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High skilled workplaces, technological change and employment: Can educational reform do it?

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ABSTRACT

Human capital, and related theories such as skills biased technological change, argue that skills development is a central strategy for individuals to succeed in an increasingly global and digitalised labour market. One of the main shortcomings of these theories, however, is their focus on the individual and their detachment from the organisational context in which workers operate and deploy their skills. In this article, we incorporate this context in the analysis, and explore the importance of the company characteristics in sheltering workers from unemployment when technological change occurs in their firm, using rich establishment-level data. Our results suggest that 'high-skilled' workplaces do not protect workers against automation. By contrast, the results point to the importance of companies' competitive strategies and management perceptions in sheltering workers from automation. The findings underline the relevance of social relations in the analysis of the future of work, and question accounts that focus exclusively on skills and educational reform to protect workers and create inclusive labour markets.

1. Introduction

Human capital, and related theories, argue that skills development is a central strategy for individuals to do well in an increasingly global and digitalised labour market. One of the main shortcomings of these theories is their focus on the individual and their detachment from the context in which workers deploy their skills. This article explores how the organizational context of firms mediates the relationship between technological change and labour substitution. Automation refers to the introduction of technological change that replaces workers in tasks that they previously performed (Acemoglu & Restrepo, 2019). A burgeoning literature has emerged examining the potential of technology, -including artificial intelligence (AI), machine learning and robotics, amongst other technologies-, to automate labour (Lamb, Munro, & Vu, 2018; Parker & Grote, 2022). However, the effects on technological change on employment are widely contested. Some studies argue that almost half of existing jobs are at high risk of automation, whereas others provide much lower estimates (Arntz, Gregory, & Zierahn, 2016; Frey & Osborne, 2017; Mondolo, 2022).

Much of this work is characterized by an over-reliance on industrial expert opinion and a 'de-contextualised' focus on occupations and job tasks, with little account of the role of organizational context in mediating the relationship between technology and employment. This is a serious omission because as Shestakofsky (2017:379-380) notes, "the effects of technology on work are (…) inseparable from the social settings – more specifically the organizational contexts - in which they interact. The existence of a technological object alone does not indicate if or how an organization will use it" (see also Wajcman, 2006).

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Two literatures related to human capital, skills-biased technological change (SBTC) and skills biased organizational change (SBOC), devote specific attention to the relationship between technology and work (Berman, Bound, & Machin, 1998; Bolli & Pusterla, 2023; Caroli & Van Reenen, 2001). SBOC gives more attention to the organizational level than SBTC, but less to technology, which enters the analysis mainly as an enabler of organizational change. The main focus of both theories, however, has been on the change in the skills composition of the workforce, associated with either the introduction of technology or high performance work practices. They have less to say about the effect of technology on the number of jobs *within* firms.

By contrast, we are primarily interested in whether certain firm characteristics can have a 'sheltering effect' on jobs within firms when technology is introduced (Ashton, 1986). This is a matter of theoretical interest, but also of practical interest, as job seekers make decisions on what firm to join. We include a wide range of firm characteristics in the analysis: firms' stock of skills, organizational structure, competitive strategies and management's perception of their workforce. Our findings suggest that neither skill levels in the firm nor high performance organizational practices have a sheltering effect. Instead, two key factors emerge as relevant in mediating the relationship between technological change and labour substitution: firms' competitive strategies and managers' perceptions of the competence and commitment of their workforce. This reinforces the message that technology is not destiny, but also points to the limitations of relying on 'high skills' workplaces as shelters against automation.

In order to explore these issues the article makes use of a unique dataset, the Business Performance and Skills Survey (BPSS), in Singapore. The BPSS is a large-scale face-to-face employer survey, which gathered data at the commercial establishment level.[1] A distinct advantage of this survey to explore the relationship between technological change, organizational characteristics and workforce reduction, is the inclusion of questions on the introduction of technological and non-technological change in the firm and changes in their number of workers. This enables a shift in the focus of the enquiry from technological possibilities – prevalent in the literature - to organizational realities, and adds to a growing body of literature on the effects of firm level technology adoption (e.g. Bessen, Goos, Salomons, & Van den Berge, 2023; Genz, Gregory, Janser, Lehmer, & Matthes, 2021). The remainder of the article is structured as follows: section two presents a review of the literature on the impact of technology on employment, and on SBTC and SBOC theories. Section three outlines our methodology, section four findings and section five conclusions.

2. Literature review

Studies on the relationship between technology and jobs differ greatly in their predictions. Some look at what machines *are* able to do now, others what machines *will* be able to do in the future and others look at what they *have done* (Pouliakas & Souto-Otero, 2022). They also vary in the 'machines' (e.g. industrial robots, general purpose computerized technologies) they look at in assessing the potential for labour substitution and in the dependent variable: impact on jobs, where most of the public interest concentrates, or impact on job tasks. The results do not provide a clear answer on the effect of technology adoption. What the bulk of these studies do have in common is an absence of a company-level analysis in mediating the relationship between the introduction of technologies and jobs.

2.1. Prospective studies on the impact of technology on employment

Prospective studies, or forecasts, have used experts' views on the occupations and tasks that machines can or will be able to do. Frey and Osborne (2017) study how automation may affect jobs, based on an occupation-led approach. They categorised 'occupations according to their susceptibility to computerisation' (Frey & Osborne, 2017:254), based on the views of machine learning researchers, supplemented by information from O*NET and concluded that 47 percent of total employment in the USA is at high risk of automation 'over some unspecified number of years, perhaps a decade or two' (Frey & Osborne, 2017:265). Their approach was rolled out to other geographies (see Haldane (2015), Houses of Parliament (2016)), with similar results.

