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# Toward a Socioeconomic Company-Level Theory of Automation at Work

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## ABSTRACT

The current understanding of automation is dominated by "routine-biased technological change" (RBTC). This theory predicts a strong automation dynamic in jobs with high routine-task share and a polarization of employment structures. While RBTC theory has many merits, this paper develops a systematic critique of the theory and a counter-proposal of a socioeconomically grounded company-level theory of the automation of work. It distinguishes between feasibility conditions of automation, technology choices, and social outcomes. With regard to feasibility conditions, the relevant factor is not routine-task intensity but the interaction between product architecture (product complexity) and process complexity. Which technology choices are made in this feasibility space is in turn influenced by companies' profit strategies and power relations between management and labor. The social outcomes of automation depend on these technology choices, but also on managerial strategies pursued in the restructuring of organizational roles and skills. These managerial strategies are shaped by national institutional systems.

# 1 Introduction

The automation of work has for some time been one of the most prominent topics in research, as well as in public and political discussion. Prominent theses predict a new digital industrial revolution which will affect wide areas of the economy and destroy many jobs (Brynjolfsson & McAfee, 2014; Frey, 2019; Schwab, 2017). However, while the topic of automation plays a central role in these discussions, a socioeconomic theory of automation is still missing.

The current discussion on automation is dominated by "routine-biased technological change" (RBTC) theory (Autor et al., 2003; Frey & Osborne, 2013). This theory was developed in the field of labor economics and focuses on the calculation of automation potentials based on the 'routine-task intensity' of jobs or occupations. The theory predicts a strong automation dynamic in manufacturing and white-collar jobs due to the high routine-task share of many activities. It also predicts the polarization of employment structures, as automation affects many middle-class and skilled workers' jobs, while high-paying creative activities and jobs with a high demand for physical dexterity are less affected (Frey & Osborne, 2013; Özkiziltan & Hassel, 2020).

While RBTC theory may appear seductively simple and plausible at first glance, this paper develops a critique of the theory and a counter-proposal of a socioeconomically grounded company-level theory of the automation of work. It argues that the RBTC theory's claims about the feasibility of automation fall prey to technological determinism. It builds on a number of critiques of this theory which have been formulated in the last years (e.g. Belloc et al., 2020; Benanav, 2020; Bonin et al., 2015; Krzywdzinski, 2021; Pfeiffer, 2016) in order to develop an alternative socioeconomic theory of automation in the workplace. It suggests that such a theory should address three questions:

1) Which factors determine the feasibility (sociomaterial conditions) of automation in the workplace?

2) Which factors determine the social choices of automation technologies in the workplace?

3) Which factors determine the social outcomes of automation processes in the workplace?

The topic of automation in the workplace cannot be addressed without combining technological, economic, and sociological perspectives. It requires an understanding of how technology works, of the economic logics of technology choice and adoption in capitalist enterprises, and of the social processes of technology choice and adoption in organizations. The present theory is, at its core, an interdisciplinary endeavor.

The paper is organized as follows. In Section 2, RBTC theory is presented in brief, alongside criticisms formulated against it. In the following sections, an alternative socioeconomic theory of automation is developed. Section 3 deals with the sociomaterial conditions of automation, Section 4 with processes of social choice of automation technologies, and Section 5 with the social outcomes of automation. The final section deals with conclusions regarding the limitations and further development of the theory.

## 2 The challenge: Routine-biased technological change

The relationship between technological change and employment is a central theme of labor economics. Automation is defined as a technology that can perform a task without human intervention (Nof, 2009). This includes mechanical devices, electronically controlled machines and robots, and software systems that process data automatically. A number of influential analyses have addressed the links between technology, employment, and income development, first under the concept of "skill-biased technological change" (e.g. Katz & Murphy, 1992) and later under the concept of "routine-biased technological change" (Autor et al., 2003; Frey & Osborne, 2013; Goos et al., 2009). This research has multiple intersections with sociological analyses and informs contemporary discussions of the consequences of automation. I argue, however, that the theoretical underpinnings of these analyses suffer from significant weaknesses. Chief among these are a misunderstanding of the sociomaterial underpinnings of automation processes (and a misapprehension of the dynamics of automation) and a technological determinism that neglects processes of "social shaping of technology" (MacKenzie & Wajcman, 1999).

The RBTC theory of automation can be summarized as follows.

\ The *feasibility of automation* (also referred to as "replacing technologies" (Frey, 2019, p. 13) depends on the routine-task intensity. Routinization can concern manual activities (e.g., in production) or cognitive activities (e.g., in processing). As routine activities can be mapped algorithmically, they can be taken over by computers and machines. The focus for determining the feasibility of automation is the individual task.

\ If routine-task intensity is high, RBTC theory assumes that the job will be automated in a foreseeable time (though this is never precisely determined). Studies in labor economics have shown that in addition to the feasibility of automation, costs matter (Acemoglu & Restrepo, 2018a). However, empirical analyses usually only use the routine-task intensity indicator and do not control for other factors. *Processes of social choice* or social shaping of technology are not present in this theory; a steadily accelerating (exponential - cf. Brynjolfsson & McAfee, 2014) technological progress is assumed.

Accordingly, in Frey's (2019) historical analysis of technological development, the history of automation is presented as a force of destiny, becoming increasingly threatening with the advent of AI. Social processes can at best slow down automation; workers can resist (Frey, 2019), and organizations may have to first develop new skills to implement new technologies (Brynjolfsson et al., 2017).

