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JAQ of All Trades: Job Mismatch, Firm Productivity and Managerial Quality

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Abstract

We develop a novel measure of job-worker allocation quality (JAQ) by exploiting employer-employee data with machine learning techniques. Based on our measure, the quality of job-worker matching correlates positively with individual labor earnings and firm productivity, as well as with market competition, non-family firm status and employees' human capital. Management turns out to play a key role in job-worker matching: when existing managers are replaced by better ones, the quality of rank-and-file workers' job matches improves. JAQ can be constructed for any employer-employee data including workers' occupations, and used to explore research questions in corporate finance and organization economics.

JEL classification: D22, J24, J31, L22, L23, M12, M54.

Keywords: jobs, workers, matching, mismatch, machine learning, productivity, management.

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1 Introduction

Matching workers to their best possible job is of paramount importance for firms: hiring or firing the wrong people, or matching employees to the wrong task may sap a firm’s productivity at least as much as it damages the employees’ careers, by slowing down their skill acquisition process, reducing their wage growth and possibly inducing them to switch to another employer. In fact, the ability to match workers to the right jobs is a hallmark of a good manager, on a par with other management skills that have been shown to contribute to firm productivity (Bertrand and Schoar, 2003; Bennedsen et al., 2020; Bloom and Van Reenen, 2007, 2010; Bloom et al., 2013, 2019; Scur et al., 2021). However, managerial practices measured by existing research on human resource management focus on workers’ incentives, and neglect choices regarding the allocation of workers to jobs. This shortcoming probably reflects the fact that managerial practices have so far been measured by surveying managers regarding how they run their firms’ operations, monitoring, incentives and targets, while it would be difficult to use surveys to inquire whether managers allocate workers to their best possible use within the firm.

This is where our paper comes in: we develop a novel measure of job allocation quality (*JAQ*, for short) by applying machine-learning (ML) techniques to administrative employer-employee data rather than building on responses to questionnaires, and validate our measure in a variety of ways, which also bear witness to its versatility. *JAQ* is built in four steps. First, we estimate via a ML algorithm how workers’ characteristics map into jobs, using as a benchmark for match quality the allocation of workers to jobs in the most productive firms. This is similar in spirit to how Bloom and Van Reenen (2007) benchmark management practices against standards set by a leading management consulting firm and how Fredriksson et al. (2018) gauge mismatch of junior workers by the distance between their skills and those of senior workers holding the same job. Second, we predict worker suitability for each job based on the function estimated via the ML algorithm. Third, we build an indicator of whether an employee’s actual job coincides with her most suitable one (*eJAQ*). Fourth, we average this indicator across all the employees of each firm to construct our firm-level measure of match quality (*JAQ*).

Our ML algorithm, on which *JAQ* is constructed, maps employees' curricular characteristics such as education, age, gender and experience into a job assignment rule. In general, experience and education turn out to be the most important determinants of worker suitability to jobs, although their role appears to differ across occupations. For example, holding a relevant college degree is a key predictor of the suitability for legal professions, while for other jobs tenure and experience tend to have a much more prominent role. We decompose the variation in *eJAQ* between employees that stay in the firm and those who move to a new firm, and find that the vast majority of the variation in *eJAQ* is accounted for by employees remaining with their current employer. This also applies at the firm level, where increases in *JAQ* are typically associated with employees who retain their initial job and improve their match quality as their experience accumulates.

We then validate the employee-level measure, testing whether workers' careers benefit from their job match quality. It is natural to expect employees to be increasingly assigned to more suitable jobs over their careers, as managers learn about their characteristics (Fredriksson et al., 2018), and employees themselves fine-tune their skill set via on-the-job training (Guvenen et al., 2020). Also, insofar as better job allocation enhances productivity, workers can be expected to appropriate at least part of the gain in the form of higher wages. Both of these predictions find support in our data. The goodness of worker-job matches (*eJAQ*) rises significantly over the span of working lives, the largest gain occurring in the first few years. Moreover, workers allocated to their most suitable job earn significantly more than mismatched workers with the same characteristics or with the same job, and are less likely to switch to a new employer. Both of these findings dovetail with those reported by Fredriksson et al. (2018), despite differences in methodology and sample used.

Next, we validate the firm-level measure of job allocation quality (*JAQ*) by showing that it correlates positively with market competition, non-family firm status, workers' human capital and, most importantly, with productivity, just as management practices do (Bloom and Van Reenen, 2007, 2010; Bloom et al., 2013, 2019). In particular, we show that *JAQ* has a significant, sizeable and robust positive correlation with log value added and log sales per employee, even upon

controlling for the firm-level variables generally associated with productivity (industry, capital and labor, ownership) and for the workers' characteristics used to predict *JAQ*.

One may suspect that this finding is affected by circularity, as we first train the ML algorithm to assign workers to jobs based on data for the most productive firms, and then investigate whether *JAQ* correlates with firm productivity. The first counter to this criticism is that the correlation between *JAQ* and productivity is estimated dropping the observations used to train the ML algorithm. However, the correlation between *JAQ* and productivity may still arise because the assignment rule is estimated on the most productive firms, so that its estimation error may correlate by construction with firm productivity. We perform a number of exercises that dispel remaining circularity concerns, by training the ML algorithm on samples that are not constructed on the basis of firm productivity. First, we perform a placebo test replacing actual firm productivity with a noise variable that has the same distribution as the replaced variable, and show that the relationship between *JAQ* and firm performance is not purely mechanical. Second, we retrain the algorithm on random subsamples of firms, so as to calibrate *JAQ* on the basis of the average firm in our sample rather than on top-productivity firms, and perform a Monte Carlo experiment to explore the robustness of the resulting measures to sampling variability. Third, we construct an alternative data set to train the algorithm based on the residuals of an AKM wage regression model (Abowd et al., 1999), as these residuals capture the surplus from worker-job matches and therefore can be used to identify better allocated workers. All of these robustness checks confirm our baseline results.

Finally, we investigate the role of managers in shaping a firm's job allocation quality by testing whether improvements in management quality bring about a better allocation of rank-and-file workers to tasks. Upon constructing two distinct *JAQ* measures for rank-and-file workers and for managers, the former turns out to be positively and significantly correlated with the latter, as well as with the average experience of the firm's management team, even when only within-firm variation is exploited. In turn, the job allocation quality of the firm's managerial team has a sizeable and robust correlation with firm productivity. Interestingly, the quality of rank-and-file workers' allocation rises significantly when turnover leads to an improvement of the allocation of manage-

ment, which tends to occur in the wake of a deterioration in the allocation of rank-and-file workers. Conversely, when managerial turnover results in a worse assignment of managers, it is associated with a persistent disruption in the allocation of rank-and-file workers. These results persist even when the analysis is restricted to changes in management associated with the death of an incumbent manager, although in this subsample the estimates are imprecise due to the paucity of observations.

We additionally investigate the effects that the two types of managerial turnover events have on the frequencies of employees' internal reallocation, firings and hirings, and on the allocation quality of rank-and-file workers. Better management improves the job allocation quality of incumbent rank-and-file workers ("stayers"), mostly by retaining them in their current positions and letting them accumulate job experience. In contrast, the arrival of worse managers lowers the job allocation quality of stayers via misguided job reassignments.

Thus, our contribution is twofold. First, we build a new firm-level measure that can be used to investigate the importance of worker-job matches for firm performance, and can be constructed for any country and time period where survey or administrative data on workers' characteristics and job titles exist, without requiring expensive targeted surveys (Bloom and Van Reenen, 2007; Bloom et al., 2019) or detailed expert evaluations of the skills required for each job (Lise and Postel-Vinay, 2020; Guvenen et al., 2020). Second, we contribute to the literature on the importance of managers in shaping firm performance by highlighting the role that the quality and the allocation of managers play in the assignment of rank-and-file workers to their jobs.

As already mentioned, the measure that we propose complements the research on the role of managerial practices and of human capital for firm productivity (Scur et al., 2021). Most closely related are Ichniowski et al. (1997), Bloom and Van Reenen (2007), Bloom et al. (2013), Bloom et al. (2019) and Cornwell et al. (2021), who study how management practices relate to productivity, Bender et al. (2018), who investigate the relationship between productivity, management practices, and employee ability, the study by Fox and Smeets (2011) on the role of workers' quality in explaining the dispersion in productivity, and Minni (2023) on the role of managers for workers careers. Our distinctive contribution here is to focus on managerial policies governing the alloca-

tion of workers to jobs within the firm, and relate job-worker mismatch to firm productivity. Our measure of mismatch is likely to be informative not only about the role of labor misallocation at the firm level, but also at higher level of aggregation, to investigate for example how technological innovation and regulatory changes influence overall productivity, and to assess how skill mismatch varies over the business cycle or during financial crises (Bowlus, 1995; Baley et al., 2022).

Furthermore, our paper relates to an emerging strand of research that exploits ML to address questions at the interface between labor and finance.¹ Examples include the appointment of board of directors (Erel et al., 2021), the screening of resumes in recruitment (Li et al., 2020), the measurement of corporate culture based on earnings call transcripts (Li et al., 2021), and the assessment of what managers do (Bandiera et al., 2020). Our results on the correlation between managerial quality and the match quality of rank-and-file workers directly relate to the research on managers' role in allocating human capital within the firm and in shaping workers' careers (Minni, 2023; Pastorino, 2024) and more generally for firm performance (Bertrand and Schoar, 2003; Malmendier and Tate, 2005; Bennedsen et al., 2007; Malmendier and Tate, 2009; Kaplan et al., 2012; Lazear et al., 2015; Mullins and Schoar, 2016; Bandiera et al., 2018; Bennedsen et al., 2020). More broadly, this measure can be deployed to investigate several other questions in corporate finance, such as the role of human capital in private equity interventions and mergers, where worker reallocation from combining the workforce of two firms may lead to higher productivity and lower costs. It can also shed light on the relationship between match quality and the financial returns on human capital investments, such as employee training, development programs, and recruitment strategies.

Finally, our work complements the vast research in labor economics on how workers match with firms (Jovanovic, 1979; Cahuc et al., 2006; Postel-Vinay and Robin, 2002; Chiappori and Salanié, 2016; Eeckhout and Kircher, 2018; Adenbaum, 2023; Pastorino, 2024) and with tasks (Perry et al., 2016; Lindenlaub, 2017; Deming and Kahn, 2018; Lise and Postel-Vinay, 2020; Guvenen et al., 2020; Ocampo, 2022), and on how managers match with firms (Terviö, 2008; Lippi and Schivardi, 2014; Benson et al., 2019; Bandiera et al., 2020). A particularly relevant

¹For surveys on how ML can be applied to economics research in general, see for instance Varian (2014), Mullainathan and Spiess (2017), or Abadie and Kasy (2019), Athey (2019).

study is Fredriksson et al. (2018), who investigate the impact of job mismatch on starting wages and subsequent labor market outcomes, measuring mismatch as the absolute distance between senior workers' and new hires' talent. While their method only applies to the measurement of junior workers' match quality, our measure of job assignment quality applies to the allocation of all workers, which is key to evaluating how job assignment quality correlates with firm productivity.

The road map reads as follows. The next section describes our data and Section 3 details how we construct *JAQ* and describes how it correlates with some firm characteristics. Section 4 relates *JAQ* to firm performance, and Section 5 explores the relationship between the quality of rank-and-file worker-job matches and the quality of management, especially in the wake of managerial turnover. The last section concludes.

2 Data

To develop and estimate the *JAQ* measure proposed in this paper we use Swedish registry data. This data set is ideal for our purposes for at least two reasons. First, it allows us to observe over time the entire population of workers and firms in Sweden, including a number of variables regarding workers' job histories, such as occupations and wages over their career. Second, despite their institutional differences, labor markets are surprisingly similar in their functioning in Scandinavian countries, Belgium, France, Germany, Italy, the Netherlands and the United States (Lazear and Shaw, 2009), which bodes well for the external validity of our results.

The bulk of our data come from the Statistics Sweden LISA database that covers the whole Swedish population of individuals who are at least 16 years old and reside in Sweden at the end of each year. This longitudinal matched employer-employee database integrates information from registers held by various government authorities. We have data for the 1990–2010 interval but our analysis focuses on the 2001–10 interval since occupation information is not available prior to 2001. However, we draw on 1990–2000 data in constructing worker job histories.

The estimation of a worker's suitability for a given job is based on the same type of informa-

tion that would typically be included in individual resumes available to managers assigning workers to jobs, namely, background information, education, and past work experience. Background information, drawn from LISA, includes age, gender, an indicator for immigrant status, residence municipality and a mobility indicator equal to one for workers employed in a county different from the county of birth. As for education, we observe both the education level (basic, high school, vocational, or university) and the education subject (no specialization, law, business and economics, health and medicine, natural sciences, teaching, engineering, social sciences, services, or other specializations). Finally, past work experience is captured by labor market experience (measured as years since graduation), tenure at the current firm, number of firms and number of two-digit industries where an individual previously worked, total number of unemployment days since 1992 (when the unemployment data starts in LISA), years of experience in each occupation, years of experience in each 2-digit industry, and years of experience in each decile of the distribution of firms' number of employees or total assets.

The firm-level variables drawn from LISA are firm age, 2-digit industry, size (measured by the number of employees), sales, and total assets, as well as ownership categories measured by indicators of state-ownership, listed status, or family ownership.² Information on listed status is drawn from the Statistics Sweden's FRIDA database, and the indicator of family firm status is obtained by combining information on firm ownership from FRIDA with data on board members and CEOs from the Swedish Companies Registrations office and the multi-generational register on biological parent-child relationships at Statistics Sweden. Following Keloharju et al. (2023), a family firm is defined as one managed or owned by at least two members of the same family.

