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WORKING PAPER 4

Technological Change and Labour Substitution: Can Firm Characteristics Shelter Workers Against Automation?

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Abstract
A burgeoning literature has emerged examining the potential of technology to automate labour. Much of this work, however, has relied on expert opinions and is 'de-contextualised', with little use of data on firms' actual behaviour. We employ a rich dataset of over 3,800 companies to explore whether certain firm characteristics (firms' stock of skills, organizational structure, competitive strategies and management's perception of their workforce) can have a 'sheltering effect' on jobs when technology is introduced in the workplace. The results suggest, first, that technology-related changes in work processes are leading to the destruction of jobs at the firm level -to a greater extent than non-technology related changes in work processes. Second, our results challenge skills biased technological change and skills biased organizational change theories, which argue that firms with a large proportion of high-skilled workers and flexible work organization are less prone to technology related labour substitution. By contrast, the results point to the importance of the competitive strategies of firms and management perceptions of workforce competence and commitment, as organisational characteristics that shelter workers against technological replacement. The role of management perceptions, in particular, points us to the relevance of social relations, and not only economic calculations or the limits of technological possibilities, in the analysis of the future of work.

Keywords: Technological change | Labour substitution | Automation | Skills | Skills-Biased Technological Change | Skills-biased Organisational Change | Competitive strategies | Management Perceptions

1. Introduction

This article explores how the organizational context of firms mediates the relationship between technological change and labour substitution. A burgeoning literature has emerged examining the potential of technology - including artificial intelligence (AI), machine learning and robotics - to automate labour (Lamb, Munro and Vu 2018:19). Despite this potential the implications for 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 (Frey and Osborne 2017, Arntz et al. 2016).

This work, however, has been 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).

Two related literatures, skills-biased technological change (SBTC) and skills biased organizational change (SBOC), also devote substantial attention to the relationship between technology and work (Berman, Bound and Machin 1998; Caroli and 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. Moreover, the main focus of these theories has been on the *relative* change in the skills composition of the workforce -associated with either the introduction of technology or high performance work practices. While SBTC has also been used to explore the impact of technology on aggregate unemployment levels, it has 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 across skill levels when technology is introduced in the workplace (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.

In order to explore these issues this article makes use of a unique dataset, the Business Performance and Skills Survey (BPSS), in Singapore. The city-state has a highly developed and competitive market economy, with one of the highest GDP per capita, low levels of unemployment and most flexible labour markets in the world (WEF 2019). Singapore also has a high quality education system and advanced technological infrastructure. Singaporean society places high value on 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 all stages of formal education as well as workforce development, receives strong support from the State (Sung and 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.

The BPSS is a large-scale face-to-face employer survey, which gathered data on technological change, skills utilization, workforce composition, high-performance workplace practices, value added strategies and management perceptions at the commercial establishment level.[1] A distinctive advantage of this survey to explore the relation between technological change, organizational characteristics and workforce reduction, is the inclusion of questions on the introduction of technology and non-technology change in the firm and the extent of reduction in the number of workers. This enables a change in the focus of the enquiry from technological possibilities – prevalent in the literature - to organizational

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

realities. The remainder of the article is structured as follows: section two presents a review of the literature, section three 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*. They also vary in the 'machines' they look at in assessing the potential for labour substitution: for example, industrial robots or general-purpose computerization and digital technologies. There are also differences in the dependent variable: impact on jobs, where most of the public interest concentrates, or impact on job tasks.[2] The results do not provide a clear answer on the effect of technology on jobs. What the bulk of these studies do have in common is an absence of 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 made use of data on experts' views on the occupations and tasks that machines can or will be able to undertake. Frey and Osborne (2017) provide a picture of how automation may affect jobs, based on an occupation-led approach. They categorise 'occupations according to their susceptibility to computerisation' (Frey and Osborne 2017:254), based on the views of machine learning researchers supplemented by information from O*NET on the level of perception and manipulation, creativity and social intelligence required to perform the job in the occupation (which Frey and Osborne see as limiting the potential for computerisation). They 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 and Osborne 2017:265). Their approach has been rolled out to other geographies (see Pajarinen and Rouvinen (2014), Haldane (2015), Houses of Parliament (2016)), with broadly similarly stark 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 2014:39). Because of this, technology often leads to changes in tasks within occupations rather than changes in employment shares between occupations (Arntz et al. 2016). Using PIAAC individual level data on actual tasks performed, Arntz et al. (2016:12) take into account the ways tasks vary within the same occupation and across countries, not relying on the assumption that task structures will be constant within these. 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