\ The *social outcomes of automation* are essentially determined by the fact that workers in routinized jobs find themselves in a race against the machine (Brynjolfsson & McAfee, 2014; Frey & Osborne, 2013). Job losses either occur or are held back by stagnating or falling wages, both outcomes leading to rising social inequalities compared with employees working in non-routine jobs (Autor & Dorn, 2013). However, these outcomes are moderated by country-specific institutional systems and power relations. Labor power and the terms of trade union rights and regulation of collective bargaining (Parolin, 2019) are important factors. As Frey (2019) argues, with reference to Farber et al. (2018), the presence of a strong labor movement in the collective bargaining system can reduce inequalities resulting from technological change. A second important factor is training systems. If technological progress can be viewed as a race between technology and education (Goldin & Katz, 2008), powerful training systems that contribute to broad skill upgrading in society will reduce the effect of replacing technologies on employment and wages (Frey, 2019, p. 213).

While RBTC theory dominates the current discourse it is facing a number of criticisms which can be summarized as follows:

\ Some studies question the methodology. The concept of routine and routinization is hardly ever clearly defined (Fernández-Macías & Hurley, 2016; Pfeiffer, 2016, 2018). Repetitive unskilled work seems to be the implicit reference for the understanding of "routine", but Pfeiffer (2018) shows that even repetitive unskilled jobs require considerable experience and creative problem-solving and improvisation. She therefore criticizes the usage of the routine concept. Barley (2020) argues that the task-based approach to calculating routine intensity and the resulting automation probabilities are strongly reductionist.

\ A number of studies question the predictions of RBTC theory based on empirical findings. The predicted losses of jobs with high routine-task intensity cannot be demonstrated in all countries and all sectors (Arntz et al., 2019; Bonin et al., 2015; Dauth et al., 2017; Krzywdzinski, 2021; Murphy & Oesch, 2018; Spitz-Oener, 2006). There is considerable variation in the relationship between automation and employment which questions the plausibility of the focus on routine intensity.

- Other studies criticize technological determinism and the neglect of the role of social processes in the design and implementation of automation technologies. Belloc et al. (2020) argue that the choice of automation technologies is determined by job design strategies in the company, which in turn depend on the presence and strength of employee representation. Strong employee representation is associated with job enrichment and job enlargement strategies which lead to jobs with a lower risk of automation.
- Some studies have questioned the thesis of rapid (and accelerating) automation. Krzywdzinski's (2021) analysis of the automotive industry shows that the level of automation is changing very slowly. Gordon (2016), Benanav (2020) and Smith (2020) point to long-term trends of low productivity growth and weak investment dynamics, contradicting the thesis that ICT technologies are triggering a surge in automation.

This paper aims at combining and building on these criticisms to develop an (interdisciplinary) socioeconomic theory of automation and an alternative to RBTC, summarized in Figure 1 below. The first element of a socioeconomic theory of automation is the analysis of the conditions of feasibility of automation. These are understood as sociomaterial conditions and include technical, social, and organizational elements. While RBTC theory focuses on routine-task intensity, the socioeconomic theory of automation is centered around process complexity and product variety. Process complexity is based on the physical and organizational conditions of automation outlined in the engineering and management literature (Schuh et al. 2014). Product variety results from companies' product strategies, and its effects also depend on product architectures (Wheelwright/Clark 1992; Fisher et al. 1995; MacDuffie et al. 1996; Boothroyd et al. 2002; Fujimoto 2000).

The second element of the theory is the social choice of technologies, organizational structures, and skill strategies. In RBTC theory there is no such choice. In the socio-economic theory of automation, however, automation decisions are made in the context of overarching profit strategies and power relations. This creates a variety of trajectories characterized by considerable path dependency.

Figure 1: RBTC and the socioeconomic theory of automation

| | **Routine-biased technological change** | **Socioeconomic theory of automation** |
|---|---|---|
| *Sociomaterial conditions* | • Task level: routine-task intensity | • Process level: complexity<br>• Product level: variety |
| *Social choice* | • Technology externally given<br>• Social factors (conflicts, skills) may slow down implementation | • Technology is the result of social choices<br>• Social choices shaped by firm-level profit strategies and power relations (embedded in industrial relations systems) |
| *Social outcomes* | • Polarization of skill structures<br>• Educational systems and labor power moderate social outcomes | • Even given the same technology, variety of outcomes determined by managerial strategies regarding skills and organizational roles (shaped by educational systems) |

Source: Author.

Finally, in a socioeconomic theory of automation, different trajectories of technology choices and organizational strategies lead to different effects of automation decisions on work, skills, and other factors. This contrasts with RBTC, in which there is a clear impact of technology on skills, income and inequality.

## 3 Sociomaterial conditions of automation: Process complexity and product variety

In order to develop an understanding of the conditions of automation, social sciences can benefit from a closer look at the management and engineering literature. Based on contributions from these fields, I develop two elements of a socio-economic theory of automation. First, I emphasize the role of process complexity, which is related to the physical and organizational characteristics of production. Second, I address the role of product variety and product architectures, whose importance is completely overlooked in RBTC theory.

## 3.1 Process complexity

RBTC theory argues that the feasibility of automation depends on the routine task intensity of a given activity. In contrast, the socioeconomic theory of automation emphasizes that the feasibility of automation is determined by the complexity of the conditions of the production processes. In engineering literature (H. Fujimoto et al., 2003; Lotter & Wiendahl, 2006; Schuh et al., 2013), complexity refers to the variety of product variants produced, the variety of parts built into the products and their processing methods, the conditions of handling parts and fixing them (including workpiece stiffness), spatial conditions (space, accessibility), and the planned production speed (cf. Hesse, 2006). Production processes are also linked to other external processes via supply chains. Complexity is created by the interaction of all these factors. Focusing on the automotive industry, Waltl and Wildemann (2014, p. 8) argue that overall vehicle production complexity is exponentially related to the number of components and processes. Production complexity leads to organizational complexity (Helbing, 2009), as there are multiple optimal solutions to the organization of production and small perturbations can lead to huge and unforeseeable dynamics.