We identify jobs based on international ISCO-88 (COM) 3-digit classification of occupations, based on data provided primarily by official wage statistics drawn from yearly surveys of around 11,000 companies. Companies with more than 500 workers are surveyed every year and the remainder is a random sample of firms. Occupation data is gathered for around a million workers each year. The second source is a yearly survey sent out by mail to around 30,000–47,000 com-

²See Olsson and Tåg (2024) for details on the state-owned firm dummy.

panies that are not selected for inclusion in the official wage statistics survey (a total of around 150,000 private sector companies per year). The surveys are sent out on a rolling basis: all 150,000 companies are surveyed at least once in five years time. In total, over our entire sample period over 90% of workers are sampled at least once.³

In extracting our sample of firms from the LISA database, we apply two screens by firm size: we only retain firms whose median number of employees in the sample period is between 30 and 6,000. The lower bound is due to the sparsity of occupational information for firms with less than 30 employees: including these firms would introduce large noise in the estimation of the job-employee matching rule. These firms employ about 30% of the total reported workforce and on average report 2.9 employees per year. The upper bound of 6,000 employees excludes from the sample very large firms that may otherwise dominate the estimates of the job-employee matching rule, despite featuring a quite different structure from other firms, e.g., a more layered corporate hierarchy and a richer set of possible occupations. These firms account for 20% of the total reported workforce, but are few: out of a total of 945,385 firms in the database, there are only 80 such firms, which drop to 11 in the industries retained in our analysis.

Our sample includes firms in three industries: (i) manufacturing; (ii) real estate, renting and business activities; and (iii) wholesale and retail, which include 62% of the firms and 70% of the employees present in the LISA database over our sample period (after applying the screen based on firm size), and thus employ far more workers than other industries.⁴ Moreover, these industries feature the most complete and heterogeneous set of occupations in the Swedish economy: they include the greatest number of occupations, namely, 99%, 98% and 96% of the total 110 jobs, against a mean of 72% in other industries. The first two of these industries also feature a more diversified set of occupations than others, making the workers' assignment problem more relevant: the Herfindahl–Hirschman index measuring the concentration of occupations is 4% and 6% respec-

³See Tåg (2013) and Tåg et al. (2016) for additional details and descriptive statistics on occupations and hierarchical structures within firms.

⁴The excluded industries are: agriculture, hunting, forestry and fishing; mining; utilities; construction; hotels and restaurants, transport, storage, and communications; financial intermediation; public administration and defence; education; health and social work; other service activities.

tively, compared to a mean of 14% in other industries.⁵ After applying these filters, our sample comprises 9,023 firms, employing a total of 1,541,343 employees over the 2001-10 period.

3 Measuring Job Assignment Quality

Suppose that managers strive to allocate workers to jobs so as to maximize productivity, by picking a job assignment function that maps observable worker and firm characteristics to jobs within the firm. The allocation can vary depending on the firm's size and industry, and on workers' location and thus on features of the local labor market. However, firms may deviate from the most efficient assignment rule, incurring in errors that reduce their productivity, because of managerial shortcomings and/or information and learning frictions. As noted by Bloom and Van Reenen (2007), firms may also choose not to implement optimal management practices because doing so may be too costly for their managers. Furthermore, firms may adopt non-meritocratic personnel policies if these yield private benefits to their controlling shareholders in the form of power over the firm (Pagano and Picariello, 2022) or of utility from workplace discrimination (Becker, 1957). As external circumstances change, firms may also not immediately adjust to the new optimal assignment rule due to adjustment costs.

In order to assess the job allocation quality (*JAQ*) of a firm it is necessary to estimate the rule that managers use to assign workers to jobs. In principle, this can be done using a random subsample of firms. However, insofar as the rule maximizes productivity, the firms that apply it most rigorously should deviate less often from it and thus feature the highest productivity. Hence, the rule can be observed with the least noise for the most productive firms.

Thus, a key feature of our measure is that it is generated by benchmarking against the matches in the most productive firms. As such, it is consistent with any model of labor market search and worker assignment to firms that predicts higher match quality in more productive firms, such as Moen (1997), Postel-Vinay and Robin (2002), and Cahuc et al. (2006). In these directed search

⁵This does not apply to the wholesale and retail industry, whose concentration index is 18%.

models, more productive firms can afford to pay higher wages, thus attracting higher quality workers and producing better match outcomes. Such productivity advantage may stem from managers being better at solving the multidimensional skill mismatch problem due to the discrepancy between the portfolio of skills required by an occupation and the portfolio of abilities a worker has to acquire those skills, as in Guvenen et al. (2020).

Accordingly, we use a machine learning (ML) algorithm to estimate the rule using only observations that refer to firms in the top decile of the productivity distribution. The benchmark provided by this ML prediction enables us to measure how close the job allocation adopted by any given firm is to that predicted by the estimated rule. Of course, the rule estimated by the ML algorithm is bound to be efficient only on average: firms are likely to condition their job-worker matches on more information than that available to us in estimating the algorithm. Hence, some of the observed firm-level deviations from the estimated rule may reflect firm-specific information not captured by the algorithm rather than firm-level errors in applying the optimal rule.

3.1 Mapping workers' characteristics to jobs via machine learning

In our framework, managers use the job assignment rule $J = g(X, Z)$ to identify the job J to which each worker is best assigned, based on workers' observable characteristics, X , and on firm's characteristics Z . We do not observe g , but we can recover it by estimating the conditional probabilities $P(J|X, Z)$ for firms that are likely to adhere most closely to the rule, i.e., the most productive firms. We do not impose any particular restriction or parametric form on g , and allow for the possibility that firms with different characteristics rely on different rules.

For computational reasons, the sample is broken up in various subsamples to train the algorithm: this significantly reduces the estimation time compared to that required to estimate the algorithm on the full sample.⁶ The sample split is based on firm characteristics: firms are sorted across the three industries described above and three size classes, resulting in 9 size-industry bins.

⁶Attempts to perform the estimation on the full sample exceeded the 1,000-hours limit to computation time set by the Statistics Sweden server.

The three size classes are based on firms’ median number of employees, N , over the sample period: (i) small ($30 \leq N \leq 50$); (ii) medium ($51 < N \leq 250$); (iii) large firms ($N > 250$). The algorithm is estimated separately for the firms in each size-industry bin, taking into account that firms in different bins may use different rules to match their employees to occupations: for instance, larger firms typically have more layers in their hierarchy than smaller ones, and manufacturing firms have a greater variety of occupations than those in wholesale and retail trade. Hence, this approach amounts to estimating bin-specific conditional probabilities $P_z(J|X) \equiv P(J|X, Z = z)$, for $z \in \{1, \dots, 9\}$, where Z is a variable identifying the size-industry bin a firm belongs to.

Within each size-industry bin, we define the “learning sample” used to estimate the conditional probabilities $P_z(J|X)$ as the subsample of firms in the top decile of the productivity distribution. More precisely, in order to include in the learning sample only firms that are consistently more productive, for each size-industry bin we (i) estimate a model of value added per employee with firm fixed effects and calendar year effects, (ii) consider the distribution of fixed effects for firms present in the 2010 subsample, and (iii) select firms belonging to the top decile of this distribution. We then use 2010 data for these firms to train our algorithm: being the last year available in our sample, it contains the longest job histories that can be exploited to learn how firms allocate employees to jobs. Using data for these firms, we estimate bin-specific conditional probabilities $\hat{P}_z(J|X)$ to predict workers’ allocation to jobs in remaining firms – referred to as the “main sample” – within the corresponding bin.

Table 1 compares the characteristics of the workers included in the main sample and in the learning sample: the workers included in the latter earn higher wages, are more educated, and have longer tenure and fewer days of unemployment than workers included in the former. These differences are consistent with the fact that the learning sample includes more productive firms, where workers can be expected to feature more productive matches, hence experience fewer separations.

Insert Table 1 here

Despite these differences, the two samples are sufficiently similar as to have common support: this is shown by Figure 1, which displays the distributions of the predicted wages for workers in

the two samples. For both samples, the predictions are obtained from wage regressions estimated on the main sample, whose explanatory variables are the worker characteristics included in the ML algorithm. The figure shows that the support of the two distributions overlaps considerably, even though the distribution of the learning sample places more weight on high predicted wages than that of the main sample. This evidence supports our assumption that the learning sample can be used to estimate an allocation rule that is relevant for workers in firms included in the main sample.

Insert Figure 1 here

Within the learning sample, we estimate the conditional probability of each occupation via the Random Forests algorithm (Breiman, 2001).⁷ There are three advantages to using Random Forests (RF) in our setting: (i) they are among the best performing algorithms for classification (Zhang et al., 2017);⁸ (ii) they feature few-to-none tuning hyperparameters, dramatically reducing total estimation time;⁹ (iii) they easily handle multi-class classification problems and mixed-type characteristics (continuous and categorical), which are relevant in our data.¹⁰

As occupations are not all equally frequent in the sample, we adjust our estimation procedure by forming a balanced subsample via bootstrap, under-sampling more frequent occupations, and use this subsample to train a random forest with 50 trees. This is repeated 100 times and the results from the 100 random forests are averaged together—a strategy that combines ideas from EasyEnsemble proposed by Liu et al. (2008) and Balanced RF in Chen et al. (2004).

We evaluate the performance of our algorithm via an average of the F1 scores, computed across jobs (labeled as the macro F score in Sokolova and Lapalme (2009)), with weights equal to job

⁷As implemented by Robnik-Šikonja and Savicky (2020), with the R language.

⁸Although some of the measures we build rely on the full set of estimated conditional probabilities $P_z(J|X)$, our main measure of job assignment quality relies solely on workers' classification into their most suitable jobs. Moreover, we use a bagging procedure for estimation, which significantly mitigates possible calibration issues related to the estimation of conditional probabilities (Wallace and Dahabreh, 2012).

⁹Hyperparameters are parameters set by the researcher to control the learning process, such as the number of trees and the number of features selected at each a node in random forest algorithms. Compared with other algorithms, such as neural networks, random forests require fewer parameters to be specified, making them relatively easier to tune. This reduces the overall estimation time due to the limited need to estimate multiple models in order to choose the best performing one.

¹⁰To deal with categorical variables with a high number of levels, we use the coding proposed by Micci-Barreca (2001).

frequencies to address the unbalancedness of the sample.¹¹ The average F1 score is computed via a stratified 5-fold cross-validation: the learning sample is randomly partitioned in 5 subsamples, where each subsample has the same job frequencies as the initial sample, and the algorithm is trained using 4 subsamples and tested on the remaining one; the procedure is repeated until all of the 5 subsamples are used as a test set, so as to obtain a total of 5 pairs of weighted F1-scores (where each pair refers to a training set and to the corresponding test set); finally, these 5 weighted F1-scores are averaged. The average of the resulting F1 scores is 78% when computed for the training set and 68% when computed for the test set. This performance is reassuring, considering that a random allocation of workers to jobs would at most achieve an average weighted F1-score of $2/(K + 1)$, where K is the total number of jobs. Since the minimal number of jobs in our training and test sets is 38¹², the maximal weighted F1 score resulting from a random allocation of workers to jobs in our sample would be at most 5.1%.¹³

To characterize our algorithm, we explore the role that each worker characteristic plays in identifying the allocation of jobs across workers. To this purpose, we compute the explanatory power of each of the workers' features used in the random forest algorithm, i.e., its discriminatory power in the correct classification of the instances, as described in Robnik-Šikonja (2004) and Robnik-Šikonja and Savicky (2020). Figure 2 displays a box plot of this measure for all the features used in the ML algorithm, which are listed on the horizontal axis.

Insert Figure 2 here

On the whole, Figure 2 highlights that both education and experience play a prominent role

¹¹The F1 score for a given class is computed as the harmonic mean of the estimator's precision and recall scores for such class. The precision score is defined as the ratio between the number of instances correctly identified as belonging to the class and the total number of instances that the estimator attributes to the class: it indicates the ability to estimate the class "precisely". The recall score is defined as the ratio between the number of instances correctly identified as belonging to the class and the total number of instances belonging to the class: it indicates the ability of the estimator to retrieve instances of that class.

¹²This is because in estimation strategy we split the full sample in size-industry bins. The minimal number of unique jobs in a bin is 38.

¹³This can be seen as follows. Denote job frequencies by π_k , $k = 1 \dots K$. If the algorithm were to assign workers to jobs at random with equal probability, the probability of assigning a worker to a given job is $1/K$. Hence, the precision and recall for class k , in large samples, are roughly π_k and $1/K$, respectively, so that the F1 score for class k is $2\pi_k/(K\pi_k + 1)$, and the weighted F1 score is $2\sum_k \pi_k^2/(K\pi_k + 1)$. The maximal value of this expression is $2/(K + 1)$, which is achieved when $\pi_s = 1$ for some s and $\pi_k = 0$ for $s \neq k$.

in job allocation. However, the type and level of education appear to matter more than tenure, experience, occupation-specific and industry-specific experience, suggesting that generic human capital is more important than firm-specific one in job-worker matching. However, the numerous outliers that can be observed for occupation-specific and industry-specific experience indicate that match quality in some industry-size bins is sensitive to experience in a few specific jobs, such as computing professionals, legal professionals, writers and creative performing artists, as well as metal and mineral products machine operators, building finishers, and office clerks. The same applies to the geographic location of employees: while typically a worker’s municipality appears to play little role in determining match quality, it is quite important to match workers who live in a few specific areas, such as Stockholm, Gothenburg and Malmö.

3.2 Job assignment quality at employee level

To predict the quality of worker-job matches in the main sample, we use the algorithm trained on the learning sample to construct an employee-level measure of job assignment quality ($eJAQ$, where “ e ” is a mnemonic for “employee”). This measure equals 1 if the employee’s job coincides with the most suitable one, i.e., the job to which the algorithm assigns the highest conditional probability for that worker, and 0 otherwise: formally, if \hat{J}_i is the job predicted for worker i and J_i is the actual job held by that worker, then $eJAQ_i = \mathbf{1}_{\{J_i = \hat{J}_i\}}$. This indicator is the key building block of our measure of job assignment quality at the firm level (JAQ), which is simply obtained by averaging $eJAQ$ across the employees of the same firm in a given year.

