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Abstract

The aim of this study is to investigate how the diffusion of the new digital technologies (Economy 4.0-technologies) effects the magnitude and composition of employment in Austria. For this purpose, an input-output framework is adopted taking into account direct as well as indirect effects of the new technologies by industry, occupation and gender. These employment effects are estimated as the difference between a base economy (as represented by the most recent Austrian input-output table) and the same economy after an assumed 10-year transformation period with the introduction of new production technologies and development of new products for final demand. Based on substitution potentials estimated on detailed occupational level available from previous research, we model the changes in labour productivity. Combining two different scenarios of labour productivity change with two different assumptions about collective wage bargaining outcomes gives us four possible scenarios of macroeconomic paths of Economy 4.0. The results show that due to Economy 4.0 during the next 10 years job displacement will probably be greater than job creation and aggregate employment will decline by 0.80% to 4.81% relative to total present employment. Furthermore, the results indicate that occupations gaining in employment are highly skilled while the occupations losing in employment are medium-skilled. Hereby, the female workers are adversely affected in terms of employment and labour income.

JEL-Classification: C67, D57, J16, J23, O33

Keywords: digitalisation, labour demand, projection, scenario analysis, input output analysis

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1 Introduction

For several years now, the diffusion of modern digital production technologies has been advancing steadily in large parts of the European economy. The results of company surveys on the use of technical and organizational innovations in production (such as the "European Manufacturing Survey" in Zahradnik, 2019 or the "ICT usage in enterprises" survey in Statistics Austria, 2020a) show that the use of digital production and process technologies has increased in the last 10 years significantly. This growth will accelerate further in the future (Zahradnik, 2019). From this it can be deduced that we are currently in a phase of a fundamental technological transformation, which is often referred to as the fourth industrial revolution. These changes are very far-reaching and meanwhile affect not only the manufacturing sectors but also agriculture and forestry as well as many service sectors. Furthermore, it influences almost all occupations in different ways. It thus unfolds its effects on the entire economy, which is why the term Economy 4.0[1] is also in use.

The aim of the present paper is to examine what are the likely or possible effects of the implementation of digitalisation on Austria's economy in the next 10 years. Since the introduction of advanced digital technologies is still largely ahead of us, Economy 4.0 is not yet reflected in current data and studying its impacts based on ex-post analyses proves difficult. To draw conclusions about possible future changes, an ex-ante perspective is required that not only considers developments in the past but also connects these trends with digital transformation.

Digital production technologies (Economy 4.0-technologies) do not exist in isolation but are embedded into the national and international economic and social environment. Correspondingly, broad approaches are required for analysing and quantifying its economic effects. As to the widespread impacts, we take into account the economy as a whole. Using findings of previous literature (e.g., Mönnig et al., 2019; Wolter et al., 2019 and Haiss et al., 2021) as a starting point, projections based on scenarios are developed and a detailed model is employed to investigate the possible productivity growth and the effects on production, value added and employment that may arise through the use of digital production technologies for the Austrian economy. Input-output analysis provides a straightforward approach to both define and analyse scenarios and has been employed for that purpose (e.g., Howell, 1985; Faber et al., 2007). To be more specific, we adopt a partially closed static Leontief input output model which allows performing ex-ante analysis and accounts for circular flows and feedback loops in the economy. Within this model the differential impacts of introducing new products and new processes, such as Economy 4.0-related ones, can be properly mapped (see, for instance, Kalmbach and Kurz, 1990; Leontief and Duchin, 1986; Vogler-Ludwig, 2017). Furthermore, it captures not only direct effects but also indirect effects emerging due to interrelations of sectors, out-sourcing of tasks to other firms, business stealing effects or crowding out of rivals and spill-overs via delivery of new, more productive tools and machines to users. Moreover, it allows considering or distinguishing different impact channels (or compensation mechanisms)

[1] Economy 4.0, digital economy and digitalisation are used interchangeable. In our study, the term includes the introduction inter alia of big data, autonomous systems, cloud computing, social media, mobile and self-learning systems, cyber-physical systems (CPS) / embedded systems, internet of things, horizontal and vertical integration, robust and fast internet.

and endogenizing private consumption, fixed capital formation and imports. At the same time, the model is sufficiently disaggregated that it enables us to estimate employment and income effects by occupations, industries and genders.

In our digitalisation scenario the new digital technologies are introduced in all areas of the economy. In a five-part scenario analysis, the effects of increased investments in equipment (1) and due to the building-up a fast internet (2) on the whole economy and the labour market are presented. Based on this, the changed intermediate input consumption (3) and a reduced requirement for labour and capital goods (4) are modelled. In addition, in a further sub-scenario, the labour market effects of a possibly increasing final demand for goods (5) are considered. The cumulative effects of the five sub-scenarios are compared with a reference scenario where technologies and structures remain as in 2015 ("frozen technology"). Projections start in 2021 and end in 2030.

To the best of our knowledge, there are only a few scientific papers based on a comprehensive model with empirical results about the effects of digitalisation on value added and employment. We know only a few about Germany but none about other developed economies. Our study is therefore novel in three ways. First, it is one of the first carrying out consistent and comprehensible estimates based on clearly formulated scenario assumptions and with a macroeconomic model that includes almost all relevant impact channels. Second, exceptionally differentiated and detailed statements are made about individual occupations and individual qualifications in individual economic areas. Third, this is the very first work carried out with such a model, which examines the extent to which female and male employees are differently affected by digitalisation.

The results show that Economy 4.0 will accelerate the structural change towards a larger service sector. If all assumptions are included in the analysis and working environments with and without the introduction of these technologies are compared, it becomes apparent that the two worlds differ significantly in terms of their economic, occupational and quantificational structures. Digitalisation shifts employment from the primary and secondary sectors to the tertiary sector. With regard to occupations, managers and professionals win at the expense of clerical support workers, service and sales workers as well as craft and related trades workers. For the quantificational structure, this means a shift of employment from low and medium-skilled to high-skilled workers. The changes on the labour market are accompanied by increasing value added, which, due to the changed structure of industry structure and higher skill requirements, leads to higher incomes of employed. The changes in aggregated earned income are similar to that in employment, assuming that changes in hourly wages mirror changes in labour productivity (productivity-oriented wage policy). Digitalisation shifts income from employed workers in the primary and secondary sectors to those in the tertiary sector and from the low and medium-skilled to the high-skilled. As a result of the changed occupational structure due to digitalisation, female workers lose employment as well as income relative to male.

The remainder of the paper is structured as follows. After an overview of the existing literature on consequences of technology change on employment in Section 2, we describe the applied methodology including the scenarios, the multi-sectoral macro-economic input-output-model as well as the data used in Section 3. This is followed by a presentation and discussion of the results in Section 4 before the paper closes with a short summary and conclusions.

2 Literature Review

The question of whether labour-saving technological change leads to a decrease in employment or the initial displacement of jobs can be counterbalanced by compensating mechanisms has a long history in economic thought and is still a controversial issue. The various compensation mechanisms and critiques on them are provided in Vivarelli (1995), Spiezia and Vivarelli (2002), Vivarelli (2007), Vivarelli (2013), Vivarelli (2014), Piva and Vivarelli (2017), Calvino and Virgillito (2018). Beside these studies the following review also incorporates the compensation mechanisms discussed in Acemoglu and Restrepo (2019). The Vivarelli studies and Acemoglu and Restrepo (2019) use a different terminology for similar compensation mechanisms. In the following we use the terminology of Viveralli for describing the compensation mechanisms and highlight the link to Acemoglu and Restrepo (2019).

2.1 Economic Theory

At the time of the classical economists, an age characterized by the first industrial revolution and radical technological change, two views started to compete in assessing the employment impact of technology. David Ricardo was the most prominent classical economist who questioned the long run benefit of technological innovation, stressing the labour-saving effects of new technologies: "That the opinion entertained by the labouring class, that the employment of machinery is frequently detrimental to their interests, is not founded on prejudice and error, but is conformable to the correct principles of political economy" (Ricardo, 1817). On the other hand, the academic and political debate was mainly dominated by an ex-ante confidence in the market compensation of dismissed workers based on principles of laissez-faire.

Ironically, in the meantime the English workers were destroying machines under the charismatic lead of Ned Ludd, the economic discipline was trying to dispel all concerns about the possible harmful effects of technological progress, on a basis of a rigorous, counter-intuitive and "scientific" theory. In the first half of the 19th century, classical economists put forward a theory that Marx later called the "compensation theory" (see Marx, 1961, vol. 1, chap. 13 and 1969, chap. 18). This theory is made up of different market compensation mechanisms which are triggered by technological change itself and which can counterbalance the initial labour-saving impact of process innovation. The compensation mechanisms work vià

New machines: As the result of technical progress, new machines are introduced, possibly displacing labour. A "sectoral shift" of workers from the machine-using industry toward the machine-producing one counterbalances the initial detrimental effect on employment. Similarly, Acemoglu and Restrepo (2019) acknowledge that capital accumulation triggered by increased automation (which raises the demand for capital) will also raise the demand for labour. They label this effect 'capital accumulation'.

New investments. The accumulated extra-profits in the temporal gap between the decrease in the unit costs and the subsequent decrease in prices can be invested by entrepreneurs in physical capital, expanding the productive capacity and hence the labour demand.

Decrease in prices: The increase in productivity due to the introduction of new technologies induces a reduction in production costs. This effect in competitive markets induces a subsequent reduction in prices. Lower prices should translate into higher demand, and therefore higher employment. Acemoglu and Restrepo (2019) distinguish between an increase in labour and capital productivity, and term these effects ‘productivity effect’ and ‘deepening of automation’, respectively. While the increase in labour productivity is related to extensive automation, i.e., the substitution of machines for human labour, capital productivity increases are associated with automation at the intensive margin, i.e., the substitution of new and more productive machines for less productive machines.

Decrease in wages. This mechanism acts in the market of production factors and exerts effects symmetric to the process of price reduction. Workforce displacement leads to an excess of labour supply, hence to a reduction in wages. An increase in labour demand reequilibrates the market tension which resulted from the first wave of excess labour supply.

Increase in incomes. This compensation mechanism has been put forward by the Keynesian and Kaldorian tradition. Whenever workers can appropriate gains from the increase in productivity, technical progress can lead to an increase in wages and consumption. This leads to higher demand, sparking an increase in employment via the well-known Keynesian mechanism, compensating for the initial labour displacement.

New products. The introduction of new branches and products can stimulate consumption. Higher consumption translates into higher demand and therefore higher employment.

New tasks. Acemoglu and Restrepo (2019) highlight that the creation of new labour-intensive tasks (tasks in which labour has a comparative advantage relative to capital) may be the most powerful force balancing the growth process in the face of rapid automation.

Overall, classical and current economic theorizing are characterized by an “optimistic bias”, that strongly relies on market clearing. However, compensation mechanisms can be hindered by the existence of severe drawbacks which are often either neglected or mis-specified by the economic conventional wisdom. Using the same taxonomy which has been proposed above, the main criticisms of the compensation theory can be singled out as follows:

New machines: With few exceptions (see Hicks, 1973), the compensation mechanism “via new machinery” has not received much attention lately. Indeed, Karl Marx’s critique of it was so severe that it virtually wiped out the initial line of reasoning in compensation theory. As he argued, “the machine can only be employed profitably, if it … is the (annual) product of far fewer men than it replaces” (Marx 1969, 552).

New investments: The intrinsic nature of new investments does matter. Even under the effectiveness of Say’s law, in which all the accumulated profits are reinvested, some of the new investments might be labour-saving and compensation can only be partial. The new investment channel would work if it is limited to real investments. However, nowadays the rate of investment in the real economy appears lower than the rate of investment in purely financial activities.

Decrease in prices: The effectiveness of the mechanism “via decrease in prices” depends on the hypothesis of perfect competition. If an oligopolistic regime is dominant, the whole compensation process will be seriously weakened since cost savings do not necessarily result in decreasing prices. If prices decrease, associated demand and employment increases depend on the price elasticity of the affected commodities.

Decrease in wages: This compensation mechanism collides with the Keynesian theory of effective demand. On one hand, a decrease in wages can induce firms to hire additional workers. On the other hand, decreased aggregate demand lowers employers' expectations, and they would hire fewer workers.

Increase in incomes. The income channel revealed to be effective mostly under a Fordist mode of production, where unionized labour was able to exert significant pressure on capitalists. Currently, the more fragmented labour force appears to be intrinsically less able to lay collective claims, partly as a result of an industrial relationship which is increasingly based on certain degrees of flexibility and individual bargaining.

New products: The new products channel looks rather subtle. For instance, ICT has been one of the sectors with the highest rate of employment absorption in the last three decades, responsible for significant product innovation (such as personal computers, mobile phones, and so forth). However, ICT also represents a process innovation for many related industries which use ICT.

Summing up, economic theory cannot claim to have a clear answer in terms of the final employment impact of innovation. The effectiveness of compensation mechanisms depends on market structures, demand elasticities and the way how business expectations are shaped. Economists sometimes forget that compensation can be partial and that it depends on historical and institutional circumstances.

2.2 Empirical Literature

In the light of the discussion in the previous section, it is obvious that economic theory cannot provide a clear-cut answer about the employment effects of digitalisation. Hence, this section focuses on macroeconomic empirical analyses investigating the employment effect of new technologies. The focus is on macroeconomic studies because micro-level and sectoral studies fail to account for all direct and indirect effects of technological change (cf. Vivarelli, 2007). We restrict our attention to studies most closely related to ours, i.e., studies applying scenario techniques in combination with sectoral macro-economic models, to be more precise (macro-econometric) input-output models in the tradition of Wassily Leontief (cf. Leontief, 1987). Studies applying other approaches, e.g., econometric studies or aggregate macroeconomic models are not considered in this review.[2]

Earlier studies on the employment effects of automation in the context of the uprising micro-electronic technologies of the 1980s and 90s (robotics and computer integrated manufacturing) include Leontief and Duchin (1986) for the USA, Whitley and Wilson (1982, 1987) for the UK, Edler (1990), Kalmbach and Kurz (1990, 1992) and Meyer-Krahmer (1992) for West-Germany, Tomaszewicz et al. (1992) for the USA and Japan, Yamada (1992) for the USA, Japan and West-Germany, and WIFO-ÖAW (1981) for Austria. The employment ef-

[2] For a review of the literature dealing with these class of models see, e.g., Vivarelli (2014) and Piva and Vivarelli (2017).

fects of biotechnology are studied in Wydra (2010, 2011) and of technological development in scenarios based on the International Panel on Climate Change (IPCC) scenario framework is investigated in Faber et al. (2007) and Wilting et al. (2008).

Most closely related to our study, the employment effects of digitalisation are explored in Wolter et al. (2015, 2016, 2019) and Vogler-Ludwig (2017) for Germany. While Wolter et al. (2015) focuses exclusively on the digitalisation of the manufacturing sectors, the analysis is expanded to the entire economy including service sectors in Wolter et al. (2016, 2019). The most recent version of these series of studies finds that Economy 4.0 will accelerate the structural change towards more services. Employment movements between sectors, occupations and qualifications are significantly greater than the change of the number of employees overall. After the realization of Economy 4.0 in Germany, 3.23 million new jobs are created, and 3.80 million are destroyed until the end of the introduction of Economy 4.0 technologies. About 15% of the 44.3 million jobs in Germany will be affected by the changes. The balancing of the newly created and the lost jobs shows a low net loss of 0.57 million jobs (-1.3%). The GDP is €112,9 billion (+3.3%) higher than without digitalisation, labour compensation is €28.1 billion and profits are €42.3 billion higher than without Economy 4.0. Digitalisation causes the trade balance surplus to be around €5 billion higher at the end of the introduction of Economy 4.0 technologies. Contrary to the decrease of overall employment found in Wolter et al. (2019), Vogler-Ludwig (2017) estimates an increase of the employment by 0.25 million persons. According to Vogler-Ludwig (2017) the GDP is 4% higher than without Economy 4.0 at the end of the introduction of the new digital technologies.

However, none of these studies investigate if female and male workers are differently affected by digitalisation. Kutzner and Schnier (2017) detect that the gender perspective in the debate on digitalisation of labour is almost missing. Since women tend to work in different occupations than men (cf. Dengler and Matthes, 2016; Bock-Schappelwein, 2016; Piasna and Drahokoupil, (2017)), associated with different tasks and skills, their risk of being subject to automation might be considerable different. As far as the authors know, there are six studies comparing the automation risk of women and men, i.e., Dengler and Matthes (2016) for Germany, Piasna and Drahokoupil (2017) for the 28 EU member states, OECD (2017) for 29 OECD countries, Krieger-Boden and Sorgner (2018) for selected OECD countries, Brussevich et al. (2018) for 28 OECD member countries, Cyprus and Singapur, and Haiss et al. (2021) for Austria.

