Self-declaration of the notoriety act
Art. 47 D.P.R. 445 del 28 December 2000

With regard to the publication: “Automation technologies and the risk of substitution of women: Can gender euqality in the institutional context reduce the risk”, published in Technological Forecasting and Social Change, Volume 191, June 2023, n. 122528, Online ISSN: 1873-5509, Print ISSN: 0040-1625,

Emilia Filippi, Mariasole Bannò, and Sandro Trento

DECLARE

under their personal responsibility that the article is the outcome of their common considerations. Specifically:

1. Introduction is attributable to Mariasole Bannò and Sandro Trento

2. Literature review
2.1 The impact of automation on women is attributable to Emilia Filippi
2.2 The influence of the institutional context in terms of gender equality is attributable to Mariasole Bannò

3. Hypothesis development is attributable to Emilia Filippi and Mariasole Bannò

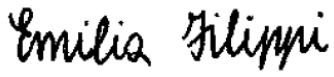
4. Empirical setting
4.1 Data is attributable to Emilia Filippi
4.2 Method is attributable to Emilia Filippi and Mariasole Bannò
4.3 Variable definition is attributable to Emilia Filippi

5. Empirical analysis
5.1 Descriptive statistics is attributable to Emilia Filippi
5.2 The risk of substitution faced by workers is attributable to Emilia Filippi
5.3 Econometric results is attributable to Emilia Filippi and Mariasole Bannò

6. Discussions, implications and limitations is attributable to Emilia Filippi, Mariasole Bannò and Sandro Trento

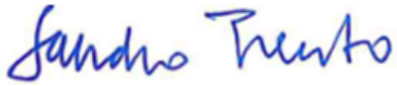
7. Conclusion is attributable to Sandro Trento

Emilia Filippi



Mariasole Bannò

Sandro Trento



Technological Forecasting & Social Change 191 (2023) 122528

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Automation technologies and the risk of substitution of women: Can gender equality in the institutional context reduce the risk?

Emilia Filippi [a,*], Mariasole Bannò [b], Sandro Trento [c]

[a] Doctoral School of Social Sciences, University of Trento, Via Verdi, 26, 38122 Trento, Italy
[b] Department of Mechanical and Industrial Engineering, University of Brescia, Via Branze, 38, 25121 Brescia, Italy
[c] Department of Economics and Management, University of Trento, Via Inama, 5, 38122 Trento, Italy

ARTICLE INFO

Keywords:
Probability of automation
Risk of substitution
Gender
Institutional context
Gender equality

ABSTRACT

This study investigates how the institutional context in terms of gender equality (in general and in the education and work components) affects the risk of substitution faced by European women, i.e., their risk of being replaced by automation technologies. To this aim, the risk of substitution is estimated by applying the task-based approach and by considering which skills cannot be automated (i.e., perception and manipulation, creative intelligence, and social intelligence). Then, the influence of the institutional context on the risk of substitution is evaluated. European women face a slightly lower risk of substitution than men (0.5755 versus 0.5816). In institutional contexts where gender equality is high, women and men face a higher risk of substitution, but the gender gap in this risk increases in favour of women, who face a significantly lower risk than men. Since automation reduces the general gap women face in society and gender equality in the institutional context contributes to reducing this gap, European policies should promote gender equality in the institutional context to foster a narrower gender gap following the adoption of automation technologies.

1. Introduction

Automation technologies (i.e., artificial intelligence, big data analytics, and industrial robots) are among the main factors that have contributed to the recent radical transformation of the world of work (Cortes and Pan, 2019; Spencer, 2018). These technologies have caused shifts in the occupational structure, the place and timing of work, and career patterns (Brussevich et al., 2019). Exponential advances in automation technologies have also enabled the performance of a wide range of work activities and thus the potential replacement of workers, both women and men, in a growing number of occupations (Blanas et al., 2019; Filippi et al., 2023; Wajcman, 2017).

Much research has been done concerning the consequences of automation technologies on work including the estimation of the risk of substitution faced by workers (probability of automation of occupations), i.e., the extent to which machines can substitute workers in performing the work activities that constitute the occupation (Cortes and Pan, 2019; Frey and Osborne, 2017). However, limited attention has been paid to how the impact of automation, and specifically the risk of being replaced by machines, differ between women and men (Rodriguez-Bustelo et al., 2020) and the few existing studies on the issue have yielded conflicting results. In Europe and the United States, women face a lower risk of substitution compared to men (Mason, 2021; Pouliakas, 2018) whereas in OECD countries and Latin America, it is women who face a greater risk (Egana-delSol et al., 2021; Nedelkoska and Quintini, 2018). According to previous studies, women and men face a different risk of substitution as they perform different occupations and work activities even within the same occupation (Cortes and Pan, 2019). We contend that the institutional context in terms of gender equality may contribute explaining the different risk of substitution faced by women and men. Understanding how automation will affect women and which is the influence of the institutional context in terms of gender equality is of paramount importance and many international organisations (e.g., the United Nations, the International Labour Organization, and the World Bank) have raised concerns about how the current digital transformation impacts women (Delgado Cadena, 2020). Automation technologies are transforming society and may impact women and men differently (Madgavkar et al., 2019; Roberts et al., 2019). Specifically, in the future women may face complex challenges that will add to the existing gaps (Delgado Cadena, 2020).

This study addresses this issue by developing a gender perspective on automation, considering how technological developments interact with

* Corresponding author.
E-mail addresses: emilia.filippi@unitn.it (E. Filippi), mariasole.banno@unibs.it (M. Bannò), sandro.trento@unitn.it (S. Trento).

https://doi.org/10.1016/j.techfore.2023.122528
Received 2 July 2022; Received in revised form 4 February 2023; Accepted 16 March 2023
0040-1625/© 2023 Elsevier Inc. All rights reserved.

existing social inequalities, gendered barriers and gender segregation patterns in the labour market. Specifically, this study aims to answer the following questions:

- Are European women more at risk of being substituted by automation technologies than European men?
- How does the institutional context in terms of gender equality affect the risk of substitution faced by European women?
- What is the role of gender equality in education and in the labour market in relation to the impact of automation technologies on women?

To answer these questions, we assume that in principle women and men face the same risk of substitution. However, the level of gender equality in the institutional context may result in women and men doing different work activities (with different probability of automation) so that when the level of gender equality is low, women may be relegated to perform automatable work activities and thus face a higher risk of substitution than men. Regarding the method, first, the probability of automation of European occupations is estimated by applying the task-based approach, i.e., assuming that work activities instead of entire occupations can be automated (Arntz et al., 2016). Then, the influence of the institutional context in terms of gender equality (in general and in the education and work components) on the risk of substitution faced by women is evaluated. The analysis is based on the European Skills and Jobs Survey (ESJS) database for 2014 and considers about 49,000 adult workers (24–65 years). It emerges that overall, women face a slightly lower risk of substitution than men: the average risk is 0.5760 for women and 0.5835 for men. Therefore, contrary to the majority of studies stating that automation will have more negative effects on women (e.g., Brussevich et al., 2019; Delgado Cadena, 2020; García-Holgado et al., 2019; Nedelkoska and Quintini, 2018; Shook and Knickrehm, 2018), in Europe automation technologies have a small favourable impact on women than on men. In institutional contexts where gender equality is high, women and men face a higher risk of substitution, but the gender gap in this risk increases in favour of women, who face a significantly lower risk than men. In institutional contexts with high gender equality, women face less stereotypes, discrimination, structural barriers and socially constructed disadvantages in education and in the labour market. Thus, women can acquire non-automatable skills and enter occupations with a lower probability of automation. Gender equality in education (specifically, the level of attainment and participation and the level of segregation) and work (specifically, the level of participation and the level of segregation and quality of work) has a similar effect. Since automation reduces the general gap women face in society and gender equality in the institutional context contributes to reducing this gap, European policies should promote gender equality in the institutional context to foster a narrower gender gap following the adoption of automation technologies. Depending on the level of gender equality in education and the labour market, varying priorities can be given to the two dimensions of gender equality.

This study contributes to the literature on the automation of occupations in two ways. First, it considers a gender perspective on the issue, which has almost been neglected. To our knowledge, this study is the first to analyse the gender dimension of automation in Europe, which is characterised by significant and different gender gaps depending on the country. By applying the task-based approach, the risk of substitution for European workers is estimated and then the gender gap in the average risk of substitution is evaluated. To our knowledge, no other study has applied the task-based approach to Europe with a gender perspective.

Second, previous studies have analysed the consequences of automation without considering the level of gender equality in the institutional context. This research gap exists although the literature is unanimous in stating that gender equality has important consequences for women: it affects the discrimination and structural barriers faced by women and their ability to access valuable opportunities, realize their potential, access all occupations and avoid gender gaps in the tasks performed (Mikkola and Miles, 2007; Morais Maceira, 2017; Piasna and Drahokoupil, 2017). Moreover, it has been observed that women have lower participation rates in the labour market, are employed in different occupations and sectors, earn lower wages, and are less present in management positions than men (Egana-delSol et al., 2021) and all these aspects have important consequences that depend on the institutional context (and its level of gender equality) in which women work. Since European countries are characterised by different levels of gender equality, the aforementioned aspects have different consequences among European countries. Again, this study is the first one considering this issue not only in reference to Europe but also worldwide.

This research has also policy and managerial implications. Identifying the differences in the impact of automation on specific groups of workers and in specific contexts will inform the design of policies that improve the conditions of groups that are expected to be negatively impacted by technological change and that are devised taking into account the characteristics of each context. Specifically, the results of this study offer a preliminary indication of the direction to be taken to close gender disparity at the employment level. Alternatively, at the firm level, some interventions must be designed to close the gender disparity in the institutional context. Policy and managerial implications will be further discussed at the end of the study.

The remaining part of the paper is structured as follows. Section 2 reviews previous literature regarding the impact of automation on women and explains the role of the institutional context in terms of gender equality. Section 3 is devoted to hypothesis development. Section 4 describes the empirical setting of the analysis and specifically the data used, the method adopted, and the variables' definition. Section 5 presents the descriptive statistics, the results on the risk of substitution faced by women and men (probability of automation of occupations), and the results regarding the influence of the institutional context. Section 6 is devoted to discussing the results, their implications and the limitations of the study. Section 7 concludes.

2. Literature review

2.1. The impact of automation on women

The few existing studies analysing how automation will impact the work performed by women and men report conflicting results. According to most studies, automation will have more negative effects on women for several reasons. First, the larger impact on women is due to their underrepresentation both in the employment in fastest-growing sectors of STEM (Science, Technology, Engineering, and Mathematics) and in education in STEM fields (Delgado Cadena, 2020; Shook and Knickrehm, 2018).[1] This evidence has been confirmed by García-Holgado et al. (2019), according to which the scarce presence of women in science and technology sectors represents a disadvantage and could massively expel women from the labour market. A second reason for the negative impact of automation on women is linked to the adoption of automation technologies to perform simple routine tasks, which are mainly performed by women (Delgado Cadena, 2020). Only a few studies found that automation will have a smaller impact on women (Pampliega, 2019).

Conflicting results have also emerged from studies estimating the risk of substitution faced by women and men in different countries. In European countries and the United Kingdom, women face a lower risk of substitution because they tend to carry out non-automatable tasks (Pouliakas, 2018). At the same time, men usually perform automatable tasks and occupations with a higher probability of automation

[1] This occurs despite women being educated in various fields (Delgado Cadena, 2020).

Table 1
Summary of the countries in which women face a lower or higher risk of substitution than men.

Risk of substitution faced by women	Country	Authors
Women face a lower risk of substitution than men	European countries and the United Kingdom	Pouliakas (2018)
	Italy	Bannò et al. (2021)
	Mexico	Ramos et al. (2022)
	Norway	Pajarinen et al. (2015)
	Slovakia	Vitáloš (2019)
	United States	Mason (2021)
Women face a higher risk of substitution than men	ASEAN-5 (Cambodia, Indonesia, the Philippines, Thailand and Viet Nam)	Chang and Huynh (2016)
	Austria	Haiss et al. (2021)
	Brazil	Lima et al. (2021)
	China	Zhou et al. (2020)
	Latin America (Bolivia, Chile, Colombia, El Salvador)	Egana-delSol et al. (2021)
	OECD countries	Nedelkoska and Quintini (2018)
	Singapore	Fuei (2017)
Women and men face a nearly identical risk of substitution	Canada	Frenette and Frank (2020)
	Finland	Pajarinen et al. (2015)
	Hungary	Illéssy et al. (2021)
	Japan	David (2017)

Source: Our elaboration.