While the $eJAQ$ measure has the benefit of simplicity, it has two shortcomings: first, it only captures changes in match quality if workers switch to (or away from) their best possible match, thus neglecting any intermediate change in match quality; second, it does not take into account that workers may feature different suitability to the best possible match, depending on the specialization of their skill set: for instance, the probability that a position as computing professional is the top job for an electronic engineer may be, say, 90%, while a worker with a high-school degree may be well suited to several jobs as machine operator with equal probability of 30%. To overcome both

limitations, we also construct a continuous measure of employee-level job match quality (*epJAQ*) by estimating the probability that the algorithm assigns to the actual job held by a worker: formally, $epJAQ = P_z(J_i|X_i)$ for worker i . This alternative measure is a gauge of a worker’s fit for her actual job compared to other jobs that she might perform, and as such it captures the change in match quality associated with any job switch, as well as differences in the degree of specialization across workers. Indeed, the *epJAQ* measure ranges between zero and a worker-specific maximum, \bar{p}_i , defined as the highest predicted probability with which the algorithm assigns worker i to any job: formally, $\bar{p}_i = \max_{j \in \text{Jobs}} P_z(j|X_i)$. Hence, the upper bound of the *epJAQ* measure is greater for workers with more specialized skill sets.¹⁴ The corresponding firm-level average is denoted as *pJAQ*.

3.2.1 Characterizing employee assignment

Table 2 provides evidence that illustrates the mapping from characteristics to jobs exploited by our algorithm. For a pool of selected jobs, the table shows the average characteristics of employees who, according to our ML algorithm, are very likely to be assigned to those jobs. The jobs included in the table are selected to provide information on the following broad occupation classes: 1) all managerial positions (ISCO codes: 121, 122, 123, 131), 2) professionals (242), 3) technicians and clerks (411), 4) skilled manual workers (723), 5) machine operators and assemblers (815), and 6) elementary occupations (932).¹⁵ While for the first occupation class we include all the managerial positions, for other occupation classes we select jobs with the highest average predicted probability, $P(j|X)$.

Insert Table 2 here

The typical employee characteristics associated with each job are obtained by averaging over the subset of the 1,000 employees (990 and 998, for jobs 242 and 723, respectively) with the

¹⁴A measure that does not capture such difference in specialization across workers, and is merely a continuous counterpart of the *eJAQ* metric, one can normalize the *epJAQ* measure by \bar{p}_i . We find that the results obtained when using this continuous metric (which we label *ecJAQ*) are quite similar to those based on the *eJAQ* measure, and therefore we report them only as a robustness check in the Appendix of this paper.

¹⁵Skilled manual workers include service and shop sales workers, skilled agricultural and fishery workers, and craft and related trade workers. The exact job titles are indicated in the caption to Table 2.

highest predicted conditional probability for the corresponding job, $P(j|X)$, as estimated by the ML algorithm. The table shows that these are typically senior employees, as shown by the average age (around 50 for almost all jobs), as well as by their tenure and experience. Moreover, employees tend to have several years of experience in the same job, confirming not only the importance of general experience, but also that of job-specific experience, probably due to on-the-job learning. This is consistent with the prominent role that experience and tenure play in our ML algorithm according to Figure 2.

Legal professionals (242) are the only exception, as they are younger than other employees and feature lower experience and tenure, but have greater and more specialized education, as they all hold a college degree in the same subject, clearly a reflection of compulsory requirements to practice legal professions: these special characteristics enable the algorithm to identify these workers with almost perfect confidence (99.8%).

Female workers are a tiny minority in managerial positions (121, 122) and are also unlikely to work as other specialist managers (123), as well as in low-skill jobs (723, 815, 932), whereas they are almost equally represented as males in legal professions (242) and in small enterprises' managerial positions (131), while they account for the totality of office secretaries and data entry operators (411).

Workers holding low-skill jobs (723, 815 and 932) feature a higher average number of unemployment days, likely associated with more frequent separations and/or longer unemployment spells. Moreover, these employees tend to work closer to their birthplace than employees in other jobs. Immigrant status does not seem to vary appreciably across jobs, consistently with its weak role in the algorithm highlighted in Figure 2.

While Table 2 illustrates how individual characteristics of well-matched workers vary across occupations, it is also instructive to ask whether the likelihood of a good match varies across the same occupation groups. We do so by looking at the frequency of mismatches in the six job classes defined above. The upper panel of Figure 3 shows the percentages of instances in which workers fail to be allocated to their most suitable job in the main sample, averaging such percentages within

each of the six job classes defined above. Thus, for each job class, the corresponding bar in the figure indicates the frequency of cases in which a worker holding a job in that class should have been allocated to a different job according to our algorithm. The graph shows that the frequency of mismatches is quite uniform across job classes, except for a slightly lower value for professionals (39%) and a considerably larger value for elementary occupations (65%): in the remaining classes, mismatches range from 56% for managers and 54% for technicians and clerks to 47% for skilled manual workers and 52% for machine operators and assemblers.

Insert Figure 3 here

The greater frequency of mismatches for elementary occupations may be due to two concomitant reasons. First, these are low-skill jobs and as such they do not require very specific worker profiles, so that job-worker mismatches may arise more easily than for other occupations. Second, fewer workers hold these jobs, so that fewer observations inform their allocation rule. Indeed, elementary occupations account for a relatively small fraction of jobs in the economy (6%), not dissimilar from that of managers (7%), while the bulk of workers hold jobs in intermediate classes, as shown in the lower panel of Figure 3. Hence, the absolute frequencies of mismatches in the extreme job classes is much lower than in the intermediate ones: the inefficiency arising from the misallocation in the two extreme classes is mitigated by their relatively lower size.

3.2.2 Employee match quality, wages and separations

We now provide evidence that validates $eJAQ$ and $epJAQ$ as measures of workers' job assignment quality. First, it is natural to expect that the likelihood of being assigned to a more suitable job increases along workers' careers, as managers learn about employees' characteristics (Fredriksson et al., 2018), and employees themselves adapt their skills via on-the-job training (Güvenen et al., 2020). Second, insofar as an improvement in job allocation generates productivity gains, these are likely to be partly appropriated by workers in the form of higher wages. Hence, one can expect wages to be positively related to $eJAQ$. Third, separations should be less likely for workers that are matched to their most suitable job, as found by Fredriksson et al. (2018).

All these predictions find support in our data. Figure 4 shows the binned scatter plot of $eJAQ$ against labor market experience: the likelihood of being assigned to the job predicted by the ML algorithm increases with experience, as the goodness of worker-job matches rises significantly (from 35% to 57%) over the span of a 50-year working life. The largest gain (about 12 percentage points) occurs in the first 5 years of a worker’s career: this accords with the intuition that learning is faster for junior workers, and that their reallocation to more suitable jobs is easier than for senior employees (Farber and Gibbons, 1996).

Insert Figure 4 here

Moreover, better matches between workers and jobs are systematically associated with higher compensation, suggesting that assigning workers to the right jobs brings about efficiency gains. This is shown in columns 1-4 of Table 3, where Panel A reports the estimates of the following earnings regression:

$$w_{it} = \alpha_j + \beta eJAQ_{it} + \gamma X_{it} + \delta Z_{f(i,t)} + \lambda_t + u_{it}, \quad (1)$$

where w_{it} is the logarithm of annual earnings of worker i in year t ; α_j are job indicators; $eJAQ_{it}$ is a dummy variable that equals 1 if worker i is allocated to her most suitable job in year t , and 0 otherwise; X_{it} are all the workers’ characteristics included in the ML algorithm; $Z_{f(i,t)}$ are the characteristics of the firm f that employs worker i in year t (e.g., 2-digit industry dummies, firm age, indicators for family firm, listed company, presence of a human resources manager), and λ_t are year dummies. Panel B shows the estimates of the same specification, simply replacing $eJAQ_{it}$ with $epJAQ_{it}$.

Insert Table 3 here

Column 1 of Panel A reports the estimate of β in a version of equation (1) that includes only job and year effects and the machine learning variables. The resulting estimate is 0.024: a worker allocated to her most suitable job ($eJAQ_{it} = 1$) is estimated to earn 2.4% more than a mismatched worker with the same characteristics or with the same job ($eJAQ_{it} = 0$). The estimate of β increases slightly upon controlling for 2-digit industry dummies and firm characteristics (column 2),

it decreases slightly upon considering only within-worker variation in $eJAQ_{it}$ (column 3), while it increases controlling for unobserved heterogeneity across firms (column 4): the estimated β in a specification that includes worker, jobs and year effects is 2.7% and highly statistically significant. These findings are in line with the -2% estimate of the coefficient of job mismatch in wage growth regressions reported in column 1 of Table 7 in Fredriksson et al. (2018), despite the differences in methodology and sample.

We also analyze the correlation of $epJAQ$ with labor earnings in Panel B of Table 3 to provide a robustness check of the results obtained using the $eJAQ$ indicator with a continuous measure of workers' suitability to jobs. The estimates shown in Panel B indicate that labor earnings are also positively and significantly correlated with this second measure of job match quality over workers' careers. The 0.05 coefficient estimate in column 1 indicates that a 10 percentage points increase in a worker's $epJAQ$ (amounting to half of its standard deviation) is associated with a 0.5% increase in labor earnings. This effect is qualitatively similar and precisely estimated in the specification with industry fixed effects and firm-level controls shown in column 2, and in those with worker fixed effects (column 3) and both worker and firm fixed effects (column 4).¹⁶

Columns 5 through 8 show the relationship between the likelihood of an employer change from one year to the next and the two measures of job allocation quality, $eJAQ$ and $epJAQ$, in Panel A and B respectively. Specifically, we estimate a version of equation (1) where the outcome variable is a separation indicator, which equals 1 if worker i changes employer between year t and year $t + 1$ and 0 otherwise.

Column 5 in Panel A shows that well-matched workers (i.e., those with $eJAQ_{it} = 1$) are 1.25 percentage points less likely to change employer than mismatched workers (i.e., those with $eJAQ_{it} = 0$) with the same characteristics. The coefficient drops slightly upon adding firm controls and industry fixed effects (column 6). In the specification of column 7 we exploit only within-worker variation, namely, we ask how much less likely a given worker is to switch to a new employer when

¹⁶In the Appendix we also estimate these regressions replacing the $eJAQ$ variable with the $ecJAQ$ measure, which is its continuous counterpart: the resulting estimates are qualitatively similar to those reported in Table 3 and actually larger than those obtained for the $eJAQ$ variable, especially for the specifications shown in columns 1 and 2.

she goes from being mismatched to being well-matched: interestingly, in this case the likelihood of a separation drops by 2.7 percentage points. In column 8 we also control for unobserved heterogeneity in turnover rates across firms: in this specification, the likelihood of a separation reverts to being close to 1 percentage point lower for well-matched workers than for mismatched ones. Columns 5 through 8 in Panel B show that a 10 percentage points increase in $epJAQ$ is associated with a reduction in the likelihood of changing firm between 1.7 and 0.5 percentage points.

While Table 3 shows that labor earnings are positively correlated with worker match quality, even controlling for workers' unobserved heterogeneity, it is not informative about whether the relationship is symmetric, namely, whether increases in $eJAQ$ are associated with wage rises and decreases in $eJAQ$ are associated with wage penalties. We address this question by focusing on instances in which workers either increase or decrease their match quality relative to cases in which they do not: to the extent that $eJAQ$ captures the match quality between a worker and her job, one would expect labor earnings to increase upon switching from a mismatched job ($eJAQ = 0$) to the most suitable one ($eJAQ = 1$), and decrease upon a switch in the opposite direction (from $eJAQ = 0$ to $eJAQ = 1$), relative to switches that do not entail changes in $eJAQ$. We perform this analysis for workers who switch across both occupations and employers, because this enables us to condition on homogeneous events.¹⁷ We further require workers to be employed at least for two consecutive years in both the old and new job and estimate two distinct event-study regressions: the first compares the evolution of log labor earnings from two years before to one year after a switch from an occupation with $eJAQ = 0$ to one with $eJAQ = 1$, relative to switches across two occupations with $eJAQ = 0$; the second event-study regression compares switches from occupations with $eJAQ = 1$ to occupations with $eJAQ = 0$, relative to switches across two occupations with $eJAQ = 1$. Figure 5 shows that in the first case wages increase by about 3%, while in the second they drop by about 10%, and in both cases the change in relative log wages is statistically significant at the 1% level. Hence, at times in which employees switch both to a new job and to a new employer, wages

¹⁷As the likelihood that occupation changes are associated with firm switches differs depending on the initial and final level of $eJAQ$, in a pooled sample containing all occupation switches the relationship between wage growth and changes in $eJAQ$ would partly reflect the effect of separations, creating an omitted variable bias.

respond both to rises and to drops in match quality, though more strongly to the latter. We find qualitatively similar, but quantitatively smaller wage responses when considering only job changes that are not associated with separations.

Insert Figure 5 here

3.3 Job assignment quality at firm level

The next step in the analysis is to average $eJAQ_{it}$ for all the employees i of any firm f in a given year t : we refer to the resulting firm-level measure of job allocation quality as JAQ . By the same token, we average the $epJAQ$ measure across the employees of each firm, to produce a firm-level continuous metric of job-workers match quality, $pJAQ$. As our approach builds on the assumption that firms differ in their ability to assign workers to jobs, we expect to observe heterogeneity in both of these variables across firms.

Insert Figure 6 here

The top panel of Figure 6 shows the kernel density estimate of firm-level JAQ for firms in the main sample and in the learning sample. The bottom panel shows the two corresponding densities for $pJAQ$. As expected, the density of both match quality measures in the main sample assigns greater probability mass to lower values than the corresponding density for the learning sample. Moreover, the dispersion in JAQ across firms in the main sample exceeds that in the learning sample. This is as expected, for two reasons. First, the learning sample is used to train the ML algorithm at the core of our match quality measures, so that by construction this sample features a better fit between firms' observed choices and the estimated allocation rule. Second, our learning sample is formed by firms in the top productivity decile: insofar as their higher productivity results from fewer mistakes in applying the most efficient allocation rule, they should feature more concentrated JAQ than firms in the main sample. In the limit, if there were no noise in the estimation procedure, the learning sample should feature no dispersion in JAQ (i.e., we should observe

$JAQ = 1$ for all firms), while there should be dispersion in JAQ in the main sample, reflecting deviations from the allocation rule estimated on the learning sample.