[2] The reminder of section 2 relies on Brown, P., Lloyd, C. and Souto-Otero, M. (2018) The prospects for skills and employment in an age of digital disruption: A cautionary note. Oxford: Skope working paper.

and through higher competitiveness' (Ibid. p.4; see also Farquhar 2016, IFR 2017). Arntz et al.'s task-based approach still relies on experts' assessment rather than actual use of technologies in the workplace.

Other occupation or task-based analyses have also suggested that job losses would be lower than initially thought. McKinsey (2017) analysed 2,000 work activities across 800 occupations, to report that 'less than 5 percent of all occupations can be automated entirely using existing technologies'. More occupations will change than will be automated away' (McKinsey 2017: 8). Yet, some studies focusing on activities offer different results. Grace, Salvatier, Dafoe, Zhang and Evans (2018) surveyed 352 machine-learning researchers on when they believe 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 next ten years, in a number of other activities within 40-years (working in retail, writing a bestselling book, working as a surgeon) and that '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 on how robotics and artificial intelligence will affect jobs over the next decade reported that 48% of the experts envisioned a future in which robots and digital technologies had displaced significant numbers of workers whereas 52% expected technology not to displace more jobs than it creates by 2025.

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) covering 19 industries between 1990 and 2007 in the US. They show 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 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 and 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 find some evidence that robots reduced the hours of low-skilled workers relative to middle and high skilled workers.

Dauth et al. (2017) underline the importance of the national institutional context. Making use of data from the IFR for Germany, a highly robot-intensive country, they report 'effects close to zero' on aggregate employment. While one robot replaces two manufacturing jobs on average, jobs workers were not fired and jobs were not destroyed; instead recruitment in manufacturing decreased significantly, directing new labour market entrants towards the service sector. These trends can be 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 making estimations of the impact of machines on jobs presents four main shortcomings. First, it relies overwhelmingly on expert judgments, which tend to

overestimate the capacity of new technologies, focus on occupations or tasks –rather than actual jobs- and look at the potential use of technology, with few studies looking at actual use. However, occupations or tasks rarely disappear or are automated altogether, in the way that specific jobs in companies can do. While "retrospective" studies have appeared to address some of these shortcomings, these 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 account of the ways in 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 take-up of labour-replacing technology is conspicuously absent in the analysis[3].

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 and 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 new and 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 (Piva, Santarelli and Vivarelli 2005; Caroli and Van Reenen 2001). Together, SBTC and SBOC link technology adoption, workplace organization, firms' skill structures and performance, but their consequences for changes in employment levels within firms have received much less attention.

The locus 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 the expansion of incumbent firms as they become more competitive. 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 work organisation. Companies with

[3] This contrasts with, recent 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).

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.

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 expansion derived from growth in added value associated to changes in volumes and prices. Moreover, Chennells and Van Reenen (1999) argue that firms tend to introduce technology when they expect demand conditions to improve; which may push their employment counts upwards. Piva et al. (2006), however, found a labour-saving effect of technology on manufacturing firms in Italy, of a non-skilled biased nature: the reduction in employment affected both white-and-blue-collar workers. Moves towards the 'flexible firm', by contrast, favour workforce renewal through greater job destruction and creation; which change firms' occupational structure (making firms more management heavy) but has little impact on the level of employment (Greenan 2003) as destruction and creation of jobs broadly level off.