(Pouliakas, 2018). Women face a lower risk of substitution also in Italy (Bannò et al., 2021), Mexico (Ramos et al., 2022), Norway (Pajarinen et al., 2015), Slovakia (Vitáloš, 2019), and the United States (Mason, 2021). Instead, in OECD countries, women face a higher risk of substitution since they perform more automatable tasks despite being more active in occupations with a lower probability of automation (Nedelkoska and Quintini, 2018). Women do not carry out tasks requiring non-automatable skills such as analytical input and abstract thinking (e.g., processing of information) (Brussevich et al., 2019). Similarly, in Latin America (specifically, Bolivia, Chile, Colombia, and El Salvador) women are more at risk of substitution as tasks requiring non-automatable skills (e.g., problem-solving tasks, communication, management, tasks regarding information and communications technology, and tasks related to STEM disciplines) are usually performed by men (Egana-delSol et al., 2021). Women face a greater risk of substitution also in the ASEAN-5 (Cambodia, Indonesia, the Philippines, Thailand and Viet Nam) (Chang and Huynh, 2016), Austria (Haiss et al., 2021), Brazil (Lima et al., 2021), China (Zhou et al., 2020), and Singapore (Fuei, 2017). Finally, men and women face nearly identical risk of substitution in Canada (Frenette and Frank, 2020), Finland (Pajarinen et al., 2015), Hungary (Illéssy et al., 2021), and Japan (David, 2017).

Table 1 summarises the countries where women face a lower or higher risk of substitution than men.

Summarising, previous literature suggests that the risk of substitution faced by women is influenced by the type of occupation and the tasks performed. However, we contend that since women face a lower risk of substitution than men in some countries while in others the opposite is true, the institutional context in terms of gender equality may play a role.

2.2. *The influence of the institutional context in terms of gender equality*

Gender equality is a complex concept (Beer, 2009) and can be understood in a formal and substantive way (Subrahmanian, 2005). Formal gender equality is expressed in "attitudes, beliefs, behaviors and policies that reflect an equal valuing and provision of opportunities for both genders" (Mikkola and Miles, 2007, p. 6). This means that formal gender equality is the equality stemming from the consideration of men and women as the same (Subrahmanian, 2005). Instead, gender inequality implies an unequal power relation or hierarchical gender relation in which men are above women so that women are considered inferior and less valued due to their gender and not due to their merit (Kaushik et al., 2014; Mikkola and Miles, 2007). Substantive gender equality starts from the consideration that women face some socially constructed disadvantages and are thus constrained in many ways (Subrahmanian, 2005). For example, women may be subjected to common stereotyping practices, which cause discrimination and/or structural barriers against them (Byrne and Fayolle, 2010; Eagly and Karau, 2002). Moreover, society may invest and allocate resources in an unequal way to women and men (Subrahmanian, 2005) and as a consequence women may have fewer opportunities (Ahl, 2006). In some cases, even when having access to opportunities, women may be unable to take full advantage of them because of discrimination (Subrahmanian, 2005).

Gender equality is a multidimensional concept, which can be evaluated using three domains: capabilities, which refer for example to education and health; opportunities, which regard the access to resources (e.g., credit, property, and labour market); and empowerment, namely the degree of women representation in deliberative bodies (e.g., legislature and board of directors) (Beer, 2009). Gender equality in education and work is particularly relevant to this study.

In many European countries, women are more educated than men and the economic conditions for women regarding occupation and earnings have improved in recent years (Castellano and Rocca, 2018). Despite these improvements, some issues still need to be addressed. Regarding education, structural inequalities, discrimination and gender stereotypes are still present (Blaskó et al., 2022) and, as a consequence, women are not able to realize their full potential (Morais Maceira, 2017; UNESCO, 2022). Similarly, in the labour markets gender inequality persists in terms of opportunities, participation and security (Castellano and Rocca, 2018). For example, women face gender gaps in the tasks carried out, segregation by gender regarding occupations, barriers in accessing some occupations and other types of disadvantages (Cortes and Pan, 2019; Morais Maceira, 2017; Piasna and Drahokoupil, 2017). Women may thus be employed in lower-paying jobs (Verheul and Thurik, 2001) and be confined to unrecognised vital tasks (Delgado Cadena, 2020).

Gender equality in education and gender equality in work are linked. Greater education and higher gender equality in education increase gender equality in the labour market reducing, for example, occupational gender segregation (Stier and Herzberg-Druker, 2017). Similarly, gender inequality in education translates into gender inequality in the labour market (Stier and Herzberg-Druker, 2017). Despite there has been a decline in gender segregation in some fields of study and women are increasingly working in male-dominated professions (Stier and Herzberg-Druker, 2017), old stereotypes may still induce women to choose fields of study that lead to less profitable careers (Castellano and Rocca, 2018). Moreover, despite education is generally associated with better opportunities (Hout, 2012), the higher education attained by women does not always lead to better career prospects: women are required to have a higher level of education than men to obtain certain jobs and face disparities in power (UNESCO, 2012).

3. Hypothesis development

We contend that the level of gender equality in the institutional context may influence the impact of automation technologies on women, including the risk of substitution they face.

As seen in Section 2, gender equality enables women to have the same opportunities as men and take full advantage of them (Mikkola and Miles, 2007). The reason is that in gender-equal institutional contexts,

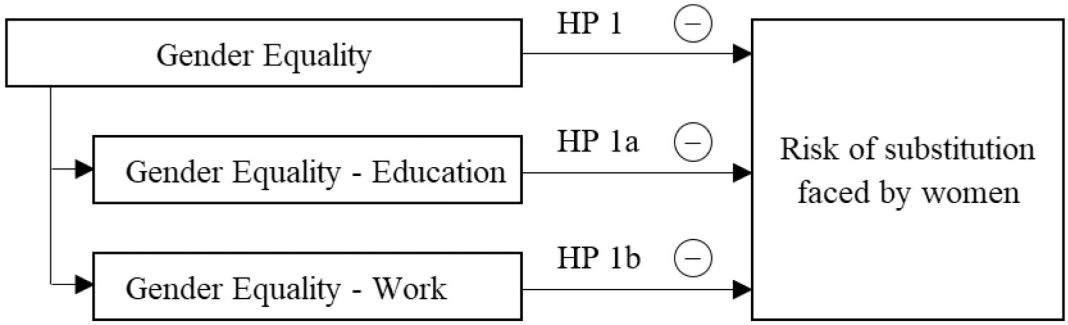


Fig. 1. Theoretical framework.

Table 2
Automatable and non-automatable occupations.

Automatable occupations	Non-automatable occupations
Business and administration associate professionals	Building and related trades workers, excluding electricians
Business and administration professionals	Chief executives, senior officials and legislators
Customer services clerks	Cleaners and helpers
Drivers and mobile plant operators	Health associate professionals
Food preparation assistants	Health professionals
General and keyboard clerks	Legal, social and cultural professionals
Numerical and material recording clerks	Legal, social, cultural and related associate professionals
Sales workers	Personal care workers
Science and engineering associate professionals	Personal service workers
	Science and engineering professionals
	Teaching professionals

Source: Our elaboration based on Frey and Osborne (2017).

women face less stereotypes, discrimination, structural barriers and socially constructed disadvantages (Byrne and Fayolle, 2010; Eagly and Karau, 2002; Subrahmanian, 2005). Gender equality in education and work are similarly important. Gender equality in education enables women to realize their potential (Morais Maceira, 2017; UNESCO, 2022), while gender equality in the labour market ensures that women have access to all occupations and do not face gender gaps in the tasks performed (Piasna and Drahokoupil, 2017; Stier and Herzberg-Druker, 2017). Concerning automation and its impacts on workers, gender equality enables women to acquire all relevant skills, including those that machines cannot automate: perception and manipulation, creative intelligence, and social intelligence (Arntz et al., 2016; Frey and Osborne, 2017). Thanks to this, women can enter occupations with a lower probability of automation.

On the contrary, gender inequality reduces the opportunities available to women (Ahl, 2006) due to stereotypes and structural barriers (Byrne and Fayolle, 2010; Eagly and Karau, 2002). Thus, women cannot acquire the same skills as men and cannot access some occupations. Concerning automation and its impacts on workers, gender inequality impedes women from developing the skills that machines cannot automate. Women are thus forced into low-skilled occupations that can be easily automated or, if employed in medium- or high-skilled occupations, are relegated to performing many routine tasks, exposing them to a higher risk of substitution.

Based on the above, the following hypotheses are advanced:

Hypothesis 1. A greater gender equality in the institutional context reduces the risk of substitution faced by women.

Hypothesis 1a. A greater gender equality in education in the institutional context reduces the risk of substitution faced by women.

Hypothesis 1b. A greater gender equality in work in the institutional context reduces the risk of substitution faced by women.

The theoretical framework shown in Fig. 1 is proposed based on the analysis.

4. Empirical setting

4.1. Data

Two sources of data are used to analyse how the institutional context in terms of gender equality (in general and in the education and work components) influences the risk of substitution faced by women.

The European Skills and Jobs Survey (ESJS) for 2014 is used to estimate the risk of substitution faced by workers (probability of automation of occupations). The ESJS is developed by the European Centre for the Development of Vocational Training (Cedefop) with experts, the OECD, and Eurofound (Cedefop, 2015). It is a survey of about 49,000 adult workers (24–65 years) employed in different occupations and sectors in the 27 European countries and the United Kingdom. It aims to inform European policies concerning employment, education and training. Information contained in the ESJS regards aspects such as the socio-demographic characteristics of the worker (e.g., age, gender, and education), job characteristics (e.g., firm dimension and type of contract), job-skill requirements (e.g., cognitive and manual skills), skill mismatches (e.g., skill gaps), participation in training and its reason, labour market outcomes (e.g., wage, job satisfaction, and job insecurity).

The Gender Equality Index for 2015 is used to evaluate the level of gender equality in the 27 European countries and the United Kingdom. The index is provided by the European Institute for Gender Equality (EIGE), an autonomous body of the European Union to promote gender equality and fight against gender discrimination. The index consists of six components (i.e., work, money, knowledge, time, power, and health) and two additional domains (i.e., violence against women and intersecting inequalities), thus offering a comprehensive measure of gender equality. The index ranges from 0 to 100, with higher values denoting higher gender equality. The index aims to inform policy makers to design effective gender equality policies.

4.2. Method

The method adopted consists of two steps. In the first one, the risk of substitution faced by workers (probability of automation of occupations) is estimated. In the second one, it is examined how the institutional context in terms of gender equality (in general and in the education and work components) influences the risk of substitution faced by women.

To estimate the risk of substitution, two main approaches can be applied. According to the occupation-based approach, whole occupations can be automated. This approach has been criticised for two main reasons: first, tasks and not entire occupations are usually automated (Arntz et al., 2016; Bessen et al., 2020); second, within an occupation, tasks performed by workers vary considerably (Autor and Handel,

Table 3
Variables corresponding to non-automatable skills.

Technical limitations to total automation	Variables	ESJS definition
Perception and manipulation	Technical skills	e.g., Specialist knowledge needed to perform job duties; Knowledge of particular products or services; Ability of operating specialised technical equipment
Creative intelligence	Autonomous tasks	Choosing yourself the way in which you do your work
	Learning skills	e.g., Learning and applying new methods and techniques in your job; adapting to new technology, equipment or materials; Engaging in own learning
	Learning tasks	Learning new things
	Non-routine tasks	Responding to non-routine situations during the course of your daily work
	Problem solving skills	e.g., Thinking of solutions to problems; Spotting and working out the cause of problems
Social intelligence	Communication skills	e.g., Sharing information with co-workers/clients; Teaching and instructing people; Making speeches or presentations
	Customer handling skills	e.g., Selling a product/service; Dealing with people; Counselling, advising or caring for customers or clients
	Foreign language skills	e.g., Using a language other than your mother tongue to perform job duties
	Planning and organisation skills	e.g., Setting up plans and managing duties according to plans; Planning the activities of others; Delegating tasks; Organising own or other's work time
	Team-working skills	e.g., Cooperating and interacting with co-workers; Dealing and negotiating with people

Source: Our elaboration based on Pouliakas (2018) and European Skills and Jobs Survey.