Dengler and Matthes (2016) and Krieger-Boden and Sorgner (2018) find that male-dominated occupations have on average a higher risk of automation than women. This is because in low-skilled occupations, which are at high risk in general, women are usually much less at risk than men. Though, women are only a minority in the sector with the best prospect of income and promotion opportunities. The OECD (2017) concludes that summing across all industries, the average risk of automation is similar for men and women. Though, some large industries with high shares of women are at a high average risk of automation including the food and beverage service activities, and retail trade. Piasna and Drahokoupil (2017) are less optimistic about the future employment prospects of women. Their analysis reveals that women are more at risk of automation as they tend to perform routine tasks more often than men, even within the same occupational category. This view is supported by the evidence provided in

Haiss et al. (2021). Also, Brussevich et al. (2018) find that women perform more routine tasks and participate less in sectors that are intensive in science, technology, engineering, and mathematics (which are deemed to be automation-proof in the near future).

Beside studies comparing the automation risk of women and men, Acemoglu and Restrepo (2020) investigate the effects of industrial robots on US local labour markets and find that the adverse effects of robotization on employment are greater for men than for women.

3 Data and Methodology

This section describes the assumptions of our digitalisation scenario and explains the methods for estimating the effects of Economy 4.0. Among other variables, such as value added and net exports, we mainly address the development of employment by sector, occupation and gender. Our ex-ante analysis relies on a quantitative and fully integrated, macro-economic input-output model that explicitly considers circular flows and feedbacks in the economy.

The data used in this study mainly stem from the official Austrian input-output table for the year 2015 (Statistics Austria, 2019). The structure of our data is intertwined with our set of assumptions and the structure of the model, so it will be discussed in the following two sections which are dedicated to the scenarios and the model description, and in a more detailed model description in the Appendix.

3.1 The Economy 4.0 Scenario

The scenario analysis is a method for handling the uncertainty of future development. Typically, a reference scenario, which serves as a baseline, is compared to an alternative scenario, going beyond the baseline scenario by also capturing the relevant changes in the Economy to be studied. The difference in the results shows the impacts induced by the changes to be investigated.

We use the scenario technique to study the effects of Economy 4.0 induced innovations on employment, value added and production and assume that the transformation starts in 2020 and is completed by 2030. The reference-scenario is taken to be the one in which no further change in the methods of production takes place, i.e., the Austrian economy in 2015, as described by the input-output tables 2015 (cf. Statistics Austria, 2019), frozen in until 2030. Note, that we are not interested in forecasting the time profile of e.g., employment (absolute values) until 2030. Rather, we are interested in simulating exclusively those employment effects that accompany the diffusion of the Economy 4.0 innovations. To put in the words of Hicks ‘We compare two alternative paths that extend into the future. Along one of those paths some new cause is not operating; along the other it is. The difference between the paths is the effect of that cause.’ (Hicks, 1983).

The Economy 4.0 scenario is based on a wide range of assumptions on future investments, cost developments, demand increases and labour market developments. Due to a lack of research and uncertainty about the future not all assumptions can be verified by empirical evidence. Table 1 summarizes the assumptions on the Economy 4.0 scenario. Excellent scenario-technique based studies on the transformation to Economy 4.0 exist for Germany (see e.g., Wolter et al. 2015, 2016, 2019; Mönnig et al., 2019). In general, the assumptions are inspired by Wolter et al. (2015, 2016, 2019) and are adopted to the Austrian case. In few cases it is not possible to gather Austrian specific data for the development of the Economy 4.0 scenario and the assumptions are directly borrowed from Wolter et al. (2019). What follows below is a detailed description of the assumptions on the Economy 4.0 scenario. We assume that the transformation towards an Economy 4.0 starts in 2020 and will be completed by 2030.

Table 1: Assumptions on the Economy 4.0 Scenario

1 Equipment Investments	Costs
Ass. 1: Investments in new equipment and intangible assets	
Ass. 2: Refitting of capital stock, sensor technology	
Ass. 3: Refitting of capital stock, IT-services	
2 Building Investments	
Ass. 4: Investment in fast internet	
3 Intermediate Input Cost Structure	
Ass. 5: Costs for further education	
Ass. 6: Costs for consulting services	
Ass. 7: Costs for IT-services	
Ass. 8: Reduction of material input	Benefits
Ass. 9: Reduction of logistic costs	
4 Primary Input Cost Structure (labour costs and capital costs)	
Ass. 10: Labour cost structure by occupations and sectors	
Ass. 11: Capital cost structure	
5 Demand Increase	
Ass. 12: Higher state consumption expenses for IT security	
Ass. 13: Additional demand of private households	
Ass. 14: Increase in export demand	

3.1.1 Equipment Investments

Assumption 1: Investments in new equipment and intangible assets

We assume that firms need to make additional investments in new equipment and intangible assets to reap the benefits of digitalisation. Thereby, yearly investments in equipment as well as in intangible assets increase by 5% for the period 2020-2029. This amounts to €175 million per year consisting of €93 million of investments in equipment and €82 million of investments in intangible assets. The €93 million are invested in i) computer, electronic and optical products, ii) electrical equipment, iii) machinery and iv) repair and installation services of machinery and equipment. According to the Austrian input-output table for the year 2015, the share of those commodities in total equipment investments amounts to 14%, 7%, 37% and 13%, respectively. Accordingly, the €93 million investment in new equipment is distributed among those commodities. The €82 million investment in intangible assets is flowing to computer programming, consultancy and related services, information services.

Assumption 2: Refitting of capital stock, sensor technology

We assume that firms need to make additional investments in sensor technology for adapting their capital stock and making it compatible with an Economy 4.0. Fifty percent of the machinery installed in the years 2010 to 2014 is equipped with new sensor technology between 2016 and 2024. The refitting of the machinery installed in 2010 starts in 2016 and the investments are stretched over a period of five years. The same applies to the machinery installed in the years 2011, 2012, 2013 and 2014, for which the refitting starts in 2016, 2017, 2018 and 2019, respectively. The input-output table for the year 2007 (Statistics Austria, 2011) shows that investments in medical, precision, and optical instruments amounted to €1.38 billion. The share of precision instruments is estimated to be 25% amounting to €350 million. Since only 50% of the machinery installed in the years 2010 to 2014 is refitted with new sensors, additional investments amount to €175 million for each vintage of machinery investments. Since our scenario starts in 2020 this implies €520 million of additional investments for the years 2020-2024.

Assumption 3: Refitting of capital stock, IT-services

Further, we assume that not only investments in precision instruments but also investments in IT-services are necessary to integrate the refitted machines into the new production processes. For IT-services the same considerations as for the sensor technology, outlined in Assumption 2, apply. Since the investments in IT-services (€4.16 billion, cf. input-output table 2010; Statistics Austria, 2014) are about three times larger than the investments in medical, precision, and optical instruments the additional investments for the years 2020-2024 amount to €1.56 billion.

3.1.2 Building Investments

Assumption 4: Investments in fast internet

Investments in fast and ultra-fast internet networks are a prerequisite for Economy 4.0. The broadband strategy 2030 of the Austrian Federal Ministry of Transport Innovation and Technology (BMVIT, 2019) aims to provide 100% of enterprises and households with 1 GBit/s broadband services by 2030. The necessary investments until 2030 are estimated to be €10 billion to €12 billion, i.e., about €1 billion for each year from 2020 to 2029. Currently, about €700 million are invested in technical telecommunication infrastructure each year (RTR, 2020). To cover the investment needs, additional investments of €300 million per year are necessary until 2030, i.e., a total of €3 billion investment for the years 2020-2029. Since cable-bound technologies are used it mainly concerns investments in constructions and constructions works as well as electrical equipment. Where one quarter or €0.75 billion are investments in electrical equipment and three quarters or €2.25 billion are investments in construction works.

3.1.3 Intermediate Input Cost Structure

The assumptions so far only concerned investments in Economy 4.0 technology and infrastructure. Next, we describe assumptions regarding the cost structure of industries. Assumptions 5–7 are cost increasing, assumptions 8–9 reduce costs.

Assumption 5: Costs for further education

Further education for employees is needed to acquire knowledge for handling the new technologies. We assume that by 2030 80% of all employees will have obtained further education in the context of Economy 4.0. According to the Continuing Vocational Training Survey 2015 (CVTS5) the costs for an upgrade training course amount to €617 per person for primary sectors and production industries and €591 per person for service industries (Statistics Austria, 2018). Given the number of employees in each sector, this makes up additional costs for further education of about €215 million per year until 2030 or a total of €2.15 billion.

Assumption 6: Costs for consulting services

Firms require additional consulting services to implement the new production technologies. We assume that each sector's additional, yearly consulting services from 2020 to 2029 amount to 1.5% of consulting services in 2015. That is a total of €1.73 billion additional costs for consulting services until 2030 or €173 million for each year from 2020 to 2029.

Assumption 7: Costs for IT-services

All sectors purchase more IT-services as intermediate inputs, i.e., the input-coefficient for IT-services increase. The increase is higher for those sectors having a lower degree of digitalisation (e.g., agriculture) to catch-up with highly digitalized sectors (e.g., telecommunication) and lower for the latter ones. The sectors are grouped into six categories dependent on their degree of digitalisation and for each of this group a number is given by which the current input-coefficient is multiplied (i.e., 2.35, 1.75, 1.70, 1.47, 1.30, 1.06) to obtain the input-coefficient for the year 2030. The path from the actual to the new coefficient is linear. Since no sectoral information on the degree of digitalisation for Austria could be obtained, we assume that the grouping of sectors according to their degree of digitalisation is the same as in Germany following Wolter et al. (2019). For details on the multipliers of the input-coefficients also see Wolter et al. (2019).

Assumption 8: Reduction of material input

More precise production technologies reduce defective goods production and material input demand, i.e., all inputs purchased from primary and manufacturing sectors. The material input demand of primary sectors and manufacturing decreases by 0.72% and for services by 1.2% until 2030. The path from 2020 to 2030 to achieve this reduction follows a linear trend.

Assumption 9: Reduction of logistic costs

The costs for logistic services decrease by 0.8% until 2030 for the primary sectors, manufacturing, and service sectors. Logistic services include land transport services and transport services via pipelines as well as postal and courier service.

3.1.4 Primary Input Cost Structure

Assumption 10: Labour cost structure by occupations and sectors

In recent years, numerous studies have been published on the replaceability of human work with modern, networked and digitally controlled machines and equipment. The best-known work is Frey and Osborne (2013, 2017) for the USA, which resulted in a number of studies, such as Pajarinen et al. (2015) for Finland and Norway, Bonin et al. (2015) and Dengler and Matthes (2018) for Germany and Haiss et al. (2021) for Austria. These studies estimate the maximum technical replacement potentials of individual activities or occupations over the next 10 to 20 years. However, for various reasons such as macroeconomic aspects, especially adjustment processes, this potential will probably never be fully exploited. For a comprehensive discussion of these reasons see Haiss, et al. (2021).

Our study is based on the replacement potentials differentiated by occupations estimated by Haiss et al. (2021). These potentials are connected with the considerations on the probable exhaustion by Wolter et al. (2019, p. 16) resulting in replacement probabilities by occupations and industries. If we strictly followed this procedure, then the overall labour productivity would increase by 0.64% annually. Since this is not realistic given a long-term annual average increase of approx. 1%, we only view this as an upper limit. In addition, a second variant is assumed with half the productivity growth of 0.32% per year. Because in most sectors in Austria wages and salaries are strongly influenced by negotiations between the social partners and the negotiators in the past often orientated themselves towards the development of labour productivity in the respective economic sector, at least two variants of wage development are conceivable: no or complete compensation for the increase in labour productivity through wage policy (i.e., productivity-oriented wage policy). Following these considerations, four variants of assumptions for labour costs were developed, each combines one of the two productivity considerations with one of the two wage policies. In the two variants without compensation for labour productivity gains, the labour unit costs (i.e., labour costs by one unit of output) decrease, while in the two variants with compensation the labour unit costs remain approximately the same. For the sake of simplicity, we also assume that the labour income of the self-employed develops in the same way as that of the employed. In order to integrate this information into the database of our model, the employment vector and labour income vector of the input-output table 2015 (Statistic Austria, 2019) were extended to occupation-sector-matrices using the results of the Microcensus Labour Force Survey 2015 (Statistics Austrian, 2020b).

Assumption 11: Capital cost structure

We set new, reduced uses of physical capital per output unit (in parallel to the procedure for labour input). For this purpose, we assume that the total consumption of capital per unit of production will decrease by 1.88% over the entire projection period (i.e., 0.19% per year), whereby we distinguish between individual types of assets according to a possible impact by Economy 4.0. For this purpose, Statistics Austria provided us with capital stock data differentiated according to assets and sectors, which we used to create an asset-sector matrix. The reduced capital usage (per output unit) at unchanged depreciation rates taken from national accounts should then result in reduced depreciations per output unit (at prices of the base year). Total depreciations per output will decrease by 3.52% over the entire projection period (0.35% per year), whereby the changes differ from sector to sector depending on the composition of the capital stock by asset type. Furthermore, we assume that no old investments (assets) were withdrawn prematurely. For the sake of simplicity, we leave the profits per output unit unchanged (even if they are part of the cost of capital according to the user cost of capital theory).

3.1.5 Demand Increase

Assumption 12: Higher state consumption expenses for IT-security

According to the Austrian Ministry of Finance (BMF, 2018) 4,100 additional police officers are employed by 2022. It is argued that additional staff requirements are necessary because of bottlenecks in the area of the Federal Office of Immigration and Asylum and additional resource requirements for cyber security. We assume that 5% of the 4,100 additionally established posts, i.e., 205, are fully dedicated to the area of cyber security related to increasing cybercrime and cyber defence efforts due to Economy 4.0. The yearly costs of one policeman are estimated to be €75,000 (cf. Bundesgesetz mit dem das Bundesfinanzrahmengesetz 2019 bis 2022 erlassen wird; BGBl. I Nr. 20/2018). The police staff is increased gradually from 2018 to 2022. The increase is completed in 2022 and the additional costs are stabilized until 2030. The additional state personal consumption expenditures for IT-security from 2020 to 2029 amount to €150 million.

Assumption 13: Additional demand of private households

According to Arntz et al. (2016) and the IAB QuEst-survey (Quality in Establishment Survey)[3] firms expect an increase in turnover because of the creation of new products related to Economy 4.0 technologies. This expectation is higher in service sectors than in production industries. Product innovations may emerge from mass-individualization of product design (cf. Koren et al., 2015), the possibilities offered by 3D-printers, the demand for interconnectedness of end products with, e.g., buildings and homes (smart buildings, smart homes) or cars. We assume that innovative products incentivize an increase in private household consumption expenditures on primary sectors' and manufacturing goods by 2% and expenditures on services by 3% until 2030. The path from 2020 to 2030 to fully realize the demand increases follows a linear trend. Overall, additional demand for primary sector and manufacturing products worth €3.6 billion and additional demand for services worth €20.47 billion is generated from 2020 to 2029.

Assumption 14: Increase in export demand

The increase in exports relies on the assumption that Austria's industry is a pioneer in Economy 4.0 technology. Other economies lag 5 years behind. The demand for new products and services increases worldwide, which stimulates export demand. Following Wolter et al. (2015) we assume that increases in private household consumption expenditures in other countries increase Austrian exports by 1% until 2029. The path from 2020 to 2029 to fully realize the export increases follows a linear trend. In addition, we assume that other country's demand for machines and sensor technology for the transformation to Economy 4.0 starts to increase in 2025. This rises the demand for Austrian machines and electrical equipment. The additional yearly exports for the years 2025 to 2029 of these goods amount to 1% of gross

[3] QuBe: Qualifikationen und Berufe in der Zukunft. For details see www.qube-projekt.de

output of the respective sectors. Overall, additional exports worth €9.5 billion are generated between 2020 to 2029.

3.2 The Model

3.2.1 Introduction

Input-output modelling has long been considered as an appropriate tool to forecast the economic impact of technological changes (e.g., Howell 1985). Linking input-output with scenario analysis is a straightforward method to analyse the impact of technological change because it enables a clear separation of what is endogenous to the model and what is exogenously given by the analyst. Our model shares this advantage. To define technological change via technical coefficients is a transparent method but a simplification of the real world. We will therefore have to discuss some limitations that this conception of technological changes brings with it.

In the remainder of this section, we first give a general characterisation of the model and present its stepwise structure. More details of the model and its equations, using elaborated mathematical notation, can be found in the methodological appendix. An important aspect of the output of the model is whether it concerns variables in real or in nominal terms. We devote a second short subsection to the clarification of this issue.

The discussion of the impacts of technological changes often discerns direct effects and compensating effects where the former usually are taken as employment decreasing and the latter as employment increasing. One of the advantages of our model is that some of the compensating effects can be captured particularly well, while others cannot be moulded distinctly within the framework of input-output analysis. A third subsection will go through the various direct and compensating effects that are named in the literature and ask whether the present analysis can claim to cover them appropriately.

3.2.2 The Structure of the Model

The calculations are based on a multi-period input-output model that goes beyond the classic Leontief model in several ways. At its core is a static input-output model extended by income and investment effects. In this model, the final demand, technology, and hourly wages are specified exogenously, while all other variables are determined endogenously by the model. The technology is represented by technical input coefficients, which encompasses intermediate inputs and primary inputs, in particular fixed capital consumption and employment. Together with price assumptions for primary inputs, such as replacement prices (which, for simplicity, are assumed to be constant) and hourly wages, this determines value added coefficients. The Economy 4.0 scenario induces changes in final demand, technology and hourly wages relative to the base scenario, allowing to assess the impact of Economy 4.0 on sectoral output, value added and employment.