Instead, $pJAQ$ is more concentrated around low values for the main sample than it is around high values for the learning sample. Again, this is for two reasons. First, firms in the main sample may assign workers to less suitable jobs because they deviate more often from the allocation rule estimated on the learning sample. Second, being based on the learning sample, the algorithm tends to predict jobs' conditional probabilities with lower confidence in the main sample, lowering the probability assigned to the most suitable job. Indeed, it turns out that on average the algorithm places a 27% probability on the most suitable job for employees of main-sample firms, against 52% for employees of learning-sample firms.

To further corroborate the idea that firms differ systematically in their ability to assign workers to the correct job, we also investigate how changes in labor earnings and in $eJAQ$ correlate with switches across firms with different JAQ . Indeed, one would expect that the individual worker-job match quality and (consequently) wages increase upon switching from a firm with low JAQ to one with high JAQ and vice-versa. Following Card et al. (2013), we restrict our sample to employer switchers with at least two consecutive years in both the origin and destination firm; next, we classify these firms by quartiles of the distribution of average $eJAQ$ of current coworkers, and partition the switches in cells based on the possible combinations of origin and destination quartiles. Finally, we compare changes of log labor earnings and $eJAQ$ occurring around switches from firms in the bottom quartile of match quality to those in the top quartile, and viceversa: in the first case, both wages and $eJAQ$ increase significantly relative to workers that remain in the same quartile, while in the second case wages do not change significantly and $eJAQ$ drops (see Figure A1 in the Appendix). Hence, the ability of firms to allocate workers to jobs matters for both their wages and for their individual match quality.

3.4 What accounts for changes in job assignment quality?

In principle, the quality of the match between workers and firms can change for one of four reasons: employees (i) accumulate experience or are retrained so as to improve their fit with their existing jobs within the same firm; (ii) switch to more suitable positions within the same firm; (iii) perform the same task in a new firm with which they have a better fit; (iv) switch to a new task in a new firm, in which case the match quality improvement may stem from the change in the task and/or the employer. To account for the relative importance of these four sources of change in job allocation quality in our data, we focus on the instances in which a mismatched employee at year t ($eJAQ_{i,t} = 0$) becomes correctly allocated in the subsequent year $t + 1$ ($eJAQ_{i,t+1} = 1$), or the opposite occurs. Figure 7 shows the frequency for these events in the main sample.

Insert Figure 7 here

Most of the changes in $eJAQ$ (and thus in JAQ) appear to stem from employees improving their match from one year to the next, while retaining both their position and employer. Learning-by-doing is thus likely to be the prevalent reason behind improvements in match quality. Instead, employees changing job (either within the same firm or upon switching to a new one) account for the majority of cases in which we observe a deterioration in the match quality. However, these year-by-year changes may be transitory, so that even if changing job initially results in a poorer match, the match quality may subsequently recover: Section 5 shows that this is indeed the case, especially when the job change coincides with the replacement of a previous manager by a better one. It is interesting to note that the vast majority of the variation in $eJAQ$ is not due to hiring (employees switching employer from one year to the next), but is accounted for by employees remaining with their current employer.

This is also confirmed by Figure 8, which shows the change in the firm-level JAQ (ΔJAQ), normalized by the average number of employees working in the firm, from one year to the next. The figure shows box plots for year-by-year changes in JAQ , and splits it in the variation referring to employees moving to a different firm (*Churn*) and that referring to employees remaining with

the same firm (*Stayers all*). The latter variation is further split between workers reallocated to a different job (*Stayers changing job*) and those retaining the same job (*Stayers retaining job*).

Insert Figure 8 here

From the graph, it is evident that increases in *JAQ* (employees moving from a bad to a good match) are typically due to stayers retaining their job, improving their match quality as their experience accumulates. On the contrary, hiring, firing and reallocation to different jobs are typically associated with a negligible net effect on the allocation quality of the overall workforce (also due to the limited occurrence of these events compared to cases in which employees do not change job and employer from one year to the next). However, the magnitude of the whiskers of the first plot in the graph reveals that there are cases where hirings and firings sizably increase or reduce a firm's job match quality, even by a large amount.

3.5 How does job assignment quality vary across firms?

The quality of management practices—defined as managers' ability to monitor performance, set targets and incentivize employees—has been shown to be consistently higher in firms facing harsher product market competition, those run by non-family managers, and those with a better educated workforce (Bloom and Van Reenen, 2007, 2010). These correlations have been respectively interpreted as reflecting the selection and incentive effects of competition, the inefficiencies stemming from dynastic succession in control, and the ability of better managed firms to attract more skilled employees.

It is reasonable to expect similar correlations between these characteristics and the measures of job allocation quality presented in Section 3.3: product market competition can be expected to focus managers' attention on matching employees to the most suitable jobs; family management is likely to have a greater tendency to promote family and friends rather than the most deserving candidates; finally, more educated workers may seek jobs in firms where they can expect to be correctly assigned, especially in view of the evidence in Section 3.2 that better matches are associated

with higher earnings. The estimates shown in Table 4 are consistent with all three predictions.

Insert Table 4 here

The first four columns of the table present regressions of measures of job allocation quality on the Lerner index of market competition. The dependent variable is *JAQ* in columns 1 and 2 and *pJAQ* in columns 3 and 4. The Lerner index is defined for each firm as $1 - \text{profits/sales}$, lagged by two years to remove any potential contemporaneous feedback, and averaged across all firms in the same 2-digit industry excluding the firm itself. All specifications include year and industry dummies (where industries are manufacturing, real estate, renting and business activities, and wholesale and retail). The specifications of the even-numbered columns include the following additional controls: the share of employees with a college degree, log employment, log capital, log firm age, indicator for listed firms, years of managerial experience averaged over employees in the firm. In all the specifications, firms operating in more competitive markets turn out to allocate their employees more closely in line with the estimated allocation rule, according to both our measures.

The last four columns of the table present regressions of measures of job allocation quality on a family firm dummy, which is constructed on the basis of family relations among major shareholders (called owners by the tax authorities) and directors.¹⁸ For each owner and director in a firm, we calculate the number of other family members who are directors or owners in the company. A company is a family firm if at least two family members are owners or board members, or at least one owner and one director comes from the same family. The estimates show that family firms feature significantly lower job allocation quality in most specifications: based on the estimates in columns 5 and 6, in family firms the probability that an employee is matched to his/her most suitable job is between 0.8 and 2.6 percentage points lower than in non-family ones. This finding complements existing evidence that family firms are more poorly managed than non-family firms (Bloom and Van Reenen, 2007, 2010; Bandiera et al., 2018; Lemos and Scur, 2019).

¹⁸An individual's family comprises his parents, grandparents, children, grandchildren, siblings, and partner(s). A partner is the person with whom the individual has a child.

Finally, the coefficient of the share of employees with a college degree is positive and significantly different from zero in all the specifications where this variable is included among the explanatory variables: a 10-percent increase in this measure of employees' human capital is associated with about a 1 percentage point increase in the probability of a suitable job assignment. This correlation can either be seen as suggesting that better job-worker matching attracts more qualified employees or as indicating that managers pay more attention to the job assignment of employees with a college degree, or both.

4 Job Assignment Quality and Firm Performance

This section explores how the heterogeneity in JAQ and in $pJAQ$ correlates with firm performance, as measured by sales per employee, value added per employee, and operating return on assets (OROA): we wish to determine whether these two measures capture meaningful variation in the quality of workforce allocation, rather than just statistical noise or firm heterogeneity in productivity. Our exercise parallels the approach used by Bloom et al. (2019) to validate their measure of structured management practices, by investigating their correlation with various indicators of firm performance.

4.1 Descriptive evidence

Figure 9 shows that firm-level productivity correlates positively with both JAQ and $pJAQ$. The figure shows partial regression plots of value added per employee against these two job-worker match quality variables, conditioning on year effects and 2-digit industry effects. The two top panels refer to main-sample firms, and the bottom two to learning-sample ones. The left-side panels of the figure show how value added per employee correlates with JAQ , and the right-side ones how it correlates with $pJAQ$. A positive relationship is evident in the two top graphs, providing preliminary evidence that main-sample firms tend to feature higher productivity insofar as they allocate employees more closely along the rule estimated from the learning sample.

Insert Figure 9 here

Specifically, the positive correlation with JAQ indicates that firms where workers are more often allocated to their most suitable job are more productive than others. Moreover, the positive correlation with $pJAQ$ suggests that the specialization of a firm's workforce also plays a role. As explained in Section 3.2, a firm's employees may feature high $epJAQ$ not only if they are well assigned within the set of jobs they can possibly hold (p_i close to \bar{p}_i), but also if they are highly specialized (\bar{p}_i close to 1), in the sense that their characteristics make them highly suitable to a specific job profile.¹⁹

The two lower panels of Figure 9 instead show that no correlation between productivity and either JAQ or $pJAQ$ is present for firms in the learning sample. This is to be expected, as for these firms variation in measures of match quality should only reflect sampling variability stemming from random deviations from the estimated allocation rule. This can be easily illustrated by considering an extreme example: if firms in the learning set were to adhere perfectly to a common deterministic allocation rule, then JAQ would equal 1 for all of them, and would feature no relationship with productivity. To the extent that the variation in JAQ detected in the learning sample reflects firms' random deviations from the same allocation rule, one would not expect it to feature a systematic relationship with firm productivity.

4.2 Regression analysis

Table 5 explores further the firm-level correlation between productivity (as well as profitability) and JAQ , controlling for other determinants of productivity. All the specifications presented in the table include year dummies and municipality dummies: the first control for aggregate movements in productivity, the second for productivity differentials across locations. The latter may arise not only from location-related technological advantages, but also from access to deeper and more diversified local labor markets. Hence, the relationship between productivity and JAQ captured by

¹⁹Indeed, we find that firms' productivity is positively and significantly correlated with firm-average \bar{p}_i , which can be regarded as a measure of specialization of its workforce, even after controlling for workers' characteristics.

our estimates is not driven by differences in the availability of workers or labor market conditions across firms' locations.

In Panel A of Table 5, column 1 reports the OLS estimates of a regression of log sales per employee on *JAQ* including only year dummies. We find a highly significant coefficient of 0.366, implying that a 10-percentage-point increase in *JAQ* is associated with a 3.66% increase in sales per employee. Equivalently, a one-standard-deviation increase in *JAQ* (0.31) is associated with a 11.5% increase in sales per employee. To put this estimate in perspective, Bloom et al. (2019) find that a one-standard-deviation increase in their management score is associated with a 26.2% increase in sales per employee. The difference in magnitude between the two estimates may reflect the fact that *JAQ* focuses on the gains stemming from the efficient allocation of employees, while the score constructed by Bloom et al. (2019) is a broader synthetic indicator of management practices. It may also reflect the fact that our sample excludes the most productive firms in the economy.

Insert Table 5 here

In column 2 of Table 5, the dependent variable is the log of value added per employee, and the coefficient of *JAQ* is again positive and highly significant: a 10-percentage-point increase in *JAQ* is associated with an average increase in value added per employee of 1.95%, implying a 6% increase upon a one-standard-deviation increase in *JAQ*.

These results are not robust to the inclusion of firm fixed effects, possibly because of attenuation bias due to measurement error. However, we control for various possible sources of omitted variable bias, namely, firm characteristics, differences in firms' occupation structures and differences in workers' quality across firms.

First, the correlation between productivity and our measures of job allocation quality is robust to the inclusion of 2-digit industry indicators, log number of employees, log capital, and the fraction of employees with at least a college degree among the regressors, as shown by the estimates in columns 4 and 5 of the table. The estimated coefficients of *JAQ* in columns 4 and 5 drop in magnitude, but remain positive and significantly different from zero.

A second possible concern in the previous specifications is that the firms being compared may have different occupation structures. Two otherwise comparable firms may structure their internal hierarchy in a different fashion: if for instance a firm has an inefficiently large number of managerial positions relative to technical ones compared to other firms in its industry, and those managerial positions are harder to fill with suitable employees, it is likely to end up both with lower productivity and lower JAQ , creating a spurious correlation between the two variables. To address this issue, Panel B of Table 5 reports the estimates of the following specification:

$$y_{ft} = \theta_0 + \theta_1 JAQ_{ft} + \theta_2 F_{jft} + \theta_3 Z_{ft} + \lambda_t + \gamma_h + u_{ft} \quad (2)$$

where y_{ft} is $\log(\text{sales/employees})$, value added per employee or operating return on assets, F_{jft} is the fraction of workers in firm f assigned to job j in year t ; Z_{ft} are the characteristics of firm f in year t , namely their age, family firm status, state-owned status, listed firm status, an indicator for the presence of a human resources (HR) manager, its log number of employees and its log of total assets; λ_t are year dummies, and γ_h are 2-digit-industry dummies. In columns 1, 2 and 3 of Panel B this specification is estimated omitting the firm characteristics Z_{ft} , while in columns 4, 5 and 6 these are also included. The results are qualitatively similar to those in Panel A: the estimated coefficients of JAQ drop in magnitude, but remain positive and statistically significant in columns 1, 2, 4 and 5.

A third possible source of omitted variable bias is that firms with higher JAQ may feature higher-quality workers, irrespective of the job they are allocated to. Thus, in Panel C of Table 5 we augment specification (2) with the workers' characteristics included in the machine learning algorithm, averaged across all workers employed in firm f in year t . In columns 1, 2 and 3 we control for year effects, occupation structure and workers' characteristics. Columns 3, 4, and 5 also add industry dummies and firm characteristics. The coefficient of JAQ remains positive and statistically significant also in these very conservative specifications, even though in some of them it drops further in magnitude.²⁰

²⁰The results reported in Table 5 are obtained using the main sample. Upon estimating the same specifications with

In almost all of the specifications shown in Table 5, profitability, as measured by operating return on assets (OROA), is not significantly correlated with our measure of efficient job allocation, as shown in columns 3 and 6 of the table. A possible interpretation of this finding is that in Swedish firms the productivity gains afforded by better job-worker matches in 2001-10 translated mostly into higher wages, rather than increases in firm profitability.