Arntz et al. (2016) took issue with Frey and Osborne's occupation-based approach because 'occupations labelled as high-risk occupations often still contain a substantial share of tasks that are hard to automate' (Arntz et al., 2016:4; Autor, 2014). As a result technology often leads to changes in tasks within occupations rather than in employment shares between occupations (Arntz et al., 2016). Using PIAAC individual level data on tasks performed by workers, Arntz et al. take into account the ways tasks vary within the same occupation and across countries -instead of relying on the assumption that task structures will be constant, as Frey and Osborne do. They estimate that, on average for the 21 OECD countries that they study, 9 percent of jobs are fully automatable. Arntz et al. underline that this is still likely an overestimation given (1) economic, legal, social and ethical barriers to automation, (2) possibilities of job-task reorganization and workers switching tasks to focus on those that are not automated and (3) the creation of additional jobs 'through demand for new technologies and through higher competitiveness' (Ibid. p.4; see also Cirillo, Mina, & Ricci, 2021; Farquhar, 2016; IFR 2017). Arntz et al.'s task-based approach still relies on experts' assessment on how automatable tasks are. Other occupation or task-based analyses (like McKinsey 2017) forecast more modest effects of automation than envisaged by Frey and Osborne and claim that: 'more occupations will change than will be automated away' (McKinsey 2017: 8).

Yet, some studies offer different results. Grace, Salvatier, Dafoe, Zhang, and Evans (2018) surveyed 352 machine-learning researchers on their beliefs on when AI would outperform humans on a range of activities. Respondents predicted that AI will outperform humans in many activities (such as translating languages, writing school essays, driving a truck) in the follwing ten years and that

[1] In this article we refer to 'firm' and establishments interchangeably.

'there is a 50 % chance of AI outperforming humans in all tasks in 45 years and of automating all human jobs in 120 years' (Grace et al., 2018:1). Industry experts' views are also split. A 2014 Pew's Research Centre poll of over 1,800 industry experts reported that 48 % expected robots and digital technologies to displace significant numbers of workers over the following decade, whereas 52 % expected technology not to displace more jobs than it creates by 2025. The use of generative AI and Chatboxes like ChatGPT has brought about further interest in the potential of digital technologies to change job tasks and substitute human labour, including in professional work (Kalla & Smith, 2023).

2.2. Industrial robots and employment levels

Acemoglu and Restrepo (2020) moved away from experts' opinions to focus on the actual use of industrial robots, drawing on data from the International Federation of Robotics (IFR). They analyse data from 19 industries between 1990 and 2007 in the US and report that the introduction of robots has robust negative effects on employment, even after controlling for increases in employment in other areas of the economy through the productivity effects produced by automation. They estimate that 'one more robot per thousand workers reduces the employment to population ratio by about 0.2 percentage points and wages by 0.42 percent' (Acemoglu & Restrepo, 2020:2188). Graetz and Michaels (2015) analyse the effects of increased use of industrial robots between 1993 and 2007 in 17 developed countries using data from the IFR and note no significant effect on total hours worked or hours worked by workers with a college degree or above, but found evidence that robots reduced the hours of low-skilled workers relative to middle and high skilled workers. Dauth, Findeisen, Suedekum, and Woessner (2017) underline the importance of the national regulations and institutional context. Using data from the IFR for Germany, a highly robot-intensive country, they report 'effects close to zero' on aggregate employment, which they explained with reference to German industrial relations, especially its strong trade-unions and work councils, which were willing to accept wage reductions in exchange for high employment.

The bulk of research on the impact of machines on jobs presents several shortcomings. First, it relies overwhelmingly on expert judgments, which tend to overestimate the capacity of new technologies, focuses on occupations or tasks –rather than actual jobs- and potential use of technology -with few studies that look at actual use. While "retrospective" studies have addressed some of these shortcomings, they have so far been largely restricted to the use of industrial robots. Second, prospective studies are generally vague in the specification of the time-frames in which 'automation' could be expected to have an effect on employment. Third, there is little consideration of the extent to which economic and social factors affect the replacement of workers by technology. Fourth, studies most often explore the aggregate national level, ignoring the organizational level, which is of crucial interest to individual workers. While the effects of technology on employment are unlikely to be monotonic, the context in which tasks are performed and how workplace level variations may affect the introduction of labour-replacing technology is conspicuously absent from the analysis[2].

2.3. Skills Biased technological and organizational change (SBTC and SBOC)

SBTC and SBOC aim to explain, primarily, the increasing demand for skilled workers in the labour market. Their main concern is not employment levels but the relative distribution of employment across skills categories –the structure of employment. According to SBTC technology is complementary with high skilled workers, as they are able to exploit technology to increase their productivity –although see Acemoglu (2002). Thus, high skills protect workers from automation and enable them to reap the productivity rewards that technology offers. Routine tasks associated with lower skills work are much more vulnerable to automation (Golding & Katz, 2009). Because automation increases productivity it raises earnings and increases the demand for labour: automation may not decrease the number of jobs (Autor, 2015). In SBOC it is flexible organizational structures and practices –reduction of hierarchical levels, shorter chains of command, delayering and decentralization of responsibility, delegation of decision-making, multiskilling- that explain changes in the skills structure, because such practices require more involved, autonomous and skilled workers (Caroli & Van Reenen, 2001; Piva, Santarelli, & Vivarelli, 2005).