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. Some studies take into account the national institutional context and the characteristics of local labour markets. However, there is limited literature on how firms' characteristics mediate the relation between technologies and labour substitution. When the firm context is considered the focus of the literature has been on skills levels and work organization. We are able to extend our understanding beyond existing studies by considering a range of firm related variables including competition strategies and management perceptions (on workforce competence and effort). 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 (Aleksander 2017; Autor 2015; Goldin and Katz 2009). High levels of education in the workforce are believed to protect employees against the negative consequences of automation. Skills can be developed through education and on the job experience. Other common proxies for skills used in the literature are occupational roles and wages. Indeed, it's assumed that the introduction of new technologies will improve labour productivity by complementing the workers in high skilled occupations, and that high skills and productivity are reflected in higher wages. BPSS data enables us to include a wide variety of skills' proxies in our analysis.

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 relation between training and automation has increased recently (Feng and Graetz 2020). The introduction of new technology itself requires IT-related technical skills and expertise, and training to use the new technology (Lamb et al. 2018). New technology is also seen to transform jobs and associated skills requirements, leading to a need for retraining (McKinsey 2017). In this narrative, automation and training are linked to attracting high-added value work as a route to growth, rather than to job losses. Career planning and training are ways to ease the transition into the use of new technologies (Bruque and 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 and 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 job autonomy, the freedom and independence that workers have 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, with little net impact on employment (Greenan 2003). MacCrory et al. (2014) note, initiative and independence remain important skills in the US labour market. Judgment is related to discretion, and has been seen to decrease likelihood of automation (Levy and Murnane 2013), because computers are less sophisticated than humans in tasks where exercising judgment is key, as they are difficult to codify (Autor 2015:1).

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, based on price or quality, may affect the decisions that firms make regarding the introduction of labour-replacing technologies. Lamb et al. 2018 argue that technology can combine improved capabilities and product quality with cost reduction. However, companies that compete on price could be expected to opt for labour replacing technologies to reduce costs, whereas companies that compete on quality may aim to preserve human labour as a sign of quality and care in design, production and customer relations.

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

2.4.5 Workforce competence

Job competence can be defined as an employee's contribution to the organizational goals and objectives (Cleopatra et al. 2004). Lack of employees' capacity, or engagement, to

competently perform duties impacts on organizational performance (Bal and 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 (Gates and Langevin 2010). But low performance can also be addressed through the replacement of workers by technologies that can perform their tasks. A key question is who judges performance and to what effect: positive perceptions of workforce performance by management could result in lower use of technology to replace labour. However, performance appraisal is difficult and often biased (Bellé, Canterelli and Belardinelli 2017), which underlines the social character of firms' decisions and the importance of understanding how these judgments are made, in contrast to the purely economic costs calculations of SBTC and SBOC.

Hypothesis 5: Lack of perceived capacity to competently perform workforce duties is positively associated with labour substitution.

2.4.6 Workforce effort

Perceptions of performance are also linked to perceptions of discretionary effort. It is typically 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 could 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 and 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 are expected 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 workforce effort will be negatively associated with labour substitution

2.4.7 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 Finkel (2017) makes reference to preferences for human interaction in some sectors, such as 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. Kanamori and Motohashi (2006) and Caroli and Van Reenen (2001) find that the productivity effects of technology and organizational change is greater for large firms. 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 and 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 their workforce, which can lead to – other things being equal- more job protective strategies.

3. Methodology

3.1) Questions

This article analyses how automation, relating to labour substitution, impacts on the workers in different firm contexts in Singapore. Given 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: these may increase or mitigate the negative workforce consequences of technological change. In line with this argument, the article explores how those firms that have introduced significant changes to production processes related to technology but have not reduced their workforce differ in their stock of skills, organizational structures, competitive strategies and management's perception of their workforce from other firms. The analyses control the other firm characteristics, as discussed in the previous section: industry (classified according to the Singapore Standard Industrial Classification), size, headquarters' location (country in which headquarters are located) and whether the firm is family owned or not.

3.2) Data and methods

We employ a novel dataset in our analysis, the Institute for Adult Learning's Business Performance and Skills Survey (BPSS). This survey enables us to go beyond existing studies relying on expert opinion or the penetration of industrial robots, to examine labour-replacing decisions in their firm contexts more broadly. 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 of 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. Table 1 presents the characteristics of our sample.