To check the robustness of these results, in Table 6 we repeat the estimation of the specifications shown in Table 5 upon measuring worker-job match quality by $pJAQ$. The estimated coefficient of this variable is positive and significantly different from zero in all the specifications of the productivity regressions. The baseline estimates shown in columns 1 and 2 of Panel A imply that a 10 percentage points increase in firm-level suitability of workers to jobs is associated with a 10 percentage points increase in log sales per employee and a 7 percentage points increase in value added per employee. These results are qualitatively robust to the addition of other controls, even though they drop considerably in size. Differently from JAQ , columns 3 and 6 show that increases in $pJAQ$ weakly correlate with increases in profitability.²¹

Insert Table 6 here

4.3 A circularity issue?

One last concern is that of potential circularity in the construction and validation of JAQ and $pJAQ$ performed up to this point: as explained in Subsection 3.1, we train the ML algorithm to assign workers to jobs in firms from the top decile of the productivity distribution, and then check whether the measures thus obtained correlate with firms' productivity. The obvious counter to this criticism is that the correlation between these measures and productivity is tested on the main sample, and not on the learning sample used to train the algorithm, and indeed the correlation is present only for the main and not for the learning sample, as shown in Section 4.

the learning sample, no robust relationship between JAQ and productivity emerges, consistently with what is shown in Figure 9.

²¹As shown in column 6 of Table A2 of the Appendix, profitability is positively associated with job allocation quality also when the latter is measured by $cJAQ$.

In this section we further dispel circularity concerns, by constructing learning sets that do not rely on firm productivity and using them to retrain the ML algorithm. First, we perform a placebo test replacing actual firm productivity with a noise variable that has the same distribution as firm productivity. Second, we retrain the algorithm on random subsamples of firms. Third, we construct the learning set based on the residuals of an AKM model (Abowd et al., 1999).

Placebo test. The selection of firms into the learn set based on productivity may create a mechanical correlation between our measures of job allocation quality and firm productivity: the out-of-sample prediction error may be systematically lower for firms that are more similar to those included in the learning set, driving a positive correlation between JAQ and productivity. To address this issue, we perform a placebo test: we replace firms' actual productivity (the log of value added per employee) with a noise variable, obtained by randomly reshuffling the original variable across firms, and use it in place of the original productivity measure to re-estimate the algorithm. That is, the learn set is now built using the top 10% firms in terms of the noise variable, and is used to compute again the JAQ and $pJAQ$ measures, as explained in Subsection 3.1. By construction, the new productivity variable used for the placebo test has the same distribution as the original one, but is independent from the rest of the data.

Note that this placebo test leaves intact the relationship between employees' characteristics and task allocations, and only alters the selection of firms into the learn set. If the positive relationship between our measures of job assignment quality and firm productivity is indeed generated by this selection process, one should also expect to find a positive and significant correlation between them and the noise productivity measure in the placebo test for the main sample. If instead there is no mechanical relationship induced by the learn set selection process, no significant relationship should be present. This is indeed what emerges from the top panels of Figure 10, which plot the results of the regression of the placebo productivity measure on JAQ (left-hand chart) and on $pJAQ$ (right-hand chart). The lack of correlation between these two variables contrasts with the positive and significant correlation obtained in the main estimation strategy and shown in the top panel of

Figure 9.

Insert Figure 10 here

Random JAQ. In the regressions of Table 5 and Table 6, JAQ and $pJAQ$ may spuriously correlate with productivity. Suppose for instance that the most productive firms are all located in large cities, and that they only hire residents from those cities. Then, estimating the job allocation rule on the learn sample would generate a JAQ measure positively associated with hiring residents of large cities, creating a spurious correlation between JAQ and productivity in the main sample. To address this additional concern, we re-train our ML algorithm on a random subsample of firms, so as to calibrate the reference rule on the basis of the average firm in our sample, rather than top-productivity firms, and investigate whether the resulting measures of job assignment quality still correlate significantly with productivity across firms. Specifically, we redefine the learning sample used to train our ML algorithm as a 10% random draw of firms (in the same size-industry class) from our entire sample. We refer to the resulting measures of job allocation quality as JAQ^R and $pJAQ^R$, where the superscript R is a mnemonic for “random”. Both JAQ^R and $pJAQ^R$ turn out to correlate positively and significantly with productivity, as shown by the two partial regression plots of the log of value added per employee (controlling for year and industry effects) in the bottom panel of Figure 10. The regressions shown in Table A3 in the Appendix show that these correlations are robust to the inclusion of firm and worker controls.

It is worth comparing the graphs shown in the two bottom panels of Figure 10 with the corresponding graphs in the top panel of Figure 9, which are based on the measures of job allocation quality calibrated on top-productivity firms. In the bottom panel of Figure 10 the positive correlation appears to be present especially for firms in the bottom and middle portion of the productivity distribution, rather than for the entire support of the distribution as in the top panel of Figure 9. As a result, the relationship between the two variables has an inverse-U shape. This is precisely as expected: since now the rule reflects the behavior of the average firm, the firms that adhere most closely to this rule (i.e., those with the highest value of JAQ^R and $pJAQ^R$) cannot hope to achieve

more than an average productivity level. Still, conforming more closely to such an allocation rule is associated with productivity improvements for the typical firm in the sample, because it reduces firms' deviations from the estimated rule in allocating their employees. This applies in particular to firms in the lowest part of the support of the distribution, i.e., those that conform the least to the estimated rule: for such firms, an increase in JAQ^R and $pJAQ^R$ is associated with a steep productivity gain.

The results for JAQ^R and $pJAQ^R$ in the bottom panel of Figure 10 are not tied to a particular random draw of firms: they hold on average for any random draw of firms, as shown by the Monte Carlo experiment illustrated in Figure 11. We sample 150 learn sets at random, calibrate the JAQ^R and $pJAQ^R$ measures for each of them, and estimate their coefficient point estimates in the productivity regressions, controlling for year and industry fixed effects.²² Figure 11 shows the Monte Carlo distribution of these estimates, where the solid vertical lines indicate the analogous point estimate obtained using the 10% top-productivity firms as learn set.

Insert Figure 11 here

All the densities place higher mass on positive values, indicating that JAQ measures positively correlate with productivity when the learn set is selected at random. However, the coefficient estimates obtained for the 10% top-productivity firm is significantly higher (solid vertical line) than the average estimate obtained using these random draws, as shown by the p-value reported in the top-right of each graph. This is perfectly in line with the aforementioned intuition that conforming to average firms typically leads to a productivity increase, but not as large as the increase obtainable by conforming to the rule used by top productivity firms.

AKM-based learning set. Yet another robustness check of our results is to produce an alternative measure of JAQ that defines the learning sample not on the basis of firm productivity, but on the residuals of an AKM wage regression, which capture the surplus from worker-firm matches

²²Due to limitations in computing power, the procedure described above is carried out on a 15% random subsample of firms, drawn independently at each Monte Carlo iteration.

(Lachowska et al., 2018; Kugler et al., 2020). As long as this surplus at least partly arises from the fit between workers' skills and their occupations, observations with the highest AKM residuals should identify better allocated workers, and thus provide a valid learning sample. To implement this strategy, we (i) estimate an AKM model including worker fixed effects, firm fixed effects, year fixed effects and workers' characteristics, (ii) define the learning set as the workers featuring the top 10% residuals in 2010, (iii) train the ML algorithm on this sample, and (iv) finally correlate firm productivity with the resulting alternative measures of job allocation quality (JAQ^{AKM} and $pJAQ^{AKM}$), excluding all the firms that employ any of the workers belonging to the learning set. The results, shown in Table 7, parallel very closely those reported in Panel A of Table 5: the coefficient estimate reported in column 2 of Panel A implies that a one-standard-deviation increase in JAQ^{AKM} (0.30) is associated with a 3.8% increase in value added per employee.

Insert Table 7 here

5 Impact of Manager Quality on Job-Worker Matches

The results presented so far are consistent with our ML algorithm capturing a best-practice rule to allocate workers to jobs, whose adoption is correlated with higher firm-level productivity. Why don't all firms in our sample follow such a best-practice rule? As workers' hiring, assignment to jobs and promotions are typically management decisions, it is natural to inquire whether workers' assignment to jobs is systematically related to managerial quality in our data. This immediately begs another question, namely, how to measure managerial quality based on the observed characteristics of managers. In line with the approach of this paper, a synthetic measure of a firm's managerial quality should be the frequency with which the ML algorithm would actually assign its managers to managerial tasks in the most productive firms. Another, simpler measure of the quality of firm's managers is their average work experience in managerial positions.

Hence, to investigate this issue, for each firm and date we split JAQ into its two components, one measuring the quality of rank-and-file employees' assignment to jobs ($R\&F-JAQ$) and the

other measuring the quality of managers' allocation to their jobs (*M-JAQ*). The first is the average *eJAQ* for all workers that hold non-managerial positions in a given firm at a given date, while the latter is the average *eJAQ* for the corresponding firm's managers. Next, we investigate the firm-level relationship between these two variables, as well as *R&F-JAQ* and managerial experience.

Table 8 presents the results of the corresponding regressions, which are based on data from 2003 to 2010: data for 2001 and 2002 are omitted in order to enable the *JAQ* measure to condition on at least two years of experience for all workers. In columns 1 to 3 *M-JAQ* refers both to top managers (CEOs and firm directors) and to middle managers, whereas in columns 4 to 6 it only refers to top managers. Columns 1 and 4 display results from baseline regressions whose dependent variable is the job allocation quality of rank-and-file employees (*R&F-JAQ*), and whose explanatory variable is the allocation quality of managers (*M-JAQ*), including only year effects. The relevant coefficient is positive and significantly different from zero in both regressions: 10 percentage points increase in the quality of managers' allocation is associated with an increase in the quality of rank-and-file workers' allocation ranging between 1 and 2 percentage points, depending on the specification. When the quality of managers' allocation only refers to the firm's top management, the coefficient approximately halves in size, indicating that middle management is also important for the correct allocation of workers to their jobs.

Insert Table 8 here

The specifications shown in columns 2 and 5 also include firm fixed effects and the average experience of the firms' managers (Manager exp), and those shown in columns 3 and 6 additionally include industry fixed effects, municipality fixed effects and firm controls (age, family firm status, state-owned status, listed firm status, an indicator for the presence of a human resources manager, log number of employees and log of total assets). In both of them, managerial experience appears to contribute positively and significantly to *R&F-JAQ*, but the coefficient of *M-JAQ* remains large and precisely estimated. Importantly, these regressions are based only on within-firm variation in the relevant variables: they indicate that better matching of rank-and-file employees to jobs tends to occur when the firm improves its management's quality and experience.

These findings beg the question of whether managerial quality and expertise, by improving the matching of workers to jobs, contribute to the firm-level productivity differentials analyzed in Section 4. Table 9 shows that indeed this is the case: both the log of value added per employee and the log of sales per employee are positively and significantly correlated with the quality of managers' allocation, irrespective of whether the specification only contains year and municipality dummies (columns 1 and 2) or also includes industry dummies (columns 3 and 4). The specifications in columns 5 and 6 suggest that not only the allocation quality of managers but also their average experience contributes to firms' productivity. Hence, the evidence is consistent with the view that managerial quality and experience, via their effects on the matching of rank-and-file workers to jobs, account for the observed productivity differentials between firms. In terms of economic significance, higher managerial quality correlates with firm productivity almost as strongly as overall labor allocation quality: one-standard-deviation increases in $M-JAQ$ and JAQ are respectively associated with a 4.8% and a 6% rise in the log of value added per employee, based on the coefficient estimates in column 2 of Table 9 and in the corresponding column of panel A of Table 5.²³

Insert Table 9 here

Since it is natural to expect improvements in managerial quality and experience to result from the hiring of better managers and/or the dismissal of incompetent ones, our next step is to test whether the allocation of rank-and-file workers improves when incumbent managers are replaced with more suitable ones, and worsens when they are replaced with less suitable ones. To perform this test, the first step is to measure the change in managers' quality associated with their turnover, relative to the counterfactual level of managerial quality associated with no turnover.