Together, SBTC and SBOC link technology adoption, workplace organization, firms' skill structures and performance, but their predictions regarding the consequences of technology and organisational structures for changes in employment levels within firms are limited. The focus of SBTC and SBOC is not on workers' headcounts in firms, and only a small number of studies have looked at this aspect. As mentioned, firms that introduce technology and flexible working practices are expected to experience increases in productivity (Bloom et al., 2017), which enables their expansion as they become more competitive. Greenan (2003) studies the relationship between organizational change, technology, employment and skills in firms. She concludes that tech firms that introduce new technologies are less likely to destroy jobs than other firms. Technology, instead, encourages employment growth through market share expansion and increased competitiveness (see also Mondolo, 2022). This is consistent with Chennells and Van Reenen's (1999) expectations, as they argue that firms tend to introduce technology when they expect demand conditions to improve, which may push their employment counts upwards. Piva, Santarelli, and Vivarelli (2006), however, found a labour-saving effect of technology on manufacturing firms in Italy, of a non-skilled biased nature, as the reduction in employment affected both white-and-blue-collar workers. More recently Cirillo, Mina, and Ricci (2022) used matched firm and employee level data from Italy and find a small effect of technology adoption in firms on job creation, concentrated in young workers, and Genz et al. (2021) document a range of positive outcomes for employers and employees deriving from technology adoption in German companies, although these are

[2] This contrasts with advances from both economics and sociology in the analysis of the firm's role in income inequality (Song et al. 2019) and sociological analyses of variations in firm occupational hierarchies (Holt et al. 2019).

unequally distributed between different types of workers. Moves towards the 'flexible firm', by contrast, Greenan found, favour workforce renewal through greater job destruction and creation, which change firms' occupational structure (making firms more management heavy) but have little impact on the level of employment as job destruction and creation broadly level off (Greenan, 2003).

2.4. Factors affecting the relationship between technology and workforce reduction: the firm level

The studies discussed present valuable information about the potential effects of automation on employment. However, there is limited literature on how firms' characteristics mediate the relationship between technologies and labour substitution. We extend our analysis beyond existing studies by considering a range of firm related variables, including competition strategies and management perceptions (on workforce competence and effort), which have been consistently absent. To examine the impact on firm-level characteristics we developed six hypotheses.

2.4.1. Workforce skills

Education and skills are seen as the primary factors to protect against labour substitution and high levels of education in the workforce are believed to protect employees against the negative consequences of automation (Aleksander, 2017; Autor, 2015; Goldin & Katz, 2009). Skills can be developed through education and on the job experience (Souto-Otero, 2021). Other common proxies for skills used in the literature are occupational roles and wages. Companies with high skilled labour would have higher incentives for the automation of labour, as labour costs per employee are larger. However, there are counterweights to this incentive. High skilled labour is considered more difficult to automate and complementary with technology, as well as flexible forms of work organisation. Companies with a highly skilled workforce would also be more able to afford keeping low skilled workers in support tasks, a primary target of automation, as their replacement by technology would only bring marginal savings. Consistently with these arguments, Domini, Grazzi, Moschella, and Treibich (2021) find that automation spikes do not conform to SBTC theory expectations as workforce skills composition does not change significantly following automation.

Hypothesis 1. *Higher levels of skill within the establishment are negatively associated with labour substitution.*

2.4.2. Workforce development

Interest in better understanding the relationship between training and automation has increased recently (Feng & Graetz, 2020). Perceived automation risks, which can be increased when a company introduces new technologies, affect workers' intentions to invest in human capital (Innocenti & Golin, 2022). The introduction of new technology itself requires IT-related technical skills and expertise, and training to use the new technology (Lamb et al., 2018). Technology also transforms jobs and skills requirements, leading to a need for retraining (McKinsey 2017). In this narrative, automation plus training are linked to high-added value work and growth, rather than to job losses. Career planning and training are considered ways to ease the transition into the use of new technologies (Bruque & Moyano, 2007) and protect workers against automation. Moreover, given that training has a cost, companies that train broadly could be expected to want to retain their workers (Boockamnn & Steffes, 2010), to obtain returns on their investment.

Hypothesis 2. *Higher levels of support for workforce development initiatives, such as training and career planning, are negatively associated with labour substitution.*

2.4.3. Work organization and job autonomy

SBOC highlights the importance of workers' autonomy, freedom and independence in designing or carrying out their work. As noted, SBOC is expected to reduce the demand for unskilled workers and increase the demand for skilled workers, but have little net impact on employment (Greenan, 2003). MacCrory, Westerman, Alhammadi, and Brynjolfsson (2014) note that initiative and independence are important skills in the labour market (see also Brown & Souto-Otero, 2020; Deming, 2021). Judgment is related to discretion, and has been linked to decreases in the likelihood of automation (Levy & Murnane, 2013), because computers are less sophisticated than humans in tasks where exercising judgment is key, as this is difficult to codify (Autor, 2015).

Hypothesis 3. *Higher levels of job autonomy within the establishment are negatively associated with labour substitution.*

2.4.4. Competitive strategy

There is surprisingly little discussion in the sociology and economic literatures as to how competitive strategies (see Porter, 1996) may affect firms' decisions on the introduction of labour-replacing technologies. Lamb et al. (2018) argue that technology can combine improved capabilities and product quality with cost reduction. While the sociological literature on post-fordism and job enrichment provides examples of workforce upskilling and product quality improvement through the introduction of technology (Vidal, 2011), companies often will aim to automate tasks to increase efficiency and save costs (Winroth, Safsten, & Stahre, 2007). Previous research has found cost strategies to be a predictor of outsourcing (cost oriented firms being more likely to outsource, reducing the set of tasks undertaken by their workers), by contrast with firms that have less cost-oriented differentiation strategies (Martínez-Sánchez, Vela-Jiménez, de Luis-Carnicer, & Pérez-Pérez, 2007). As such, companies that compete on price could be expected to opt for labour replacing technologies to reduce costs, whereas those that compete on quality may want to preserve human labour as a sign of quality and care for design, production and customer relations.