Table 1. Characteristics of the sample

	Mean	**SD**
Percentage of establishments with reduction in the number of workers	71.44	
Skills proxies		

	Mean	SD
Percentage of establishments with reduction in the number of workers	71.44	
*Knowledge workers^*	0.35	0.33
*Jobs require degree^*	0.32	0.31
*Jobs require experience^*	0.42	0.30
*Managers and professionals^*	0.25	0.23
*Associate professionals^*	0.38	0.30
*High wage^*	0.14	0.18
*Low wage^*	0.24	0.25
Workforce development		
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	14.50	
None	14.53	
<10%	24.49	
10-50%	36.89	
>50%	24.09	
High potential talent program	35.98	
Work organization		
Job autonomy (1-5 scale)	3.26	1.07
Competitive strategy		
Compete premium goods (1-5 scale)	3.93	0.83
Compete cost competition (1-5 scale)	3.33	0.97
Management perceptions of workforce		
Staff with inadequate performance		
None	21.75	
<10%	45.00	
10-25%	19.41	
26-50%	9.15	
>50%	4.27	
*Difficulty to cope with duties^*	0.10	0.13
Discretionary effort		
None	2.24	
<10%	15.65	
10-25%	26.32	
26-50%	27.85	
>50%	27.95	
Other firm characteristics		
Size (log)	31.6	0.89
Family owned	32.22	
Headquarters Singapore	86%	
Headquarters other	14%	

	Mean	SD
Percentage of establishments with reduction in the number of workers	71.44	
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	

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

The main data used in our analysis comes from a question that 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 asked to report on the extent to which 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'. 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 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 are explained below:

Workforce skill levels (related to Hypothesis 1)

Skill levels in the establishment were approximate using a comprehensive range of variables related to formal education, experience, occupation, job tasks and wages. We use data on formal *educational level* (the proportion of jobs requiring a degree); proportion of jobs requiring significant *experience;* workers in managerial or professional and in associate professional roles; *a*nd the proportion of workers in the establishment that are *knowledge workers,* defined in the survey as: "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." Pay level was measured through the percentage of staff who were high (*who earned more than $6,000 Singapore dollars* per month) and low (who *earned less than $1,700* per month) earners. The first figure amounts to a 50% higher than average monthly wage in Singapore in 2016, whereas the second is around 40% of the average wage (see Ministry of Manpower 2020).

Workforce development initiatives: career planning and training (related to hypothesis 2)
Career planning was measured as the extent to which the establishment offers career planning to its staff, captured through the question: "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%)). A dummy variable indicating whether the establishment had a *high-potential talent program* was also used. Training activities were identified through a question on *job-related training,* which asked: "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).

Job autonomy (related to hypotheses 3)
While most work on flexible organisations traditionally use dummy variables related to the introduction of organizational change, we capture *job autonomy* through an ordinal measure, employing the question "To what extent is your workforce organized in the following way - Employees have a great deal of discretion over how they do their work" [1: not at all – 5: to a great extent].

Competitive strategy (related to hypothesis 4)
The identification of business strategy in BPSS was measured through the extent to which the establishment was *competing in the market for premium goods* and services or was *reliant on cost competition.* Two questions using a 5 point Likert style scale were employed: "You compete in a market for premium quality products or services" and "Compared to others in your industry, the competitive success of your establishment's products or services is wholly dependent on price".

Management perceptions on workforce competence (related to hypothesis 5)
Competence was gauged through two questions on workers' *not coping with duties and inadequate performance*. Inadequate performance was obtained by asking "What proportion of your staff that you had observed have inadequate performance?" and the extent to which workers could not cope with their duties was established by asking "Please approximate the percentage of the existing staff at this establishment who are currently unable to cope with their existing duties".

Management's perceptions on discretionary effort (related to hypothesis 6)
Workforce discretionary effort was gauged by asking the respondent: "At your establishment, what percentage of staff are going above and beyond the call of duty even when not asked?".

Controls
A series of controls are also included in our analysis: establishment size (logged), Industry dummies (SSIC 1-digit), a dummy on whether the firm is family owned and a headquarter location (country).