The model extends the classic input-output approach also by considering the impact on commodity prices and their further repercussions on consumer demand. Here, the Leontief price model is applied and merged with a simple model of consumer demand. Thus, the model goes a step towards a CGE or other multisectoral macroeconomic models. Unlike a CGE model, prices and quantities are not determined simultaneously, but in a stepwise procedure. And they are not driven by scarcity or oversupply but according to the assumptions of the Leontief price model, i.e. depending on the validity of the vertical balance equation for input-output tables in current prices. In contrast to a CGE model, not all prices are treated endogenously as our model allows the analyst to specify the development of wages exogenously, reflecting, e.g., assumptions about collective bargaining agreements and wage policy.

Furthermore, through its multi-period character the model goes a step towards a dynamic input-output model. However, it is not fully dynamic in the sense of a dynamic Leontief model, as the vectors of gross capital formation do not consistently determine the vector of capital stocks in later periods. Nevertheless, we apply some general plausibility checks on the relations of core variables across time.

The four steps of the model calculations are visualized in Figure 1.

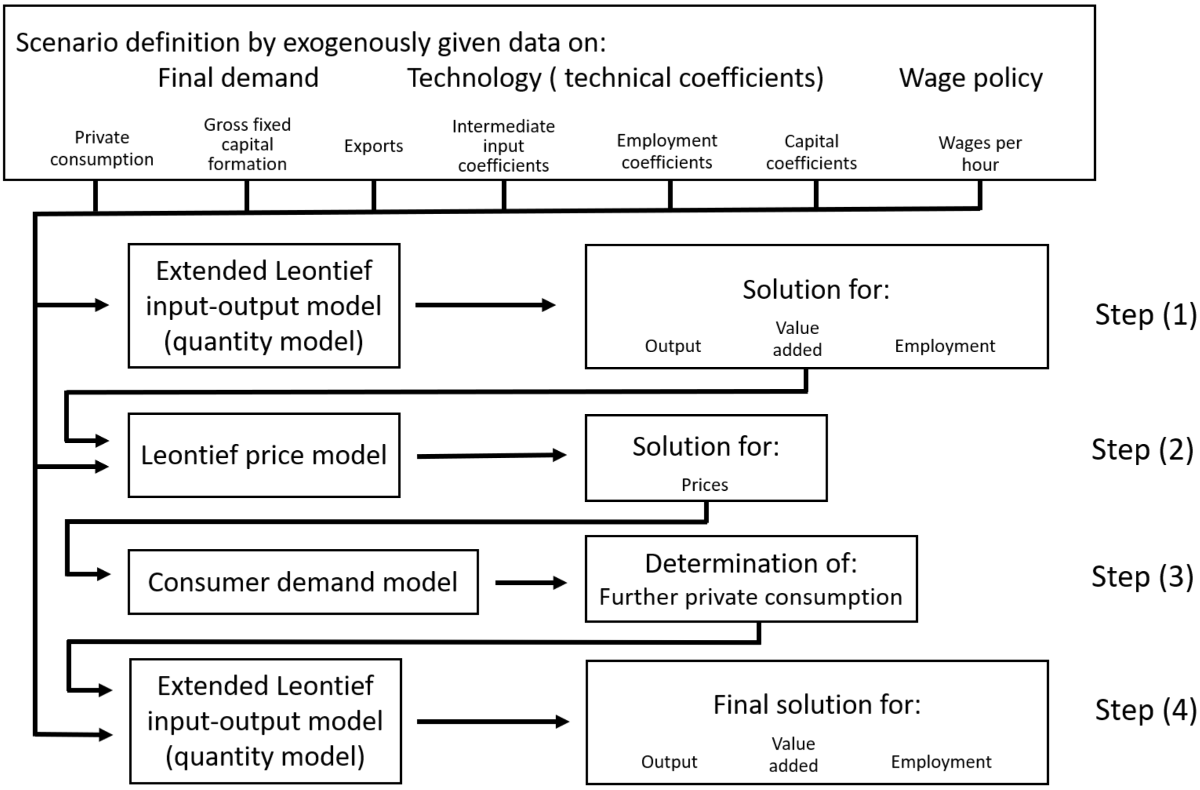

Fig. 1: Stepwise model calculation process

Step (1): An extended Leontief input-output model, with partly endogenized private consumption and gross fixed capital formation, is calculated. This model is a quantity model as it delivers as solution the quantities for output, value added and employment. The changes induced by Economy 4.0 are specified exogenously to the model and encompass changes in final demand (increase in private and public consumption, gross fixed capital formation and exports), changes in input coefficients (intermediate inputs, labour, and fixed capital consumption), and assumption on wage policy resulting in changes in hourly wages.

Step (2): Based on the solution of the quantity model in step (1) and assumptions on the nature of competition (Are cost reductions passed on to buyers?) a Leontief price model is calculated, determining new product prices, i.e., price indices with respect to the base year.

Step (3): In a simple consumer demand model, further changes in private consumption due to the price changes found in step (2) are determined (based on the application of own price elasticities).

Step (4): After adding the additional private consumption found in step (3) to the final demand vector we started with, the input-output quantity model is calculated again. The final solution contains thus the additional effects on production, value added and employment that result from the increase in private consumption as a result of lower prices in Economy 4.0.

3.2.3 Real versus nominal Effects

Based on the model solutions we have both quantities and prices for every year of the Economy 4.0 scenario. Most variables in the model have a quantity and a price component. This allows us to report the effects both in real and in nominal terms. The focus, however, is on real effects.

Since the changes in technology are specified in the form of changes of technical coefficient matrices relative to the input-output table of the base year, all effects on production, whether in total or differentiated by sector and uses, are given in real terms, i.e. in prices of the base year. While based on the price model we are able to produce results in nominal terms, we do not report them.

For value added and its components the situation is more differentiated. The only value-added component that, as a cost component, bears a clear distinction between price and quantity is gross wages and salaries. Here we focus on the quantity aspect in the form of employment in hours worked. As a cost component, we report the gross wages and salaries in nominal terms. The consumption of fixed capital is modelled only in real terms, i.e., we assume no changes in replacement cost. Other components of value added have no price component (e.g., taxes on production) or are conceived as a residuum containing several subcomponents (net operating surplus).

Another perspective of gross wages and salaries is the income generation. To compute the real gross income generated by gross wages and salaries, i.e., what is commonly termed "real wages and salaries", it is necessary to correct nominal gross wages and salaries by its purchasing power. This is done by applying prices and weights of private consumption.

Though, real value added is a much-criticized concept, we also report it. Its calculation is based on the so-called double deflation procedure. It is defined as the output per sector at the prices of a base year minus the vector of intermediate input demand per sector at the prices of the base year.

3.2.4 Employment Effects of Digitalisation: Direct Effects versus Compensation Effects

In our literature review (section 2), we discussed the various effects that possibly might be compensating for an initial displacement of jobs caused by the introduction of labour-saving technologies. This section discusses whether and how these compensation effects are covered by our model. The introduction of labour-saving technologies is, obviously, modelled by changes in employment coefficients. As the matrix of employment coefficients discerns between sectors and occupation, the direct effect can be captured in a comparatively precise manner.

New machines. With technological progress, in particular digitalisation, new machines are introduced, possibly displacing labour. A shift of employment from the machine-using industry toward the machine-producing one and a general process of capital accumulation counterbalances the initial detrimental effect on employment. In our model, this effect is considered by the additional demand for fixed capital, which is to be specified exogenously.

New investments. New technology generates opportunities for extra-profits, at least as long as not eroded by competition. If profits are reinvested by entrepreneurs in physical capital, productive capacity will expand and further labour demand will be stimulated. This effect has not been integrated in our model because an investment function that makes capital formation dependent on profits goes beyond our input-output framework. However, the partly endogenized investment effects accommodate the additional capital formation that is needed when output is expanding.

Decrease in prices. The increase in productivity due to the introduction of new technologies induces a reduction in production costs and, if markets are competitive, a reduction in commodity prices. Lower prices should translate into higher demand, and therefore higher economic activity and employment. In our model we can capture a good part of this mechanism by integrating the stimulation of private consumption by lower prices. However, other demand categories that are part of this compensating channel, could not be covered. For instance, intermediate demand would react to lower prices of intermediate inputs by raising demand and substitution of some inputs by others. But in our model technology is given exogenously in the form of technical coefficients, which cannot be endogenously moderated in our framework.

Decrease in wages. Raised labour productivity, ceteris paribus, reduces the demand for labour and therefore causes a first wave of labour displacement. Taking on a neoclassical concept of labour markets, the relative abundance of labour supply leads to a reduction in wages. As at lowered wages firms start to hire more workers, this process goes on until a new equilibrium in labour markets is reached and the initial labour displacement has been compensated. This equilibrating process is not taking place on labour markets alone but involves other markets as well, thus triggering further compensating effects, e.g., via further decreases in commodity prices. The model presented in this paper is not designed to integrate labour markets as wages are given exogenously.

Increase in incomes. This compensation mechanism emphasises that workers can appropriate the gains from the increase in productivity. Thus, technical progress can lead to an increase in wages and incomes, thus furthering consumption and economic activity. The resulting increase in employment compensates for the initial labour displacement. As in our model wages are given exogenously, the analyst can specify wages by taking into account, e.g., information on the shortage or abundance of labour in certain qualifications and occupations, and institutions like collective wage bargaining.

New products. The introduction of new branches and products opens new opportunities for consumption. Higher consumption translates into higher demand and therefore higher employment. This compensating effect is present in our model in the form of exogenously specified consumption of new products based on digitalisation and its new chances.

New tasks. Acemoglu and Restrepo (2019) highlight that the creation of new labour-intensive tasks (tasks in which labour has a comparative advantage relative to capital) may be the most powerful force balancing the growth process in the face of rapid automation. In this perspective, technological progress in the form of new tasks is seen as a consequence of market forces. The model used in this paper cannot accommodate such a mechanism, since technological progress is specified exogenously and causality runs only from technology to market forces, not in both directions.

The comparison of the array of compensation mechanisms with the capabilities of our modelling approach reveals the strengths and limitations of our model. On the one hand, to define technological progress by changes in technical coefficients, which are exogenously given is a helpful simplification of reality that allows for transparency of assumptions and traceability of effects. On the other hand, several compensation mechanisms that imply a more flexible operationalisation of technological progress and interaction between technology and markets cannot easily integrated into this framework.

4 Empirical Results

4.1 Overview

Table 2 provides a summary of the projected effects of Economy 4.0 on gross (total) output, gross domestic product (GDP), employment, and prices by four different scenarios. The table shows the changes of these macroeconomic indicators after the full implementation of Economy 4.0 in 2030 relative to the reference scenario, i.e., a world without realisation of Economy 4.0. The four scenarios are characterized by different assumptions on Economy 4.0 induced labour productivity growth and collective wage bargaining outcomes. Whereas Scenarios 1 and 2 assume a productivity-oriented wage-policy, i.e., nominal wages per hour grow at the same rate as real labour productivity, Scenarios 3 and 4 assume that nominal wages per hour of workers are unaffected by Economy 4.0. Consequently, in Scenarios 3 and 4 real labour productivity gains are mostly reaped by firms while workers can benefit only insofar as lower consumer goods prices raise their real incomes.

Table 2: Economy 4.0 induced changes in the Austrian Economy by 2030

Change in …	Productivity-oriented wage-policy		No compensation of workers for increase in labour productivity	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Real labour productivity change (annual) between 2021-2030	0.32%	0.64%	0.32%	0.64%
Total output (in billions of euros, real)	15.84 (2.49%)	15.71 (2. 47%)	13.26 (2.09%)	10.69 (1.68%)
Gross domestic product (in billions of euros, real)	7.36 (2.14%)	7.27 (2.11%)	5.64 (1.64%)	3.93 (1.14%)
Employment (total, in 1 000 full time equivalents)	-29.56 (-0.80%)	-150.35 (-4.07%)	-43.98 (- 1.19%)	-177.47 (-4.81%)
Mean prices of goods and services (in %)	-0.58%	-0.65%	-2.37%	-4.08%

Note: Changes are relative to the reference scenario, i.e., a world without realisation of Economy 4.0 (an Economy in its state of 2015), are shown. Percentage changes are shown in parenthesis, except of changes in the mean prices of goods and services.

We find that in 2030 the projected, price change adjusted GDP of Austria is between €3.93 billion (1.14%) and €7.36 billion (2.14%) higher than without implementation of Economy 4.0. This is smaller than the (percentual) effects of Economy 4.0 on GDP in Germany found by Vogler-Ludwig (2017) [4.0%] and Wolter et al. (2019) [3.3%]. Total output increases between €10.69 billion (1.68%) and €15.84 billion (2.49%). The projected decline in employment ranges from 177,470 full-time equivalents (FTE) (4.81%) under Scenario 4 to 29,560 FTEs (0.80%) under Scenario 1. Compared to the results of Wolter et al (2019) for Germany [-1.3%], employment in Austria declines less in Scenarios 1 and 3 and more in Scenarios 2 and 4. Economy 4.0 is expected to reduce the aggregate price level by 4.08 to 0.58%. In contrast to scenarios 3 and 4, in Scenarios 1 and 2 the nominal gross wages and salaries per hour increase to the same extent as the hourly labour requirement decreases (or labour productivity increases). As a result, the labour costs per unit remain almost the same, which dampens the price effect. In Scenarios 1 and 2 the productivity-oriented wage policy leads to a higher increase in GDP and weaker price effects compared to Scenarios 3 and 4 assuming no compensation of workers for increases in labour productivity. The higher GDP growth in Scenarios 1 and 2 is a direct and indirect consequence of the greater increase in private consumption, which in turn comes from a higher increase in labour income.

Although in Scenario 2 the annual increase in labour productivity between 2021 and 2030 is twice as high than in Scenario 1 (0.64% vs. 0.32%), the macroeconomic effects in terms of total output growth, GDP growth, and cheaper products and services are quite similar in magnitude. This can be explained by the productivity-oriented wage policy which tends to stabilize unit labour costs (a main driver of prices), workers' aggregate income, private consumption, and final demand expenditures. Hence, the changes in GDP in Scenarios 1 and 2 are mostly driven by direct and indirect effects originating from exogenous changes in final demand expenditures (private consumption, gross fixed capital formation and exports). To a lesser extent, a higher capital productivity also contributes to GDP growth and is the main driver of decreasing prices of goods and services in Scenarios 1 and 2. A comparison of Scenarios 3 and 4 reveals that without compensating workers for labour productivity increases, the positive effect of Economy 4.0 on GDP is more pronounced under the low labour productivity growth scenario (i.e., 0.32% p.a.). This is because the price effect, i.e., lower unit labour costs and prices leading to more private consumption, is dominated by the income effect, i.e., a decline in employment and workers' income reducing private consumption.

The employment effects of Economy 4.0 are mainly driven by the growth rate of labour productivity, but the effect is moderated somewhat in the scenarios with a productivity-oriented wage policy. While the scenario assuming low labour productivity growth (0.32% p.a.) and a productivity-oriented wage policy indicates a decline in employment by 29,560 FTEs, the decline without a compensating wage policy amounts to 43,980 FTEs. The corresponding numbers for the scenarios assuming high labour productivity growth (0.64% p.a.) indicate a loss of 150,350 FTEs and 177,470 FTEs, respectively.

4.2 Gross Domestic Product by Components and Employment

In this section we present the detailed effects of Economy 4.0 on GDP and its components, as well as on employment by sector, occupation, and gender. We focus on the results obtained from Scenario 1, which we consider to be the most realistic scenario for the following reasons.

First, the growth rate of real hourly wages in Austria is closely linked to the growth rate of real labour productivity. The OECD (2018) finds for Austria that between 1995 and 2013 the average annual growth rate of real labour productivity and real hourly wages was 1.1% and 1.0%, respectively. Estimates at the other end of the spectrum indicate for Austria that between 1999 and 2018 real labour productivity and real hourly wages grew by 20% and 13%, respectively (Fenz et al., 2019). Therefore, Scenarios 1 and 2 assuming a productivity-oriented wage policy seem to be closer to reality. Second, the average annual labour productivity growth rate in Austria was around 1% in the last two decades. In the light of this fact, Scenarios 2 and 4, which assume that Economy 4.0 increases the annual labour productivity growth rate by 0.64 percentage points seem to be rather unrealistic. In addition, although the magnitude of the employment effects varies across the four scenarios, the sectoral, occupational and gender-dependent composition of the employment effects is similar across the scenarios.

Fig. 2 shows the effect of the digitalisation on GDP growth and its components. In 2030 the real GDP is €7.36 billion (or 2.14%) higher than in the reference scenario without the realisation of the digital transformation. The increase in GDP is mainly driven by the rise of consumption expenditures of private households by €8.29 billion. Investments in equipment and construction contribute €0.91 billion to the rise in GDP. Economy 4.0 worsens the trade balance, which has a negative effect on GDP growth. Imports are growing more than twice as fast as exports resulting in a decrease of the trade surplus by €1.86 billion.