High complexity also means high susceptibility to failure, because of the large potential for deviation from the standard and errors. High complexity, therefore, creates an enormous need for problem solving and adjustment. This explains why in many occupations classified by Frey and Osborne (2013) as highly routinized, research shows very high proportions of improvisation and problem-solving activities (Pfeiffer, 2016). These activities do not reveal themselves in an approach that focuses on the individual assembly task, but are visible when the complexity (and thus the susceptibility to failure) of the overall process is considered.

One example of highly complex production processes is assembly (Spingler & Beumelburg, 2002). Even though the individual tasks of assembly workers are quite routine and repetitive, assembly processes are very difficult to automate. Several thousand different parts are installed in the assembly of a modern automobile. Even within a single process step, there are often a variety of parts with some being hard, others flexible or soft, and each require very different gripping, which is difficult for robots or automatic devices to manage.

Problems in automating assembly processes have accompanied the development of the automotive industry for a long time. Even the ambitious assembly automation projects by Volkswagen and General Motors in the 1980s managed to increase the degree of automation only to a limited extent—the majority of assembly steps are still carried out manually (Krzywdzinski, 2021). Recently, Tesla attempted a leap in assembly automation, but had to abandon the attempt due to huge problems (Boudette, 2018). The problems of automating assembly are by no means unique to the automotive industry. Apple also invested heavily in attempts to automate the assembly of its products in collaboration with the Taiwanese contract manufacturer Foxconn, but the results were very discouraging (Ma, 2020).

The case of assembly illustrates that even if individual tasks appear highly routinized, the multitude of different tasks as well as the required speed often create a complexity that makes automation difficult. Accordingly, and contrary to the predictions of Frey and Osborne (2013), the share of assembly workers in industrial employment remains high, even in high-wage countries where incentives to automate manual labor are particularly high. Frey and Osborne (2013) calculate the probability of automating assembly work in the automotive industry at 98%! By contrast, Table 1 shows that the number of assembly workers in the German and U.S. automotive industries has not decreased over the last twenty years, there has also not been any decrease in relation to the number of vehicles produced, and in the German case, an increase. We will later show that this is related to developments in product architectures and product diversity.

Table 1: Assembly workers in the U.S. and German automotive industry

| | **1999** | **2007** | **2012/2013*** | **2018** |
|---|---|---|---|---|
| *USA, Assembly workers* | | | | |
| \ Number of workers | n/a | 319,800 | 248,600 | 377,000 |
| \ In % of automotive employment | n/a | 30.9 | 32.6 | 37.9 |
| \ Per 1000 cars produced | n/a | 30 | 24 | 33 |
| *Germany, Assembly workers* | | | | |
| \ Number of workers | 113,100 | 135,500 | 163,800 | 169,800 |
| \ In % of automotive employment | 18.0 | 19.4 | 20.0 | 18.6 |
| \ Per 1000 cars produced | 20 | 22 | 29 | 33 |

Source: Krzywdzinski 2021. * US 2012, Germany 2013.

## 3.2 Product variety

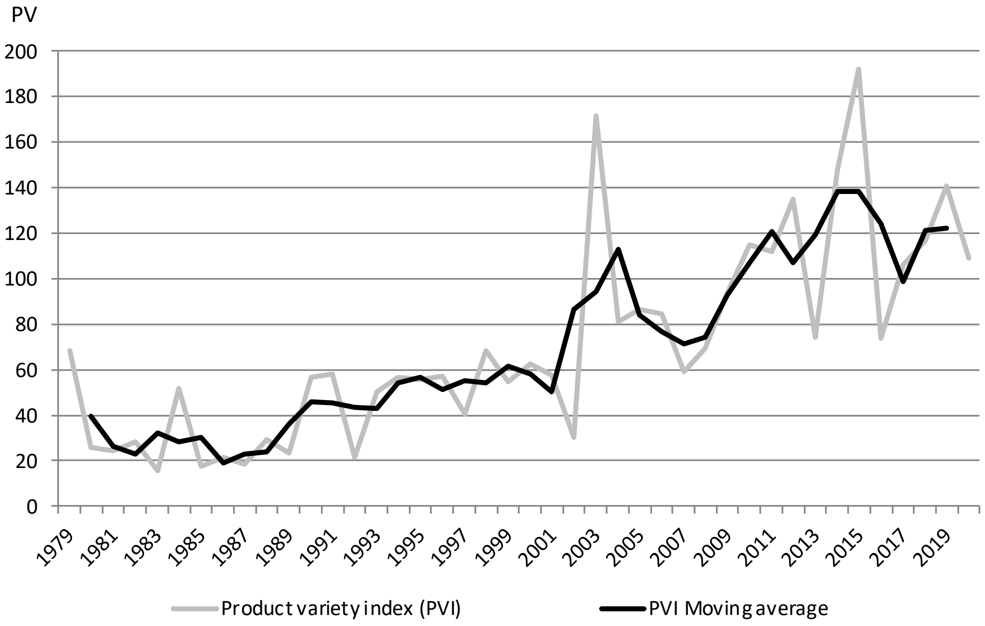
The design of the *product*, e.g. with regard to the variety of parts and their assembly, plays an important role in the feasibility of *process* automation. The relationship between product and process innovations (in this case, automation) has been a research topic for some time (Boothroyd, 1994; Ulrich, 1995; Utterback & Abernathy, 1975; Wheelwright & Clark, 1992). In older models, this relationship was thought of sequentially. In the 1980s, the concept of design for manufacture came to prominence (Boothroyd, 1994) and the concepts of simultaneous or also concurrent engineering emerged (Prasad, 1996; Sobek et al., 1999), in which the product and production processes are developed in parallel. This development was inspired by the success of Japanese companies and Japanese production models (Clark & Fujimoto, 1989; Jürgens, 2000). It had become clear that the efficiency of Japanese companies was also based on very early consideration of production requirements in the development process (T. Fujimoto, 2000; Jürgens, 2000).