Table 4
Description and sources of variables used to estimate the risk of substitution (probability of automation of occupations).

Variable name	Variable definition	Source
Perception and manipulation		
Technical skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS
Creative intelligence		
Autonomous tasks	Categorical variable describing the frequency of this task, with 1 = "Never", 2 = "Sometimes", 3 = "Usually", and 4 = "Always"	ESJS
Learning skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS
Learning tasks	Categorical variable describing the frequency of this task, with 1 = "Never", 2 = "Sometimes", 3 = "Usually", and 4 = "Always"	ESJS
Non-routine tasks	Categorical variable describing the frequency of this task, with 1 = "Never", 2 = "Sometimes", 3 = "Usually", and 4 = "Always"	ESJS
Problem solving skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS
Social intelligence		
Communication skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS
Customer handling skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS
Foreign language skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS
Planning and organisation skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS
Team-working skills	Categorical variable describing the importance of the skill, with 0 = "Not at all important", 5 = "Moderately important", and 10 = "Essential"	ESJS

Source: ESJS database.

2013). Alternatively to the occupation-based approach, the task-based approach can be applied, according to which work activities instead of entire occupations can be automated.

In this study, the risk of substitution faced by workers is estimated by applying the task-based approach and by following the methodologies proposed by Frey and Osborne (2017) and by Nedelkoska and Quintini (2018). In line with the studies just mentioned, an estimate of the overall probability of automation at the occupation level will be produced, which will describe the risk of substitution faced by the worker.

The methodology starts by constructing a training set by assigning to some occupations a dummy variable equal to 1 if they can be automated and 0 otherwise. Labelled occupations are based on those considered by Frey and Osborne (2017). Some examples are provided in Table 2.

In estimating the risk of substitution, it is necessary to consider which tasks cannot be automated with existing machines. Despite recent progress in automation technologies enabling more tasks to be automated than in the past, there are still three *Engineering bottlenecks* that prevent the automation of some non-routine tasks (Frey and Osborne, 2017). These technical limitations are linked to three capabilities that only humans currently possess: perception and manipulation, which is the ability to handle objects and orient oneself in complex situations; creative intelligence, defined as the ability to produce new and valuable ideas; and social intelligence, i.e., the ability to respond to a person in an empathetic and intelligent way (Arntz et al., 2016; Frey and Osborne, 2017). Since the tasks requiring these skills will not be automatable in the next two decades, the probability of automation of an occupation can be estimated considering the importance of these capabilities in performing the occupation (Frey and Osborne, 2017).

Thus, the variables of the ESJS database that describe non-automatable skills are selected (Table 3). The selection is based on Pouliakas (2018).

Finally, the risk of substitution is estimated using a Gaussian process classifier, by following the steps described by Frey and Osborne (2017). Specifically, a model is built based on the training set and is then applied to the entire dataset to estimate the risk of substitution (probability of automation of occupations) associated with all occupations.

Once the risk of substitution is estimated, six linear regressions are run to examine how the institutional context in terms of gender equality (in general and in the education and work components) influences the risk of substitution faced by women, controlling for worker and job characteristics. Specifically, the following models are estimated:

Model 1a *Risk of substitution = f (gender, gender equality, control variables)*

Model 1b *Risk of substitution = f (gender, gender equality, gender × gender equality, control variables)*

Model 2a *Risk of substitution = f (gender, gender equality − education, control variables)*

Model 2b *Risk of substitution = f (gender, gender equality − education, gender × gender equality − education, control variables)*

Model 3a *Risk of substitution = f (gender, gender equality − work, control variables)*

Model 3b *Risk of substitution = f (gender, gender equality − work,*

Table 5
Description and sources of variables used to analyse how the institutional context in terms of gender equality affects the risk of substitution faced by women.

Variable name	Variable definition	Source
Dependent variable		
Risk of substitution	Variable describing the risk of substitution and taking a value between 0 and 1, estimated in the first phase	Our estimate
Independent variables		
Gender	Dummy variable taking the value 1 if the worker is woman, 0 if man	ESJS
Gender Equality	Gender Equality Index	EIGE
Gender Equality - Education	Gender Equality Index - Knowledge component	EIGE
Gender Equality - Work	Gender Equality Index - Work component	EIGE
Control variables		
Socio-demographic characteristics of the worker		
Age	Age of the worker	ESJS
Education	Categorical variable describing the highest level of education or training completed by the worker, with these levels: "No completed education", "Low education", "Medium education", "High education"	ESJS
Vocational qualification	Dummy variable taking the value 1 if the worker has received some learning in the workplace (e.g., through apprenticeships, internships, or other forms of work-based learning) or if the highest qualification was a vocational qualification, 0 otherwise	ESJS
Skills	Worker's level of skills compared to that required for the job (self-assessment)	ESJS
Job-specific factors		
Private company	Dummy variable taking the value 1 if the worker is employed in "A private company or partnership", 0 otherwise	ESJS
Firm size	Categorical variable describing the organisation's size, with these levels: "It varies", "Micro and small firm", "Medium firm", "Large firm"	ESJS
Years on the job	Number of years in total the worker has been working for the current employer	ESJS
Weekly hours	Average number of working hours per week	ESJS
Indefinite contract	Dummy variable taking the value 1 if the worker is employed on an "Indefinite/ permanent contract", 0 otherwise	ESJS
Training	Dummy variable taking the value 1 if the worker attended training courses (work-based, classroom based and online), 0 otherwise	ESJS
Training reasons	Dummy variable taking the value 1 if the worker attended training courses to stay up-to-date with changing skill needs for the job or to perform better at the job, 0 otherwise	ESJS
Occupation-, industry-, and country-specific variables		
Occupational class	Categorical variable describing worker's occupation, with these levels: "Building, crafts or a related trade person", "Clerical support", "Elementary occupations", "Manager", "Plant and machine operator and assembler", "Professional", "Sales, customer or personal service worker", "Skilled agricultural, forestry and fishery worker", "Technician or associate professional", "Other"	ESJS
Industry routine level	Categorical variable describing the routine intensity of the industry, with these levels: "Low routine-intensive", "Medium-low routine-intensive", "Medium-high routine-intensive, and "High routine-intensive"	ESJS
Country	Categorical variable describing worker's country, with these levels: "Austria", "Belgium", "Bulgaria", "Cyprus", "Czech Republic", "Germany", "Denmark", "Estonia", "Spain", "Finland", "France", "Greece", "Croatia", "Hungary", "Ireland", "Italy", "Lithuania", "Luxembourg", "Latvia", "Malta", "Netherlands", "Poland", "Portugal", "Romania", "Sweden", "Slovenia", "Slovakia", "United Kingdom"	ESJS

Source: Our elaboration.

gender × gender equality - work, control variables)

4.3. Variable definition

Two sets of variables are used in the analysis. The first one includes the variables used to estimate the risk of substitution (probability of automation of occupations) (Table 4). These variables relate to non-automatable skills: perception and manipulation, creative intelligence, and social intelligence. Perception and manipulation are described with the variable *Technical skills*, which is a categorical variable describing the importance of the skill, from 0 = "Not at all important" to 10 = "Essential". Creative intelligence is described with five variables: *Autonomous tasks*, *Learning tasks*, and *Non-routine tasks* are categorical variables describing the frequency of this task, from 1 = "Never" to 4 = "Always", while *Learning skills* and *Problem solving skills* are categorical variables describing the importance of the skill, from 0 = "Not at all important" to 10 = "Essential". Social intelligence is described with five variables: *Communication skills*, *Customer handling skills*, *Foreign language skills*, *Planning and organisation skills*, and *Team-working skills*, which are all categorical variables describing the importance of the skill, from 0 = "Not at all important" to 10 = "Essential".

The second set of variables regards those used to analyse how the institutional context in terms of gender equality (in general and in the education and work components) influences the risk of substitution faced by women (Table 5).

4.3.1. Dependent variable. The dependent variable is the risk of substitution, which takes a value between 0 and 1 and is estimated in the first phase.

4.3.2. Independent variables. Four independent variables are considered. *Gender* is a dummy variable taking the value 1 if the worker is a woman and 0 if the worker is a man. *Gender Equality* refers to the level of gender equality in the institutional context and is measured with the Gender Equality Index for 2015. *Gender Equality - Education* refers to the level of gender equality in education, understood as the level of attainment and participation and the level of segregation. The Gender Equality Index - Knowledge component for 2015 is used. *Gender Equality - Work* refers to the level of gender equality in work, understood as the level of participation and the level of segregation and quality of work. The Gender Equality Index - Work component for 2015 is used.

4.3.3. Control variables. Several control variables regarding the socio-demographic characteristics of the worker, job-specific factors, and occupation-, industry-, and country-specific variables are considered. The socio-demographic characteristics of the worker relate to worker's age, her/his education, her/his vocational qualification, and her/his skills. *Age* measures worker's age. *Education* is a categorical variable describing the highest level of education or training completed by the worker, from "No completed education" to "High education". *Vocational qualification* is a dummy variable taking the value 1 if the worker has received some learning in the workplace (e.g., through apprenticeships,

Table 6
Summary statistics – Variables used to estimate the risk of substitution (probability of automation of occupations).

Variable	Panel A				Panel B				
	Full sample (48,648 workers)				Women (21,404 workers, 44 %)		Men (27,244 workers, 56 %)		Wilcoxon rank test (1) vs (2)
	Mean/%	Std. Dev.	Min	Max	Mean/% (1)	Std. Dev.	Mean/% (2)	Std. Dev.	
Technical skills	7.21	2.67	0	10	6.81	2.87	7.53	2.45	***
Autonomous tasks: Never	8.50 %	0.28	0	1	8.88 %	0.28	8.21 %	0.27	***
Autonomous tasks: Sometimes	22.97 %	0.42	0	1	22.42 %	0.42	23.41 %	0.42	**
Autonomous tasks: Usually	38.88 %	0.49	0	1	37.79 %	0.48	39.73 %	0.49	***
Autonomous tasks: Always	29.65 %	0.46	0	1	30.91 %	0.46	28.66 %	0.45	***
Learning skills	7.69	2.28	0	10	7.77	2.36	7.63	2.22	***
Learning tasks: Never	4.17 %	0.20	0	1	4.35 %	0.20	4.03 %	0.20	*
Learning tasks: Sometimes	42.12 %	0.49	0	1	41.28 %	0.49	42.78 %	0.49	***
Learning tasks: Usually	32.50 %	0.47	0	1	32.07 %	0.47	32.84 %	0.47	*
Learning tasks: Always	21.21 %	0.41	0	1	22.30 %	0.42	20.35 %	0.40	***
Non-routine tasks: Never	6.14 %	0.24	0	1	7.07 %	0.26	5.41 %	0.23	***
Non-routine tasks: Sometimes	35.78 %	0.48	0	1	36.85 %	0.48	34.95 %	0.48	***
Non-routine tasks: Usually	32.35 %	0.47	0	1	30.54 %	0.46	33.78 %	0.47	***
Non-routine tasks: Always	25.73 %	0.44	0	1	25.55 %	0.44	25.87 %	0.44	
Problem solving skills	8.12	2.16	0	10	8.12	2.25	8.12	2.09	
Communication skills	7.94	2.31	0	10	8.18	2.32	7.76	2.29	***
Customer handling skills	6.70	3.37	0	10	7.08	3.36	6.40	3.36	***
Foreign language skills	4.71	3.44	0	10	4.60	3.48	4.80	3.40	***
Planning and organisation skills	7.47	2.61	0	10	7.58	2.68	7.39	2.55	***
Team-working skills	7.98	2.22	0	10	8.15	2.25	7.85	2.18	***

Wilcoxon Rank test: Significance levels: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.
Source: Our elaboration.