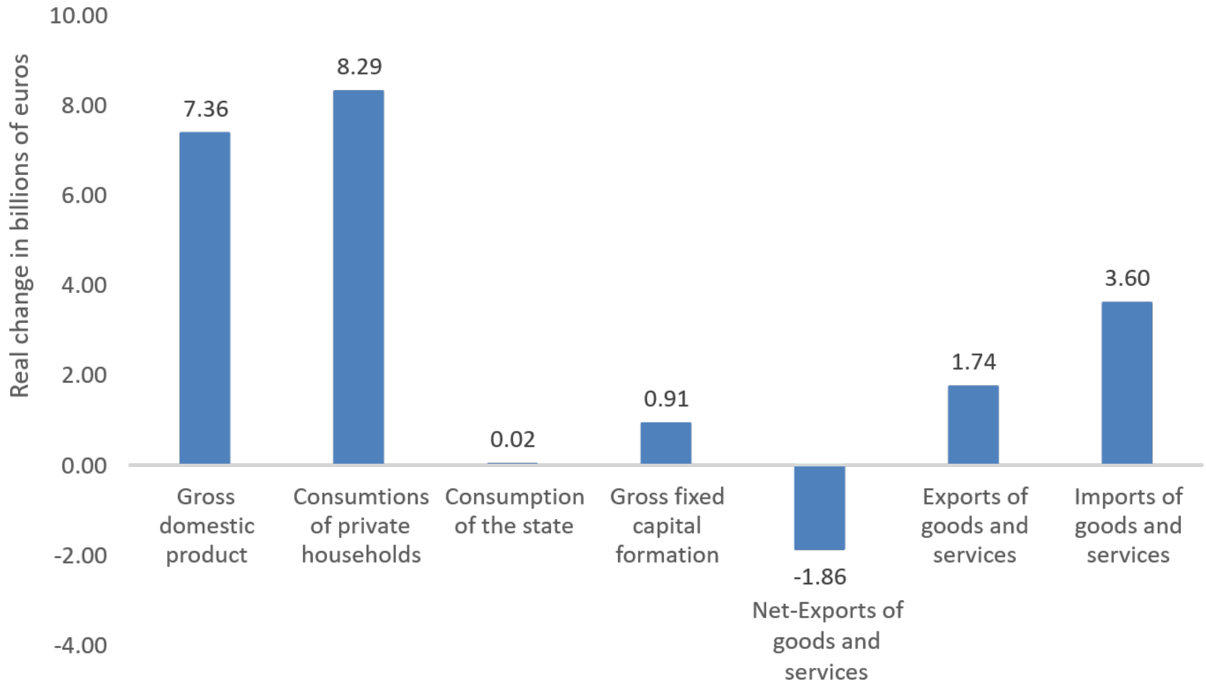

Fig. 2: Economy 4.0 induced changes in real GDP and its components under Scenario 1. *Changes are reported in billions of euros and relative to the reference scenario without the realisation of Economy 4.0. Changes in consumption of private non-profit organizations, changes in valuables, and changes in inventories are assumed to be zero.*

Regarding the changes of real gross value added by sectors we find that digitalisation will accelerate the structural change towards a larger service sector. This result is in line with the findings of Wolter et al. (2019). The real gross value added of the primary, the secondary and the tertiary sector increases by €0.06 billion (1.91%), €1.25 billion (1.64%), and €4.73 billion (2.08%), respectively. The increase of total real gross value added sums up to €6.04 billion (1.97%).

Fig. 3 provides a detailed decomposition of Economy 4.0 induced real gross value added change.[4] All sectors show an increase where the largest growing sectors in absolute terms are real estate services (+€1.2 billion), wholesale & retail trade (+€0.74 billion), accommodation (+€0.68 billion), manufacturing (+€0.67 billion), and ICT services (+€0.65 billion). However, the growth rate of real value added is highest in ICT services (+5.18%). Within manufacturing, the value added of individual sectors is developing quite diversly, and the strongest increases might be expected for food products (€0.13 billion or 3.55%), machinery and equipment n.e.c. (€0.12 billion or 1.83%) and motor vehicles, trailers and semi-trailers and (€0.08 billion or 2.29%), cf. Table A2 in Appendix A.

[4] It is structured by the one-digit level of the ÖCPA, which is the Austrian version of the Classification of Products by Activity (CPA) from EUROSTAT. The CPA is a product classification whose elements are related to activities as defined by general industrial classification of economic activities within the European Union (NACE) For details see EUROSTAT (2014).

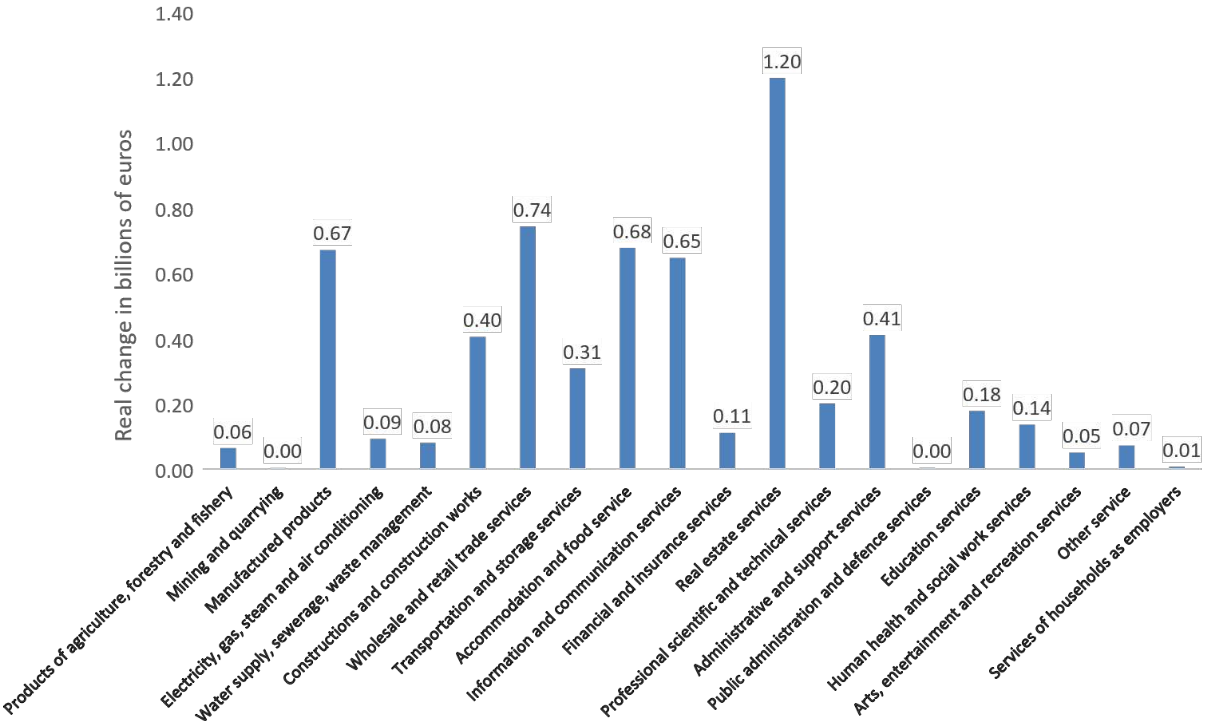

Fig. 3: Economy 4.0 induced changes in real gross value added by sectors under Scenario 1. *Changes are reported in billions of euros and relative to the reference scenario without the realisation of Economy 4.0.*

The employment decline of 29,560 FTEs under Scenario 1 can be decomposed into a loss of 12,820 FTEs held by female workers and 16,740 FTEs held by male workers. This is not surprising, since men hold substantial more FTEs than women (about 2.18 million vs. 1.51 million FTEs in 2015). Therefore, comparing the employment growth rates of women and men is more appropriate and reveals that the employment of women decreases by 0.85%, while the employment of men declines clearly less, i.e., 0.77%. Regarding the effect of Economy 4.0 on the real gross income of employed persons, both genders gain. The real gross income of male workers increases by €2.73 billion and that of female workers by €1.44 billion. Again, comparing the growth rates shows that the real gross income of female workers (+2.8%) increases less than the real gross income of male workers (+3.26%). As a result, women workers' shares in both total employment and total real gross income will decline. This result also holds for Scenarios 2, 3 and 4, as shown by Table A1 in Appendix A.

Regarding the sectoral distribution of the employment decline, we find that digitalisation will shift the shares of sectoral employment from the primary and secondary sector to the tertiary sector. Until 2030 employment in the primary, secondary, and tertiary sector declines by 5,310 FTEs (-3.64%), 21,490 FTEs (-2.62%) and 2,770 FTEs (-1.10%), respectively.

Fig. 4 decomposes the total employment decline of 29,560 FTEs by gender on a detailed sectoral level. Only a few sectors exhibit an increase in employment: ICT services (+13,870 FTEs, +12.02%), professional scientific and technical services (+2,760 FTEs, +0.86%), financial and insurance services (+1,000 FTEs, +0.93%), and accommodation and food services (+810 FTEs, +0.34%). The sectors with the largest employment decline are manufacturing (-11,070 FTEs, -2.16%), construction and construction works (-10,230 FTEs, -3.87%), agriculture, forestry, and fishery (-5,310 FTEs, -3.64%), transportation and storage services (-5,110 FTEs, -2.77%), and public administration and defence services (-5,080 FTEs, -2.31%). Within the broad manufacturing group, employment decreases the most in food products, fabricated metal products, except machinery and equipment and furniture with 2.110 FTEs (3.61%), 1.480 FTEs (2.30%) and 960 FTEs (3.88%), respectively (cf. Table A3 in Appendix A).

The greatest absolute decline in male employees is to be found in construction and manufacturing and, where a particularly large number of men work. The largest absolute decline in female employment is in manufacturing and health. The strongest absolute (and relative) growth in male and female employees is to be expected in ICT services, whereby the increase in men is likely to be significant. In this sector, the proportions of men vs. women shift the most.

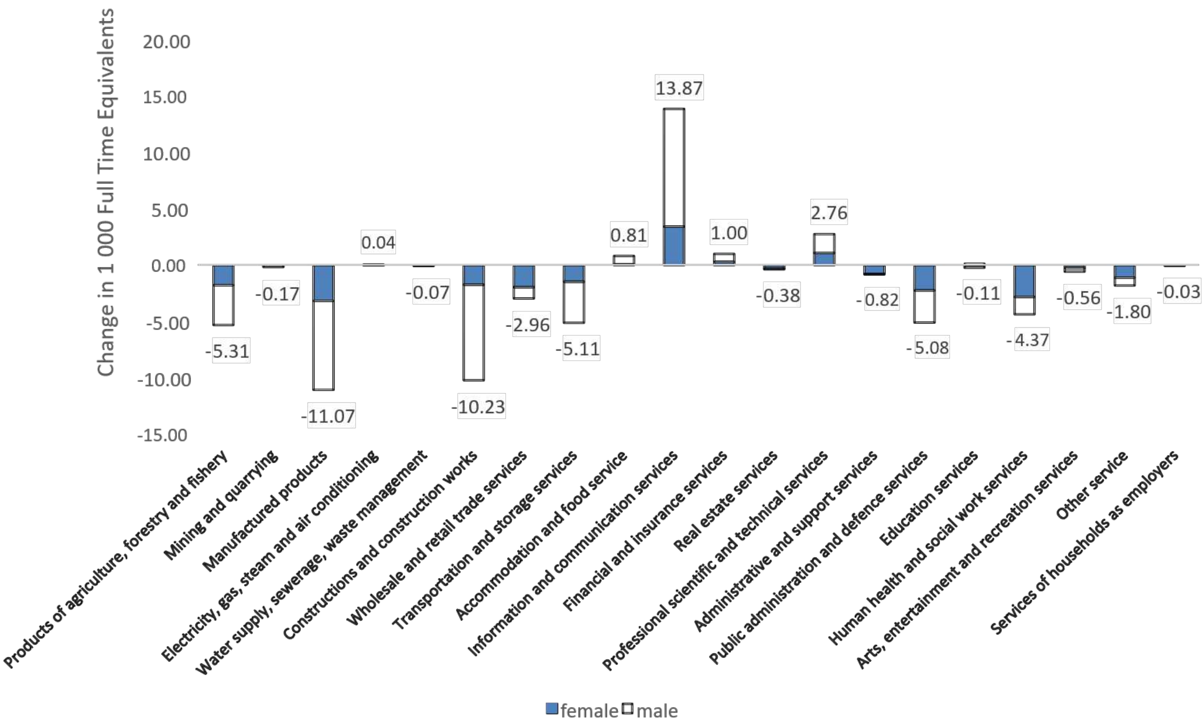

Fig. 4: Economy 4.0 induced sectoral employment changes by gender. *Changes are reported in 1,000 full-time equivalents and relative to the reference scenario without the realisation of Economy 4.0.*

Regarding the occupational distribution of the employment decline we find that digitalisation will shift employment from occupations with low- and medium-skill requirements to occupations with high skill requirements. While the employment of high-skilled workers increases by 17,570 FTEs (+1.12%) until 2030, the employment of medium-skilled, and low-skilled workers declines by 42,720 FTEs (-2.29%) and 4,420 FTEs (-1.78%), respectively. The employment of unclassifiable (i.e., armed forces occupations) increases by around 14 FTEs (+ 0.13%).

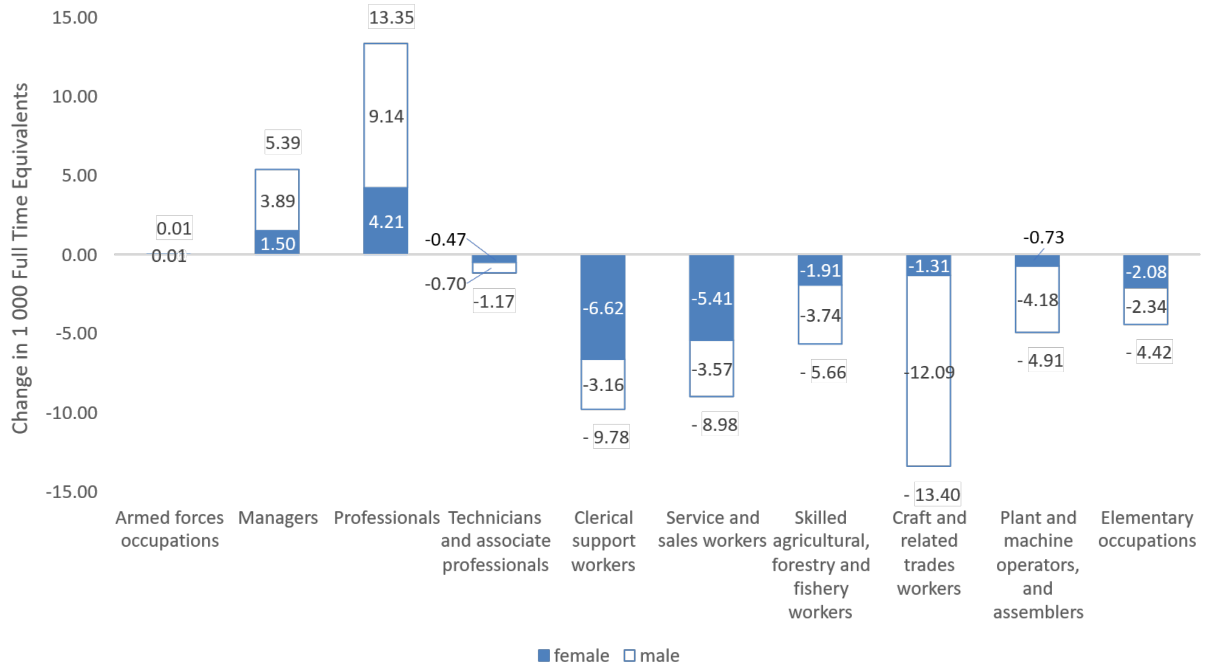

Fig. 5: Economy 4.0 induced occupational employment changes by gender. *Changes are reported in 1,000 full-time equivalents and relative to the reference scenario without the realisation of Economy 4.0.*

Fig. 5 shows the employment effects and shifts of Economy 4.0 by occupation and gender. The demand for two occupations, namely managers and professionals, increases. These occupational groups, predominantly consisting of high-skilled workers, gain from Economy 4.0. Employment of managers increases by 5,390 FTEs (+2.39%) and that of professionals by 13,350 FTEs (+2.22%). However, the occupational groups of managers and professionals consist of quite heterogenous sub-groups. It is worth to mention that more than two thirds of the increased employment of professionals comes from the demand for information and communications technology professionals (+5,180 FTEs, +7.96%), teaching professionals (+2,160 FTEs, +1.18%) and science and engineering professionals (+2,000 FTEs, +2.19%). This highlights the shift towards a more knowledge-based economy. Since these occupations are dominated by men, we expect that women profit less from this development. While employment of male professionals increases by 9,140 FTEs (+2.78%), employment of female professionals increases by 4,210 FTEs (+1.55%).

The Economy 4.0 induced employment change of all other occupations, besides managers and professionals, is negative. The strongest loosing occupations mainly consist of medium-skilled workers: craft and related trades workers (-13,400 FTEs, -2.66%), clerical support workers (-9,780 FTEs, -2.72%) and service and sales workers (8,980 FTEs, -1.49%). Interestingly, the employment decline of the strongest shrinking occupation, i.e., craft and related trades workers, almost only effects men. This is because the employment decline in this occupational group is attributable to the diminishing employment of building and related trades workers (-5,920 FTEs, -3.68%), metal, machinery, and related trades workers (-3,500 FTEs, -2.06%) and food processing wood working, garment and other craft and related trades worker (-3,070 FTEs, -3.91%). These occupations are predominantly carried out by men. The opposite is true for clerical support workers and of service and sales workers. These occupations have high shares of women workers in total employment. More than two thirds of the declining employment of clerical support workers, and more than 60% of service and sales workers concern women.