An important lesson from these discussions is that a socioeconomic theory of automation must consider how strongly the product influences the conditions for process design, and thus also the conditions for automation (Bailey & Leonardi, 2015). A major factor here is the trend towards greater product variety (Fisher et al., 1995; Waltl & Wildemann, 2014). Increasingly differentiated demand in highly individualized societies and the increasing competitive pressure in a globalized economy lead to product differentiation being a central element of corporate strategies. While, customer preferences differ between markets, the pressure for product differentiation is strongest in mature markets like Europe (Stäblein et al., 2011).

The shift toward greater product variety has been repeatedly documented. At the beginning of the 20th century, Ford had success with a product strategy tailored to just a few products (and especially the Model T) and high productivity (Fisher et al., 1995). However, once certain principles of manufacturing organization were adopted by other companies, the productivity gap narrowed and Ford began to fall behind. General Motors' product differentiation strategy now proved more successful (Fisher et al., 1995, p. 116). In the German automotive industry, we observe the trend of increasing product differentiation until today, as Figure 2 shows for the period since the 1980s.

The grey and black lines represent the product variety index (PVI) for the German automotive industry. The PVI value for each year equals the number of all new product launches (multiplied by the number of body and engine variants available for these models) for Volkswagen, Audi, Opel, BMW, and Daimler (the major German car manufacturers). Model facelifts were included and counted as 30% of a full model launch's value. As the PVI is quite volatile, the figure also includes a moving average (the black line). The figure shows a continuing increase in annual product launches, from between 20 and 60 in the 1980s to between 80 and 190 in the 2010s.

Figure 2: Product variety in the German automotive industry, 1979-2020



Source: Author, based on manufacturers' data and internet sources.

Increasing product differentiation generates headwinds for automation because it means a higher variety of manufacturing processes and parts and therefore strongly increases the complexity of production.

A particularly important strategy to cope with increasing variety and complexity is the modularization of the product (Fixson, 2005; MacDuffie, 2013; Ulrich, 1995; Waltl & Wildemann, 2014). Modularization enables the subdivision of processes and the automation of sub-processes. It also increases the potential for economies of scale, and thus the possibility of amortizing the high investment costs for automation, as some modules can be used for different product variants and be produced with the same equipment.

The impact of product modularization on automation can be seen in the change in product architectures from the combustion engine to the electric motor. In the Volkswagen Group's Zwickau plant, which became the model plant for the production of electric vehicles, the degree of assembly automation has increased from 12% to 30% (Krzywdzinski, 2021). The increasing automation is related to a change in product architecture: the powertrain in electric vehicles is significantly simpler than in cars with combustion engines, and this significantly reduces the complexity of assembly in the engine compartment and in the powertrain. Tesla have also attempted to increase automation in production. Major advancements in the automation of the production of the cars' underbody were made when the company replaced "70 components glued and riveted into the car's rear underbody with a single module made using an aluminum casting machine" (Automotive News Europe, 2020).

At the same time, however, research shows that modularization of product architecture is not easy - especially in the case of products such as the automobile, whose performance depends on the interaction of its components (T. Fujimoto, 2007). In industries such as the automotive industry, the first "race" is not between humans and machines, but between the development of product diversity and product architectures. In times when product diversity increases faster than simplification or modularization of the product architecture advance, opportunities for automation are reduced. If, however, major changes in the product architecture are achieved, this can lead to advancements in the automation of production processes which are not related to improvements in process technologies (Ulrich, 1995).

### 3.3 Summary

With regard to the feasibility of automation, the socioeconomic theory of automation formulates different expectations to RBTC theory. The latter focuses on individual tasks and their routine intensity. The socioeconomic theory of automation focuses on the entire work process and its complexity. In addition to process complexity, socioeconomic theory focuses on the product strategies of companies. Companies' competitive strategies lead to increasing product variety, generating headwinds for automation strategies. The feasibility conditions of automation depend strongly on the question how far companies succeed to develop simpler and modularized product architectures which can compensate for increasing product diversity.

Research on automation therefore must focus on the relationship between the development of product architectures and process technologies. It has to reconsider the assumption of continuously advancing automation and take into account the considerable number of studies on dramatically failed automation strategies (Boudette, 2018; Heßler, 2014; Ingrassia & White, 1994; Ma, 2020).

## 4 Social choice of automation technology

The feasibility conditions of automation do not determine whether companies actually automate processes. Central to a socio-economy theory of automation, therefore, are the processes of the social shaping or social choice of technology. This perspective is missing in RBTC theory (Frey, 2019).