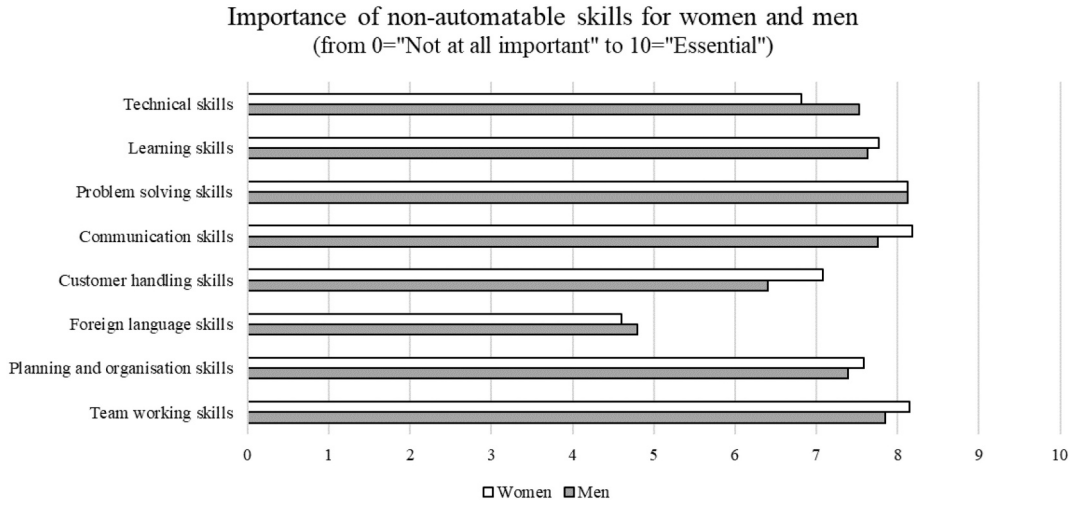


Fig. 2. Importance of non-automatable skills for women and men. Source: Our elaboration.

internships, or other forms of work-based learning) or if the highest qualification was a vocational qualification and 0 otherwise. The variable *Skills* describes the worker's level of skills compared to that required for the job based on self-assessment.

The variables describing job-specific factors regard the type of company (private company), firm size, years on the job, weekly hours, indefinite contract, training, and training reasons. *Private company* is a dummy variable taking the value 1 if the worker is employed in "A private company or partnership" and 0 otherwise. *Firm size* is a categorical variable describing the organisation's size with levels ranging from "It varies" to "Large firm". *Years on the job* measures the number of years in total the worker has been working for the current employer. *Weekly hours* measures the average number of working hours per week. *Indefinite contract* is a dummy variable taking the value 1 if the worker is employed on an "Indefinite/permanent contract" and 0 otherwise. *Training* is a dummy variable taking the value 1 if the worker attended training courses (work-based, classroom based and online) and 0 otherwise. *Training reasons* is a dummy variable taking the value 1 if the worker attended training courses to stay up-to-date with changing skill needs for the job or to perform better at the job and 0 otherwise.

Occupation-, industry-, and country-specific variables are three: *Occupational class* is a categorical variable describing worker's occupation; *Industry routine level* is a categorical variable describing the routine intensity of the industry, from "Low routine-intensive" to "High routine-intensive"; *Country* is a categorical variable describing worker's country.

5. Empirical analysis

5.1. Descriptive statistics

Table 6 reports the means and standard deviations for the explanatory variables used to estimate the risk of substitution (probability of automation of occupations). The results are reported for the full sample (Panel A) and the two subsamples of women and men (Panel B).

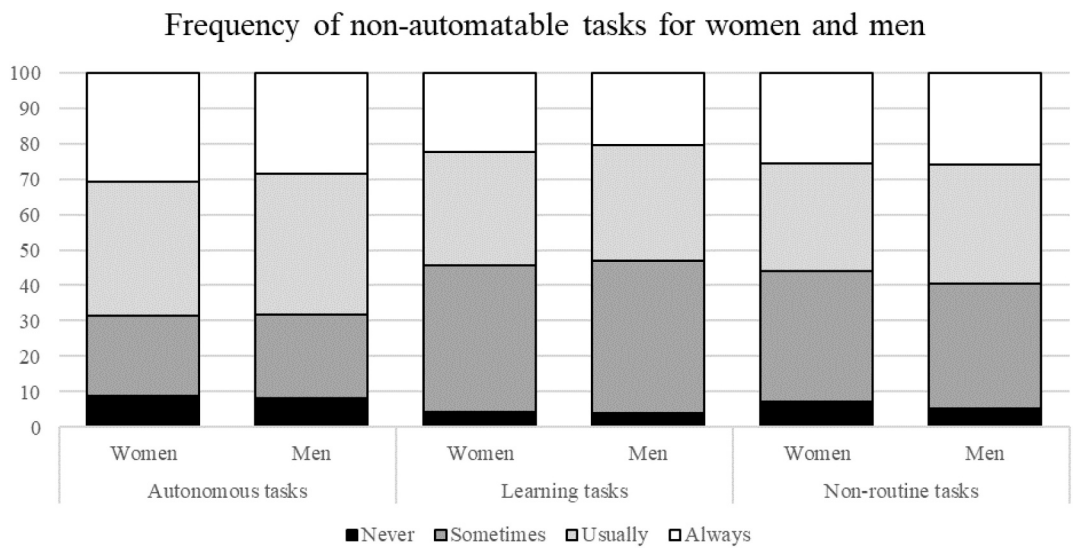


Fig. 3. Frequency of non-automatable tasks for women and men. Source: Our elaboration.

Wilcoxon rank tests were performed to analyse the differences between the means of the variables for women and men. The importance of almost all skills is statistically different between women and men, with the only exception of *Non-routine tasks: Always* and *Problem solving skills*.

As shown in Table 6, in the full sample and the subsamples of women and men, the importance of almost all non-automatable skills is generally rated equal to 7 or 8 on a scale from 1 ("Not at all important") to 10 ("Essential"). The only exception regards *Foreign language skills*, whose importance is rated less than 5.

Non-automatable skills are generally more important for women than for men (see also Fig. 2). The contrary is true only for *Technical skills* and *Foreign language skills*. Instead, *Problem skills* are equally important for women and men.

Around 67 % of workers usually or always carry out autonomous tasks; lower percentages (i.e., 53 % and 57 %) of workers perform learning activities and non-routine activities with the same frequency. No particular differences emerge between women and men (see also Fig. 3).

Table 7 reports the means and standard deviations for the explanatory variables used to analyse how the institutional context in terms of gender equality affects the risk of substitution faced by women. The results are reported for the full sample (Panel A) and the two subsamples of women and men (Panel B). Wilcoxon rank tests were performed to analyse the differences between the means of the variables for women and men. In general, the descriptive statistics are statistically different for women and men. The only exceptions concern the level of skills, the distribution of respondents in some countries, and the level of gender equality in the institutional context.

In the full sample, workers face an average risk of substitution of 0.5789. Women face a similar risk of substitution (0.5755) while men face a higher risk of substitution (0.5816). The results regarding the risk of substitution will be analysed in more detail in Section 5.2.

In the full sample, 44 % of workers are women.

The level of gender equality (in general and in the education and work components) in the institutional context where women and men work is similar among the full sample and the subsamples of women and men. Fig. 4 shows the level of gender equality in European countries. The Northern and Central European countries (e.g., Norway, Finland, Germany, France, and the United Kingdom) show higher levels of gender equality than the Eastern European countries (e.g., Poland, Hungary, Romania, Greece). The education and work components of gender equality show a similar trend, but some differences can be identified. If we examine gender equality concerning education, the situation is very similar to that regarding gender equality in general, although some improvements and worsening can be identified. Concerning the work component, the Northern European countries register high levels of gender equality, while the countries of Central Europe maintain good levels. In Eastern European countries, the situation improves compared to gender equality in general. Instead in Italy, the situation worsens.

Moving to worker-related variables, the first set of variables relates to the socio-demographic characteristics of the worker (e.g., age, education, vocational qualification, and skills). The average age of workers in the full sample is 42 years and on average, women are one year younger than men. 42 % of workers in the full sample have a medium education, while 46 % have a high education. Women are more educated than men. 71 % of workers in the full sample have received some learning in the workplace or have a vocational qualification. This percentage is slightly higher for women (73 %) and lower for men (69 %). Both in the full sample and the subsamples of women and men, workers' level of skills compared to that required for the job is evaluated as high (almost 82 on a scale of 0 to 100).

The second set of variables relates to job-specific factors (e.g., private company, firm size, years on the job, weekly hours, indefinite contract, training, and training reasons). 64 % of workers in the full sample, and specifically 57 % of women and 70 % of men, are employed in a private company, which is micro or small in half of the cases. On average, tenure with the current employer is 10 years both for the full sample and the subsamples. Average working hours per week amount to 38 h, but are less for women (36 h) and more for men (40 h). 83 % of workers are employed under an indefinite contract (81 % for women and 84 % for men). 70 % of workers in the full sample have attended training courses mainly to stay up-to-date or to perform better at the job. Similar percentages are observed for women and men.

The third set of variables includes the occupation-, industry-, and country-specific variables. Focusing on the occupational class, "Professional" and "Clerical support" are among the most represented occupational classes both in the full sample and the subsamples of women and men. Moving to the industry-specific variables, about 68 % of the workers in the full sample are employed in an industry with low or medium-low routine intensity. About 78 % of women and 60 % of men are employed in these industries, while about 13 % of women and 26 % of men are employed in an industry with high routine intensity. Finally, as regards country-specific variables, no particular differences emerge in the distribution of women and men in European countries.

Table 7
Summary statistics – Variables used to analyse how the institutional context in terms of gender equality affects the risk of substitution faced by women.