If management changes in a given firm in year τ (meaning that at least one of its managers changes), the concomitant change in managerial quality, denoted by $\Delta M-JAQ_\tau$, is the difference between the average quality of the new management team, $M-JAQ_\tau$, and that of the firm's previous

²³The standard deviations of $M-JAQ$ and JAQ are respectively 0.36 and 0.31. The rank-and-file allocation quality also features a similar correlation with firm productivity: replacing $M-JAQ$ with $R\&F-JAQ$ in the specification of column 2 of Table 9, we find that its estimated coefficient is 0.174 (significant at 1% level), implying that a one-standard-deviation increase (0.32) in $R\&F-JAQ$ is associated with a 5.5% increase in the log of value added per employee.

management team $M-JAQ_{\tau-1}$, which in turn reflects both the average quality of the $N_{\tau-1}^s$ managers who “stay” in the firm and that of the $N_{\tau-1}^d$ managers who are “dismissed” in year τ :

$$\begin{aligned} \Delta M-JAQ_{\tau} &\equiv M-JAQ_{\tau} - M-JAQ_{\tau-1} = M-JAQ_{\tau} - \frac{\sum_{i=1}^{N_{\tau}^s} eJAQ_{i\tau}^s + \sum_{j=1}^{N_{\tau-1}^d} eJAQ_{j\tau-1}^d}{N_{\tau-1}} \\ &= \underbrace{M-JAQ_{\tau} - \frac{\sum_{i=1}^{N_{\tau}^s} eJAQ_{i\tau}^s + \sum_{j=1}^{N_{\tau-1}^d} eJAQ_{j\tau-1}^d}{N_{\tau-1}}}_{\Delta M-JAQ^{TO}} + \frac{\sum_{i=1}^{N_{\tau}^s} (eJAQ_{i\tau}^s - eJAQ_{i\tau-1}^s)}{N_{\tau-1}^s} \frac{N_{\tau-1}^s}{N_{\tau-1}}. \quad (3) \end{aligned}$$

To identify in this expression the change in managerial quality related to turnover, one must shut down the part of variation in $\Delta M-JAQ_{\tau}$ due to changes in job assignment quality of managers who stay within the firm. This is done in the last step of equation (3), by adding and subtracting the average job assignment quality of stayers at time τ , weighted by their share in the managerial team at time $\tau - 1$. Then the first term, $\Delta M-JAQ^{TO}$, is the difference between the current and past levels of job assignment quality of the managerial team, net of the change of managerial quality of the “stayers”, and thus measures the change in managerial quality due to turnover; the second term, instead, measures the change in the average quality of the $N_{\tau-1}^s$ managers who stay in the firm also in year τ , weighted by their share $N_{\tau-1}^s/N_{\tau-1}$ in the managerial team.²⁴ Importantly, the measure $\Delta M-JAQ^{TO}$ is designed so as to only track changes in the quality of the managerial team associated with changes in its composition: it disregards the change in the average quality of retained managers between years τ and $\tau - 1$, as this change would occur irrespective of managerial turnover. Indeed, $\Delta M-JAQ_{\tau}$ is zero by construction if no managers are dismissed ($N_{\tau-1}^d = 0$) and no managers are hired.

We then define a “positive turnover event” to occur for a given firm in year τ if in that year $\Delta M-JAQ^{TO}$ in (3) turns positive for the first time for that firm, and this rise in managerial quality persists over time, i.e., is not subsequently reversed or more than reversed. Symmetrically, a “negative turnover event” occurs in year τ if in that year $\Delta M-JAQ^{TO}$ turns negative, and this drop

²⁴We note that in the third term of (3), the job assignment quality at year τ is re-weighted by the number of employees at time $\tau - 1$, $N_{\tau-1}$, as any change in the workforce, including the total number of employees, should be attributed to turnover.

in managerial quality is persistent over time. This is done to purge the event of interest from the confounding effects of sequences of transitory changes in managerial quality associated with turnover. In our data, 1,451 firms (19.9% of the total) experience positive turnover events, 1,668 (22.9%) experience negative ones, and the remaining 4,173 (57.2%) experience none.

Our final step is to investigate whether such positive and negative managerial turnover events are associated with significant changes in the allocation quality of rank-and-file workers. To this purpose, we estimate the parameters of the treatment effects of these managerial turnover events on *R&F-JAQ*, exploiting variation in treatment timing. To estimate the dynamic treatment effects of interest, we employ the estimator proposed in Callaway and Sant'Anna (2021). This estimator bypasses the pitfalls related to the interpretation of the TWFE estimators – see for instance de Chaisemartin and D'Haultfœuille (2020), Goodman-Bacon (2021), Borusyak et al. (2021), Sun and Abraham (2021), Athey and Imbens (2022), and Baker et al. (2022). It is particularly well-suited to our setting because it focuses on recovering treatment effect dynamics with variation in the timing of the treatment. Figure 12 show the estimated dynamic treatment effects on rank-and-file workers around managerial turnover events, respectively associated with an increase (left chart) or a decrease (right chart) in the *JAQ* of the relevant firm's management.

Insert Figure 12 here

The chart on the left shows that replacement of incumbent managers with better ones tends to occur in the wake of sharp and statistically significant deterioration in the allocation of rank-and-file workers to jobs (by about 5 percentage points on average), and are followed by a significant improvement over the subsequent five years, starting at about 3 percentage points at the time of the event, and eventually vanishing. Conversely, the chart on the right indicates that replacement of incumbent managers with worse ones tend to occur in firms starting from a normal level of rank-and-file workers allocation quality, but are associated with a strong and persistent deterioration in the allocation of rank-and-file workers, especially in the first three years. Overall, this evidence suggests that persistent changes in managerial quality are an important driver of changes in work-

ers' allocation, and therefore of organizational change within firms.²⁵ To address causality, we repeat the estimation using only the 350 managerial turnover events associated with the death of the incumbent management, and find results that are qualitatively similar, although the effects are barely statistically significant due to the paucity of observations (see Figure A2 in the Appendix). On the whole, this evidence rhymes well with the finding in Bender et al. (2018) that firms with better management have workers with higher human capital.

In principle, the organizational changes brought about by new management may involve reallocation of existing employees to different tasks, changes to the composition of the firm's workforce via new hires and/or dismissals, or both of these. Moreover, the extent to which the new managerial team relies on each of these two strategies may differ depending on whether it is better or worse than the preexisting one according to our metric. To investigate these points, in Table 10 we present the Callaway-Sant'Anna estimates of the impact effect (i.e., the time-0 parameter) of the positive and negative managerial turnover events on several outcome variables.

Insert Table 10 here

The first three rows of the table illustrate the effects that managerial turnover events have on the frequency of employees' internal reallocation, firing and hiring. Upon the arrival of better management, firms feature a significant drop in the internal reshuffling of employees across jobs, a marked decrease in the frequency of hirings and an increase in the frequency of firings. In contrast, a worse incoming management team engages into a significantly larger reallocation of existing workers and into substantial firings, while its hiring activity is negligible. On balance, however, the more moderate activism displayed by the new managerial team in the first case appears to be much more beneficial to the job allocation quality of rank-and file workers than its greater activism in the second case: on impact, *R&F-JAQ* increases by 3% upon a positive managerial turnover event, while it drops by 9% upon a negative one. Most of the decrease in job allocation quality

²⁵We also find limited evidence that increases in managerial quality lead to higher productivity, if one focuses on positive turnover events triggering a large impact effect on the job allocation quality of rank-and-file workers (i.e., an increase in *R&F-JAQ* above the 75th percentile). The corresponding results are shown in Figure A3 of the Appendix.

triggered by negative managerial turnover events is accounted for by a drop in the job allocation quality of workers who “stay” in the same firm, i.e., $R\&F-JAQ^s$.

Next, we consider the impact of managerial turnover on the change of job allocation quality of rank-and-file employees relative to the previous year, i.e., $\Delta R\&F-JAQ$, rather than on its level. It turns out that positive managerial turnover events trigger a statistically significant 8.4 percentage points increase in the change of match quality of rank-and-file workers relative to the previous year, while the corresponding outcome for negative managerial events is close to zero and insignificant.

Finally, we partition this overall change into a component associated with turnover (hires and fires) and one reflecting the change in allocation quality of retained employees, analogously to equation (3) for managers’ allocation quality.²⁶ Relying on notation similar to that used in equation (3), we denote by $R\&F-JAQ^{TO}$ the change in the allocation quality of rank-and-file workers stemming from employee turnover, and by $\Delta R\&F-JAQ^s$ the change in the job allocation quality of “stayers”. The figures in the last two rows of the table show that positive managerial turnover events raise the change in match quality of the relevant firms’ workforce both via the turnover of employees and via the change in match quality of existing employees. The result that a better managerial team raises the change in the match quality of existing employees is not in contrast with the above-noted fact that such a team reduces internal reallocation, as the match quality of “stayers” may simply improve as a result of the increased job experience of employees that do not switch jobs. In contrast, negative managerial turnover events do not affect the change in match quality of rank-and-file workers via the turnover channel, but trigger a strong and significant decrease both in the level and in the change of match quality of “stayers”: hence, they appear to engage in misguided reshuffling of employees.

²⁶However, this decomposition is not precise as that shown in equation (3), as the allocation quality of employees who “stay” in the firm is not re-weighted by their fraction over the total workforce.

6 Conclusions

This paper proposes a novel measure of job-worker allocation quality (*JAQ*) by combining employer-employee data with machine learning techniques and validates it by exploring its correlation with workers' wages over their careers, firm performance, and with managerial turnover.

Our evidence shows that workers earn significantly more as they are better allocated to jobs over their careers, and that workers better matched to their jobs are less likely to switch to a new employer. Job allocation quality is found to vary systematically across firms: companies that operate in more competitive markets, those that are not family-managed and those with a more educated workforce do a better job at matching their employees to jobs. Most importantly, firm productivity correlates robustly with our measure of job-worker allocation quality.

Hence, our measure correlates with key firm characteristics in the same way as management practices do, uncovering a hitherto unmeasured dimension of management's ability. Indeed, we find that the quality of management plays a key role in the efficient assignment of workers to jobs: rank-and-file workers' allocation improves significantly when managerial turnover leads to better assigned and more experienced managers.

The measure proposed in this paper can be constructed for any employer-employee data that include workers' occupations, without requiring either expensive surveys or detailed expert evaluations of the skills required for each job, and can be applied to explore a vast range of research questions in organizational economics and corporate finance, as witnessed by the evidence provided by this paper.

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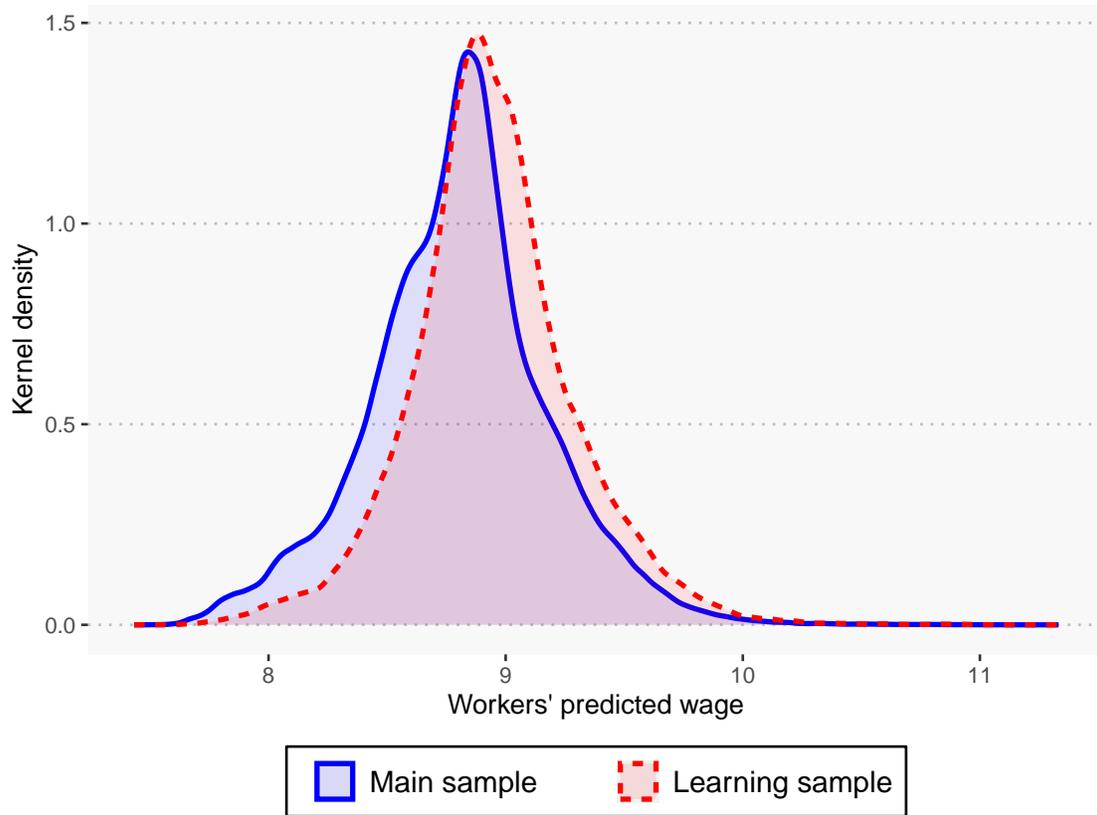


Figure 1: Common support of worker characteristics in the main and the learning samples

This figure shows the distributions of the predicted wages for workers in the learning sample (red line) and the main sample (blue line). For both samples, the predictions are obtained from wage regressions estimated on the main sample using as explanatory variables the worker characteristics included in the ML algorithm. These are age, gender, an indicator for immigrant status, residence municipality, a mobility indicator equal to one for workers employed in a county different from the county of birth, education level (basic, high school, vocational, or university), education subject (no specialization, law, business and economics, health and medicine, natural sciences, teaching, engineering, social sciences, services, or other specializations), labor market experience (measured as years since graduation), tenure at the current firm, number of firms and number of two-digit industries where an individual previously worked, total number of unemployment days since 1992 (when the unemployment data starts in LISA), years of experience in each occupation, years of experience in each 2-digit industry, and years of experience in each decile of the distribution of firms' number of employees or total assets. The figure shows that the support of the two distributions almost perfectly overlaps.