Social choice, or the social shaping of technology, is a major topic of Science and Technology Studies (STS) (Howcroft & Taylor, 2022; MacKenzie & Wajcman, 1999). As Pinch and Bijker (1984) argue, the genesis of technology is a process of negotiation and conflict between "relevant social groups". The form of use of a technology is thus not predetermined but rather shaped by "technological frames" (Bijker, 1987) which include the shared understanding of problems, goals, problem-solving strategies, organizational restrictions, design methods, and ways of using the technology (cf. Orlikowski & Gash, 1994). The STS perspective formulates an apt critique of technological determinism and has inspired a large number of empirical studies. At the same time, its theoretical framework remains quite abstract and does not provide specific points of departure for a theory of automation in the workplace. To analyse the processes of social shaping of automation technologies at work, I suggest to focus on two important factors: (a) manufacturing and profit strategies, and (b) power relations in companies.

## 4.1 Manufacturing and profit strategies

In business studies literature, the choice of technologies (e.g., automation technologies) is conceived as an element of 'manufacturing strategies' (Skinner, 1969; Wheelwright & Hayes, 1985). Automation is not a quasi-natural process driven by the evolution of technology. Rather, companies evaluate the extent to which technically feasible automation can help realize corporate goals and the overall manufacturing strategy (Bailey & Leonardi, 2015; Winroth et al., 2007).

Manufacturing strategies are themselves embedded (together with product strategies) in profit strategies (Boyer & Freyssenet, 2002; Winroth et al., 2007). Decisions on which products to manufacture and how to manufacture them form the core of profit strategies. Profit strategies address a number of important issues: targeted cost level, production quantity and delivery speed, quality level, and flexibility of production. These elements raise a number of questions: can these targets be better achieved with automated solutions or with manual work? Can automated solutions be implemented in the available space? Are the supply chains reliable enough for the requirements of automation?

Embedding choices regarding automation in profit strategies also means that the focus of automation can change. For example, Pfeiffer (2022) argues that in recent decades the focus of automation strategies has shifted from production to logistics and distribution ( "distributive forces"). Krzywdzinski et al. (2022) examined the extent to which there was a surge in automation during the Covid-19 pandemic and found it primarily in the distribution and back-office activities of firms, given the increased customer acceptance of automated online services during the pandemic. For the purposes of this article, however, we focus on manufacturing processes.

Research by the GERPISA network (Boyer et al., 1999; Boyer & Freyssenet, 2002) identified different profit strategies among car manufacturers. The Ford strategy was based on mass production of a highly standardized product. This was later superseded by the Sloan strategy, which adhered to standardized mass production but introduced a diversity of models “on the surface”. The Sloan strategy became dominant in the USA after World War II and also influenced European manufacturers such as Volkswagen. However, it differed from the strategies of Japanese companies. Toyota, for instance, emphasized flexibility of production and permanent reduction of costs. Finally, German manufacturers Daimler and BMW focused on high product quality and innovation.

Fujimoto (1997) and Freyssenet (1999) argue that companies’ profit strategies and associated manufacturing strategies shape automation decisions. Some profit strategies tend to lead to high-tech automation approaches, in which attempts are made to maximally exploit all existing technical scope for the automation of work processes, since automation is seen as the guarantee of high productivity and, in particular, quality. These strategies include Volkswagen’s high volume and product diversity strategy (Heßler, 2014; Krzywdzinski, 2021), in which the orientation toward mass production leads to high-tech automation. However, an upmarket and premium strategy can also promote such an approach, as it requires particularly high standards for the quality of production processes, which can often only be realized with automation.

Other profit and manufacturing strategies tend to lead to “low-cost automation” (T. Fujimoto, 1997) with a focus on the cautious use of proven and robust systems, long-term use of equipment, and abandonment of automation of auxiliary work activities. Toyota’s focus on continuous improvement and cost reduction, for instance, has led to a preference for robust and easily controllable technologies. In addition, a core principle of the company’s lean production system is the just-in-time principle. This principle leads to a reluctance and caution towards automation measures; with fluctuating market demand and the need to utilize plants to capacity, automation can lead to waste in the form of overproduction and an increase of parts stocks in the plant.

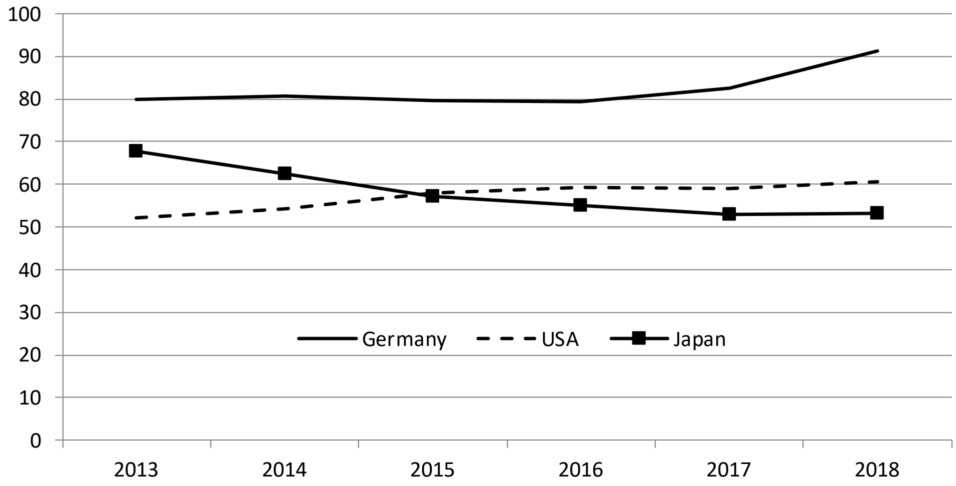
Both high-tech and low-tech automation imply the use of robots (and other machines), even if the former will be associated with a higher number of more flexible robots. However, they have different effects on employment and skills, as shown in table 2 (see also Acemoglu & Restrepo, 2018b).