Fig. 6 and Fig 7 provide a decomposition of real gross income gains of employed persons by gender until 2030 on a detailed sectoral- and occupational level, respectively. Contrary to the diverse employment developments we find that all sectors and occupations experience an increase in gross income received by employees. This is because the assumed productivity-oriented wage policy means that unit labour costs remain almost unchanged. Thus, the gross wage costs per employee develop very similarly to the output per employee. Because the total output of all sectors increases, this causes an increase in the gross wages and salaries from which the real gross income of employees is derived.[5]

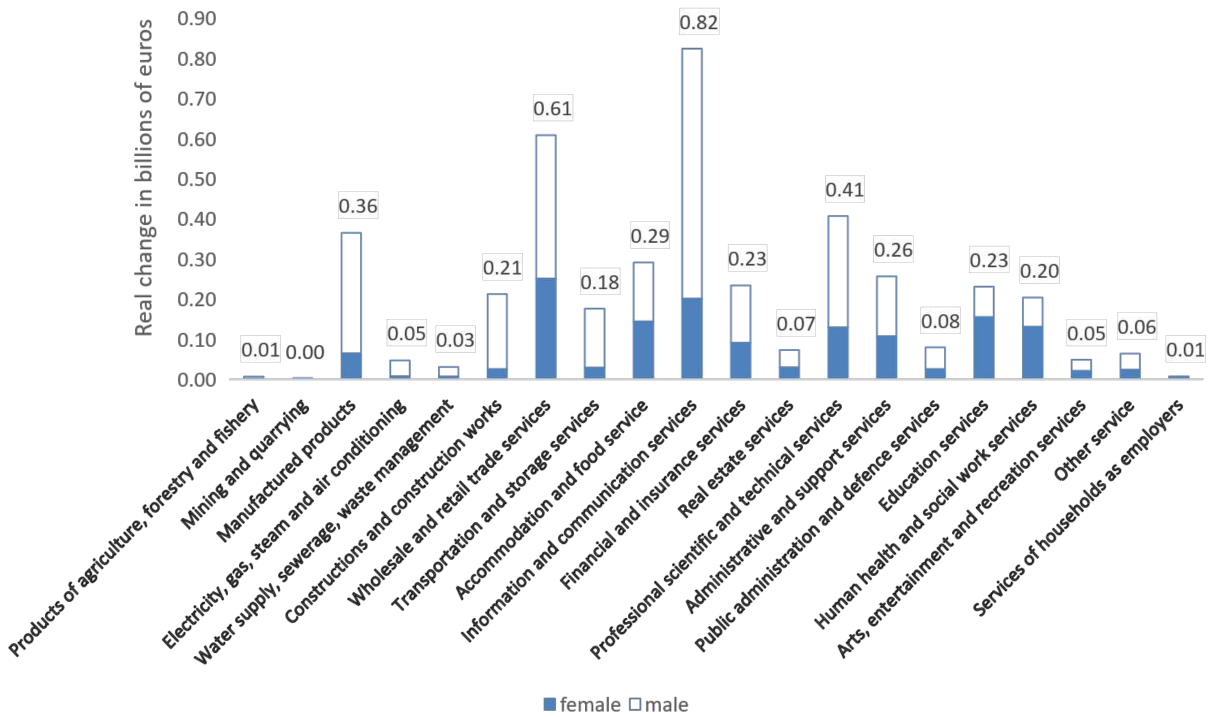

Fig. 6: Economy 4.0 induced sectoral changes of real gross income of employed by gender. *Changes are reported in billions of euros and relative to the reference scenario without the realisation of Economy 4.0.*

Regarding the real gross income of employed persons by sector, we find that digitalisation will decrease the share of labour income of workers in the primary and secondary sector. Real gross income of employed persons in the primary sector, secondary sector and tertiary sector increases by €0.01 billion (1.62%), €0.66 billion (1.90%) and €3.50 billion (3.50%), respectively. Total real gross income of employed persons increases by €4.17 billion (3.09%).

The sector with the largest employment gains, i.e., ICT-services, also experiences the strongest increase in real gross income of employed persons (€0.82 billion, 13.89%) and is followed

[5] The real gross income of employed is derived from gross wages and salaries by adjusting for the increased purchasing power because of lower prices of consumer goods.

by wholesale and retail trade services (€0.61 billion, 3.49%), professional scientific and technical services (€0.41 billion, 3.35%) and manufacturing (€0.36 billion, 1.61%). Interestingly, the sectors with the largest employment decline, i.e., manufacturing and construction and construction works, exhibit a substantial increase in real gross income received by employees.

Regarding the distribution of real gross income gains of employed persons by occupational groups we find that the share of labour income earned by low- and medium-skilled workers will decline. The real gross income of high-skilled, medium-skilled, and low-skilled workers increases by €3.01 billion (4.26%), €0.98 billion (1.73%) and €0.16 billion (2.29%), respectively. The real gross income of employed persons of unclassifiable (i.e., armed forces occupations) increases by around €0.02 billion (3.17%).

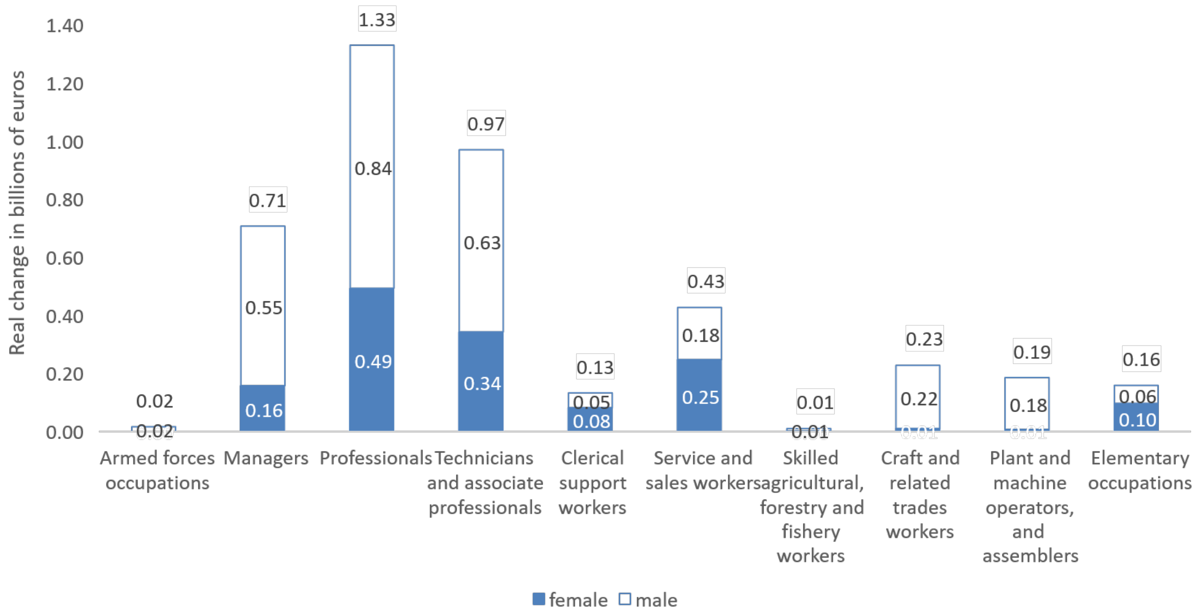

Fig. 7: Economy 4.0 induced occupational changes of real gross income of employed by gender. *Changes are reported in billions of euros and relative to the reference scenario without the realisation of Economy 4.0.*

The two single occupations with employment gains, i.e., managers and professionals, exhibit the largest and the third largest increase in real gross income of employees: €1.33 billion (4.78%) and €0.71 billion (5.72%), respectively. Interestingly, we find the second and fourth largest increase in real gross income for occupations with a slight and a pronounced employment decline: technicians and associate professional (€0.97 billion, 3.20%) and service and sales workers (€0.43 billion, 2.62%). Real gross income gains of managers, professionals, and technical and associate professionals account for about 75% of total real gross income gains of employees. Since men are overrepresented in these groups of occupations, they can benefit more from real gross income gains than women: 66% of the real gross income gains in these occupational groups are reaped by men.

4.3 Functional Income Distribution

In all scenarios, digitalisation increases total workers' income and total corporations' profits. Clearly, the distribution of the gains from Economy 4.0 between labour and capital depends on the collective wage bargaining outcomes. Under a productivity-oriented wage-policy, i.e., Scenarios 1 and 2, the real gross income of employed persons increases fasters in absolute and relative terms than the real gross corporate income. The opposite is true under Scenarios 3 and 4, where workers are not compensated for the increase in labour productivity. Table 3 presents the Economy 4.0 induced changes in the functional income distribution in the Scenarios 1 and 3. The relationships in Scenarios 2 and 4 are similar in tendency to those in Scenarios 1 and 3.

Scenario 1, which is characterized by a productivity-oriented wage policy, is most beneficial to workers (€4.17 billion or 3.09% additional real gross income). Scenario 2, where the employed are not compensated for the increase in labour productivity, is most profitable for corporations (+€2.87 billion or +3.86%).

Table 3: Economy 4.0 induced changes in the functional income distribution by 2030

Change in …	Productivity-oriented wage-policy	No compensation of workers for increase in labour productivity
	Scenario 1	Scenario 3
Real labour productivity change (annual) between 2021-2030	0.32%	0.32%
Real gross income of employed persons (in billions of euros)	4.17 (3.09%)	2.19 (1.62%)
Real gross corporate income (in billions of euros)	1.89 (2.54%)	2.87 (3.86%)

Note: Percentages are given in parentheses. Changes are relative to the reference scenario without the realisation of Economy 4.0.

5 Conclusions

This study aims to analyse and quantify the possible impacts of the continuous and ongoing transformation of the economy towards a digitalized production and work environment (Economy 4.0) on employment in the next 10 years in Austria. To answer this question, digitalisation scenarios based on a number of assumptions are developed. These scenarios are used in an input-output model to estimate the possible future macroeconomic effects of digitalisation. The effects of the scenarios are compared with a reference scenario where technologies and structures remain as in 2015 ("frozen technology"). Projections start in 2021 and end in 2030.

According to our results during the next 10 years job displacement due to Economy 4.0 will probably be greater than job creation. Depending on the assumptions chosen aggregate employment will decline by 0.80% to 4.81% relative to total present employment. The replacement of human by machine work and the changes in skill requirements on employees will result in changes in the occupational and skill-structures of employment. Employment in higher-skilled occupations (i.e., managers and professionals) will increase while that of medium-skilled occupations (i.e., clerical support workers, service and sales workers, skilled agricultural workers, craft and related trades workers, and machine operators) will decrease. The structure of employment by economic sectors will also change. Employment will increase in the tertiary sector while in primary and secondary sectors it will decline. A parallel development will take place in value added and incomes of the employed. Overall, digital transformation will intensify the shift towards services. By and large, these results and conclusions broadly confirm the outcomes of comparable empirical studies.

In addition, it can be expected that the distribution of income between men and women as well as between employees and firms is likely to change. Due to the digital transformation, women are likely to lose their share of the income compared to men. The same will presumably also apply to employment. The impact of digitalisation on the functional distribution of income will likely depend on the results of collective wage bargaining. Depending on this, the distribution will shift either in favour of employees (with productivity-oriented wage policy) or in favour of firms (without production-oriented wage policy).

The results presented here paint a more optimistic picture compared to the fears often expressed in the public debate of massive job losses as a result of digitalisation. Against the background of clear structural changes, however, they should not hide the fact that extensive efforts are necessary to prepare the workforce for the new challenges. This applies in particular to investments in vocational training. Furthermore, digitalisation could become a concern not only for educational policy, but also for distribution policy as well as for social policy and for environmental policy. These important aspects could only inadequately or not at all be investigated in the present work and will be reserved for later studies.

We are aware that digitalisation is not a step that can be completed at a certain point in time. It is a process that will continue. The results should therefore be viewed as estimates based on currently known expert opinions and findings from the literature, and should therefore be interpreted with caution. These are no predictions but only projections that show possible future developments. It is very difficult to estimate how much and especially in which areas technologies such as 3D printing will prevail. Nevertheless, our approach is a step in the direction of falsifiability.

There are other limitations of our analysis as well. In our model labour demand depends only on output and not on wages, thus leaving no role for elasticity of the demand for labour. Moreover, changes of hourly wages are exogenously introduced instead of determined endogenously. Furthermore, the model does not account for limits of labour supply in terms of occupations and qualifications or location mismatch as well as regulations causing rigidness on the labour market and other impacts or influences of labour institutions that may matter. Since no other detailed labour supply forecasts (e.g., by occupation) are available for Austria, we cannot say anything about a possible future oversupply (i.e., unemployment) or shortage of skilled workers based on the results of our study. Additionally, our results do not allow any conclusions on quality (i.e., skill content, promotion perspectives, job stability, wage schemes, working hours, required flexibility, etc.) of lost vs. created jobs. Moreover, the model does not take into account monopolistic or oligopolistic market structure on product markets because it assumes that changes of unit costs are passed on to demanders and customers (i.e., cost-saving effects of labour-saving technologies were fully transferred into decreasing prices).

As evident from these statements, much remains to be done to get a complete picture of the economic consequences of the digital transformation. The studies conducted and the approaches developed in this paper can be enhanced to investigate inter alia the possible impacts on interpersonal income distribution, effects on tax revenues in a tax system that is largely based on the taxation of labour and, as a result, on the financial viability of a social system. This would shed more light on the social dimension of digitalisation. These economic and social analyses can in turn be expanded to include ecological aspects, for example by measuring the effects on greenhouse gas emissions. In this way, one can arrive at a comprehensive analysis of the consequences of digitalisation on sustainability. Two other possible extensions/directions toward an in-depth analysis would be, firstly, to investigate the knowledge spill-overs that may arise through the use of digital production technologies in more detail and, secondly, to describe how digital technologies increase the resilience of the economic system in times of crisis.

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Appendix A: Detailed Description of the Model

This appendix provides a detailed description of the model. In section 2.1 we make some general remarks on the mathematical notation used. Then the model is developed according to the calculation steps specified in section 1.2 of the main text. Sections 2.2 to 2.7 are devoted to the quantity model that is at the core of the model. Here, we first discuss the parameters that are given exogenously (sections 2.2 to 2.5): final demand, technical coefficients, employment coefficients and wages per hour. The coefficients for all value added components except profits are also given exogenously but not profits and value added as a whole, which are considered as residual variables. The model itself is described in section 2.6. It provides as its solution the vector of output by sectors. From this, in section 2.7, solutions for other variables of interest are derived. Section 2.8 describes the price mechanism according to the Leontief price model and the effect of price changes on private consumption. Finally, section 2.9 discusses the quantity model that is estimated based on the further consumption due to price changes. The focus of this section is on how, with the help of the commodity prices available from the Leontief price model, and wages, nominal and real variables can be defined, and how these should be interpreted.

Remarks on Notation

Vectors and matrices are indicated by bold and upright symbols, matrices additionally by capitalization. Scalars, e.g., the individual elements of a vector or matrix, are written in italics. For instance, the matrix of technical coefficients is written as $\mathbf{A}$, and its elements are given by a_{ij}. This is also expressed as follows: $\mathbf{A} = [a_{ij}]$. Subscripts to scalars are used to specify the sector. For the further labelling of scalars (e.g., domestic versus imported), superscripts are used, whereby the same symbols are used as subscripts for vectors and matrices. Since a scenario typically covers several years, all variables have a time dimension indicated by the index $t = 0, \ldots, T$, of which year 0 is also referred to as the base year. For instance, the matrix of the domestic technical coefficients of the year t is written as $\mathbf{A}_d(t) = [a_{ij}^d(t)]$. The time dimension is omitted when it is not of particular importance. The apostrophe is used for the transposition of a vector or a matrix. Vectors, by default, are column vectors. Inversion of a matrix and diagonalization of a vector are denoted by adding -1 as superscript and putting a "hat" over the symbol, respectively. Elementwise multiplication of matrices or vectors is denoted by a small dot.