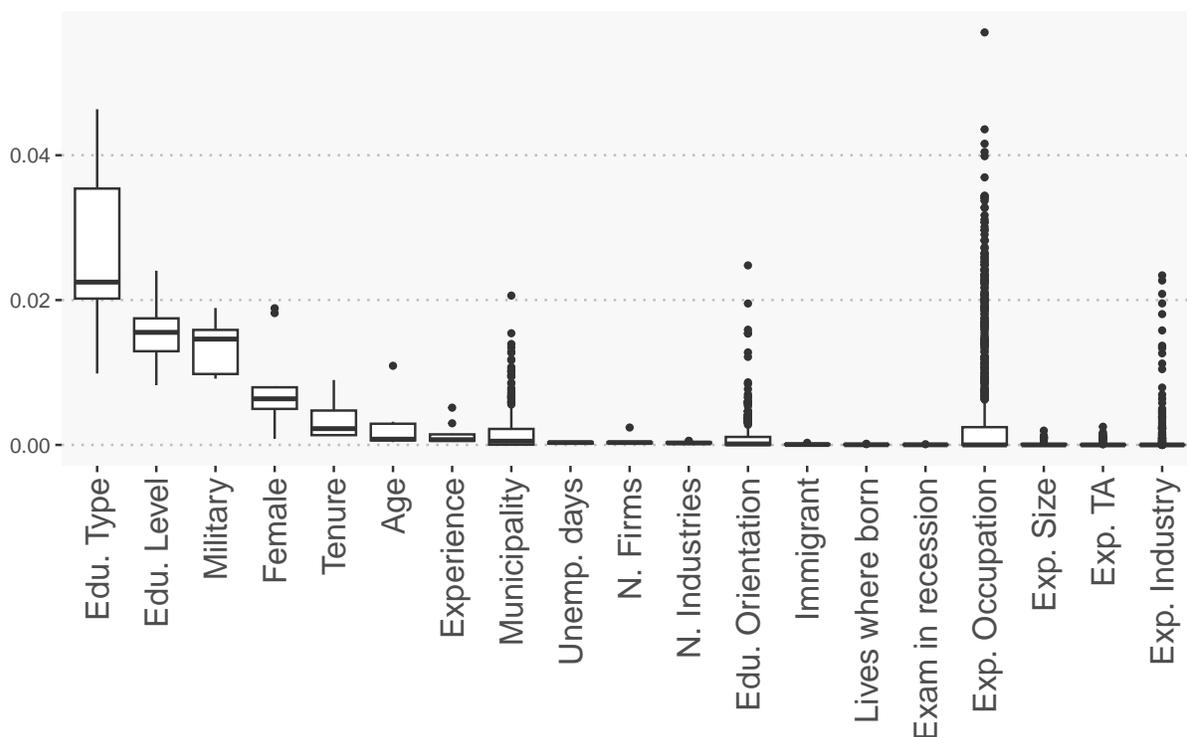


Figure 2: Importance of workers' features in the random forest algorithm

The graph plots the maximum explanatory power of all the workers' features used in the random forest algorithm. Features are listed on the horizontal axis, and the importance of each feature—defined as in Robnik-Šikonja (2004) and Robnik-Šikonja and Savicky (2020)—measures its discriminatory power in the correct classification of the instances. Some features are aggregated under a single label: “Exp. Occupation” aggregates the years of experience in each occupation, “Exp. Industry” those in each industry, “Exp. TA” those in firms with given total assets, and “Exp. Size” those in firms with given number of employees. “Edu. Type” aggregates features related to education specialization. “Tenure” is the years of employment in the current firm, “Municipality” codes the worker’s residence, “Female” and “Experience” are the worker’s gender and years of experience, “N. Industries” and “N. Firms” the number of industries and firms where a worker was employed, “Unemp. days” the number of unemployment days. “Military”, “Immigrant” and “Lives where born” are dummy variables indicating whether the worker performed military service, is an immigrant and lives in his/her birthplace, respectively.

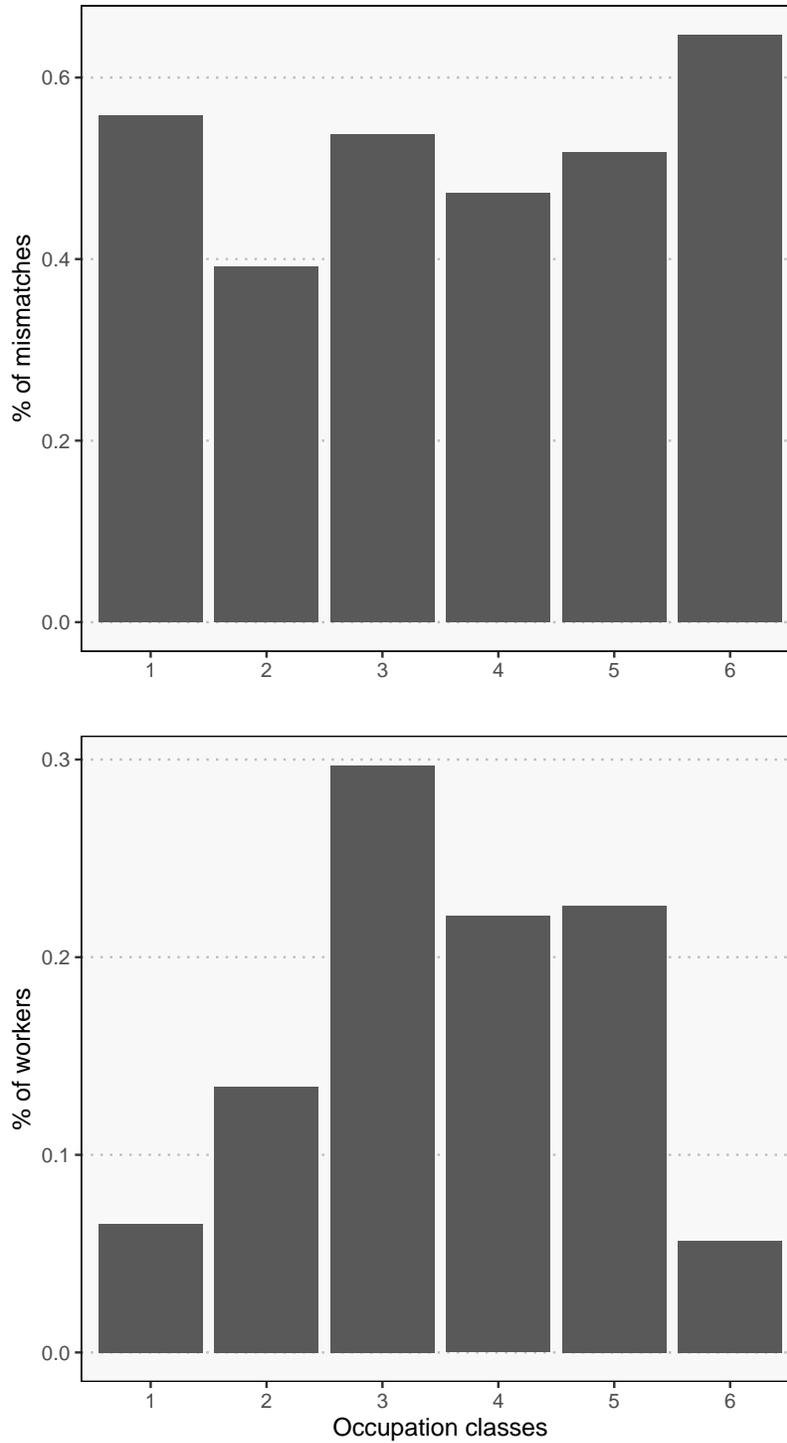


Figure 3: Distribution of mismatches and workers by occupation classes

The top graph shows the percentage of mismatches in each occupation class in the main sample. A mismatch occurs when an employee's observed job differs from the job predicted by the estimated allocation rule. The bottom graph shows the percentage of workers by occupation classes in the main sample. Occupation classes are defined as follows: 1) managers, 2) professionals, 3) technicians and clerks, 4) skilled manual workers, 5) machine operators and assemblers, and 6) elementary occupations.

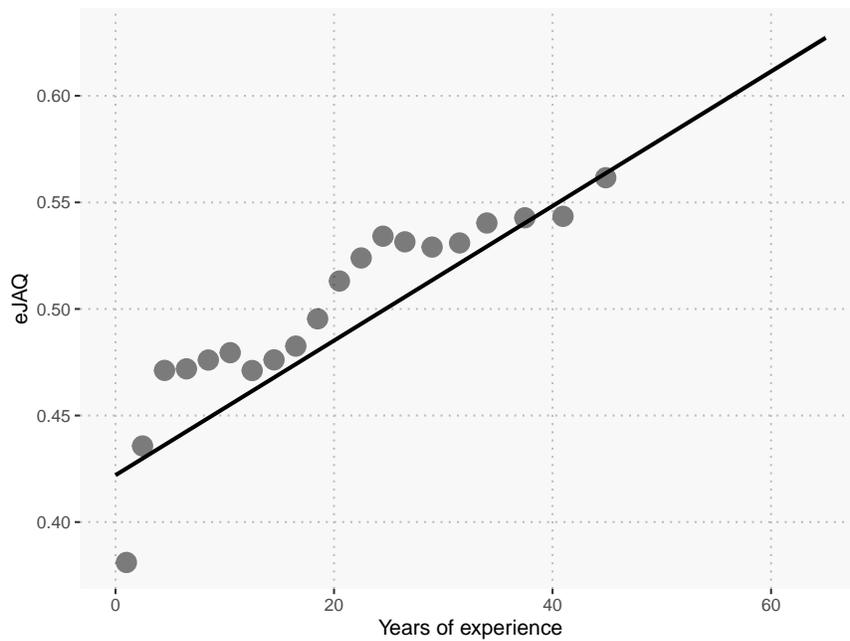


Figure 4: Worker-level job allocation quality ($eJAQ$) by labor market experience

This figure shows the binned scatter plot of an indicator for being assigned to the job predicted by the ML algorithm ($eJAQ$) against years of labor market experience.

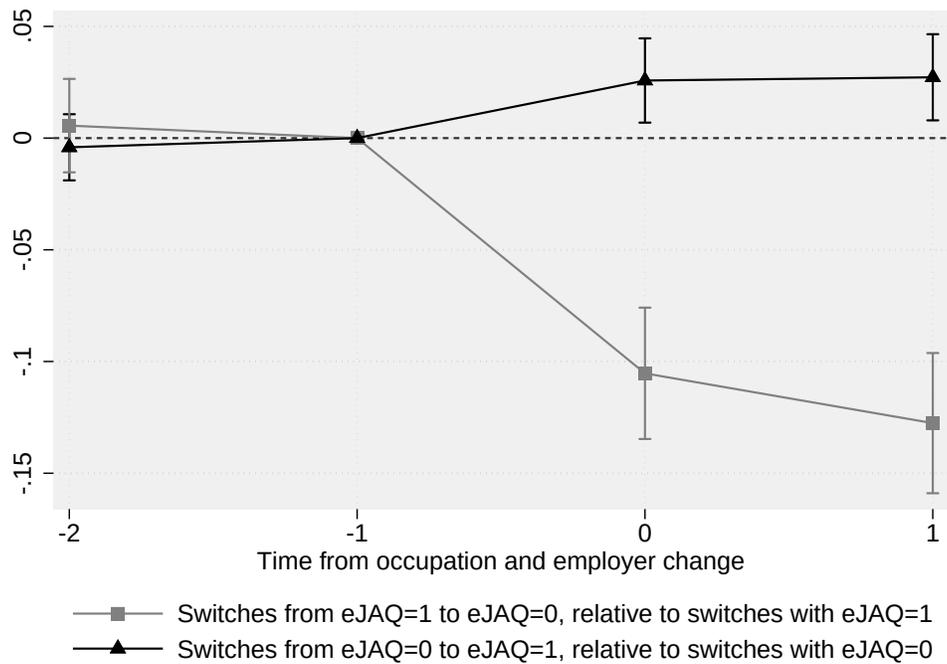


Figure 5: Response of earnings to employer and occupation switches

The figure shows the coefficient estimates and the 95% confidence intervals of two distinct event studies: the first compares changes of log labor earnings from 2 years before to 1 year after a switch from an occupation (and an employer) with $eJAQ = 0$ to one with $eJAQ = 1$, relative to the changes occurring around switches across two occupations with $eJAQ = 0$; the second compares changes of log labor earnings from 2 years before to 1 year after a switch from an occupation with $eJAQ = 1$ to occupations with $eJAQ = 0$, relative to switches across two occupations with $eJAQ = 1$.

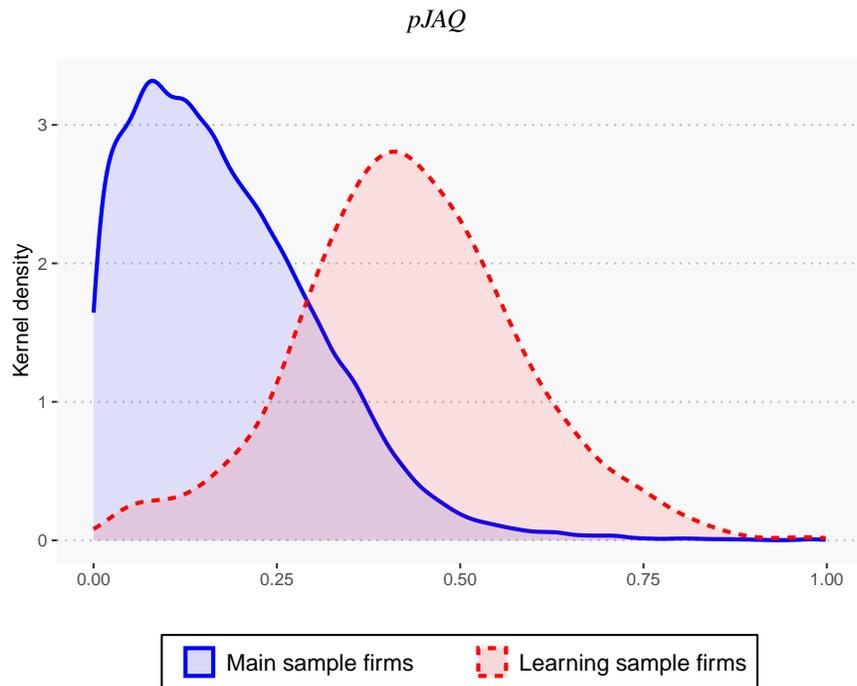
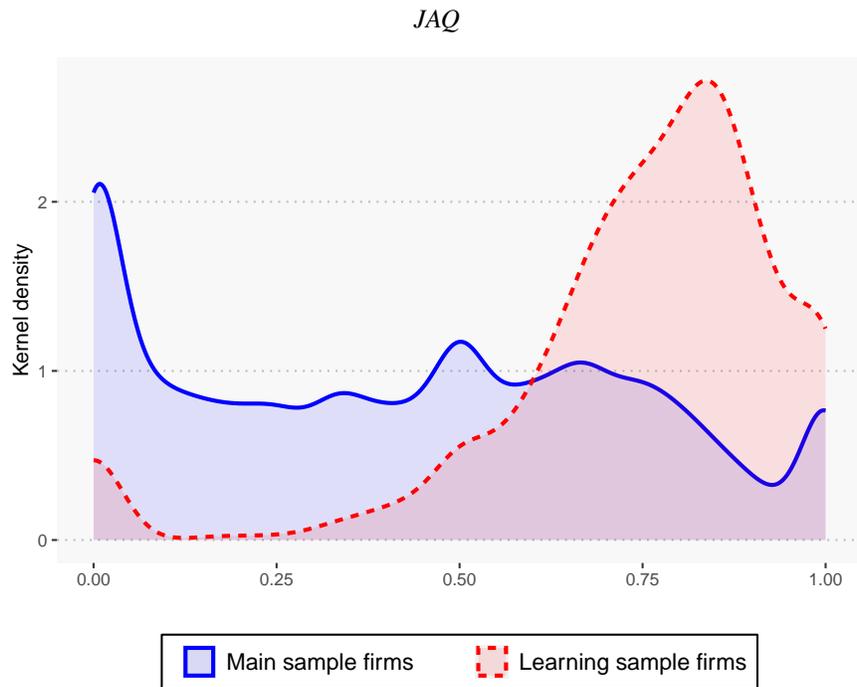


Figure 6: Distribution of match quality

The top graph shows the kernel density estimate of *JAQ* for firms in the main sample (blue line) and in the learning sample (red line). The bottom graph presents the corresponding kernel density estimates for *pJAQ*.