Table 2: Examples of high-tech and low-tech automation in the automotive industry in the 2010s

| | **High-tech automation** | **Low-tech automation** |
|---|---|---|
| Body shop | Nearly no manual work; very high demands regarding precision and production speed; robots working with different materials (steel, aluminum, plastic); high flexibility of equipment; advanced networking of equipment and monitoring systems | Nearly no manual work (or only small islands of manual work); lower requirements regarding precision and production speed make the use of simpler and specialized robots possible (also reducing the complexity of monitoring the system) |
| Assembly | Several assembly steps automated, but manual work remains dominant; introduction of collaborative robots on selected stations | Automation limited to a few production steps (e.g. window assembly), no collaborative robots |
| Logistics | Increasing use of Automated Guided Vehicles (AGVs) for supplying lines in body shop and assembly | No AGVs, traditional man-driven carriers supply the lines |
| Impact on employment and skills | Higher skill requirements due to more complex equipment; slow decrease of share of manual work | Lower skill requirements due to simpler equipment; share of manual work constant |

If we focus on the automotive sector, we can see dominant patterns of automation strategies at the country level. National robot density statistics (Figure 3) show differences between automation strategies of German, Japanese and U.S. automotive firms. Robot density is defined here as the number of installed robots related to the number of hours worked in the automotive industry. This approach has an advantage over the frequently chosen method of calculating robot density as the number of robots per number of employees, in that the differences in annual working hours between countries are considered. While German workers work around 1,500 hours per year, American and Japanese workers reach around 2,000. Robot density calculated in this way is about 50% higher in the German automotive industry than in the USA and Japan. Interestingly, Japan even shows a decrease in robot density!

Figure 3: Stock of industrial robots per 1 million hours worked in the automotive industry in Germany, Japan, and the United States, 2013–2018



Source: Own calculation based on German Statistical Office, Statistical Office of Japan, Bureau of Labor Statistics (Current Employment Statistics). In the case of the United States, only annual working hours for the whole manufacturing sector were available. These data were used and multiplied with the number of employees in the automotive industry.

These differences can be explained by Fujimoto's high-tech and low-cost automation strategies. Fujimoto (1997) and Freyssenet (1999) argue that the profit strategies of German car manufacturers (diversified mass production in the case of VW, and premium market orientation in the case of Daimler, BMW, and Audi) have supported high-tech automation. Among Japanese manufacturers, Toyota promoted a low-cost automation concept based on its Toyota Production System, which later became the template for lean production (Jürgens, 2003; Shimokawa & Fujimoto, 2009). Japanese skepticism of automation carried over to lean production concepts and quickly gained ground in the U.S.

## 4.2 Power relations

Social science research has emphasized that profit strategies are also based on 'governance compromises' (Boyer & Freyssenet, 2002) and power relations between central actors in the company. Edwards et al. (2006) and Bélanger and Edwards (2007) identify different constellations of these power relations. The authors assume that management strategies can be classified by whether they prioritize control of the labor process or the development of the company's productive forces ("developmental concerns") (cf. Vidal, 2019). Employee representatives also have certain preferences with regard to (avoiding) labor control on the one hand and the development of productive forces on the other. When management prioritizes control and the labor side prioritizes resistance, fierce "shopfloor battles" result (Edwards et al., 2006, p. 131). This constellation is portrayed in the literature on labor process theory (Braverman, 1974;

Noble, 1978) which assumes that management uses technology in the labor process to facilitate rationalization and control of work. This perspective has proven controversial (even within the labor process debate), and recent studies have emphasized that the interests of capital and labor, as well as power relations in the workplace, can take different forms (Thompson & Smith, 2010; Vidal, 2019). When management prioritizes the development of productive forces and encounters an equal response from the employee side, "productivity coalitions" emerge. Depending on the specific configuration of the interests of both sides, a variety of intermediate forms are also possible.

The company-specific forms of power relations develop over the long term. They shape the identities of the actors involved, become part of a specific organizational culture, and have a high path dependency. They are strongly influenced by the company's institutional environment, and in particular by industrial relations systems that influence the extent to which productivity coalitions (rather than shop floor battles) are encouraged.

Table 3 shows the potential impact of industrial relations on automation strategies. A high-tech automation strategy requires either the existence of a productivity coalition between management and labor, or – in the case of an antagonistic relationship between management and labor – a situation in which the power relations in the company are clearly shaped in favor of management. If the labor side is relatively strong, we can expect that shop floor battles arising from antagonistic labor relations will make the use of high-tech automation more difficult.

Table 3: Constellations of management-labor relations in the automotive industry and their impact on the feasibility of automation strategies in companies

| | **Management-labor relations** | |
|---|---|---|
| **Labor power** | **Antagonistic** | **Cooperative** |
| Weak | High-tech automation possible | High-tech automation possible |
| Strong | High-tech automation difficult | High-tech automation possible |

Source: Author.

This argument is illustrated by existing studies. Jürgens et al. (1993) demonstrated clear differences in the automation strategies of German and American car manufacturers in the 1980s. Based on cooperative relationships between management and works councils in Germany, productivity coalitions formed that facilitated the introduction of new automation approaches. However, antagonistic relations between management and unions and an ossified training and grading system in the U.S. prevented the modernization of production, both in organization and technology. Management-labor conflicts broke out over "demarcation rules" between different trades. Management tried to achieve a more flexible use of personnel and a reduced dependence on skilled labor. The unions defended the demarcation rules to prevent employment cuts.