Hypothesis 4. *A high value-added business strategy is negatively associated with labour substitution.*

2.4.5. Workforce competence

Labour process theory provides a useful framework for the study of work organization and how labour power is materialized into use values, as well as the conflictual relations generated in that process. Smith (2006:390) notes that: "labour power, what the employer hires and the worker exchanges, is indeterminate because the precise amount of effort to be extracted cannot be 'fixed' before the engagement of workers machinery and products for purposelful (…) action in the labour process". This is associated with the idea of 'indeterminacy' in the employment relationship, a concept used in the employment relations literature for example to study workplace rules of conduct, the codification of tasks or the determination of the wage-effort relationship (Hamilton, 2001; Kessler, Heron, & Dopson, 2013). We divide labour power into two elements: competence required and effort applied to undertake a task.

Both aspects are sources of indeterminacy: the competence required and the effort expected on the job are not known by the job seeker, while employers have difficulties in assessing employees' competences and effort, as the literature on human resources and talent management note (Tootell, Blackler, Toulson, & Dewe, 2009). This *dual indeterminacy* leaves room for managerial interpretations and judgment (management power), including on the basic element of exchange in the labour process: the employment nexus. Winroth et al. (2007) note that findings from various countries indicate that automation decisions are often not based on the analysis of solid facts, but on feelings and intuitions by management. Managerial expectations of employee performance and their interpretation of workers' commitment (effort/ enthusiasm) have been found to predict managers' assessments of employees better than employees' actual job performance and to shape managers' reward and sanction behaviours (García-Cruz, Real, & Roldán, 2018; Shore, Bommer, & Shore, 2008).

With regards to job competence, this can be defined as an employee's contribution to the organizational goals and objectives (Lee, 2010). Lack of employees' capacity to competently perform duties impacts on organizational performance (Bal & De Lange, 2015). Companies can take various actions, such as increased flexibility, training or use pay or other incentives to try and improve workers' performance. But they can also address low performance through the replacement of workers by technology. Performance appraisal is difficult and often biased (Bellé, Cantarelli, & Belardinelli, 2017), which underlines the social character of firms' decisions; however the importance of management perceptions is absent in the purely economic tenets of SBTC and SBOC.

Hypothesis 5. *Lack of capacity to competently perform workforce duties, as perceived by management, is positively associated with the use of technology for labour substitution.*

2.4.6. Workforce effort

Perceptions of performance are also linked to perceptions of discretionary effort. 'The precise amount of effort to be extracted cannot be 'fixed' before the engagement of workers, machinery and products for purposeful (profitable within capitalism) action in the labour process' (Smith, 2006:390). Standards of effort are, moreover, of a temporal and variable nature, even within companies –contingent for example on the level of competition, or ways of organizing work. In the work-effort bargaining, it is assumed that high skilled workers are willing to use their skills in ways that are beneficial to the firm. If workers are not perceived to behave in this way, management would be more prone to substitute them, including through automation.

In addition, the gift exchange model of employment maintains that higher levels of unemployment stimulate workforce effort, as employees are more 'grateful' for being employed (Agell & Lundborg, 1995). Companies frequently take measures to monitor the level of effort of their workforce. Shirkers are expected to be penalized and those who are perceived to be hard workers expect to receive benefits. We extend the argument of the gift exchange model to check whether employers are less likely to reduce their workforce by machines when they judge employees to go beyond the call of duty in their efforts.

Hypothesis 6. *Perceived high levels of workforce effort will be negatively associated with labour substitution*

2.4.7. Other company characteristics

In testing the above hypotheses it is necessary to consider the heterogeneity of firms. Acemoglu and Restrepo (2018) identify some sectors as having greater opportunities to use robots (automobiles, electronics, metal machinery, chemicals, plastics and pharmaceuticals industries), whereas in others there may be a preference for human interaction (Autor, 2014), such as in elderly care and education. Lamb et al. (2018) suggest that smaller firms can have difficulties in adopting new technologies due to costs and disruption effects, and Kanamori and Motohashi (2006) and Caroli and Van Reenen (2001) find that the productivity effects of technology and organizational change are greater for large firms. Moreover, size could be expected to be inversely related to firing, as larger companies are more able to readjust their headcounts in times of change through non-replacement of leavers, reducing firing risks. There is little research on how the location of companies' headquarters (local or foreign) or type of company ownership (family/ non family) may affect the introduction of technology (Bruque & Moyano, 2007). Yet, these factors could be expected to affect management views on the social desirability of labour replacing technology: family ownership and local headquarters may produce a closer relationship with a company's workforce, which can lead to –other things being equal- more job protective strategies.

3. Methodology

3.1. Questions

This article analyses how automation impacts on the workers in different firm contexts in Singapore. The city-state, has a highly developed and competitive market economy, with one of the highest GDP per capita in the world, low levels of unemployment and a highly flexible labour market characterized by the absence of strong labour market protection or robust safety nets, which can

Table 1
Characteristics of the sample.