Final Demand

The Economy 4.0 scenario (assumption 1-4 and 12-14) gives a vector of final demand satisfied from domestic production, $\mathbf{f}_d(t)$, for the year 1 to T. It is assumed that the ratio of domestic to imported final demand goods does not change over time, i.e., the growth rate of final demand for domestic and imported goods is identical. The following notation is used for the components of the final demand that are satisfied from domestic production: private consumption $\mathbf{c}_d(t)$, public consumption $\mathbf{g}_d(t)$, gross fixed capital formation $\mathbf{h}_d(t)$, exports $\mathbf{e}_d(t)$, and $\mathbf{o}_d(t)$, which combines all other components (consumption of private non-profit organizations, changes in valuables and changes in inventories). The final demand is the sum of its components:

$$\mathbf{f}_d(t) = \mathbf{c}_d(t) + \mathbf{g}_d(t) + \mathbf{h}_d(t) + \mathbf{e}_d(t) + \mathbf{o}_d(t), t = 0, \dots, T \tag{1}$$

However, in the context of the Leontief model extended to include income and investment effects, private consumption includes consumption out of gross wages and salaries that is considered as endogenous in the model and, analogously, gross fixed capital formation includes investment endogenized via capital coefficients. To accommodate this distinction, from now on, we let $\mathbf{c}_d(t)$ and $\mathbf{h}_d(t)$ denote only the exogenous part of private consumption and gross fixed capital formation, respectively. And we denote the endogenous part of private consumption and gross fixed capital formation by $\mathbf{k}_d(t)$ and $\mathbf{j}_d(t)$, respectively. If we furthermore denote the exogenous part of final demand by $\mathbf{y}_d(t)$, we can replace equation (1) by

$$\mathbf{f}_d(t) = \mathbf{c}_d(t) + \mathbf{k}_d(t) + \mathbf{g}_d(t) + \mathbf{h}_d(t) + \mathbf{j}_d(t) + \mathbf{e}_d(t) + \mathbf{o}_d(t), t = 0, \dots, T \tag{2}$$

and

$$\mathbf{y}_d(t) = \mathbf{c}_d(t) + \mathbf{g}_d(t) + \mathbf{h}_d(t) + \mathbf{e}_d(t) + \mathbf{o}_d(t), t = 0, \dots, T \tag{3}$$

To be able to make this distinction a further data preparation step must be integrated in the calculation process but otherwise no complications arise.

Assumptions 1-4 and 12-14 relate to individual components of final demand and can also be examined separately to isolate the effects of the individual assumptions. Assumptions 1-4 relate to gross fixed capital formation, assumption 12 to public consumption, assumption 13 to private consumption and assumption 14 to exports. The other components of final demand (consumption of private non-profit organizations, changes in valuables and changes in inventories) are assumed to be unchanged over time.

Intermediate Input Coefficients

The technology is specified in the context of the input-output model by means of technical coefficients. The intermediate input coefficients a_{ij}, which are summarized as matrix $\mathbf{A}$, indicate how much of the good i is required to generate one unit of the good j. In our model, we consider an economy with n economic sectors or goods. The demand for intermediate inputs is made up of the demand for domestic and imported intermediate goods, so that the following also applies to the input coefficients:

$$\mathbf{A} = \mathbf{A}_d + \mathbf{A}_m \tag{4}$$

where $\mathbf{A}_d$ indicates the coefficients for intermediate inputs delivered from domestic production and $\mathbf{A}_m$ those for intermediate inputs supplied from abroad. It is assumed that the ratio of domestic to imported intermediate goods (compared to that of the base year) does not change over time. For this reason, the determination of the domestic input coefficient matrix co-determines the two other coefficient matrices.

Based on the database of the most recent input-output table, the input coefficients for the base year are given by:

$$\mathbf{A}_d(0) = \mathbf{Z}_d(0)\hat{\mathbf{x}}^{-1}(0) \tag{5}$$

Here $\mathbf{Z}_d(0)$ is the matrix of domestic intermediate input flows (at basic prices) of the base year and $\mathbf{x}(0)$ is the output vector of the base year, whereby in equation (5) the diagonalization and inversion are indicated by the cap and the superscript, respectively. The coefficients of intermediate inputs delivered from abroad are calculated in an analogous manner. Assumptions 5 to 9 lead to new input coefficient matrices $\mathbf{A}_d(t)$ for the years $t = 1, \ldots, T$. The same applies to the coefficients of intermediate inputs obtained from abroad.

Change in Employment Coefficients

The technological change in terms of labour input is modelled by changing employment coefficients. For the base year, employment is disaggregated in hours worked according to m occupations and n economic sectors: $\mathbf{L}(0) = [l_{kj}(0)]$, where k is the running index of the occupations and j is the running index of the economic sectors. The matrix $\mathbf{L}(0)$ has the dimension m times n. The base year employment coefficients are given by

$$\mathbf{A}_l(0) = \mathbf{L}(0)\hat{\mathbf{x}}^{-1}(0) \tag{6}$$

Employment consists of self-employed and employed. The matrix of employment coefficients for the employed is given with $\mathbf{A}_e(0)$. It has the same dimension as $\mathbf{A}_l(0)$ and comes about in an analogue way. Based on the employment coefficients of the base year, the employment coefficients for the years $t = 1, \ldots, T$ are derived from assumption 10, whereby the scenario is determined directly at the level of the occupations and sectors. The vector of the sectoral employment coefficients is obtained by the column-sums of $\mathbf{A}_l(t)$:

$$\mathbf{a}_l{}'(t) = \mathbf{i}'\mathbf{A}_l(t), \tag{7}$$

where $\mathbf{i}$ is the summation vector of length m. Evaluating other measures such as full-time equivalents (FTE) and number of jobs is possible by means of bridge matrices (see below).

Value Added

Value added is defined as the difference between total output and intermediate consumption at purchasers´ prices, i.e., intermediate consumption not only including domestic and imported intermediate consumption at basic prices but also net taxes on products (taxes on products less subsidies on products):

$$\mathbf{v}' = \mathbf{x}' - \mathbf{i}'\mathbf{Z}_d - \mathbf{i}'\mathbf{Z}_m - \mathbf{q}' \tag{8}$$

where $\mathbf{v}$ is the n-dimensional vector of value added by sector and $\mathbf{q}$ is the n-dimensional vector of net taxes on products by sector. This relationship can also be expressed by coefficients:

$$\mathbf{a}_v{}' = \mathbf{i}' - \mathbf{i}'\mathbf{A}_d - \mathbf{i}'\mathbf{A}_m - \mathbf{a}_q{}' \tag{9}$$

the coefficients on the right-hand side are exogenous. In contrast, the value added or its coefficients can be regarded as endogenous in the present model, since they are residual variables.

The net taxes on products coefficients $\mathbf{a}_q$ are assumed to remain unchanged over the course of the scenario.[6]

The value added given by official input-output tables consists of different components. However, at this step of the model description we focus on gross wages and salaries, $\mathbf{v}_b$, and consumption of fixed capital, $\mathbf{v}_u$. The remaining component $\mathbf{v}_r$ thus contains all other components such as employers´ social security contributions, other net taxes on production, and the operating surplus. The following applies:

$$\mathbf{v}' = \mathbf{v}_b' + \mathbf{v}_u' + \mathbf{v}_r' \tag{10}$$

The gross wages and salaries are derived from employment of employed persons (in hours) and hourly wages, both of which are differentiated according to occupational groups and sectors:

$$\mathbf{v}_b = \mathbf{i}'(\mathbf{W} \cdot \mathbf{A}_e)\hat{\mathbf{x}} = \mathbf{i}'\mathbf{A}_b\hat{\mathbf{x}} = \mathbf{a}_b{}'\hat{\mathbf{x}} \tag{11}$$

where $\mathbf{W}$ is the $m \times n$ dimensional matrix of hourly wages. The element-wise multiplication, symbolized by the point, of $\mathbf{W}$ with $\mathbf{A}_e$ gives the matrix of the gross wage coefficients $\mathbf{A}_b$, where the kj-th element of $\mathbf{A}_b$ indicates how much gross wages and salaries have to be paid to the occupational category k in the economic sector j to produce one unit of product j. As can also be seen from equation (11), the n-dimensional vector of the sectoral gross wage coefficients, $\mathbf{a}_b$, is obtained by forming the column sums of $\mathbf{A}_b$.

The consumption of fixed capital is given as

$$\mathbf{v}_u = \mathbf{a}_u{}'\hat{\mathbf{x}} \tag{12}$$

Where the n-dimensional vector of sectoral fixed capital consumption, $\mathbf{a}_b$, is given exogenously.

The Leontief model Expanded by Income-induced Effects

The static Leontief model, extended by income-induced effects, delivers as solution the domestically produced commodities (total output vector), $\mathbf{x}(t)$, for the years $t = 1, \dots, T$. Before this model is presented, it is useful to recall the classic Leontief model. Starting from the equation

$$\mathbf{x}(t) - \mathbf{A}_d(t)\mathbf{x}(t) = \mathbf{f}_d(t) \tag{13}$$

it provides the solution

$$\mathbf{x}(t) = \left(\mathbf{I} - \mathbf{A}_d(t)\right)^{-1}\mathbf{f}_d(t) \tag{14}$$

where $\mathbf{I}$ is an n-dimensional identity matrix and $\mathbf{f}_d(t)$ is total final demand. While the classic Leontief model only takes into account the indirect effects of additional demand for interme-

[6] In a further development stage of our model, the net taxes on products can be modelled in more detail with the aid of the coefficient matrix $\mathbf{A}_q$, which makes it possible to make the development of the triggered net goods taxes dependent on the advance payments on which they depend.

diate inputs for a given final demand, the extended model presented here also takes into account i) the effects that arise when the generated gross wages and salaries lead to additional private consumption and ii) the effects that arise when the generated gross output leads to additional gross fixed capital formation. To account for these effects, Eq. (15) states that endogenous private consumption $\mathbf{k}_d(t)$ and endogenous gross fixed capital formation $\mathbf{j}_d(t)$ must also be covered by total output before the exogenous part of final demand $\mathbf{y}_d(t)$ can be satisfied:

$$\mathbf{x}(t) - \mathbf{A}_d(t)\mathbf{x}(t) - \mathbf{k}_d(t) - \mathbf{j}_d(t) = \mathbf{y}_d(t) \tag{15}$$

The equation system is supplemented by the following two equations, which are used to model the additional private consumption as endogenous variable:

$$b(t) = \mathbf{a}_b{}'(t)\mathbf{x}(t) \tag{16}$$

$$\mathbf{k}_d(t) = \mu \mathbf{s}_{c_d} b(t) \tag{17}$$

Equation (16) describes the creation of total gross wages and salaries in the economy, $b(t)$, using the gross wage and salaries coefficients. Equation (17) states that a fraction μ of the generated gross wages and salaries $b(t)$ is spent on private consumption of domestic goods. The distribution of the spending across the n commodities is governed by $\mathbf{s}_{c_d}$, representing the shares of each commodity in private consumption as observed in the base year, i.e. $\mathbf{s}_{c_d} = c_d^{-1}\mathbf{c}_d(0)$, where c_d is the sum of $\mathbf{c}_d(0)$.

Moreover, the equation system is supplemented by the following equation, which is used to model the additional gross capital formation as endogenous variable:

$$\mathbf{j}_d(t) = \rho \mathbf{S}_{h_d}\mathbf{x}(t) \tag{18}$$

Equation (18) states that a fraction ρ of the total output is spent on gross capital formation. The distribution of the spending across the n commodities is governed by $\mathbf{S}_{h_d}$, representing the capital formation shares of each commodity as observed in the base year. To be precise, the ij-th element of this matrix defines the share of commodity i needed as capital good in the overall gross capital formation of sector j.[7]

If one defines $\tilde{\mathbf{x}}' = [\mathbf{x}' \quad \mathbf{k}_d{}' \quad b \quad \mathbf{j}_d{}']$ and $\tilde{\mathbf{y}}_d = [\mathbf{y}_d{}' \quad 0 \quad \mathbf{0}' \quad \mathbf{0}']$, where $\mathbf{0}$ is a vector or a matrix of zeros of suitable dimension, then the equations (15) – (18) can be summarized as a system of equations:

$$\begin{bmatrix} \mathbf{I} - \mathbf{A}_d & -\mathbf{I} & \mathbf{0} & -\mathbf{I} \\ \mathbf{a}_b{}' & \mathbf{0}' & -1 & \mathbf{0}' \\ \mathbf{0} & \mathbf{I} & -\mu \mathbf{s}_{c_d} & \mathbf{0} \\ -\rho \mathbf{S}_{h_d} & \mathbf{0} & \mathbf{0} & \mathbf{I} \end{bmatrix} \begin{bmatrix} \mathbf{x} \\ \mathbf{k}_d \\ b \\ \mathbf{j}_d \end{bmatrix} = \begin{bmatrix} \mathbf{y}_d \\ 0 \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix} \tag{19}$$

[7] Since this is a preliminary model, we do not consider differences in the composition of capital formation across investing sectors. Thus, $\mathbf{S}_{h_d}$ contains identical columns $\mathbf{s}_{h_d}$, each representing the commodity structure of overall capital formation.

or in compact notation using the system matrix $\mathbf{M}$ and returning to a notation with time dimension:

$$\mathbf{M}(t)\tilde{\mathbf{x}}(t) = \tilde{\mathbf{y}}_d(t) \tag{20}$$

The solution of this system,

$$\tilde{\mathbf{x}}(t) = \mathbf{M}^{-1}(t)\tilde{\mathbf{y}}_d(t), \tag{21}$$

contains not only total output by sector but also endogenous private consumption by sector, gross wages and salaries, and gross capital formation by sector.

Effects on other interesting Variables

Based on final solution according to Eq. (21), the effects on other variables of interest, e.g., value added and its components, employment, and net-exports, can be inferred. First, value added, gross wages and salaries, and consumption of fixed capital by economic sector are given by:

$$\mathbf{v}'(t) = \mathbf{a}_v'(t)\hat{\mathbf{x}}(t), \quad \mathbf{v}_b'(t) = \mathbf{a}_b'(t)\hat{\mathbf{x}}(t), \text{ and } \quad \mathbf{v}_u'(t) = \mathbf{a}_u'(t)\hat{\mathbf{x}}(t) \tag{22}$$

The $m \times n$ dimensional employment matrix in hours worked, is calculated at follows:

$$\mathbf{L}(t) = \mathbf{A}_l(t)\hat{\mathbf{x}}(t) \tag{23}$$

Expressing $\mathbf{L}(t)$ in other units of measurement can be achieved by using bridge matrices. For instance, if it is known how many hours of work in a particular industry and a specific occupation correspond to full-time equivalents (FTE), these relations can be summarized in the matrix $\mathbf{R}_{FTE}$ and the employment in FTE can be denoted as

$$\mathbf{L}_{FTE}(t) = \mathbf{R}_{FTE} \cdot \mathbf{L}(t). \tag{24}$$

Similarly, the share matrix $\mathbf{S}_f$ can be used to determine the effects of the Economy 4.0 scenario on employment by gender, where the kj-th element of $\mathbf{S}_f$ indicates the proportion of female workers in the k-th job in the j-th economic sector. The employment of women is given by

$$\mathbf{L}_f(t) = \mathbf{S}_f \cdot \mathbf{L}(t) \tag{25}$$

Note that in both equations the bridge matrix and the women's share matrix is time invariant. Thus, the effect of Economy 4.0 on female employment reflects structural changes and not changing shares of female employment in given occupation-sector combinations.

Next, we show how to calculate imports and net exports (balance of exports and imports) of goods and services based on Eq. (19). The import vector of goods and services is given by:

$$\mathbf{m}(t) = \mathbf{A}_m(t)\mathbf{x}(t) + \hat{\mathbf{r}}_c\mathbf{k}_d(t) + \hat{\mathbf{r}}_h\mathbf{j}_d(t) + \mathbf{y}_m(t) \tag{26}$$

where $\mathbf{r}_c$ and $\mathbf{r}_h$ are vectors representing the ratios of imported to domestically produced goods for private consumption and gross fixed capital formation, respectively. These ratios are assumed to be constant in the course of the scenario. $\mathbf{y}_m$ is the vector of import into (exogenously determined) final demand. Together with the exogenously determined exports of goods and services (assumption 14), $\mathbf{e}(t)$, net exports of goods and service (balance of exports and imports) are calculated as:

$$\mathbf{e}_{net}(t) = \mathbf{e}(t) - \mathbf{m}(t). \tag{27}$$

Price Effects

The model solution of the quantity model presented so far includes value added and its components by sector. The value added and its coefficient have been calculated as residual variables, using the vertical input-output equation, see equation (8) and (9). All coefficients for value added components are either endogenously determined (gross wages and salaries), exogenously given (fixed capital consumption coefficients) or kept fixed on their base year values. Therefore, net operating surplus accommodates all changes in input costs and value added components to fulfil the vertical input-output equality. Accepting this procedure would amount to assuming that all changes in costs due to changes in technology and wages are translated into changes in net operating profits and commodity prices would stay the same as in the base year. In competitive markets, however cost changes will largely be passed on to buyers in the form of lower or higher prices.

To estimate this effect the Leontief price model is used. The price model assumes homogenous prices for all uses and that price changes of domestic and imported intermediate consumption goods are identical. This assumption seems more stringent as it is because prices in the context of the price model are price indices, where the prices for the base year are normalised to 1. Therefore, the assumption of homogenous prices assumes only that price changes relative to the base year must be the same in all uses. The vector of sectoral price indices $\boldsymbol{p}(t)$ is obtained as follows:

$$\boldsymbol{p}(t) = \left(\mathbf{I} - \mathbf{A}'(t)\right)^{-1} \mathbf{a}_{v\ ex}(t) \tag{28}$$

In this equation, $\mathbf{a}_{v\ ex}(t)$ is a vector of extended value added coefficients, that deserves more detailed explanation, as it is the result of two different manipulations upon the value added coefficients resulting from the quantity model above. First, it is corrected for all cost changes that are passed on to buyers in the form of higher or lower prices. This is done by replacing the net operating surplus as delivered by the solution of the quantity model by the normed net operating surplus that firms can expect under competitive conditions. This normed net operating surplus contains the compensation of self-employed labour (estimated with data on labour coefficients and hypothetical wages in an analogue manner to employed labour) and remaining net operating profits per output frozen on the value as attained in the base year of the scenario. Second, $\mathbf{a}_{v\ ex}(t)$ is augmented by the net taxes on products in order to comply with the wider concept of value added in the context of the Leontief price model.