Variable	Panel A				Panel B				
	Full sample (48,648 workers)				Women (21,404 workers, 44 %)		Men (27,244 workers, 56 %)		Wilcoxon rank test (1) vs (2)
	Mean/ %	Std. Dev.	Min	Max	Mean/ % (1)	Std. Dev.	Mean/ % (2)	Std. Dev.	
Risk of substitution	0.5789	0.10	0.1987	0.9145	0.5755	0.10	0.5816	0.0983	***
Gender	44.00 %	0.50	0	1	–	–	–	–	–
Gender Equality	63.75	8.28	49.95	82.57	63.79	8.32	63.73	8.24	
Gender Equality - Education	60.89	6.95	48.90	73.61	60.74	6.99	61.00	6.92	***
Gender Equality - Work	71.14	4.51	62.44	82.57	71.31	4.40	71.01	4.58	***
Age	42.23	9.96	24	65	41.74	9.98	42.60	9.92	***
Education: No completed education	0.22 %	0.05	0	1	0.14 %	0.04	0.28 %	0.05	***
Education: Low education	12.27 %	0.33	0	1	10.01 %	0.30	14.04 %	0.35	***
Education: Medium education	41.79 %	0.49	0	1	39.73 %	0.49	43.42 %	0.50	***
Education: High education	45.72 %	0.50	0	1	50.12 %	0.50	42.26 %	0.49	***
Vocational qualification	70.96 %	0.45	0	1	73.34 %	0.44	69.09 %	0.46	***
Skills	81.74	15.70	0	100	81.84	15.66	81.65	15.72	
Private company	64.24 %	0.48	0	1	57.39 %	0.50	69.62 %	0.46	***
Firm size: It varies	0.72 %	0.09	0	1	0.62 %	0.08	0.80 %	0.09	**
Firm size: Micro and small firm	50.86 %	0.50	0	1	55.26 %	0.50	47.40 %	0.50	***
Firm size: Medium firm	25.08 %	0.43	0	1	23.55 %	0.42	26.27 %	0.44	***
Firm size: Large firm	23.35 %	0.42	0	1	20.57 %	0.40	25.53 %	0.44	***
Years on the job	10.21	9.09	1	50	9.74	8.74	10.57	9.35	***
Weekly hours	38.24	9.83	1	80	35.95	10.23	40.03	9.10	***
Indefinite contract	82.84 %	0.38	0	1	80.98 %	0.39	84.31 %	0.36	***
Training	68.98 %	0.46	0	1	69.49 %	0.46	68.59 %	0.46	**
Training reasons	52.47 %	0.50	0	1	54.06 %	0.50	51.23 %	0.50	***
Occupational class: Building, crafts or a related trade person	8.49 %	0.28	0	1	2.75 %	0.16	13.00 %	0.34	***
Occupational class: Clerical support	21.28 %	0.41	0	1	29.85 %	0.46	14.54 %	0.35	***
Occupational class: Elementary occupations	2.83 %	0.17	0	1	3.54 %	0.18	2.28 %	0.15	***
Occupational class: Manager	7.37 %	0.26	0	1	5.36 %	0.23	8.95 %	0.29	***
Occupational class: Plant and machine operator and assembler	6.55 %	0.25	0	1	1.95 %	0.14	10.16 %	0.30	***
Occupational class: Professional	21.34 %	0.41	0	1	24.34 %	0.43	18.99 %	0.39	***
Occupational class: Sales, customer or personal service worker	14.38 %	0.35	0	1	17.70 %	0.38	11.78 %	0.32	***
Occupational class: Skilled agricultural, forestry and fishery worker	0.96 %	0.10	0	1	0.53 %	0.07	1.30 %	0.11	***
Occupational class: Technician or associate professional	15.11 %	0.36	0	1	12.56 %	0.33	17.11 %	0.38	***
Occupational class: Other	1.69 %	0.13	0	1	1.42 %	0.12	1.90 %	0.14	***
Industry routine level: Low routine-intensive	35.45 %	0.48	0	1	44.53 %	0.50	28.32 %	0.45	***
Industry routine level: Medium-low routine-intensive	32.87 %	0.47	0	1	33.88 %	0.47	32.07 %	0.47	***
Industry routine level: Medium-high routine-intensive	11.30 %	0.32	0	1	8.51 %	0.28	13.49 %	0.34	***
Industry routine level: High routine-intensive	20.38 %	0.40	0	1	13.07 %	0.34	26.12 %	0.44	***
Austria	2.05 %	0.14	0	1	2.02 %	0.14	2.08 %	0.14	
Belgium	3.09 %	0.17	0	1	2.93 %	0.17	3.21 %	0.18	*
Bulgaria	2.06 %	0.14	0	1	2.14 %	0.15	1.99 %	0.14	
Croatia	2.06 %	0.14	0	1	2.06 %	0.14	2.07 %	0.14	
Cyprus	1.03 %	0.10	0	1	1.23 %	0.11	0.87 %	0.09	***
Czech Republic	3.10 %	0.17	0	1	2.95 %	0.17	3.21 %	0.18	*
Denmark	2.04 %	0.14	0	1	2.11 %	0.14	1.99 %	0.14	
Estonia	2.06 %	0.14	0	1	2.26 %	0.15	1.90 %	0.14	***
Finland	4.12 %	0.20	0	1	4.58 %	0.21	3.75 %	0.19	***
France	8.24 %	0.28	0	1	8.38 %	0.28	8.12 %	0.27	
Germany	8.24 %	0.28	0	1	8.23 %	0.28	8.24 %	0.28	
Greece	4.19 %	0.20	0	1	4.17 %	0.20	4.20 %	0.20	
Hungary	3.08 %	0.17	0	1	2.88 %	0.17	3.24 %	0.18	**
Ireland	2.06 %	0.14	0	1	2.09 %	0.14	2.04 %	0.14	
Italy	6.20 %	0.24	0	1	4.77 %	0.21	7.32 %	0.26	***
Latvia	2.06 %	0.14	0	1	2.44 %	0.15	1.77 %	0.13	***
Lithuania	2.08 %	0.14	0	1	2.52 %	0.16	1.73 %	0.13	***
Luxembourg	1.03 %	0.10	0	1	0.95 %	0.10	1.09 %	0.10	
Malta	1.03 %	0.10	0	1	0.78 %	0.09	1.22 %	0.11	***
Netherlands	3.08 %	0.17	0	1	3.10 %	0.17	3.07 %	0.17	

(*continued on next page*)

Table 7 (*continued*)

Variable	Panel A				Panel B				
	Full sample (48,648 workers)				Women (21,404 workers, 44 %)		Men (27,244 workers, 56 %)		Wilcoxon rank test (1) vs (2)
	Mean/ %	Std. Dev.	Min	Max	Mean/ % (1)	Std. Dev.	Mean/ % (2)	Std. Dev.	
Poland	8.25 %	0.28	0	1	8.67 %	0.28	7.92 %	0.27	***
Portugal	3.09 %	0.17	0	1	3.27 %	0.18	2.95 %	0.17	**
Romania	3.09 %	0.17	0	1	2.83 %	0.17	3.29 %	0.18	***
Slovakia	2.09 %	0.14	0	1	2.07 %	0.14	2.11 %	0.14	
Slovenia	2.08 %	0.14	0	1	2.31 %	0.15	1.89 %	0.13	***
Spain	8.23 %	0.28	0	1	8.09 %	0.27	8.35 %	0.28	
Sweden	2.05 %	0.14	0	1	2.14 %	0.14	1.99 %	0.14	
United Kingdom	8.22 %	0.27	0	1	8.01 %	0.27	8.39 %	0.28	

Wilcoxon Rank test: Significance levels: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.
Source: Our elaboration.

5.2. The risk of substitution faced by workers

As shown in Table 7, European workers face an average risk of substitution of 0.5789. Overall, women face a slightly lower risk than men: the average risk of substitution is 0.5755 for women and 0.5816 for men.

Table 8 reports the risk of substitution faced by European workers according to their occupation. The results are reported for the full sample (Panel A) and the two subsamples of women and men (Panel B). Wilcoxon rank tests were performed to analyse the differences between women and men in the risk of substitution faced. For most occupations, the difference is not statistically significant.

For most occupations (e.g., "Cleaners and helpers", "General and keyboard clerks", "Health professionals", "Personal care workers", "Science and engineering professionals"), women face a lower risk of substitution than men. Instead for occupations such as "Assemblers", "Food preparation assistants", and "Sales workers", the opposite is true.

Fig. 5 shows the distribution of the risk of substitution faced by women and men. It emerges that women are more present than men for low or high levels of the risk of substitution (risk between 0.35 and 0.55 and 0.7–0.8), while men are more present than women for intermediate levels of the risk of substitution (risk between 0.55 and 0.65).

5.3. Econometric results

Table 9 shows the results of the analysis of how the institutional context in terms of gender equality (in general and in the education and work components) influences the risk of substitution faced by women.[2] The coefficients of the logit estimates are reported. Fig. 6 reports the interaction graphs.

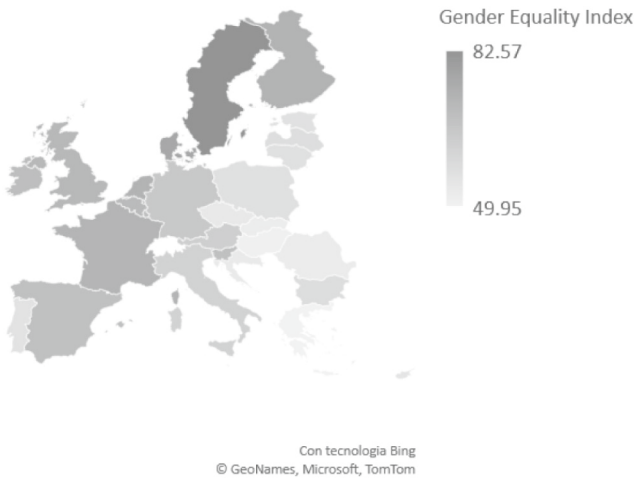
Models 1a and 1b analyse the influence of the institutional context in terms of gender equality in general. *Gender* has a negative coefficient in Model 1a ($b = -0.0122$, $p < 0.01$), meaning that women face a lower risk of substitution than men. *Gender equality* has a positive coefficient in Model 1a ($b = 0.0008$, $p < 0.01$), meaning that in institutional context with higher gender equality, the risk of substitution faced by workers is higher. Model 1b reports the interaction effects of *Gender* and *Gender equality*. The coefficient is negative and significant ($b = -0.0006$; $p < 0.01$), meaning that in institutional contexts where gender equality is higher, women face a lower risk of substitution. Overall, in institutional contexts where gender equality is higher, women face a higher risk of substitution than in institutional contexts where gender equality is lower. However, moving from lower to higher gender equality in the institutional context, the gender gap in the risk of substitution increases in favour of women, who face a significantly lower risk of substitution than men. Hypothesis 1 is thus partially confirmed. Fig. 6 Panel A depicts the effect.

Models 2a and 2b analyse the influence of the institutional context in terms of gender equality in education (understood as the level of attainment and participation and the level of segregation). *Gender* has a negative coefficient in Model 2a ($b = -0.0122$, $p < 0.01$), meaning that women face a lower risk of substitution than men. *Gender equality - Education* has a negative but not significant coefficient in Model 2a ($b = -0.0001$), meaning that higher gender equality in education does not affect the risk of substitution faced by workers. Model 2b reports the interaction effects of *Gender* and *Gender equality - Education*. The coefficient is negative and significant ($b = -0.0004$; $p < 0.01$), meaning that in institutional contexts where gender equality in education is higher, women face a lower risk of substitution. Overall, in institutional contexts where gender equality in education is higher, women face a higher risk of substitution than in institutional contexts where gender equality in education is lower. However, moving from lower to higher gender equality in education in the institutional context, the gender gap in the risk of substitution increases in favour of women, who face a significantly lower risk of substitution than men. Hypothesis 1a thus is partially confirmed. Fig. 6 Panel B depicts the effect.

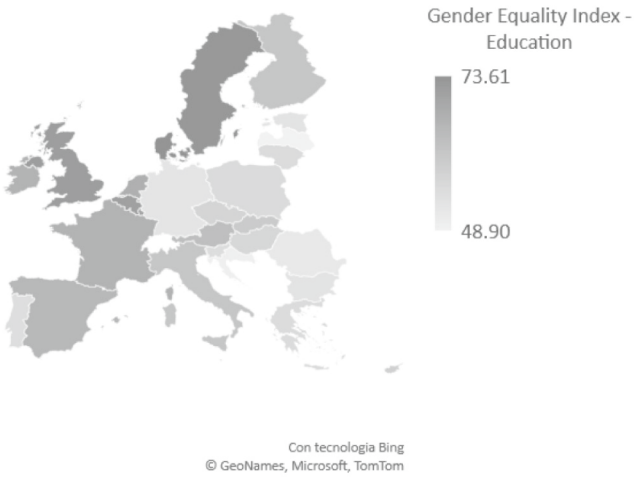
Models 3a and 3b analyse the influence of the institutional context in terms of gender equality in work (understood as the level of participation and the level of segregation and quality of work). *Gender* has a negative coefficient in Model 3a ($b = -0.0122$, $p < 0.01$), meaning that women face a lower risk of substitution than men. *Gender equality - Work* has a positive coefficient in Model 3a ($b = 0.0014$, $p < 0.01$), meaning that in institutional context with higher gender equality in work, the risk of substitution faced by workers is higher. Model 3b reports the interaction effects of *Gender* and *Gender equality - Work*. The coefficient is negative and significant ($b = -0.0013$; $p < 0.01$), meaning that in institutional contexts where gender equality in work is higher, women face a lower risk of substitution. Overall, in institutional contexts where gender equality in work is higher, women face a higher risk of substitution than in institutional contexts where gender equality in work is lower. However, moving from lower to higher gender equality in work in the institutional context, the gender gap in the risk of substitution increases in favour of women, who face a significantly lower risk of substitution than men. Hypothesis 1b is thus partially confirmed. Fig. 6 Panel C depicts the effect.

Control variables also yield interesting results. In all models, *Age* has a positive and significant coefficient, meaning that older workers face a higher risk of substitution. In all models, all levels of education

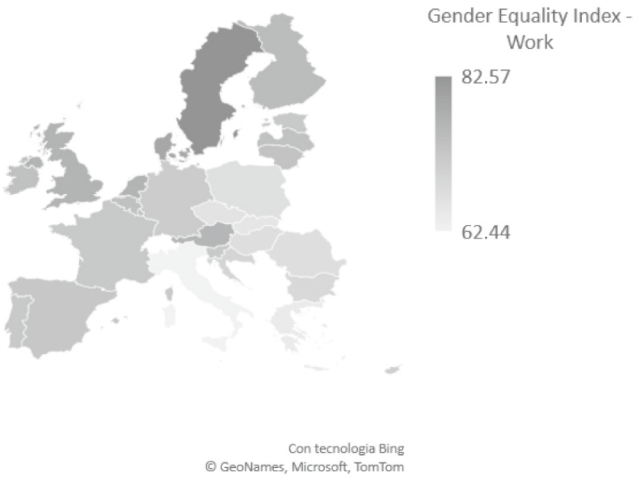
[2] The correlation matrix shows acceptable correlation indexes (Greene, 2003).