The analysis first provides descriptive statistics on the introduction of technological change and job reduction. Second, we will employ logistic regression to provide evidence on factors correlated with labour substitution resulting from technological innovation at the level of the establishment.

4. Findings: Introduction of technological changes and workforce reduction

In the recent context of decreasing costs of technology (Graetz and Michaels 2015) and low interest rates, it could be expected that many businesses lean towards 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.

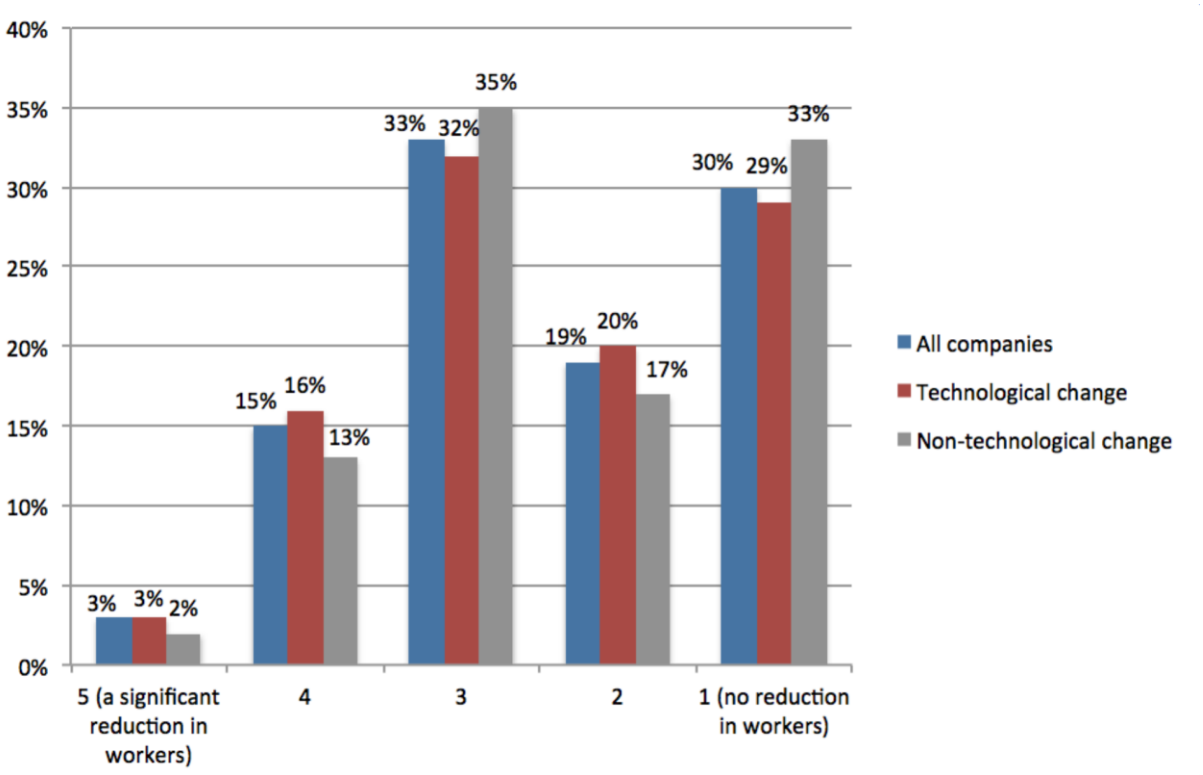
Table 2. Introduction of significant changes in work processes (last 12 months)

	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

Figure 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 of the surveyed establishments (around 18% of the establishments that had introduced significant changes in work processes). However, there are important differences depending on whether the change was related to technology or not. Nineteen percent of the establishments that reported their changes to be associated with technology reported those changes to have resulted in workforce reductions, compared to 15% for establishments that had introduced non-technological changes. This amounts to over a 25% increase in the establishments reporting large reductions (points 4 and 5 in the scale) in the number of workers when changes were related to the introduction of technological change, compared to those that had introduced non-technology related changes. Chi2 test confirms that this difference is statistically significant ($Pr(Z < z) = 0.0209$). The BPSS survey enquired about changes already implemented and measures already taken, and which have occurred in spite of economic or social barriers to the introduction of technology for labour substitution.