The stalemate was one of the factors which led companies to abandon the high-tech automation strategies they had pursued until the 1980s (Ingrassia & White, 1994) and prefer a more robust low-cost automation. This turnaround, however, also included a failure to develop shop floor skills and corresponding training systems, as lamented in U.S. research (Helper & Henderson, 2014; MacDuffie & Kochan, 1995).

Analyses of Korean companies show that high automation is even possible with antagonistic labor relations. Hyundai is characterized by antagonistic labor relations and fierce disputes between management and unions. In these disputes, technology has consistently been a means for management to reduce the company’s dependence on the skills of blue-collar workers (Jo & You, 2011; Krzywdzinski & Jo, 2022). This has been undertaken with an “engineering-led automation” strategy in which all monitoring and control activities on the shop floor are in the hands of engineers.

### 4.3 Summary

The socioeconomic theory of automation arrives at different conclusions to the RBTC theory regarding the social choice of automation technologies. The RBTC theory suggests that there is always an optimal automation technology available which companies will implement. In contrast, the socioeconomic theory of automation assumes a process of social choice of technologies and social shaping of technologies.

The process of social choice and social shaping of automation technologies is contingent; it depends on the specific historical conditions and on the interactions (cooperation and conflict) between the actors. The development of profit strategies and the associated manufacturing strategies define the framework conditions under which decisions are later made about the use of automation technologies. Power relations between management and labor play a major role. Antagonistic labor relations characterized by shop floor battles make the implementation of demanding automation solutions difficult. Cooperative management-labor relations, on the other hand, facilitate the formation of productivity coalitions as the basis for high-tech automation.

## 5 Social outcomes of automation

What are the social outcomes of automation? In RBTC theory, the situation is largely clear. Automation leads to a gradual disappearance of routine-intensive jobs. What remains are simple manual jobs, requiring so much dexterity that they cannot be automated, and creative and planning jobs. While the former are relatively low-skilled and poorly paid, the latter require high skills and are associated with high incomes. The result is social polarization (Autor et al., 2003; Goos et al., 2009).

However, since its inception, RBTC theory has had to contend with findings that showed substantial differences across countries (Fernández-Macías, 2012; Fernández-Macías & Hurley, 2016; Murphy & Oesch, 2018; Oesch & Piccitto, 2019), calling into question the thesis of a universal link between automation, the disappearance of routine-intensive jobs, and social polarization. Therefore, arguments have developed in the RBTC debate as to which factors moderate these relationships, such as the cost of technology, the time needed for reskilling and organizational change, and labor resistance (Acemoglu & Restrepo, 2018c; Frey, 2019; Özkiziltan & Hassel, 2020). The analysis of these different factors is certainly a strength of the current discussion on RBTC.

In a socioeconomic theory of automation, by contrast, the variety of feasibility conditions of automation (e.g. product architectures) as well as the variety of social choices regarding automation can result in a multitude of different social outcomes. This theory rejects the assumption of a deterministic relationship between technology and social outcomes - regardless of which moderators are introduced. In this respect, it is similar to studies from the STS field that argue that social outcomes of technological change are shaped by the way how actors in organizations try to understand new technologies and how they rearrange the organizational roles and their relations. This “role-based approach” represents a “theory of process rather than a theory of outcomes” (Barley, 2020, p. 63). In this understanding, interactions between organizational actors determine the outcomes. While empirical research may show commonalities in organizational outcomes of new technologies, “theoretical propositions about outcomes are largely irrelevant” (Barley, 2020, p. 63; see also Black et al., 2004).

The socioeconomic theory of automation proposed here follows the STS argument that research must focus on the sociomaterial feasibility conditions of automation and on the social choices regarding technology and its usage. Moreover, even if organizations use the same technologies, social outcomes may differ depending on how organizational actors negotiate the reconfiguration of organizational roles.

In difference to STS, however, a socioeconomic theory of automation tries to develop general propositions about the social outcomes of automation, and it focuses in particular on how organizations are shaped by social institutions. The core argument is that educational systems (and collective bargaining systems) influence the interest and readiness of management to invest in long-term skill development of workers and that this in turn shapes managerial strategies for adapting organizational role structures to automation (Table 4).

The explanation of managerial strategies regarding skills and organizational roles can be based on the Varieties of Capitalism (VoC) approach (Doellgast &

Wagner, 2022; Gallie, 2011). Hall and Soskice (2001) (and authors such as Sorge and Streeck (2018) before them), have argued that coordinated market economies (for instance the German system of initial vocational training and high level of protection against dismissal) incentivize companies to invest in the long-term skills of their blue-collar employees. This results in managerial strategies which react to technological change by reskilling and internal reorganization, rather than redundancies. Finegold and Soskice (1988) and Culpepper (1999) have described this constellation as a "high-skill equilibrium". In contrast, liberal market economies are characterized by a "low-skill equilibrium", at least in the field of blue-collar work; both the structure of labor markets and educational systems favor general skills. Under conditions of technological change, management does not invest in the further development of specific skills of their employees, but instead makes redundancies and hires new staff to run the new equipment.