	% of establshments in sample	
Had a reduction in the number of workers	71.44	
Workfoce development		
Offer job-related training		
Not at all	16.87	
Yes, no resources	15.14	
Yes, no monetary resources	25.20	
Yes, monetary resources	42.78	
Offer career planning to…	14.50	
No staff	14.53	
<10 % of staff	24.49	
10–50 % of staff	36.89	
>50 % of staff	24.09	
Offer a high potential talent program	35.98	
Management perceptions of the workforce		
Inadequate performance		
No staff	21.75	
<10 % of staff	45.00	
10–25 %of staff	19.41	
26–50 % of staff	9.15	
>50 % of staff	4.27	
Staff applying discretionary effort		
None	2.24	
<10 %	15.65	
10–25 %	26.32	
26–50 %	27.85	
>50 %	27.95	
Other firm characteristics		
Are family owned	32.22	
Have headquarters Singapore	86	
Industry		
Manufacturing	9.65	
Construction	11.38	
Wholesale and retail trade	23.27	
Transportation and storage	3.96	
Accommodation and food services	4.17	
Information and communications	10.77	
Financial and Insurance	3.15	
Real Estate	1.42	
Professional, scientific and technical	13.31	
Administration and support	9.35	
Education	3.15	
Health and social services	2.03	
Other services	4.37	
	Sample mean	Sample SD
Work Organisation		
Job autonomy (1–5 scale)	3.26	1.07
Competitive strategy		
Compete premium goods (1–5 scale)	3.93	0.83
Reliant on cost competition (1–5 scale)	3.33	0.97
Other firm characteristics		
Workforce size	31.6	0.89
	Share of workers at the establishement	SD
Skill proxies		
*Are knowledge workers^*	35.33	33.33
*Require degree^*	31.77	30.57
*Require experience^*	41.85	29.77
*Are managers and professionals^*	24.86	22.72
*Are associate professionals^*	37.60	30.46
*Receive a high wage^*	13.72	17.56
*Receive a low wage^*	23.92	25.44
Management perceptions of the workforce		
*Have difficulty coping with duties (management perception)^*	10.15	13.24

Characteristics of the sample included in the regression analysis. Key: ^ = reported as proportion of establishment's workforce. N = 985.

incentivise labour replacing technology adoption decisions (Cirillo et al., 2021; Waring, Bali, & Vas, 2020; WEF 2019). Singapore is also interesting being a hub for global companies from the West and from Asia, especially China, and has scaled up rapidly to be among the global leaders for digital technologies. Government has also pushed for the adoption of digital technologies in various sectors as a way to upskill its workers (Hwang, Ngo, & Teo, 2022; Workforce Singapore 2022). Singapore has a high quality education system, and Singaporean society places a particularly high value on the education and skills development amongst its population. The country has two universities that regularly feature on the top-20 in the world (National University of Singapore and Nanyang Technological University) and is regularly amongst the top performers in PISA tests. Most education, including both formal education and workforce development, receives strong support from the State (Sung & Freebody, 2017). As such, it is an interesting case for the study of the relation between jobs and technology, where business innovation is encouraged, the education system is strong and where there are few regulatory barriers to reducing employee headcounts.

As it is often argued that companies are more likely to automate jobs within 'flexible' labour markets, we expect that the introduction of significant changes in work processes related to technology to be positively associated with labour substitution, but we expect this to be mediated by the characteristics of the firm.

3.2. Data and methods

We employ a novel dataset in our analysis, the Business Performance and Skills Survey (BPSS), carried out by the Institute for Adult Learning (IAL) Singapore. One of the authors was engaged in questionnaire design and fieldwork for the survey, and the IAL provided the authors with access to the data. This survey enables us to go beyond existing studies that rely on expert opinion or the penetration of industrial robots, to examine labour-replacing decisions in practice. Direct questioning on the introduction of changes related to technology is a move away from traditional 'input' measures of technological change (R&D spending, patents, use of computers at work) predominant in the literature and which may or may not be related to 'change'.

The BPSS, completed between January and December 2016, is a large national face-to-face survey of 3,801 commercial establishments with 10 or more workers. Establishments were selected for sampling from the Singapore Accounting and Corporate Regulatory Authority (ACRA) registry of live companies. Sole proprietors and partnerships were excluded from the sampling frame, as were de-listed entities. The protocol for data collection entailed the interviewer approaching the business entity at the address listed in the sampling frame and checking that the entity was eligible and willing to participate. Interviews targeted either the owner of the business or a senior manager who had a minimum of 1 year's experience working at the establishment. If the establishment was non-eligible or refused to participate, the interviewer checked the eligibility of the nearest neighboring commercial establishment before inviting them to participate as a replacement firm.

The survey asked respondents whether the establishment had introduced significant changes in work processes in the 12 months prior to the survey, and whether those were related to technology or not. Respondents who reported that such changes had been introduced were then asked whether this had led to reductions in the number of workers required by their firm – measured through a 5 points Likert scale from 'no reduction' to 'a significant reduction'. Based on our interest in analyzing whether or not the introduction of technological change led to any kind of reduction in the workforce, we used a binary dependent variable: 0 = at least some job losses; 1 = no job losses. Out of the 3,801 companies in the database (and reported in Table 2), 1,044 had introduced significant changes in work processes related to technology in the previous 12 months. 985 of these entered the final analysis -with the other 59 cases being dropped because of missing data in some variables. The data is cross-sectional, but it implicitly compares two points in time (the time of the survey and the situation twelve months prior). The measurements for the explanatory variables identified in the previous sections (workforce skills, workforce development initiatives, job autonomy, competitive strategy, management perceptions on workforce competence and management perceptions on workforce effort) as well as control variables are explained in Annex 1. It should be noted that we do not have a direct measure of workers' skills, which is a limitation of the data; skill levels in the establishment were approximated using variables related to formal education, experience, occupation, job tasks and wages as shown in the Annex.