Panel A – Gender equality



Panel B – Gender equality - Education



Panel C – Gender equality - Work

Fig. 4. Gender Equality Index (Panel A), Gender Equality Index - Education (Panel B), and Gender Equality Index - Work (Panel C) for 2015 across European countries. Source: Our elaboration based on EIGE database.

Table 8
Risk of substitution faced by workers.

Occupation name	Panel A				Panel B				
	Full sample (48,648 workers)				Women (21,404 workers, 44 %)		Men (27,244 workers, 56 %)		Wilcoxon rank test (1) vs (2)
	Mean	Std. Dev.	Min	Max	Mean (1)	Std. Dev.	Mean (2)	Std. Dev.	
Administrative and commercial managers	0.5488	0.0839	0.2455	0.7949	0.5348	0.0882	0.5572	0.0801	***
Agricultural, forestry and fishery labourers	0.5941	0.0962	0.3171	0.7854	0.5880	0.1107	0.5964	0.0907	
Assemblers	0.5772	0.1063	0.2896	0.8452	0.5807	0.1107	0.5758	0.1048	
Building and related trades workers, excluding electricians	0.5804	0.0972	0.3043	0.8328	0.5909	0.0945	0.5799	0.0973	
Building, crafts or a related trade person - Other	0.5892	0.0665	0.5116	0.6570	0.6548	0.000	0.5783	0.0656	NA
Business and administration associate professionals	0.5754	0.0908	0.2455	0.8789	0.5697	0.0928	0.5798	0.0890	***
Business and administration professionals	0.5588	0.0929	0.2344	0.8647	0.5534	0.0971	0.5647	0.0876	**
Chief executives, senior officials and legislators	0.5291	0.0807	0.2703	0.7966	0.5223	0.0825	0.5315	0.0800	
Cleaners and helpers	0.6166	0.1048	0.2466	0.8625	0.6136	0.1039	0.6286	0.1079	
Clerical support - Other	0.5779	0.0808	0.4404	0.7414	0.5637	0.0783	0.6016	0.0828	
Customer services clerks	0.6198	0.0897	0.2696	0.9145	0.6165	0.0901	0.6245	0.0890	**
Drivers and mobile plant operators	0.6206	0.1073	0.2678	0.8847	0.6240	0.1022	0.6204	0.1076	
Electrical and electronic trades workers	0.5643	0.0967	0.3074	0.8476	0.5683	0.1200	0.5641	0.0957	
Elementary occupations - Other	0.6414	0.0962	0.4373	0.8358	0.6227	0.1062	0.6521	0.0909	
Food preparation assistants	0.6071	0.1067	0.3096	0.9016	0.6182	0.1028	0.5917	0.1108	*
Food processing, wood working, garment and other craft and related trades workers	0.5879	0.1066	0.2811	0.8500	0.5749	0.1150	0.5930	0.1027	***
General and keyboard clerks	0.6033	0.0959	0.2455	0.9113	0.6006	0.0972	0.6092	0.0928	**
Handicraft and printing workers	0.5723	0.1124	0.2266	0.8355	0.5558	0.1158	0.5798	0.1106	
Health associate professionals	0.5693	0.0949	0.2766	0.8532	0.5667	0.0946	0.5745	0.0955	
Health professionals	0.5595	0.0885	0.2393	0.8623	0.5573	0.0891	0.5639	0.0872	
Hospitality, retail and other services managers	0.5686	0.0827	0.3013	0.8391	0.5565	0.0818	0.5763	0.0826	**
Information and communications technicians	0.5752	0.0875	0.2882	0.8342	0.5593	0.0929	0.5785	0.0860	***
Information and communications technology professionals	0.5627	0.0881	0.2288	0.8115	0.5542	0.0860	0.5647	0.0885	*
Labourers in mining, construction, manufacturing and transport	0.5916	0.0986	0.3068	0.8240	0.6027	0.1156	0.5906	0.0975	
Legal, social and cultural professionals	0.5484	0.0968	0.2622	0.8485	0.5470	0.0980	0.5504	0.0951	
Legal, social, cultural and related associate professionals	0.5502	0.0900	0.2648	0.8260	0.5455	0.0969	0.5536	0.0846	
Manager - Other	0.5563	0.0867	0.3906	0.7222	0.5298	0.1721	0.5613	0.0701	
Market-oriented skilled agricultural workers	0.5687	0.1043	0.2555	0.8297	0.5559	0.0995	0.5728	0.1057	
Market-oriented skilled forestry, fishery and hunting workers	0.5609	0.0966	0.3328	0.7537	0.5454	0.1192	0.5642	0.0921	
Metal, machinery and related trades workers	0.5676	0.1059	0.2569	0.8367	0.5630	0.0978	0.5679	0.1064	
Numerical and material recording clerks	0.5844	0.0946	0.2428	0.8381	0.5784	0.0952	0.5934	0.0930	***
Other	0.5904	0.1020	0.3209	0.8201	0.5954	0.0941	0.5872	0.1070	
Other clerical support workers	0.5895	0.0944	0.2306	0.8658	0.5850	0.0974	0.5957	0.0897	***
Personal care workers	0.5686	0.1012	0.2096	0.8566	0.5650	0.1011	0.5817	0.1006	**
Personal service workers	0.6086	0.0958	0.2684	0.8731	0.6040	0.0962	0.6138	0.0952	**
Plant and machine operarator and assembler - Other	0.6443	0.1201	0.3777	0.8167	0.3777	0.000	0.6600	0.1030	NA
Production and specialised services managers	0.5421	0.0854	0.2678	0.8014	0.5364	0.0849	0.5441	0.0855	
Professional - Other	0.5534	0.0885	0.3786	0.7528	0.5794	0.0813	0.5311	0.0898	**
Protective services workers	0.5956	0.1022	0.2124	0.8269	0.5816	0.1008	0.5980	0.1023	
Refuse workers and other elementary workers	0.6219	0.1049	0.2678	0.8970	0.6227	0.1089	0.6216	0.1033	
Sales workers	0.6362	0.0905	0.3635	0.9130	0.6386	0.0946	0.6332	0.0851	*
Sales, customer or personal service worker - Other	0.6114	0.0898	0.4305	0.8103	0.6033	0.0949	0.6192	0.0859	
Science and engineering associate professionals	0.5621	0.0940	0.2578	0.8652	0.5514	0.0871	0.5659	0.0961	***
Science and engineering professionals	0.5530	0.0898	0.2528	0.8248	0.5406	0.0920	0.5591	0.0881	***
Skilled agricultural, forestry and fishery worker - Other	0.6001	0.0862	0.5176	0.7366	0.7366	0.000	0.5660	0.0464	NA
Stationary plant and machine operators	0.5610	0.1073	0.2632	0.8849	0.5565	0.1091	0.5621	0.1069	
Street and related sales and service workers	0.6353	0.0961	0.3739	0.8646	0.6501	0.1013	0.6275	0.0929	
Subsistence farmers, fishers, hunters and gatherers	0.5981	0.0945	0.4072	0.7672	0.6279	0.0661	0.5856	0.1041	
Teaching associate professionals	0.5531	0.0948	0.2347	0.7966	0.5381	0.0939	0.5656	0.0941	**
Teaching professionals	0.5074	0.0997	0.1987	0.8535	0.5013	0.0988	0.5183	0.1005	***
Technician or associate professional - Other	0.5790	0.0919	0.2798	0.8062	0.5718	0.0616	0.5798	0.0951	

Wilcoxon Rank test: Significance levels: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.
NA = not enough observations to perform the test.
Source: Our elaboration.

(variables: *Education: Low education*, *Education: Medium education*, and *Education: High education*) have a negative or positive but not significant coefficient: education does not affect the risk of substitution. On the contrary, *Vocational qualification* and *Skills* have a negative and significant coefficient in all models: having received some learning in the workplace or having a vocational qualification and having a high level of skills compared to that required for the job reduce the risk of substitution faced by the worker. In all models, being employed in a private company (variable: *Private company*) increases the risk of substitution; instead, firm size does not affect it (variables: *Firm size: Micro and small firm*, *Firm size: Medium firm*, and *Firm size: Large firm*). In all models, *Years on the job* has a negative and significant coefficient: as the number of years the worker has been working for the current employer increases, the risk of substitution decreases. The impact of *Weekly hours* is similar: as the number of hours worked per week increases, the risk of substitution decreases in all models. Contrary to expectations, being employed on an indefinite contract (variable: *Indefinite contract*) increases the risk of substitution in all models. *Training* and *Training reasons* have a negative and significant coefficient in all models: having attended training courses (work-based, classroom-based and online), especially to

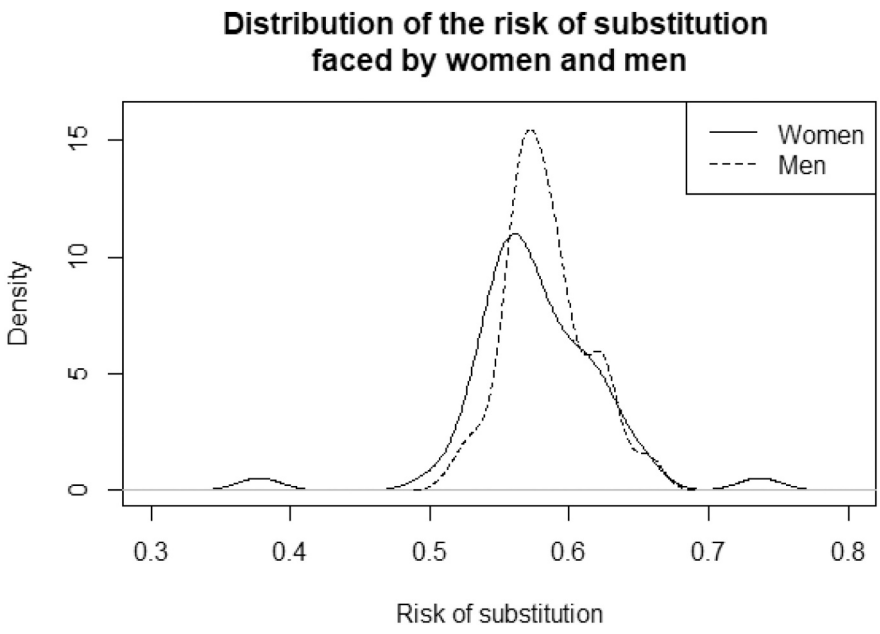


Fig. 5. Distribution of the risk of substitution faced by women and men. Source: Our elaboration.

stay up-to-date with changing skill needs of the job or to perform better at the job, strongly reduces the risk of substitution. Finally, the routine level has a different impact: when the routine level is medium-low (variable: *Industry routine level: Medium-low routine-intensive*), the risk of substitution increases; when the routine level is high (variable: *Industry routine level: High routine-intensive*), the risk of substitution decreases; when the routine level is medium-high (variable: *Industry routine level: Medium-high routine-intensive*), the impact is positive but not significant.

6. Discussion, implications and limitations

This study investigated how the institutional context in terms of gender equality (in general and in the education and work components) affects the risk of substitution faced by European women. We found that European workers face an average risk of substitution of 0.5789. Overall, women face a slightly lower risk than men: the average risk of substitution is 0.5755 for women and 0.5816 for men. Therefore, contrary to the majority of studies stating that automation will have more negative effects on women (e.g., Brussevich et al., 2019; Delgado Cadena, 2020; García-Holgado et al., 2019; Nedelkoska and Quintini, 2018; Shook and Knickrehm, 2018), in Europe automation has a small favourable impact on women than on men.