A number of studies illustrates the different ways how management reorganizes skills and organizational roles in response to automation:

- In Germany, the vocational training system, employment protection, and co-determination have led to the emergence of managerial strategies which recognize the value of skilled blue-collar work. As a result, the increasing skill requirements due to the prevailing high-tech automation strategy have been distributed among different roles within companies – engineers as well as production workers (Krzywdzinski, 2021). We can expect that this has hampered the polarization of employment structures and led to the persistence of blue-collar manufacturing employment despite the high pace of automation.
- In Korea, due to antagonistic labor relations and an institutional system focused on tertiary education (Krzywdzinski & Jo, 2020), companies invest primarily in the skills of engineers on the shop floor, while investments in blue-collar workers' skills are minimized (engineering-led automation). At the same time, there is a focus on high-tech automation with corresponding high skill requirements. We can expect that this combination leads to a more polarized employment structure than in Germany. Pushes in automation can be expected to be more strongly linked to employment losses in blue-collar employment than in Germany.
- Japanese institutions and organizational cultures emphasize long-term employment and skill development (Koike, 1994). This leads to managerial strategies which also emphasize long-term skill development for blue-collar employees. The goal is to promote multi-skilling. Even if automation occurs, workers are versatile. In Japanese automotive companies, the long-term orientation on skill development is associated with an orientation toward low-tech automation, with flexibility being a major motivation of technological change. As a result, equipment maintenance and problem-solving tasks in automated lines are not reserved for engineers, but also include

production workers (Koike, 1998). We can expect that there is no clear trend towards the polarization of employment structures.

\ An orientation toward low-tech automation can also be observed in American companies. At the same time, the institutional setting in the U.S. (the absence of a strong vocational education system, low employment protection, weak institutions of worker representation) has led to managerial strategies which often neglect to invest in the skills of blue-collar workers (MacDuffie & Kochan, 1995; Waddoups, 2016). The result is the "low-skill equilibrium" (Finegold & Soskice, 1988), at least in manufacturing companies, and a strong polarization of employment structures.

Table 4: Institutional skill regimes, automation strategies and their impact on employment structures and skills

| | **Institutional skill regime (blue collars)** | |
|---|---|---|
| **Dominant automation strategy** | **Discouraging long-term investments in skills** | **Promoting long-term investments in skills** |
| High-tech automation | Korea (limited upskilling in some parts of blue-collar workforce; tendency to polarization of employment structures) | Germany (tendency towards general upskilling; no or limited polarization of employment structures) |
| Low-tech automation | United States (deskilling; tendency to polarization of employment structures) | Japan (tendency towards stability or slow change of skills; no or limited polarization of employment structures) |

Source: Author.

The importance of managerial strategies and their embedding in institutional systems is also illustrated in Krzywdzinski's study (2017) on the development of automotive supply plants in Germany and Central Eastern Europe. This study revealed remarkable differences between Germany and Central Eastern Europe. The share of skilled blue-collar workers in the workforce of highly automated plants in Germany was significantly higher than in plants with comparable levels of automation in Central Eastern Europe. Krzywdzinski (2017) explained this by reference to the different vocational education systems that shape managerial strategies. The German system creates a supply of skilled workers that companies can use to take over control and problem-solving tasks in production. Due to the lack of vocational training in Central Eastern Europe, skilled workers are scarcer. Companies focus on forms of work organization in which control and problem-solving tasks in production are more often assigned to engineers.

These examples abstract from many influencing factors as well as from the variation within countries. But they illustrate the main argument, that the social outcomes of automation depend on the constellation of specific automation strategies and organizational role structures, and are shaped by national institutional structures.

# 6 Conclusions

RBTC theory has shaped, and will certainly continue to shape, the recent discussion on automation and its social consequences. Despite its merits, it is based on a number of questionable arguments, particularly the underestimation of process and product factors that influence the feasibility of automation, and a technological determinism that ignores processes of social choice in automation. The company-level socio-economic theory outlined here offers an alternative to RBTC theory.

The socioeconomic theory of automation distinguishes between feasibility conditions, technology choices, and social outcomes. With regard to feasibility conditions, it emphasizes the interaction between product architecture (product complexity) and process complexity. These factors define the feasibility space of automation. Which technology choices are made in this feasibility space is in turn influenced by companies' profit strategies and power relations between management and labor—while still leaving degrees of freedom for internal organizational decision processes. The social outcomes of automation thus depend on technology choices. In addition, the same level of automation can have different consequences in terms of employment and skills, depending on which managerial strategies are pursued. These managerial strategies are shaped by national institutional systems.

A number of arguments of the socioeconomic theory of automation correspond to analyses from the STS field, especially with regard to the social choice of technologies (Bailey & Leonardi, 2015; Barley, 2020; Howcroft & Taylor, 2022). While sharing arguments with STS, the theory presented here also draws on other theories (e.g., labor process theory). It goes beyond a generic focus on technology and focuses on automation as a specific form of technology application. Finally, the present study differs from STS approaches by including the institutional framework of companies with respect to the social outcomes of automation.

This framework represents a first step in the development of a theory of automation. This theory is limited by its focus on examples from the automotive industry. This industry is certainly one of the pioneers of automation, but the theory must be developed to be applied to other processes and industries. This might require adaptation and amendments to the theory.

An important limit to theory development (with which the present study also struggles) is that long-term analyses of technology choice and implementation are lacking, and technological change can hardly be studied with snapshots. Current attempts to use simple quantitative indicators (such as robot installations) for long-term analyses have very narrow limits. The available case studies often deal with a relatively short period of time. What is needed instead are qualitative reconstructions which consider how changes to the product and processes interact, and how managerial strategies evolve and are shaped by institutions and labor relations.

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