus reveals that there may well be a basin-of-attraction for high employment levels, i.e. economic forces cause a return to that state. However, in case of labor surplus and high levels of unemployment, policy interventions do seem to bolster the 'self-correcting' mechanisms to return to those levels of employment through structural change and enhanced labor mobility. As stressed before, labor mobility is of paramount importance for efficient structural change and reducing technological unemployment peaks. Moreover, it may also equalize incomes and increases chances of positive qualitative change of task sets of individual workers.

As stressed, though, revisions of the educational system and labor market institutes and regulations are required, whereby special attention should be paid to particular predispositions of the work force.

9.5 Concluding remarks on Economics of Robotization

This chapter has provided a comprehensive introduction on the economics of robotization, including: the rationales for robotization, impacts of robotization including impact on workers and structural change, and some of the proposed or emerging policy interventions in response to robotization.

The chapter opened with a discussions of what drives firms to adopt and develop robots. Firms in mature manufacturing sectors primarily adopt robots to increase efficiency, rationalize production, save labor (or overcome labor shortages), and thus remain cost competitive. In other sectors, firms adopt robots to differentiate products and services offered, alleviate human workers of particular tasks, or meet social expectations. Robot developers seek to cater to the needs of actors in both types of sectors. On the one hand, there are (often entrepreneurial) robot developers that seek to create new applications of (new types of) robots (e.g. in healthcare) and thereby quite commonly also receive public research funding. On the other hand, there are (often more established) robot developers that seek to make robots that allow customers in the manufacturing sectors to rationalize production and lower production and labor cost (*see 2.0 Robot Beginnings* [17] for a more in-depth discussion).

Beginning with an historical overview of mechanization and automation, section 9.2 studied what might be different this time around in a discussion of the possible and actual consequences of robotization for workers. If robotization results in higher productivity, fewer workers will be needed and robotization may thus result in job loss or lower wages. Robotization might also result in qualitative change to the (set of) tasks executed by human workers. Humans might get tasks that are more challenging or complex (taken to mean "less dull"), are complementary to robots and require advanced skills, or require distinctly human qualities. In contrast, hu-

16 see responsiblerobotics.eu/annex-1

17 This chapter is only included in the online version of Perspectives on Robots responsiblerobotics.eu/perspectives-on-robots

Geographical regions where robots are made may be distant from where they're applied, skewing the distribution of the benefits of economic growth and the risks of unemployment.

mans might also end up with simplified, repetitive tasks in a rationalized production process. As such, robotization is also changing the way workers experience work (*see 10.0 Meaningful Work* for a more in-depth discussion). Robotization might also affect not only the sets of tasks of human workers, but also the skills required, and demand for human workers with certain skills across a range of (existing and emerging) sectors. As such, robotization has led and may again lead to structural change in employment across sectors resulting in a need for (re)education, upskilling, and labor mobility. Moreover, robotization may even exacerbate inequality in income and labor demand between countries, e.g. by driving reshoring of production, increasing demand for workers developing robots substituting workers in another country.

In response to these expected effects of robotization on workers, skills required, and tasks performed, potential structural changes to the economy in terms of employment was explored. Returning to a historical analysis, we observe that previous technological breakthroughs have had some constructive effects, bringing about new complementary tasks, new occupations,[18] and even new sectors. So, while robotization is destroying and qualitatively changing some jobs, there are also countervailing forces that create jobs – possibly more than are being destroyed. If adoption of robots is gradual, there may be adequate time for workers to reskill or relocate. So, although robotization may cause technological unemployment, it might be temporal and the economy may rebound to high levels of employment. However, it may also be that the loss of jobs due to substitution and increasing efficiency outpaces the creation and growth of employment in new sectors. In either case, policy interventions may be required for a sustained high level of employment and to curb the widening of the income gap.

The point of this chapter is to raise awareness about the potential effects of robotization. Various policy interventions have been proposed to mitigate the potentially negative effects of robotization. This chapter addresses three main types of policy intervention: 1) a robot tax as disincentive and deceleration of robotization as well as to cover the costs of reskilling, 2) a universal basic income to stimulate consumption and thereby demand for labor, and 3) stimulating innovation and dynamic efficiency to create new jobs and enhance labor mobility. Finally, the results of REELER's labor-economic computer model simulation suggest that an integrated application of these policies, differentiated to labor economic circumstances, might be the most effective mitigation plan.

18 The "Future of Jobs 2018" report of the World Economic Forum distinguishes redundant, stable, and new 'roles'. Examples of the earlier are data entry clerks, factory workers, bank tellers, car drivers, sales agents, while examples of the latter are data scientists, digital transformation specialists, user-experience specialists, innovation professionals