We also found that in institutional contexts where gender equality (in general and in the education and work components) is high, women face a higher risk of substitution than in institutional contexts where gender equality is lower. However, moving from lower to higher gender equality in the institutional context, the gender gap in the risk of substitution increases in favour of women, who face a significantly lower risk of substitution than men. In institutional contexts with high gender equality, women face less stereotypes, discrimination, structural barriers and socially constructed disadvantages (Byrne and Fayolle, 2010; Eagly and Karau, 2002; Subrahmanian, 2005). This enables women to access valuable opportunities and take full advantage of them (Mikkola and Miles, 2007). Moreover, thanks to gender equality in education women can acquire non-automatable skills (i.e., perception and manipulation, creative intelligence, and social intelligence) while thanks to gender equality in the labour market women can access all occupations and avoid gender gaps in the tasks performed (Piasna and Drahokoupil, 2017; Stier and Herzberg-Druker, 2017). Women can thus enter occupations with a low probability of automation and therefore face a significantly lower risk of substitution than men. Instead, in institutional contexts with low gender equality, women face difficulties in acquiring non-automatable skills and are thus forced to perform occupations with a high probability of automation and routine tasks, despite still facing a lower risk of substitution than men. Therefore, gender equality in the institutional context contributes to increasing the gender gap in the risk of substitution in favour of women, thus reducing the gender gap women face in society.

These results have policy implications. Policy makers must respond to changes due to automation (Spencer, 2018) by designing targeted policies that minimise its negative consequences on workers. This analysis offers a preliminary indication that future educational and labour policies should promote gender equality to prepare both women and men for the future. Specifically, European policies should promote gender equality in the institutional context to foster a narrower gender gap following the adoption of automation technologies.

Gender equality in education should be fostered for two reasons. First, education can help to improve gender equality in the institutional context as avoiding gender stereotypes in education means reducing gender stereotypes in the culture (Aragonés-González et al., 2020), with all the positive consequences that this entails. Second, gender equality in education enables both women and men to be provided with non-automatable skills (Roberts et al., 2019) and to choose among all fields of study without facing stereotypes (Castellano and Rocca, 2018). This way, education will increase job opportunities for women (Castellano and Rocca, 2018).

At the same time, gender equality in work should be promoted. Improving women's working conditions is now a main challenge in the international political agenda (Núñez et al., 2020) and many international organisations (e.g., the United Nations, the International Labour Organization, and the World Bank) stress the importance of preventing "modern forms of segregation, displacement, or precarization of women's work" (Delgado Cadena, 2020, p. 158). In fact, gender relations in new forms of work and employment interact with the persistent disparities in the workplace associated with gender discrimination (Piasna and Drahokoupil, 2017).

Given the different levels of gender equality in education and the labour market in European countries, varying priorities can be given to the two dimensions of gender equality depending on the degree of

Table 9
Econometric results.

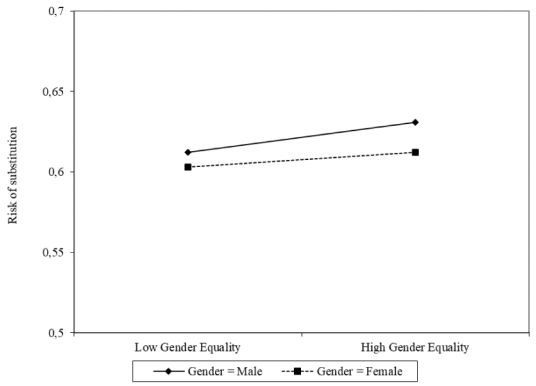
	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b
Constant	0.5670***	0.5506***	0.6318***	0.5207***	0.5191***	0.4793***
	(0.0165)	(0.0167)	(0.0152)	(0.0230)	(0.0250)	(0.0258)
Gender	−0.0122***	0.0243***	−0.0122***	0.0113	−0.0122***	0.0775***
	(0.0009)	(0.0067)	(0.0009)	(0.0076)	(0.0009)	(0.0137)
Gender Equality	0.0008***	0.0011***				
	(0.0002)	(0.0002)				
Gender × Gender Equality		−0.0006***				
		(0.0001)				
Gender Equality - Education			−0.0001	0.0015***		
			(0.0001)	(0.0003)		
Gender × Gender Equality - Education				−0.0004***		
				(0.0001)		
Gender Equality - Work					0.0014***	0.0019***
					(0.0003)	(0.0003)
Gender × Gender Equality - Work						−0.0013***
						(0.0002)
Age	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Education: Low education	−0.0014	−0.0008	−0.0014	−0.0009	−0.0014	−0.0006
	(0.0092)	(0.0092)	(0.0092)	(0.0092)	(0.0092)	(0.0092)
Education: Medium education	0.0010	0.0017	0.0010	0.0016	0.0010	0.0019
	(0.0092)	(0.0092)	(0.0092)	(0.0092)	(0.0092)	(0.0092)
Education: High education	−0.0041	−0.0034	−0.0041	−0.0034	−0.0041	−0.0032
	(0.0092)	(0.0092)	(0.0092)	(0.0092)	(0.0092)	(0.0092)
Vocational qualification	−0.0077***	−0.0076***	−0.0077***	−0.0076***	−0.0077***	−0.0076***
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)
Skills	−0.0002***	−0.0002***	−0.0002***	−0.0002***	−0.0002***	−0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Private company	0.0145***	0.0144***	0.0145***	0.0145***	0.0145***	0.0144***
	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0010)
Firm size: Micro and small firm	0.0056	0.0055	0.0055	0.0055	0.0055	0.0056
	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)
Firm size: Medium firm	−0.0025	−0.0025	−0.0025	−0.0025	−0.0025	−0.0024
	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)
Firm size: Large firm	−0.0052	−0.0051	−0.0052	−0.0051	−0.0052	−0.0050
	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)
Years on the job	−0.0002***	−0.0003***	−0.0002***	−0.0002***	−0.0002***	−0.0002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Weekly hours	−0.0006***	−0.0006***	−0.0006***	−0.0006***	−0.0006***	−0.0006***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Indefinite contract	0.0036***	0.0036***	0.0036***	0.0036***	0.0036***	0.0037***
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)
Training	−0.0044***	−0.0044***	−0.0044***	−0.0044***	−0.0044***	−0.0043***
	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0013)
Training reasons	−0.0164***	−0.0163***	−0.0164***	−0.0164***	−0.0164***	−0.0163***
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)
Industry routine level: Medium-low routine-intensive	0.0084***	0.0083***	0.0084***	0.0083***	0.0084***	0.0083***
	(0.0011)	(0.0011)	(0.0011)	(0.0011)	(0.0011)	(0.0011)
Industry routine level: Medium-high routine-intensive	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002
	(0.0016)	(0.0016)	(0.0016)	(0.0016)	(0.0016)	(0.0016)
Industry routine level: High routine-intensive	−0.0028**	−0.0028**	−0.0028**	−0.0028**	−0.0028**	−0.0029**
	(0.0014)	(0.0014)	(0.0014)	(0.0014)	(0.0014)	(0.0014)
Occupational class	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes
Observations	48,648	48,648	48,648	48,648	48,648	48,648
R-squared	0.1242	0.1247	0.1242	0.1243	0.1242	0.1249

Standard errors in parentheses, $*p < 0.1$ $**p < 0.05$ $***p < 0.01$.

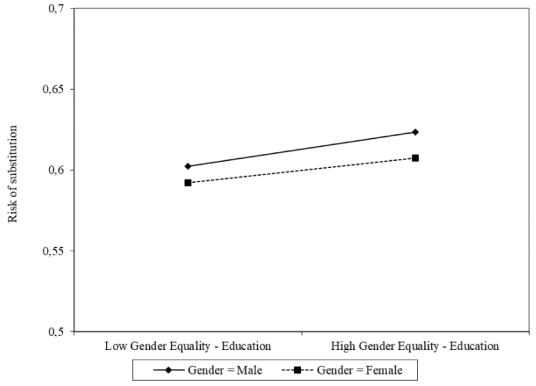
gender equality and the severity of its consequences.

The results of the study also have managerial implications. This study shows the importance of promoting gender equality in the institutional context and suggests which occupations have a high probability of automation, which exposes the worker to a high risk of substitution. Although policies at the national level have an essential role in promoting gender equality in the institutional context and, more generally, protecting the worker from the risk of substitution, interventions at the firm level are equally desirable. These should complement or replace national policies to increase gender equality in training programmes and the workplace. The risk of substitution faced by workers employed in each occupation can guide interventions for women and men at higher risk. For example, firm's managers and directors could allow workers to decide whether to introduce automation into their work and which tasks to assign to machines or keep for themselves. This kind of internal innovation and reorganisation could reduce the risk of substitution faced by workers, who would be able to determine the optimal degree of automation.

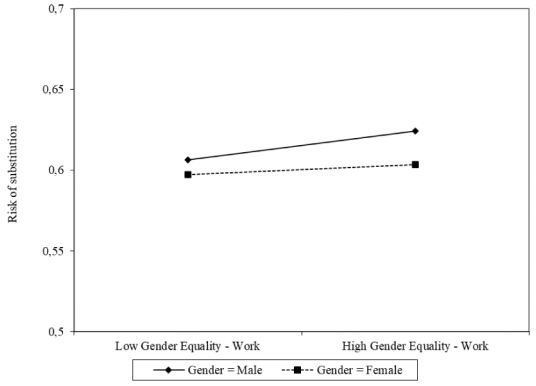
This study is not devoid of limitations, which can guide future research. First, in this study, the risk of substitution faced by workers has been estimated by applying the task-based approach and by following the methodologies proposed by Frey and Osborne (2017) and by Nedelkoska and Quintini (2018). Thus, the risk of substitution has been estimated at the occupational level taking into account which work activities cannot be automated. Although the task-based approach has been widely adopted in the previous literature on the topic, it would be interesting to replicate the analysis by adopting alternative approaches. For example, the manhour-based approach could be applied to estimate



Panel A – Two-way interaction: Gender * Gender Equality



Panel B – Two-way interaction: Gender * Gender Equality - Education



Panel C – Two-way interaction: Gender * Gender Equality - Work

Fig. 6. Interaction graphs. Source: Our elaboration.

the risk of substitution faced by workers by considering not only the tasks and the possibility of automating them, but also the time that workers devote to automatable tasks. In this way, the risk of substitution obtained would come closer to reality and would no longer be a "theoretical" risk.

Second, the sample used in the analysis consists of workers who suffer the automation decisions made by firms, without being able to limit the scope of automation. As a future research development, it might be interesting to replicate the analysis on a group of workers who have the power to personally decide whether and how to automate their work activities. This analysis could result in a lower risk of substitution faced by workers as well as a more marginal role of gender equality in the institutional context on this risk since workers would be able to decide whether to introduce automation into their work and which tasks to assign to machines.

Third, in this study, gender equality in the institutional context is measured using the Gender Equality Index provided by the EIGE. Although it is a comprehensive measure of gender equality consisting of six components and two additional domains, the index does not allow for an assessment of the barriers women face in education and the labour market when they want to protect themselves against the risk of substitution. Future studies could adopt qualitative methods to examine the barriers faced by women concerning the effects of automation and thus enable a more in-depth assessment of how the institutional context in terms of gender equality impacts the risk of substitution faced by women.

Fourth, the Gender Equality Index is a national level measure and therefore does not allow for an assessment of the differences in gender equality within each country. Future studies could use gender equality measures on a regional level, thus allowing for a more detailed assessment.

Finally, this analysis offers a preliminary indication that future educational and labour policies should promote gender equality. However, further analysis is necessary in this regard. Future research may evaluate which education and labour market policies should be adopted, their optimal characteristics and their effectiveness in reducing the risk of substitution faced by workers in different European institutional contexts.

7. Conclusion

This study shows that the institutional context in terms of gender equality affects the risk of substitution faced by women. Specifically, we found that in institutional contexts where gender equality (in general and in the education and work components) is high, the gender gap in the risk of substitution increases in favour of women, who face a significantly lower risk of substitution than men. In this way, the gender gap women face in society is reduced. Gender equality should therefore be promoted.

Without policy intervention, automation may leave social relations of gender unchanged; consequently, a continuity and reproduction of gender inequalities are to be expected. To avoid this, action should be taken to overcome existing gender barriers in education and work and to enable women to advance (Madgavkar et al., 2019; Roberts et al., 2019). The goal is to assure that women are equally able as men in accessing occupations that protect them from the risk of substitution (Madgavkar et al., 2019; Roberts et al., 2019) and, in this way, the ultimate goal is to reduce the gender gap women face in society.

Achieving gender equality is not easy and is a long-term investment (Beer, 2009): it requires time and effort by the entire society, national governments and international organisations (Delgado Cadena, 2020). This change must be made because without the full participation of both women and men, no economy can reach its potential (Georgieva et al., 2019).