The analysis first provides descriptive statistics on the introduction of technological change and job reduction. We then employed binary logistic regression to provide evidence on factors correlated with labour substitution resulting from technological innovation at the level of the establishment. A full (enter) model (based on theoretical arguments) binary multivariable (two outcomes, more than one predictor) logistic regression was chosen over other methods such as stepwise regression in order to mitigate the potential for data-snooping and overfitting (see for example Smith, 2018). No multicollinearity problems were detected in the examination of the data through Pearson correlation matrixes.

Table 1 presents the characteristics of our sample.

4. Findings: introduction of technological change and workforce reduction

In the context of decreasing costs of technology (Graetz & Michaels, 2015) and, at the time of BPSS survey, low interest rates, it could be expected that many businesses leaned towards investments in automation. Indeed, a very large proportion of establishments, almost half, reported to have introduced significant changes in work processes in the 12 months prior to the survey –see Table 2- and amongst those, a majority reported that these changes had been related to technology. On the whole, over a quarter of establishments reported to have introduced significant changes related to technology in the year prior to the survey. Given the short timeframe covered by the question (last 12 months) this suggests a very high rate of introduction of technological changes fundamentally affecting work processes.

Fig. 1 explores the extent to which these changes are associated with workforce reduction. The figure provides support to the labour replacing nature of changes in work processes, regardless of the type of change: technological or not. The largest reductions in the number of workers (points 4 and 5 in the scale) affected almost 1 in 5 establishments that had introduced significant changes in work processes. Only in about a third of establishments the introduction of significant changes in job processes was not associated with a reduction in the number of workers in the company.

There are, however, important differences depending on whether or not the change was related to technology. Nineteen percent of the establishments that reported their changes to be associated with technology reported those changes to have resulted in strong workforce reductions (4 or 5 in the Likert scale), compared to 15 % for establishments that had introduced non-technological changes. This amounts to over a 25 % increase in the establishments reporting large reductions in the number of workers when changes were related to technological change, compared to those that had introduced non-technology related changes. Chi2 test confirms that this difference is statistically significant ($Pr(Z < z) = 0.0209$). It should be noted that the BPSS survey enquired about changes already implemented and measures already taken. Thus, the chages reported had occurred in spite of the economic or social barriers to the introduction of technology for labour substitution documented in the literature (Arntz et al., 2016).

Table 3 presents the results of a binary logistic regression that examines how the different factors presented in Section 3 relate to the odds of the introduction of technology-related changes to work processes and technology-related changes to work processes that led to at least some job losses, to test our hypotheses.

The results provide little evidence that the skills levels of the establishment's workforce –in any of the dimensions covered- protect workers from the threat of labour substitution. In establishments where technology was introduced, workforce reduction was not significantly different in establishments with a more or less highly educated or skilled workforce (rejecting HYP1). Workforce development through training efforts and career planning in the workplace did not protect against technology related job losses either (rejecting HYP2), and there was little evidence to support claims that high levels of job autonomy protect against labour substitution (rejecting HYP3). The findings, thus, run contrary to both SBTC and SBOC tenets.

By contrast, the results show that business strategies are important in mediating the relationship between the introduction of technological change and job reduction, and the direction of this relationship is as expected in HYP4. A high value-added competitive strategy is negatively associated with technology related job losses, whereas a price-competition business strategy is positively associated with labour replacement. This underlines that digital technologies can be introduced for different purposes than labour replacement (Vidal, 2011). The results also suggest that business strategies deserve greater attention than extant literature gives them in the analysis of the relation between digitalisation and employment.

The results also provide evidence that management's perceptions of workforce competence and commitment can protect workers against labour replacing introduction of technology. The direction of the relationship is as expected in HYP5 and HYP6: greater managements' perceptions of workforce commitment (discretionary effort) are negatively associated with technology related job losses, as are their perceptions of workforce competence -difficulty to cope with duties is positively associated with technology related job losses. This is consistent with arguments around the importance of the labour process as a mediating factor in the introduction of automation, social exchange theory's claims that managers' perceptions of employees influence their treatment (Blau, 1964), and previous arguments around the importance managerial expectations and intuitions in employee sanctioning and reward practices (García-Cruz et al., 2018; Winroth et al., 2007). While establishments can introduce various targeted measures to improve workforce performance to protect jobs, for example through job redesign or training measures, the findings suggest that managers also implement labour replacement by technology as a route to address perceived 'performance deficits'. The results did not show strong differences in terms of establishments' ownership, size or industry -except for greater protection from automation in financial and insurance activities. Local headquarters, on the other hand, was associated with greater likelihood of introduction of labour replacing digital technologies, compared to a range of other headquarter locations both in the West and the East.

5. Conclusion

Human capital, and related theories such as skills biased technological change, argue that skills development is a central strategy for individuals to remain employable in digitalised labour market. One of the main shortcomings of these theories is their focus on the individual and their detachment from the organisational and social context in which workers operate and deploy their skills. Avent-Holt, Hällsten, and Cort (2020) note that the analysis of the relevance of the firm level in labour market studies has until recently been hampered by lack of data. Data on individuals, or countries are much more common (Avent-Holt, Hällsten, & Cort, 2020; Kristal, 2013). In this article, we incorporate the organisational context in the analysis, and examine its importance in sheltering workers from unemployment when technological change occurs, using rich establishment-level data which enabled us to move away from

Table 2
Introduction of significant changes in work processes (last 12 months).