It should be noted that using that extended value added coefficient vector together with the old prices the vertical input-output equality is not fulfilled:

$$\mathbf{a}_{v_{ex}}{}' \neq \mathbf{i}' - \mathbf{i}'\mathbf{A}_d - \mathbf{i}'\mathbf{A}_m \tag{29}$$

The purpose of the price model is to find price indices $\boldsymbol{p}(t)$ such that

$$\mathbf{a}'_{v_{ex}} = \mathbf{p}' - \mathbf{p}'\mathbf{A}_d - \mathbf{p}'\mathbf{A}_m \tag{30}$$

leading to the model as given by equation (28).

A further step in our calculations consists of a simple consumer demand model that combines the price changes found in Eq. (28) with price elasticities of private consumption to estimate the change in private consumption induced by these price changes. Let ξ denote the n-vector of our in-house estimates of price elasticities of private consumption. Then, using the private consumption vector derived from the solution of the quantity model in equation (21) as a reference value the additional private consumption due to price effects is given as

$$\Delta\mathbf{c}_d(t) = (\mathbf{c}_d(t) + \mathbf{k}_d(t))\xi\,[\boldsymbol{p}(t) - 1] \tag{31}$$

This implies a new vector of final demand which is used to solve Eq. (21) for the second time. Based on this, the final solution is obtained.

Final Solution and real versus nominal Effects

The final solution $\tilde{\mathbf{x}}'(t) = [\mathbf{x}'(t) \quad \mathbf{k}_d{}'(t) \quad b(t) \quad \mathbf{j}_d{}'(t)]$ reflects not only the effects of all exogenous variables of the first round of estimation but also the effect of additional private consumption due to fallen prices. The solution for $\mathbf{x}'(t)$ and for all use categories is in real terms, i.e., in prices of the base year. The nominal output vector is calculated by elementwise multiplication with prices, $\mathbf{p}(t) \cdot \mathbf{x}(t)$, and similarly for all vectors for use categories.

For value added and its components we proceed in a differentiated way. Rewriting equation (11), the vector of nominal gross wages and salaries by sector is given as

$$\boldsymbol{v}_b(t) = \boldsymbol{i}'(\boldsymbol{W}(t) \cdot \boldsymbol{A}_e(t))\hat{\boldsymbol{x}}(t) \tag{32}$$

Thus, the symbol $\boldsymbol{v}_b(t)$ as used in our model description denotes a nominal variable. To define gross wages and salaries as a cost component in real terms, i.e. in prices of a base year, we need to apply wages per hour of the base year:

$$\mathbf{v}_b^{real}(t) = \boldsymbol{i}'(\boldsymbol{W}(0) \cdot \boldsymbol{A}_e(t))\hat{\boldsymbol{x}}(t) \tag{33}$$

Other components of value added either do not have a price attached to them (other taxes on production, other subsidies on production) or prices are assumed to be unaffected by digitalisation (consumption of fixed capital). Therefore, for these there is no distinction between real and nominal terms.

However, value added is defined as the difference between total output and intermediate consumption at purchasers´ prices. Given the final solution for $\mathbf{x}'(t)$, value added in nominal terms is given as

$$\mathbf{v}^{nom'}(t) = \mathbf{p}'(t) \cdot \mathbf{x}'(t) - \mathbf{p}'(t)\mathbf{A}_d(t)\hat{\boldsymbol{x}}(t) - \mathbf{p}'(t)\mathbf{A}_m(t)\hat{\boldsymbol{x}}(t) - \mathbf{q}'(t) \tag{34}$$

Note that, as before, we have assumed equal price (indices) for domestic production and imports. Assuming input-output tables in real terms must also fulfil the vertical balance equation, one finds justification for calculating the real value added by sector in an analogous way, known as double deflation:

$$\mathbf{v}^{real'}(t) = \mathbf{p}'(0) \cdot \mathbf{x}'(t) - \mathbf{p}'(0)\mathbf{A}_d(t)\hat{\mathbf{x}}(t) - \mathbf{p}'(0)\mathbf{A}_m(t)\hat{\mathbf{x}}(t) - \mathbf{q}'(t) \tag{35}$$

Eq. (35) can be seen as a more explicit reformulation of Eq. (8), where, still before the application of the price model, we have implicitly assumed prices of ones, $\mathbf{p}(0) = \mathbf{i}$.

Other than as a cost component, value added and its components can be interpreted also as income. Seen from that perspective, defining real income generated by value added components requires a correction for the purchasing power of one unit of that income. Thus, real income from gross wages and salaries per sector is given as

$$\mathbf{u}_b^{real}(t) = \mathbf{v}_b^{nom}(t)/p^c(t) \tag{36}$$

Where $p^c(t)$ denotes the price index for year t defined as weighted average of commodity prices $\mathbf{p}(t)$ with consumption shares used as weights. In a similar way, the real income generated by operating surplus and mixed income can be calculated with the help of an appropriately chosen price index that considers both average consumer prices and average capital formation prices.

List of Symbols

$\mathbf{A}(t)$	Matrix of technical coefficients (or intermediate input coefficients)
a_{ij}	technical coefficient (or intermediate input coefficients), element of $\mathbf{A}$
$\mathbf{A}_b(t)$	Matrix of gross wages and salaries coefficients
$\mathbf{a}_b(t)$	Vector of gross wages and salaries coefficients by sectors
$\mathbf{A}_d(t)$	Matrix of domestic technical coefficients (or domestic intermediate input coefficients)
a_{ij}^d	domestic technical coefficient (or domestic intermediate input coefficients), element of $\mathbf{A}_d$
$\mathbf{A}_e(t)$	Matrix of employment coefficients (only employed persons)
$\mathbf{A}_l(t)$	Matrix of employment coefficients (self-employed and employed persons)
$\mathbf{a}_l(t)$	Vector of sectoral employment coefficients
$\mathbf{A}_m(t)$	Matrix of the imported input coefficients
$\mathbf{A}_q(t)$	Matrix of the coefficients of net taxes on products
$\mathbf{a}_q(t)$	Vector of the coefficients of net taxes on products
$\mathbf{a}_u(t)$	Vector of the fixed capital consumption coefficients
$\mathbf{a}_v(t)$	Vector of the value added coefficients
$\mathbf{a}_{v\ ex}(t)$	Vector of extended value added coefficients
$b(t)$	total gross wages and salaries in the whole economy
$\mathbf{c}_d(t)$	Vector of private consumption satisfied from domestic production (exogenous and endogenous parts)
c_d	Sum of private consumption satisfied from domestic production as observed in the base year
$\mathbf{e}(t)$	Vector of exports satisfied from domestic production and imports
$\mathbf{e}_d(t)$	Vector of exports satisfied from domestic production
$\mathbf{e}_{net}(t)$	Vector of net exports by sectors
$\mathbf{f}_d(t)$	Vector of final demand satisfied from domestic production
$\mathbf{g}_d(t)$	Vector of public consumption satisfied from domestic production
$\mathbf{h}_d(t)$	Vector of gross fixed capital formation satisfied from domestic production

$\mathbf{I}$	Identity matrix
$\mathbf{i}$	Vector of ones (summation vector)
i, j	Running indices of the economic sectors (branches or product groups), $i, j = 0, \ldots, n$
$\mathbf{j}_d(t)$	Vector of the endogenous part of gross fixed capital formation satisfied by domestic production
k	Running index of occupations (or occupational groups), $k = 0, \ldots, m$
$\mathbf{k}_d(t)$	Vector of the endogenous part of private consumption satisfied from domestic production
$\mathbf{L}(t)$	Employment matrix (self-employed and employed persons)
l_{kj}	Employment (self-employed and employed) of the occupation k in the economic sector j, typical element of $\mathbf{L}$
$\mathbf{L}_f(t)$	Matrix of employment of women (self-employed and employed persons)
$\mathbf{L}_{FTE}(t)$	Employment matrix in FTE (Full Time Equivalent)
$\mathbf{M}(t)$	System matrix
$\mathbf{m}(t)$	Vector of imports (intermediate goods and goods for final demand)
m	Number of occupations (or occupational groups)
n	Number of sectors (industries or commodities)
$\mathbf{o}_d(t)$	Vector summarizing the consumption of private non-profit organizations, changes in valuables and changes in inventories
$\mathbf{p}(t)$	Vector of price index
$p^c(t)$	Price index for consumer prices
$\mathbf{q}(t)$	Vector of net taxes on products by sector (balance from taxes and subsidies on products)
$\mathbf{R}_{FTE}(t)$	Matrix that specifies how many working hours in a particular sector and a specific occupation correspond to a full time equivalent (FTE)
$\mathbf{r}_c(t)$	Vector of the relations of imported to domestic goods for the private consumption
$\mathbf{r}_h(t)$	Vector of the relations of imported to domestic goods for gross fixed capital formation
$\mathbf{S}_f$	Matrix of the shares of women in occupations (or occupational groups) and sectors
$\mathbf{s}_{c_d}$	Structure of private consumption of domestic goods (vector)
$\mathbf{s}_{h_d}$	Structure of gross fixed capital formation of domestic goods (vector)
t	Time (year), running index of the investigation period; $t = 0, \ldots, T$, where 0 is the base year and $1, \ldots, T$ are the years of the projections
T	Last year of the projection period
$\mathbf{v}(t)$	Vector of value added by sectors
$\mathbf{v}_b(t)$	Vector of gross wages and salaries by sector
$\mathbf{v}_r(t)$	Vector that summarizes all value added components other than gross wages and salaries and consumption of fixed capital (i.e. residual vector)
$\mathbf{v}_u(t)$	Vector of fixed capital consumption
$\mathbf{W}(t)$	Matrix of hourly wages and salaries
$\mathbf{x}(t)$	Output vector (domestic production)
$\tilde{\mathbf{x}}(t)$	Vector, which combines $\mathbf{x}$, $\mathbf{k}_d$ and b into one vector
$\mathbf{y}_d(t)$	Vector of (the exogenous part of) final demand satisfied from domestic production
$\tilde{\mathbf{y}}_d(t)$	Vector, which combines $\mathbf{y}_d$, 0 and $\mathbf{0}$ into one vector
$\mathbf{y}_m(t)$	Vector of imports for exogenous final demand
$\mathbf{Z}_d(t)$	Matrix of domestic intermediate input flows (at basic prices)

$\mathbf{Z}_m(t)$	Matrix of imported intermediate input flows
$\mathbf{0}$	Vector or a matrix of zeros in the appropriate dimension
μ	Share of private consumption of domestic goods, which is determined by gross wages and salaries
ρ	Share of gross fixed capital formation of domestic goods, which is determined by the total output
ξ	Vector of price elasticities of private consumption

Appendix B: Detailed Results

Table B1: Economy 4.0 induced changes in employment and real gross income by gender in 2030

Change in …	Productivity-oriented wage-policy		No compensation of workers for increase in labour productivity	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Real labour productivity change (annual) between 2021-2030	0.33%	0.65%	0.33%	0.65%
Employment by female workers (in 1 000 full time equivalents)	-12.82 (-0.85%)	-62.97 (-4.16%)	-19.43 (-1.28%)	-75.38 (-4.98%)
Employment by male workers (in 1 000 full time equivalents)	-16.74 (-0.77%)	-87.37 (-4.01%)	-24.55 (-1.13%)	-102.09 (-4.68%)
Real gross income received by female employed (in billions of euros)	1.44 (2.80%)	1.31 (2.55%)	0.77 (1.50%)	-0.01 (-0.01%)
Real gross income received by male employed (in billions of euros)	2.73 (3.26%)	2.82 (3.37%)	1.42 (1.69%)	0.24 (0.29%)

Note: Percentages are given in parentheses. Changes are relative to the reference scenario without the realisation of Economy 4.0.

Table B2: Economy 4.0 induced changes in real gross value added by industries under Scenario 1

Industry	**in billions of euros**	**in %**
Products of agriculture, hunting and related services	0.05	2.38
Products of forestry, logging and related services	0.01	1.05
Fish and other fishing products; aquaculture products; …	0.00	3.14
Coal; Mineral oil and natural gas; Ores	0.00	0.45
Stones and soil; services for mining	0.00	0.04
Food products	0.13	3.55
Beverages and tobacco products	-0.19	-11.86
Textiles	0.00	0.03
Wearing apparel	-0.01	-2.87

Industry	in billions of euros	in %
Leather and related products	0.01	2.54
Wood and of products of wood and cork, except furniture; …	0.03	2.01
Paper and paper products	0.02	1.37
Printing and recording services	0.01	1.59
Coke and refined petroleum products	0.02	8.26
Chemicals and chemical products	0.07	3.02
Basic pharmaceutical products and pharmaceutical preparations	0.02	1.20
Rubber and plastics products	0.03	1.42
Other non-metallic mineral products	0.02	1.05
Basic metals	0.06	1.63
Fabricated metal products, except machinery and equipment	0.05	1.09
Computer, electronic and optical products	0.03	1.35
Electrical equipment	0.08	2.29
Machinery and equipment n.e.c.	0.12	1.83
Motor vehicles, trailers and semi-trailers	0.08	3.20
Other transport equipment	0.02	1.60
Furniture	0.00	0.08
Other manufactured goods	0.02	1.90
Repair and installation services of machinery and equipment	0.05	1.52
Electricity, gas, steam and air-conditioning	0.09	1.80
Natural water; water treatment and supply services	0.01	2.62
Sewerage; waste collection, treatment and disposal activities; …	0.06	2.22
Buildings and building construction works	0.09	1.17
Constructions and construction works for civil engineering	0.09	5.62
Specialised construction works	0.22	2.29
Wholesale and retail trade and repair services of motor vehicles and …	0.08	2.04
Wholesale trade services, except of motor vehicles and motorcycles	0.20	1.04
Retail trade services, except of motor vehicles and motorcycles	0.46	3.47
Land transport services and transport services via pipelines	0.19	2.25
Water transport services	0.00	3.49
Air transport services	0.03	5.11
Warehousing and support services for transportation	0.07	1.17
Postal and courier services	0.01	1.15
Accommodation and food services	0.68	4.27
Publishing services	0.03	2.92
Motion picture, video and television programme production …	0.01	1.51
Programming and broadcasting services	0.01	1.05
Telecommunications services	0.17	6.71
Computer programming, consultancy and related services; …	0.43	5.55
Financial services, except insurance and pension funding	0.12	1.39
Insurance, reinsurance and pension funding services	-0.03	-1.12
Services auxiliary to financial services and insurance services	0.02	1.96

Industry	in billions of euros	in %
Real estate services	1.20	3.66
Legal and accounting services	0.05	1.31
Services of head offices; management consulting services	0.04	0.74
Architectural and engineering services; technical testing and …	0.01	0.23
Scientific research and development services	0.03	0.43
Advertising and market research services	0.04	2.06
Other professional, scientific and technical services; veterinary …	0.02	1.81
Rental and leasing services	0.16	2.91
Employment services	0.13	2.88
Travel agency, tour operator and other reservation services …	-0.02	-2.98
Security and investigation services; services to buildings and ..	0.13	2.50
Public administration and defence services; compulsory social…	0.00	0.02
Education services	0.18	1.19
Human health services	0.11	0.69
Social work services	0.03	0.54
Creative, arts and entertainment services	0.04	2.17
Library, archive, museum and other cultural services	-0.01	-2.13
Sporting services and amusement and recreation services	0.02	3.86
Services furnished by membership organisations	0.00	0.00
Repair services of computers and personal and household goods	-0.02	-1.13
Other personal services	0.04	5.86
Services of households as employers; undifferentiated goods …	0.05	2.23
Services provided by extraterritorial organisations and bodies	0.01	3.67
Total	**6.04**	**1.97**

Note: Changes are relative to the reference scenario without the realisation of Economy 4.0.