Data availability

Data used are publicly available.

References

Ahl, H., 2006. Why research on women entrepreneurs needs new directions. Entrep. Theory Pract. 30 (5), 595–621. https://doi.org/10.1111/j.1540-6520.2006.00138.x.

Aragonés-González, M., Rosser-Limiñana, A., Gil-González, D., 2020. Coeducation and gender equality in education systems: a scoping review. Child Youth Serv. Rev. 111, 104837 https://doi.org/10.1016/j.childyouth.2020.104837.

Arntz, M., Gregory, T., Zierahn, U., 2016. The risk of automation for jobs in OECD countries: A comparative analysis. In: OECD Social, Employment and Migration Working Papers No. 189. https://www.oecd-ilibrary.org/social-issues-migration-health/the-risk-of-automation-for-jobs-in-oecd-countries_5jlz9h56dvq7-en.

Autor, D.H., Handel, M., 2013. Putting tasks to the test: human capital, job tasks, and wages. J. Labor Econ. 31 (S1), S59–S96. https://doi.org/10.1086/669332.

Bannò, M., Filippi, E., Trento, S., 2021. Rischi di automazione delle occupazioni: una stima per l'Italia. In: Stato e mercato, 3, pp. 315–350. https://doi.org/10.1425/103268.
Beer, C., 2009. Democracy and gender equality. Stud. Comp. Int. Dev. 44 (3), 212–227. https://doi.org/10.1007/s12116-009-9043-2.
Bessen, J., Goos, M., Salomons, A., van den Berge, W., 2020. Automation: A Guide for Policymakers. Brookings Institution.
Blanas, S., Gancia, G., Lee, S.Y., (Tim)., 2019. Who is afraid of machines? Econ. Policy 34 (100), 627–690. https://doi.org/10.1093/epolic/eiaa005.
Blaskó, Z., da Costa, P., Schnepf, S.V., 2022. Learning losses and educational inequalities in Europe: mapping the potential consequences of the COVID-19 crisis. J. Eur. Soc. Policy 095892872210916. https://doi.org/10.1177/09589287221091687.
Brussevich, M., Dabla-Norris, E., Khalid, S., IMF e-Library - York University, 2019. Is technology widening the gender gap?: Automation and the future of female employment. https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=2138076.
Byrne, J., Fayolle, A., 2010. A feminist inquiry into entrepreneurship training. In: Smallbone, In D., Leitão, J., Raposo, M., Welter, F. (Eds.), The Theory and Practice of Entrepreneurship. Edward Elgar Publishing, p. 14090. https://doi.org/10.4337/9781849805933.00010.
Castellano, R., Rocca, A., 2018. Gender disparities in european labour markets: a comparison of conditions for men and women in paid employment. Int. Labour Rev. 157 (4), 589–608. https://doi.org/10.1111/ilr.12122.
Cedefop, 2015. Skills, qualifications and jobs in the EU: the making of a perfect match?. In: Evidence From Cedefop's European Skills and Jobs Survey. : Publications Office Cedefop Reference Series; No 103 Http://www.cedefop.europa.eu/en/publications-and-resources/publications/3072.
Chang, J.-H., Huynh, Phu, 2016. The Future of Jobs at Risk of Automation. International Labour Office Bureau for Employers Activities Regional Office for Asia and the Pacific. http://www.ilo.org/public/english/dialogue/actemp/downloads/publications/2016/asean_in_transf_2016_r2_future.pdf.
Cortes, P., Pan, J., 2019. Gender, occupational segregation, and automation. In: Economics Studies at Brookings, pp. 1–32.
David, B., 2017. Computer technology and probable job destructions in Japan: an evaluation. J. Jpn. Int. Econ. 43, 77–87. https://doi.org/10.1016/j.jjie.2017.01.001.
Delgado Cadena, M.V., 2020. Gender job gaps and challenges in the digital economy: findings from global governance entities. Cuad. Adm. 36 (67), 158–171. https://doi.org/10.25100/cdea.v36i67.8767.
Eagly, A.H., Karau, S.J., 2002. Role congruity theory of prejudice toward female leaders. Psychol. Rev. 109 (3), 573–598. https://doi.org/10.1037/0033-295X.109.3.573.
Egana-delSol, P., Bustelo, M., Ripani, L., Soler, N., Viollaz, M., 2021. Automation in Latin America: are women at higher risk of losing their jobs? Technol. Forecast. Soc. Chang. https://doi.org/10.1016/j.techfore.2021.121333.
Filippi, E., Bannò, M., Trento, S., 2023. Automation technologies and their impact on employment: A review, synthesis and future research agenda. Technol. Forecast. Soc. Chang. 191, 122448. https://doi.org/10.1016/j.techfore.2023.122448.
Frenette, M., Frank, K., 2020. Automation and job transformation in Canada who's at risk?. In: Statistics Canada = Statistique Canada.
Frey, C.B., Osborne, M., 2017. The future of employment: how susceptible are jobs to computerisation? Technol. Forecast. Soc. Chang. 114, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019.
Fuei, L.K., 2017. Automation, computerization and future employment in Singapore. Journal of Southeast Asian Economies 34 (2), 388–399. https://doi.org/10.1355/ae34-2h. Scopus.
García-Holgado, A., Camacho Díaz, A., García-Peñalvo, F.J., 2019. La brecha de género en el sector STEM en América Latina: Una propuesta europea. In: Aprendizaje, Innovación y Cooperación como impulsores del cambio metodológico, pp. 704–709. https://doi.org/10.26754/CINAIC.2019.0143.
Georgieva, K., Alonso, C., Dabla-Norris, E., Kochhar, K., 2019. The Economic Cost of Devaluing "Womens Work". https://blogs.imf.org/2019/10/15/the-economic-cost-of-devaluing-womens-work/.
Greene, W.H., 2003. Econometric analysis. In: Pearson Education India.
Haiss, P., Mahlberg, B., Michlits, D., 2021. Industry 4.0–the future of Austrian jobs. Empirica 48 (1), 5–36. https://doi.org/10.1007/s10663-020-09497-z. Scopus.
Hout, M., 2012. Social and economic returns to college education in the United States. Annu. Rev. Sociol. 38 (1), 379–400. https://doi.org/10.1146/annurev.soc.012809.102503.
Illéssy, M., Huszár, Á., Makó, C., 2021. Technological development and the labour market: how susceptible are jobs to automation in hungary in the international comparison? Societies 11 (3). https://doi.org/10.3390/soc11030093.
Kaushik, N., Sharma, A., Kumar Kaushik, V., 2014. Equality in the workplace: a study of gender issues in Indian organisations. J. Manag. Dev. 33 (2), 90–106. https://doi.org/10.1108/JMD-11-2013-0140.
Lima, Y., Strauch, J.C.M., Esteves, M.G.P., de Souza, J.M., Chaves, M.B., Gomes, D.T., 2021. Exploring the future impact of automation in Brazil. Employee Relations 43 (5), 1052–1066. https://doi.org/10.1108/ER-08-2020-0364. Scopus.
Madgavkar, A., Manyika, J., Krishnan, M., Ellingrud, K., Yee, L., Woetzel, J., Chui, M., Hunt, V., Balakrishnan, S., 2019. The Future of Women at Work. In: McKinsey Global Institute, pp. 1–155.
Mason, P.L., 2021. Computerization and occupational change: assessing the impact of automation on racial and gender employment densities. Rev. Black Polit. Econ. https://doi.org/10.1177/00346446211055203.
Mikkola, A., Miles, C.A., 2007. Development and gender equality: consequences, causes, challenges and cures. In: Discussion Paper No. 159. HECER – Helsinki Center of Economic Research, pp. 1–60.
Morais Maceira, H., 2017. Economic benefits of gender equality in the EU. Intereconomics 52 (3), 178–183. https://doi.org/10.1007/s10272-017-0669-4.
Nedelkoska, L., Quintini, G., 2018. Automation, skills use and training. In: OECD Social, Employment and Migration Working Papers No. 202. OECD Publishing. https://www.oecd-ilibrary.org/employment/automation-skills-use-and-training_2e2f4eea-en.
Núñez, R.B.C., Bandeira, P., Santero-Sánchez, R., 2020. Social economy, gender equality at work and the 2030 agenda: theory and evidence from Spain. Sustainability 12 (12), 5192. https://doi.org/10.3390/su12125192.
Pajarinen, M., Rouvinen, P., Ekeland, A., 2015. Computerization threatens one-third of finnish and norwegian employment. ETLA Brief 34.
Pampliega, G., 2019. Brecha de género y automatización. Efectos de la revolución digital en el mercado laboral español. Un mundo complejo. dehttps://epampliega.com/blog/index.php/2019/07/17/brecha-de-genero-y-automatizacion/.
Piasna, A., Drahokoupil, J., 2017. Gender inequalities in the new world of work. Transfer 23 (3), 313–332. https://doi.org/10.1177/1024258917713839. Scopus.
Pouliakas, K., 2018. Determinants of automation risk in the EU labour market: A skills-needs approach. In: Discussion Paper No. 11829. IZA Institute of Labor Economics.
Ramos, M.E., Garza-Rodríguez, J., Gibaja-Romero, D.E., 2022. Automation of employment in the presence of industry 4.0: the case of Mexico. Technol. Soc. 68 https://doi.org/10.1016/j.techsoc.2021.101837.
Roberts, C., Parkes, H., Statham, R., Rankin, L., 2019. In: The future is ours: Women, automation and equality in the digital age. IPPR, the Institute for Public Policy Research, pp. 1–52.
Rodriguez-Bustelo, C., Batista-Foguet, J.M., Serlavós, R., 2020. Debating the future of work: the perception and reaction of the spanish workforce to digitization and automation technologies. Front. Psychol. 11, 1965. https://doi.org/10.3389/fpsyg.2020.01965.
Shook, E., Knickrehm, M., 2018. "Reworkingthe Revolution" Are You Ready to Compete as Intelligent Technology Meets HumanIngenuity to Create the Future Workforce? https://www.accenture.com/_acnmedia/pdf-69/.
Spencer, D.A., 2018. Fear and hope in an age of mass automation: debating the future of work. N. Technol. Work. Employ. 33 (1), 1–12. https://doi.org/10.1111/ntwe.12105.
Stier, H., Herzberg-Druker, E., 2017. Running ahead or running in place? Educational expansion and gender inequality in the labor market. Soc. Indic. Res. 130 (3), 1187–1206. https://doi.org/10.1007/s11205-015-1210-4.
Subrahmanian, R., 2005. Gender equality in education: definitions and measurements. Int. J. Educ. Dev. 25 (4), 395–407. https://doi.org/10.1016/j.ijedudev.2005.04.003.
UNESCO, 2012. World atlas on gender equality in education. UNESCO.
UNESCO, 2022. Gender report: Deepening the debate on those still left behind. UNESCO.
Verheul, I., Thurik, R., 2001. Start-up capital: 'does gender matter?'. Small Bus. Econ. 16 (4), 329–346. https://doi.org/10.1023/A:1011178629240.
Vitáloš, M., 2019. In: Susceptibility of jobs to automation in Slovakia. EDAMBA 2019, pp. 539–547.
Wajcman, J., 2017. Automation: is it really different this time? Br. J. Sociol. 68 (1), 119–127. https://doi.org/10.1111/1468-4446.12239.
Zhou, G., Chu, G., Li, L., Meng, L., 2020. The effect of artificial intelligence on China's labor market. China Economic Journal 13 (1), 24–41. https://doi.org/10.1080/17538963.2019.1681201.

Emilia Filippi is a PhD student in Economics and Management at the University of Trento, Italy. Her research interests concern technological change, innovation and the impact on work.

Mariasole Bannò is Associate Professor of Management at the University of Brescia, Italy. She gained a PhD in Economics and Management of Technology at University of Bergamo, Italy. Her research interests concern family business, the outward and inward internationalization of firms, gender issues, and the evaluation of public policies.

Sandro Trento is Full Professor of Management at the University of Trento, Italy. He studied economics at the University of Rome La Sapienza, Italy; at Northwestern University, Illinois; he has been a visiting scholar at Stanford University. His research interests are related to corporate change; innovation management; corporate governance and family business.