	Frequency	*Percent*
Yes, in relation to technology	1,044	27.50 %
Yes, not in relation to technology	676	17.80 %
No	2,077	54.70 %
Total	3,797	100 %

Source: BPSS. N = 3,797.

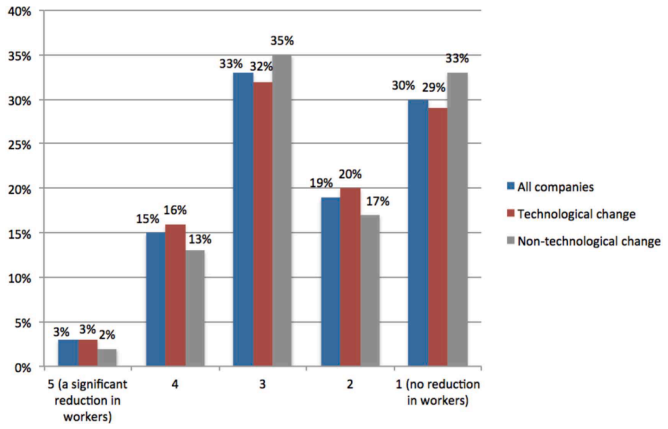

Fig. 1. Introduction of significant changes in work processes and job reduction (last 12 months).
Source: BPSS.

forecasting studies based on experts' views, to analyse companies' behavior. The use of firm-level data on firm behavior also helped us to better incorporate in the analysis social and economic factors that may impact on firms' behaviour. These factors include the labour process and competitive strategies, that may affect companies' decisions on the technological replacement of labour.

Based on these data, the article explored whether the introduction of technological change leading to changes in work processes was related to job reductions in the highly flexible Singaporean labour market, which presents few barriers to decisions on workforce retrenchment. Digital technologies, the results show, can be introduced for different purposes than labour replacement. However, the results also documented widespread use of digital technologies for labour substitution. Moreover, while Chui, Manyika, and Miremadi (2015) argue that the process of replacement of labour by technology may be spread over a long period of time we see rather widespread labour substitution in a short timeframe (12 months). The results thus suggest that the introduction of technology-related changes to work processes often lead to the destruction of jobs at the firm level. While changes of any nature in job processes are often labour saving, this is more common when the change is technological.

On the whole our results question SBTC and SBOC, in suggesting that establishments characterized by a significant proportion of high-skilled workers and flexible work organization are not immune from technology induced labour substitution. They thus suggest that 'high-skilled' workplaces are not effective in protecting workers against automation. By contrast, competitive strategies and management perceptions on workforce competence and commitment are relevant organisational characteristics in the protection against technologically related workforce reduction. The role of management perceptions, in particular, points to the relevance of social relations and the labour process, and not only to the limits of technological possibilities or economic calculations, to analyse the relation between technological change and employment.

The findings also lend support to arguments that suggest that the location of a worker within the labour market (in a firm) affects their labour market outcomes. The moral of our analysis for workers is that if they want to reduce the insecurity associated with replacement by technology they should be adviced to seek employment in companies that follow high value-added competitive strategies and where management hold positive views on the competence and commitment of their workforce.

Previous work has discussed the limitations of upskilling as a generic strategy for the achievement of employment (Brown & Souto-Otero, 2020). Since our findings do not clarify what workers are fired as a result of the introduction of technology they do not question that upskilling can help individual workers shelter against automation. What our findings question is the idea that "high skilled" workplaces protect workers. The finding that the level of education and skills at the establishment level does not prevent firm's replacement of workers by technology suggests that governments seeking to achieve sustainable increases in job quality and stability across the labour force should pay attention to other factors, to complement their focus on skills development. A "education only" approach downplays the role that organisational, economic and social factors, such as management perceptions and corporate strategies, have in shaping the demand for labour and the value attached to human work and skills. In summary, the results point to the limits of exclusively education-focused reforms in tackling technology induced job losses and stress the need for multi-pronge approaches that also consider business strategies and management practices. Given that the introduction of technology displaces workers, but can improve efficiencies in the economy and create jobs in other companies, education reforms should ensure that learners develop the general cognitive and non-cogntive competencies that enable adaptability during their careers, rather than just technical job-specific skills, and that robust pathways for retraining to facilitate workforce transitions are available. While education reform, on its own, cannot 'do it', the rise of digital technologies necessitates a greater focus on the development of transferable skills and lifelong learning to help workers adapt to future labour market changes. Educational systems need major reforms along these lines.

There are a number of other limitations to our research. The data that we employed explores the introduction of technology to change work processes only, while other uses of technology are possible. The data is cross-sectional, and it is not possible to explore whether the proportion of establishments reporting reductions are high or low compared to previous periods, or trends over time. Our results rely on the assumption that workforce characteristics and organizational practices have remained largely constant over the 12 months period under analysis, and are not the result of technological change. Future research could test our results without relying on

Table 3
Binary logistic regression: introduction of technological change and work workforce retrenchment (automation).