Figure 1. Introduction of significant changes in work processes and job reduction (last 12 months)



Source: BPSS.

Table 3 presents the results of a binary logistic regression that examines how the 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 leading to at least some job losses, to test our hypotheses.

Table 3. Logistic regression: introduction of technological change and work workforce retrenchment.

Base outcome: 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)

Base outcome: at least some job losses as a result of tech related work changes	
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)
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, Includes dummy controls for industry (One-digit SSIC) not reported in the regression.*

The results provide little evidence that the skills levels of the workforce –in any of the wide set of 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 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 (rejecting HYP2). There was also 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 strong evidence that business strategies are important in mediating the relationship between the introduction of technological change and job reduction, with the direction of this relationship being 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.

Finally, the results provide evidence that other measures of competence and commitment, as perceived by management, can protect workers against the introduction of labour replacing technology. The direction of the relationship is as expected in HYP5 and HYP6. Difficulty to cope with duties is positively associated with technology related job losses. While establishments can introduce various targeted measures to improve workforce performance to protect jobs, the findings suggest that managers also implement labour substitution by technology as a route to address perceived ‘performance deficits’. Higher

discretionary effort observed by management is negatively associated with technology related job losses.

5. Conclusion

There has been much recent debate on the relationship between automation and jobs. Much of this debate has been formulated making use of forecasting data from expert judgments, with the aim to study the future or what is possible rather than examine the present in the replacement of humans by technology. Avent-Holt et al. (2019) 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 the 'typical social space' of nation states are much more common (Avent-Holt et al. 2019; Kristal 2013). We employed a unique dataset containing a large sample of establishment-level data, comprising 3,800 companies, which enabled us to move away from forecasting studies to focus on companies' behavior. The organizational level is a crucial level of analysis since jobs reside in firms –not in individuals or nations- and also because it speaks to job (in)security, which matters to workers. The use of firm-level data on actual firm behavior also helped us to better take into account economic and social factors that may constrain companies in the replacement of workers by technology than forecasting studies.

Based on these data, the article has explored whether the introduction of technological change leading to changes in work processes has led to job reductions in a highly flexible labour market, Singapore, which presents few barriers to businesses for workforce retrenchment. Chui et al. (2015) argue that the process of replacement of labour by technology may be spread over a long period of time. Yet we see examples of labour substitution in the short timeframe analysed. The results suggest that technology-related changes in work processes are leading to the destruction of jobs at the firm level. While changes of any nature in job processes are often labour saving, this is much more common when the change is technological.

This article contributes to the existing literature by exploring the role of firm-level characteristics in protecting against technology-induced workforce replacement. It investigates a broader set of characteristics than previous studies, by extending the established focus on the role of high skills and flexible forms of work organization in sheltering workers against automation to consider the significance of firms' competitive strategy and management perceptions of workforce capabilities and performance.

Our results fundamentally challenge the core tenet of 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. In other words, skills - at the establishment level – they are not a barrier to labour substitution. 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, directs us to the relevance of social relations, and not only economic calculations or the limits of technological possibilities, in the analysis of the future of work.

The findings lend support arguments that suggest that the location of a worker within the labour market will have an effect on their labour market outcomes. The moral of our analysis for workers is that if they want to reduce the insecurity associated with replacement by changes related to technology they should seek employment in companies that follow high value-added competitive strategies and are not simply looking to cut labour costs, but to augment the value-creation of employees -regardless of the skill profile of the organization-, and where management hold positive views on the competence and commitment of their workforce. These are findings that governments seeking to achieve sustainable increases in job quality and stability should pay attention to, moving beyond the current overwhelming focus on supply-side skills measures.

There are a number of 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 how it has evolved over time. A follow-up survey to BPSS will be implemented in 2021 and will enable a longitudinal analysis. A third limitation is that 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. Exploring these aspects are fruitful avenues for future research that locate firms and their strategies as a central part of the analysis.

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