Table B3: Economy 4.0 induced sectoral employment changes by gender under Scenario 1

Industry	female	male	total	
	in 1,000 FTE			in %
Products of agriculture, hunting and related services	-1.67	-2.73	-4.40	-3.55
Products of forestry, logging and related services	-0.12	-0.78	-0.90	-4.18
Fish and other fishing products; aquaculture products; …	0.00	-0.01	-0.01	-2.42
Coal; Mineral oil and natural gas; Ores	0.00	-0.01	-0.02	-2.03
Stones and soil; services for mining	-0.04	-0.12	-0.16	-4.17
Food products	-0.86	-1.25	-2.11	-3.61
Beverages and tobacco products	-0.24	-0.41	-0.66	-4.03
Textiles	-0.10	-0.25	-0.35	-4.59
Wearing apparel	-0.08	-0.14	-0.22	-4.54
Leather and related products	-0.04	-0.11	-0.16	-4.42
Wood and of products of wood and cork, except furniture; …	-0.10	-0.27	-0.37	-1.48
Paper and paper products	-0.06	-0.15	-0.21	-1.37
Printing and recording services	-0.08	-0.14	-0.22	-2.19

Industry	female	male	total	
	in 1,000 FTE			in %
Coke and refined petroleum products	0.00	0.00	0.00	-0.67
Chemicals and chemical products	-0.06	-0.15	-0.21	-2.00
Basic pharmaceutical products and pharmaceutical preparations	-0.03	-0.08	-0.12	-1.47
Rubber and plastics products	-0.13	-0.35	-0.48	-2.02
Other non-metallic mineral products	-0.18	-0.57	-0.74	-3.11
Basic metals	-0.15	-0.57	-0.72	-2.25
Fabricated metal products, except machinery and equipment	-0.27	-1.22	-1.48	-2.30
Computer, electronic and optical products	-0.04	-0.10	-0.14	-0.87
Electrical equipment	-0.04	-0.05	-0.09	-0.31
Machinery and equipment n.e.c.	-0.15	-0.46	-0.61	-0.98
Motor vehicles, trailers and semi-trailers	-0.06	-0.19	-0.26	-1.39
Other transport equipment	-0.03	-0.10	-0.14	-1.27
Furniture	-0.29	-0.68	-0.96	-3.88
Other manufactured goods	-0.11	-0.29	-0.40	-4.00
Repair and installation services of machinery and equipment	-0.06	-0.36	-0.41	-1.13
Electricity, gas, steam and air-conditioning	0.00	0.05	0.04	0.24
Natural water; water treatment and supply services	0.00	0.00	0.00	0.10
Sewerage; waste collection, treatment and disposal activities; …	-0.03	-0.04	-0.07	-0.38
Buildings and building construction works	-0.54	-2.09	-2.63	-4.50
Constructions and construction works for civil engineering	-0.03	-0.12	-0.15	-0.56
Specialised construction works	-1.16	-6.28	-7.44	-4.16
Wholesale and retail trade and repair services of motor vehicles and …	-0.09	0.00	-0.09	-0.13
Wholesale trade services, except of motor vehicles and motorcycles	-1.13	-0.89	-2.02	-1.15
Retail trade services, except of motor vehicles and motorcycles	-0.75	-0.10	-0.85	-0.30
Land transport services and transport services via pipelines	-0.60	-2.28	-2.89	-2.54
Water transport services	0.00	0.00	0.00	-1.18
Air transport services	-0.04	0.00	-0.04	-0.57
Warehousing and support services for transportation	-0.46	-0.74	-1.19	-2.81
Postal and courier services	-0.38	-0.61	-0.99	-4.63
Accommodation and food services	0.08	0.73	0.81	0.34
Publishing services	0.07	0.13	0.19	1.61
Motion picture, video and television programme production …	0.02	0.04	0.06	0.95
Programming and broadcasting services	0.02	0.02	0.04	1.05
Telecommunications services	0.17	0.48	0.65	5.98
Computer programming, consultancy and related services; …	3.16	9.77	12.92	15.85
Financial services, except insurance and pension funding	0.07	0.37	0.44	0.72
Insurance, reinsurance and pension funding services	0.12	0.21	0.33	1.38
Services auxiliary to financial services and insurance ser-	0.10	0.13	0.23	1.03

Industry	female	male	total	
	in 1,000 FTE			in %
vices				
Real estate services	-0.31	-0.06	-0.38	-0.63
Legal and accounting services	0.21	0.28	0.49	0.98
Services of head offices; management consulting services	0.80	1.40	2.20	2.60
Architectural and engineering services; technical testing and …	-0.17	-0.39	-0.56	-0.86
Scientific research and development services	0.07	-0.02	0.05	0.08
Advertising and market research services	0.13	0.34	0.47	1.44
Other professional, scientific and technical services; veterinary …	0.04	0.07	0.11	0.46
Rental and leasing services	-0.05	-0.03	-0.09	-1.01
Employment services	0.19	0.56	0.75	0.79
Travel agency, tour operator and other reservation services …	-0.05	0.01	-0.04	-0.41
Security and investigation services; services to buildings and ..	-0.87	-0.56	-1.43	-1.39
Public administration and defence services; compulsory social…	-2.24	-2.84	-5.08	-2.31
Education services	0.12	-0.23	-0.11	-0.05
Human health services	-0.87	-0.57	-1.44	-0.68
Social work services	-1.96	-0.97	-2.93	-2.29
Creative, arts and entertainment services	0.06	0.00	0.06	0.31
Library, archive, museum and other cultural services	-0.06	-0.07	-0.13	-2.37
Sporting services and amusement and recreation services	-0.05	-0.02	-0.06	-1.35
Services furnished by membership organisations	-0.22	-0.22	-0.43	-2.15
Repair services of computers and personal and household goods	-0.46	-0.35	-0.81	-2.10
Other personal services	0.09	0.30	0.39	3.27
Services of households as employers; undifferentiated goods …	-0.76	-0.63	-1.38	-2.45
Services provided by extraterritorial organisations and bodies	-0.03	0.00	-0.03	-0.59
Total	**-12.82**	**-16.74**	**-29.56**	**-0.80**

Note: Changes are relative to the reference scenario without the realisation of Economy 4.0.

Table B4: Economy 4.0 induced occupational employment changes by gender under Scenario 1

Occupation	Male	Female	Total	
	in 1,000 FTE			in %
Armed forces occupations	0.01	0.00	0.01	0.13
Chief executives, senior officials and legislators	0.29	0.05	0.34	1.36
Administrative and commercial managers	1.58	0.57	2.15	2.65
Production and specialized services managers	0.80	0.22	1.02	1.65
Hospitality, retail and other services managers	1.22	0.66	1.88	3.30
Science and engineering professionals	1.59	0.41	2.00	2.19
Health professionals	0.39	0.47	0.86	1.31

Occupation	Male	Female	Total	
	in 1,000 FTE			in %
Teaching professionals	0.69	1.48	2.16	1.18
Business and administration professionals	1.10	0.80	1.90	1.67
Information and communications technology professionals	4.71	0.46	5.18	7.96
Legal, social and cultural professionals	0.65	0.60	1.25	1.52
Science and engineering associate professionals	-1.20	-0.11	-1.31	-0.69
Health associate professionals	0.13	0.38	0.51	0.42
Business and administration associate professionals	-1.04	-1.03	-2.08	-0.63
Legal, social, cultural and related associate professionals	0.14	0.14	0.29	0.45
Information and communications technicians	1.27	0.15	1.42	3.91
General and keyboard clerks	-1.05	-4.32	-5.38	-3.05
Customer services clerks	-0.24	-0.45	-0.69	-1.38
Numerical and material recording clerks	-1.31	-1.50	-2.81	-2.59
Other clerical support workers	-0.55	-0.35	-0.90	-3.54
Personal service workers	-1.41	-1.63	-3.04	-1.34
Sales workers	-1.49	-3.03	-4.52	-1.76
Personal care workers	-0.12	-0.62	-0.74	-0.86
Protective services workers	-0.56	-0.13	-0.69	-2.11
Market-oriented skilled agricultural workers	-3.14	-1.91	-5.05	-3.32
Market-oriented skilled forestry, fishery and hunting workers	-0.61	0.00	-0.61	-5.52
Building and related trades workers, excluding electricians	-5.75	-0.18	-5.92	-3.68
Metal, machinery and related trades workers	-3.38	-0.11	-3.50	-2.06
Handicraft and printing workers	-0.51	-0.17	-0.68	-3.32
Electrical and electronics trades workers	-0.21	-0.01	-0.22	-0.30
Food processing, wood working, garment and other craft and related trades workers	-2.23	-0.84	-3.07	-3.91
Stationary plant and machine operators	-1.63	-0.43	-2.07	-3.53
Assemblers	-0.32	-0.20	-0.52	-2.50
Drivers and mobile plant operators	-2.23	-0.09	-2.32	-1.46
Cleaners and helpers	-0.17	-1.04	-1.21	-1.14
Agricultural, forestry and fishery labourers	-0.07	-0.03	-0.11	-2.90
Labourers in mining, construction, manufacturing and transport	-1.64	-0.53	-2.17	-2.36
Food preparation assistants	-0.15	-0.42	-0.56	-2.13
Street and related sales and service workers	-0.01	0.00	-0.01	-1.02
Refuse workers and other elementary workers	-0.30	-0.06	-0.36	-1.94
Total	**-16.74**	**-12.82**	**-29.56**	**-0.80**

Note: Changes are relative to the reference scenario without the realisation of Economy 4.0.

Table B5: Economy 4.0 induced sectoral changes of real gross income of employed by gender under Scenario 1

Industry	female	male	total	
	in millions of euros			in %

Industry	female	male	total	
	in millions of euros			in %
Products of agriculture, hunting and related services	1.06	3.50	4.56	2.14
Products of forestry, logging and related services	0.23	1.97	2.21	1.07
Fish and other fishing products; aquaculture products; …	0.02	0.08	0.1	2.98
Coal; Mineral oil and natural gas; Ores	0.18	0.77	0.96	1.49
Stones and soil; services for mining	-0.09	1.81	1.73	0.94
Food products	10.43	37.89	48.32	2.57
Beverages and tobacco products	0.95	4.39	5.34	1.55
Textiles	0.36	2.82	3.18	1.15
Wearing apparel	0.25	1.84	2.09	1.43
Leather and related products	0.28	1.50	1.78	1.77
Wood and of products of wood and cork, except furniture; …	2.10	11.32	13.41	1.51
Paper and paper products	2.03	9.88	11.91	1.54
Printing and recording services	1.20	4.79	5.99	1.36
Coke and refined petroleum products	0.39	1.19	1.58	2.46
Chemicals and chemical products	1.40	8.76	10.16	1.38
Basic pharmaceutical products and pharmaceutical preparations	1.73	5.61	7.33	1.40
Rubber and plastics products	2.79	12.66	15.45	1.49
Other non-metallic mineral products	1.75	12.57	14.32	1.29
Basic metals	2.97	19.82	22.79	1.33
Fabricated metal products, except machinery and equipment	4.85	29.12	33.97	1.26
Computer, electronic and optical products	2.42	10.27	12.69	1.49
Electrical equipment	7.26	28.4	35.67	2.35
Machinery and equipment n.e.c.	9.15	46,00	55.14	1.73
Motor vehicles, trailers and semi-trailers	1.66	9.89	11.55	1.27
Other transport equipment	1.30	6.20	7.51	1.50
Furniture	1.62	8.36	9.98	1.31
Other manufactured goods	1.53	-0.46	1.07	0.25
Repair and installation services of machinery and equipment	5.60	28.03	33.63	1.81
Electricity, gas, steam and air-conditioning	7.14	39.97	47.11	3.56
Natural water; water treatment and supply services	0.46	3.94	4.40	3.62
Sewerage; waste collection, treatment and disposal activities; …	6.16	20.30	26.46	3.45
Buildings and building construction works	4.74	27.36	32.11	1.29
Constructions and construction works for civil engineering	10.69	66.8	77.48	5.18
Specialised construction works	9.42	92.95	102.37	1.88
Wholesale and retail trade and repair services of motor vehicles and …	24.24	60,00	84.24	3.87
Wholesale trade services, except of motor vehicles and motorcycles	59.24	143.71	202.95	2.55
Retail trade services, except of motor vehicles and motorcycles	166.36	154.16	320.52	4.42
Land transport services and transport services via pipelines	11.21	81.63	92.83	2.65
Water transport services	0.07	0.23	0.30	3.30

Industry	female	male	total	
	in millions of euros			in %
Air transport services	3.16	14.48	17.64	5.10
Warehousing and support services for transportation	10.33	40.12	50.45	2.28
Postal and courier services	3.86	10.98	14.84	1.77
Accommodation and food services	143.17	147.39	290.55	4.73
Publishing services	8.29	14.31	22.60	3.49
Motion picture, video and television programme production …	1.42	2.56	3.97	2.72
Programming and broadcasting services	3.72	3.86	7.58	2.33
Telecommunications services	14.32	49.09	63.41	7.87
Computer programming, consultancy and related services; …	172.56	553.66	726.21	18.13
Financial services, except insurance and pension funding	52.40	90.05	142.45	3.39
Insurance, reinsurance and pension funding services	28.30	43.02	71.32	4.31
Services auxiliary to financial services and insurance services	9.70	10.40	20.10	3.84
Real estate services	29.57	43.19	72.76	4.28
Legal and accounting services	22.80	24.72	47.52	3.33
Services of head offices; management consulting services	57.83	125.33	183.16	5.06
Architectural and engineering services; technical testing and …	7.71	35.28	42.99	1.95
Scientific research and development services	29.11	68.35	97.46	2.49
Advertising and market research services	8.28	18.32	26.6	3.65
Other professional, scientific and technical services; veterinary …	2.87	6.00	8.87	3.72
Rental and leasing services	3.91	8.97	12.87	3.26
Employment services	54.62	81.56	136.18	4.15
Travel agency, tour operator and other reservation services …	5.33	10.37	15.70	4.25
Security and investigation services; services to buildings and ..	42.47	48.84	91.31	3.28
Public administration and defence services; compulsory social…	24.91	54.69	79.61	0.81
Education services	154.00	77.20	231.20	2.26
Human health services	92.56	49.07	141.63	1.71
Social work services	37.42	24.66	62.09	1.58
Creative, arts and entertainment services	8.78	9.80	18.58	3.61
Library, archive, museum and other cultural services	1.78	2.94	4.72	2.15
Sporting services and amusement and recreation services	4.57	6.92	11.49	4.64
Services furnished by membership organisations	5.49	8.14	13.63	2.82
Repair services of computers and personal and household goods	4.84	10.69	15.53	0.99
Other personal services	3.83	12.04	15.87	7.06
Services of households as employers; undifferentiated goods …	14.67	17.32	31.99	3.84
Services provided by extraterritorial organisations and bod-	3.20	4.28	7.48	4.88

Industry	female	male	total	
	in millions of euros			in %
ies				
Total	**1,436.94**	**2,728.60**	**4,165.54**	**3.09**

Note: Changes are relative to the reference scenario without the realisation of Economy 4.0.

Table B6: Economy 4.0 induced sectoral changes of real gross income of employed by gender under Scenario 1

Occupation	Male	Female	Total	
	in millions of euros			in %
Armed forces occupations	0.00	16.20	16.20	3.17
Chief executives, senior officials and legislators	14.38	72.93	87.30	4.85
Administrative and commercial managers	85.76	265.63	351.39	6.22
Production and specialized services managers	35.59	152.86	188.45	4.91
Hospitality, retail and other services managers	21.80	58.05	79.86	7.44
Science and engineering professionals	45.96	198.59	244.55	5.37
Health professionals	50.57	42.30	92.87	3.31
Teaching professionals	197.12	88.46	285.59	3.12
Business and administration professionals	95.86	142.01	237.86	4.86
Information and communications technology professionals	35.64	301.79	337.43	10.25
Legal, social and cultural professionals	67.45	64.07	131.51	4.23
Science and engineering associate professionals	18.38	284.44	302.82	3.31
Health associate professionals	95.43	27.63	123.06	2.64
Business and administration associate professionals	181.50	194.24	375.73	2.86
Legal, social, cultural and related associate professionals	36.70	30.64	67.34	3.69
Information and communications technicians	10.74	90.43	101.16	6.43
General and keyboard clerks	23.96	6.24	30.19	0.48
Customer services clerks	28.95	19.94	48.90	2.08
Numerical and material recording clerks	24.72	21.18	45.90	1.02
Other clerical support workers	3.36	4.58	7.94	0.87
Personal service workers	86.89	97.41	184.30	3.24
Sales workers	127.15	65.08	192.23	2.82
Personal care workers	31.29	5.82	37.11	1.44
Protective services workers	2.33	11.11	13.44	1.08
Market-oriented skilled agricultural workers	1.99	8.49	10.47	1.79
Market-oriented skilled forestry, fishery and hunting workers	-0.04	-0.15	-0.19	-0.16
Building and related trades workers, excluding electricians	1.25	60.16	61.40	1.27
Metal, machinery and related trades workers	1.84	86.03	87.87	1.34
Handicraft and printing workers	0.48	2.22	2.70	0.37
Electrical and electronics trades workers	2.35	53.59	55.94	1.70
Food processing, wood working, garment and other craft and related trades workers	4.17	15.77	19.94	0.92
Stationary plant and machine operators	2.26	10.92	13.18	0.57

Occupation	Male	Female	Total	
	in millions of euros			in %
Assemblers	1.40	4.73	6.13	0.77
Drivers and mobile plant operators	3.85	162.44	166.29	3.20
Cleaners and helpers	69.78	9.55	79.32	2.88
Agricultural, forestry and fishery labourers	0.08	0.46	0.54	0.86
Labourers in mining, construction, manufacturing and transport	13.54	45.93	59.46	2.09
Food preparation assistants	12.07	4.96	17.03	2.29
Street and related sales and service workers	0.00	0.01	0.01	0.10
Refuse workers and other elementary workers	0.39	1.89	2.28	0.43
Total	**1,436.94**	**2,728.60**	**4,165.54**	**3.09**

Note: Changes are relative to the reference scenario without the realisation of Economy 4.0.