Base: at least some job losses as a result of tech related work changes	
Skills proxies	
Knowledge workers	-0.04
	(0.08)
Jobs require degree	0.07
	(0.09)
Jobs require experience	0.06
	(0.08)
Managers and Professionals	-0.09
	(0.08)
Associate professionals	0.06
	(0.08)
High wage (% who earn more than $6,000)	0.03
	(0.08)
Low wage (% who earn less than $1,500)	0.14
	(0.09)
Workforce development	
Job-related training	0.02
	(0.09)
Offer career planning	0.11
	(0.09)
High potential talent program *(dummy)*	0.11
	(0.17)
Work Organisation	
Job autonomy	-0.10
	(0.08)
Competitive Strategy	
Compete in market for premium goods	-0.30***
	(0.09)
Reliant on cost competition	0.19**
	(0.08)
Management perceptions of their workforce	
Staff with inadequate performance	0.08
	(0.09)
Difficulty to cope with duties	0.27***
	(0.09)
Discretionary effort	-0.19**
	(0.08)
Other firm characteristics	
Natural log of establishment size (no. of workers)	0.12
	(0.08)
Headquarter location (dummy, base: Singapore)	
USA	-0.28
	(0.47)
Japan	-1.35**
	(0.56)
China	-0.99*
	(0.57)
Germany	-0.27
	(0.72)
France	-0.27
	(1.19)
UK	-1.28*
	(0.65)
Others	-0.49
	(0.31)
Family owned (dummy)	-0.09
	(0.17)
Industry *(dummy)*	
Manufacturing	0.00
	(0.46)
Construction	0.09
	(0.48)
Wholesale and retail trade	0.04
	(0.42)
Transport and storage	-0.13
	(0.55)

(*continued on next page*)

Table 3 (*continued*)

Base: at least some job losses as a result of tech related work changes	
Accommodation and fodd services	0.00
	(0.56)
Information and communications	-0.54
	(0.45)
Financial and insurance activies	-1.01*
	(0.56)
Real estate activities	0.98
	(0.93)
Professional, scientific and technical activities	-0.60
	(0.44)
Administrative and support services	-0.32
	(0.46)
Education	-0.63
	(0.55)
Health and social services	-0.40
	(0.65)
Constant	1.34
	(0.40)
Log likelihood	-531.95
Pseudo R2	0.10
N	985

* $p < 0.1$;
** $p < 0.05$;
*** $p < 0.01$. *All variables except dummy variables have been standardized.*

similar assumptions as well as explore how additional factors affecting decisions on the organization of work, such as stakeholder expectations or company financialisation (Bryan, Rafferty, Toner, & Wright, 2017), may mediate the relationship between technological change and workforce reduction. Finally, our data do not provide information on the occupational and individual level characteristics of those who have lost their jobs as a result of changes in work processes, what types of tasks technology has been used to replace or what specific types of technologies have led to job reductions (Pouliakas & Souto-Otero, 2022; Bessen et al., 2023; Genz et al., 2021) and do not include direct measures of skills. Exploring these aspects are fruitful avenues for future research.

Annex 1. Questionnaire items related to variables used

Workforce skill levels (related to Hypothesis 1)	
Knowledge workers	What % of workers at your establishment are knowledge workers? (A knowledge worker is someone whose job is primarily to "think for a living". They are valued primarily for their thoughts and ideas and their jobs focus mostly on non-routine problem solving.)
Jobs require degree	What % of jobs at your establishment require at least a degree holder? (This refers to the minimum requirement for the job to be performed adequately and not in terms of 'desirability'.)
Jobs require experience	What % of jobs at your establishment require at least 3 years industry-relevant experience? (This refers to the minimum requirement for the job to be performed adequately and not in terms of 'desirability'.)
Managers and professionals	What % of jobs at your establishment are managers and professionals?
Associate professionals	What % of jobs at your establishment are technicians and associate professionals?
High wage	What % of jobs at your establishment pay more than $6,000 (SGD) per month? (This amounted to 50 % higher than the average monthly wage in Singapore in 2016 -see Ministry of Manpower 2020)
Low wage	What % of jobs at your establishment pay less than $1900 (SGD) per month? (This amounted to around 40 % of the average monthly wage in Singapore in 2016 -see Ministry of Manpower 2020)
Workforce development initiatives: career planning and training (related to Hypothesis 2)	
Job-related training	To what extent does your establishment support education that is job-related? (4 categories: not at all, yes, without resources, yes with non-monetary resources and yes, with monetary resources).
Offer career planning	To what extent do you practice career planning with your staff? (4 categories covering no career planning offered, offered to a minority of staff (<10 %); up to half of the staff (10–50 %) or a majority of staff (more than 50 %))
High potential talent programme	Do you currently have any formal program in your company for managing high potential staff? (Dummy variable)
Job autonomy (related to Hypothesis 3)	
Job autonomy	Employees have a great deal of discretion over how they do their work (1: Strongly disagree – 5: Strongly agree)
Competitive strategy (related to Hypothesis 4)	
Compete premium goods	You compete in a market for premium quality products or services (1: Strongly disagree – 5: Strongly agree)
Compete cost	Compared to others in your industry, the competitive success of your establishment's products or services is wholly dependent on price (1: Strongly disagree – 5: Strongly agree)
Management perceptions on workforce competence (related to Hypothesis 5)	
Staff with inadequate performance	What proportion of your staff that you had observed have inadequate performance?
Difficulty to cope with duties	What proportion of staff have you observed that are unable to cope with their existing duties?

(*continued on next page*)

(*continued*)

Management's perceptions on workforce effort (related to Hypothesis 6)	
Discretionary effort I	What % of workers have you observed going above and beyond the call of duty even when not been asked?
Controls	
Size	As of today, approximately how many staff members (working proprietors and employees directly employed by you) were working at your establishment?
Ownership	Is your company family owned?
Headquarter location (Singapore/other)	In which country is the headquarters of your company located?
Sector	I have [SSIC DESCRIPTION ON SAMPLE] as an industry classification for your establishment. Does this sound about right?

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