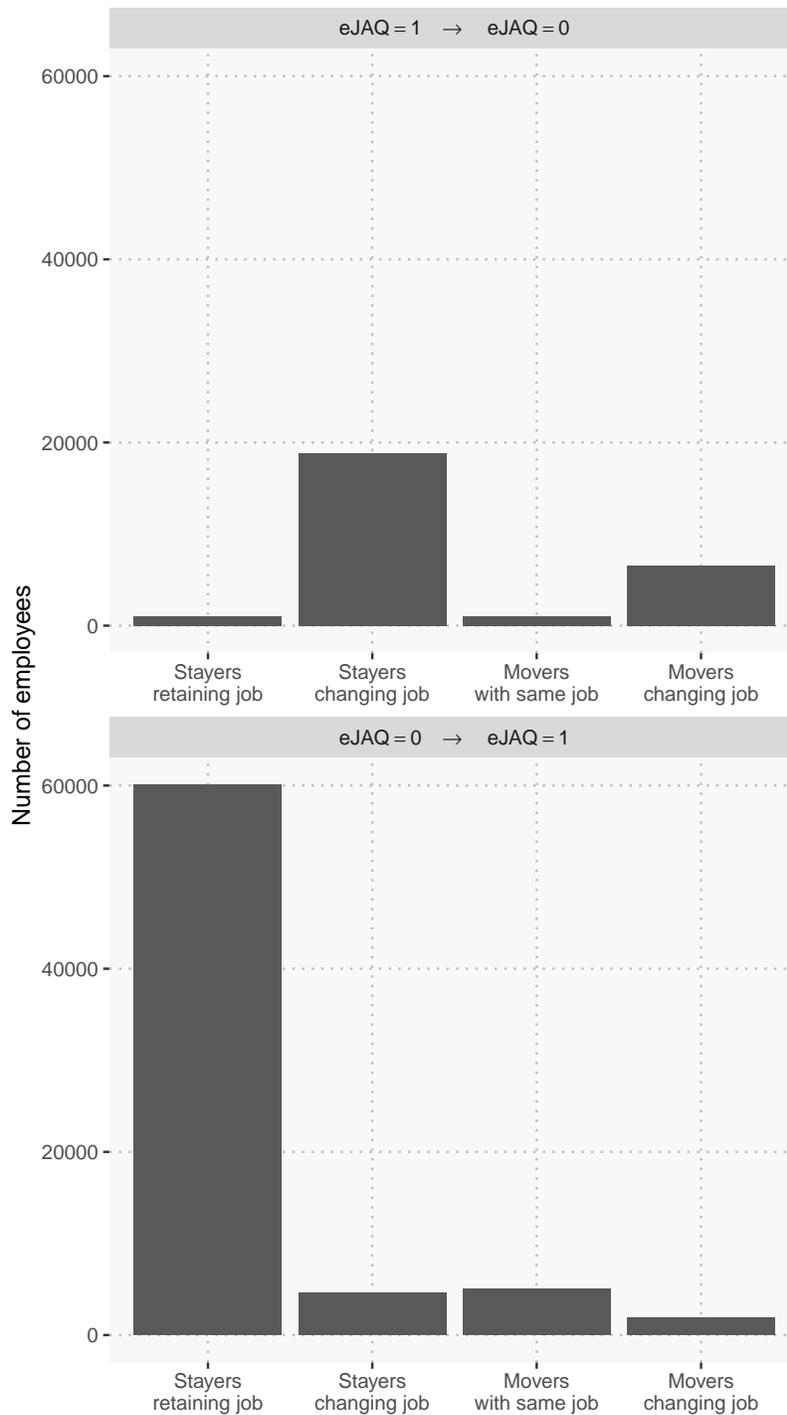


Figure 7: Accounting for changes in employee-level match quality ($eJAQ$)

The top graph shows the number of well matched employees ($eJAQ_{i,t} = 1$) who become mismatched in the subsequent year ($eJAQ_{i,t+1} = 0$), while the bottom graph shows the number of mismatched employees who become well matched in the subsequent year. In each of the two graphs, the four bars respectively refer to employees who (i) keep their jobs in the same firm; (ii) switch to a new job within the same firm; (iii) switch to a new firm while retaining the same job; (iv) switch to a new job and a new firm.

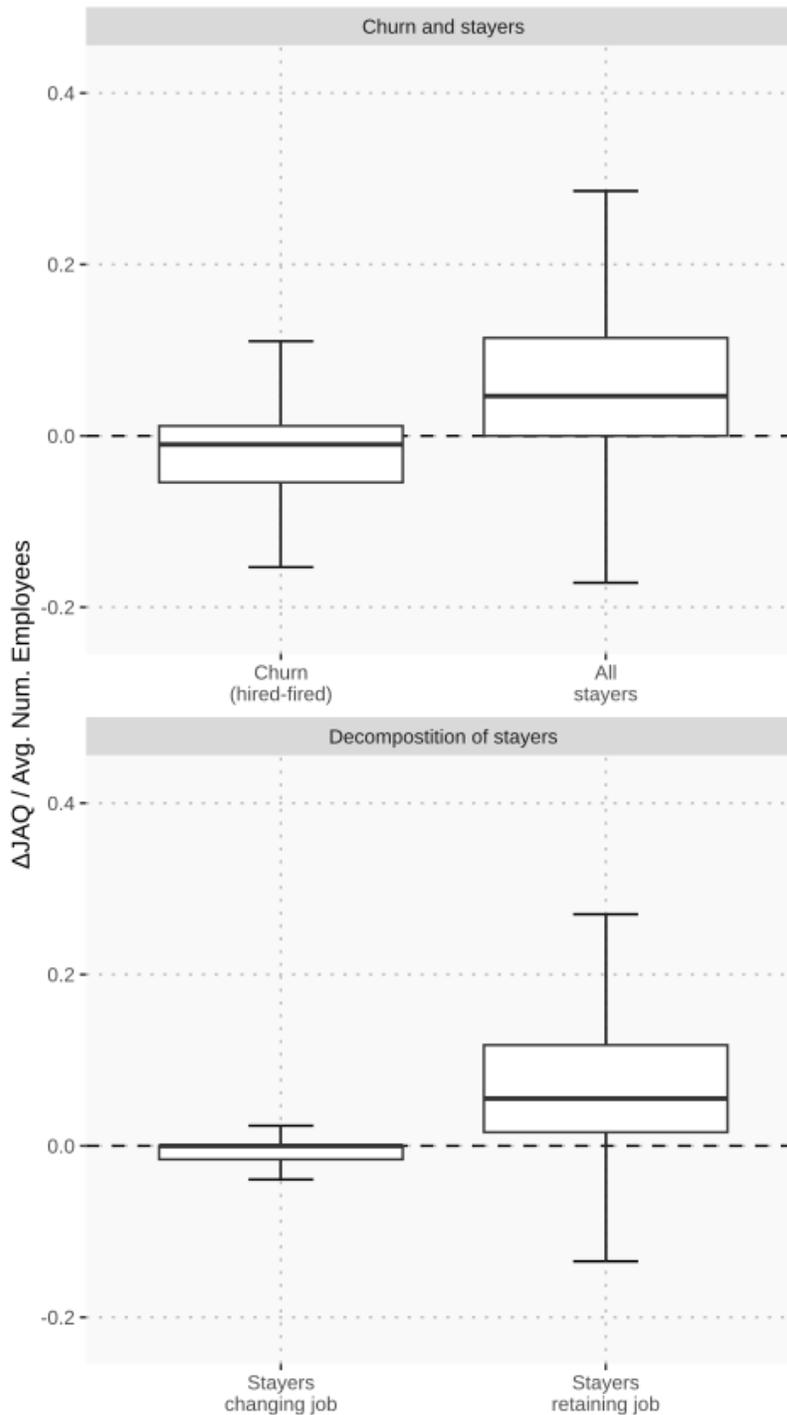


Figure 8: Accounting for changes in firm-level match quality

The figure shows box plots for year-to-year changes in JAQ , normalized by the average number of employees over the two relevant years. The top graph splits changes in JAQ in variation referring to employees moving to a different firm (*churn*) and that referring to employees remaining with the same firm (*all stayers*). The bottom graph further breaks down changes in JAQ for *stayers* between workers who are reallocated to a different job within the same firm (*stayers changing job*) and those who are not (*stayers retaining job*).

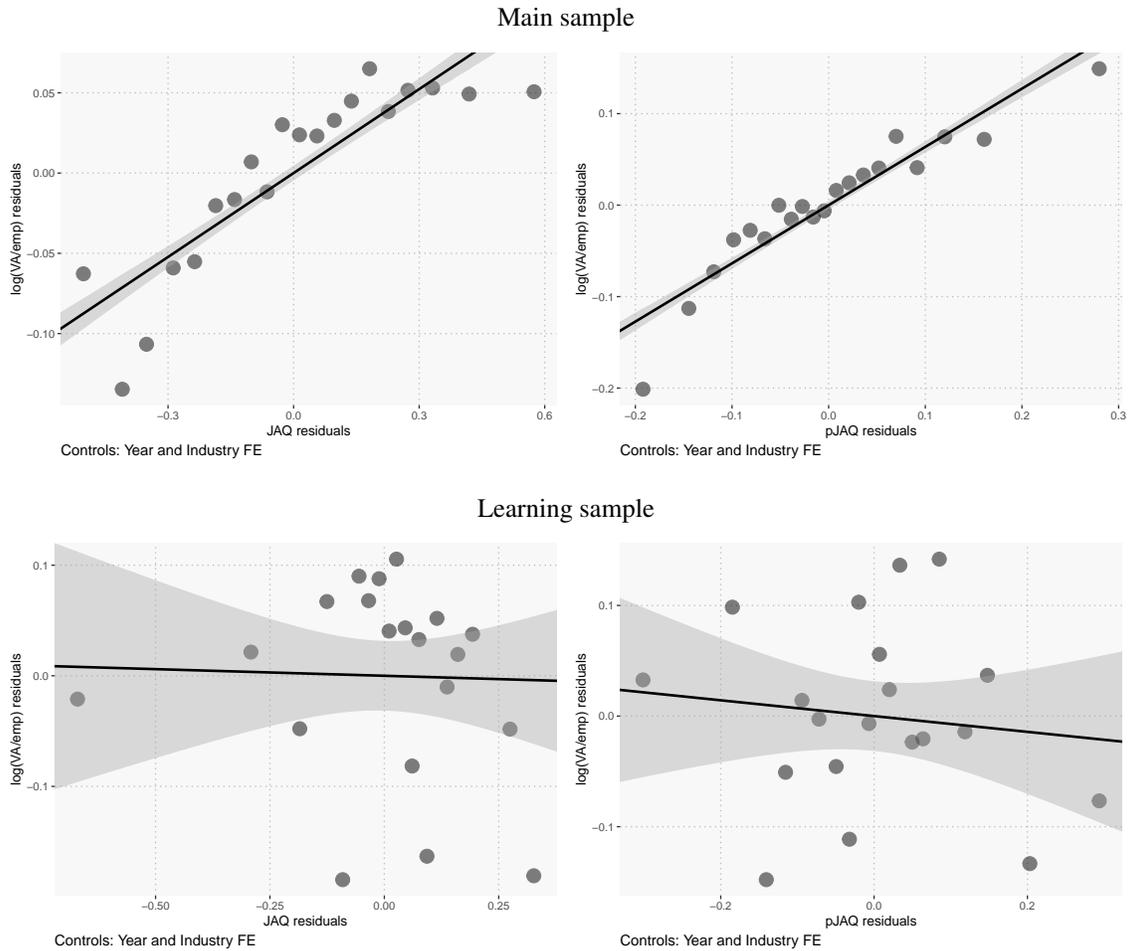


Figure 9: Correlation between productivity and job allocation quality

The figure shows binned scatter plots of productivity, as measured by log value added per employee, against job allocation quality, as measured by JAQ in the left charts and by $pJAQ$ in the right charts, in each case controlling for year and industry fixed effects. The two top charts refer to the main sample and the two bottom ones to the learning sample. The regression lines are shown together with the respective 95% confidence intervals (shaded area). The points shown in the graphs represent the residuals of the partial regression plots and are computed as follows: residuals are first split into 20 equal-sized bins on the horizontal axis; points in a bin are represented with a unique point, with coordinates given by the average of the coordinates of the points in that bin. The regression line shown fits the residuals and not the binned points.

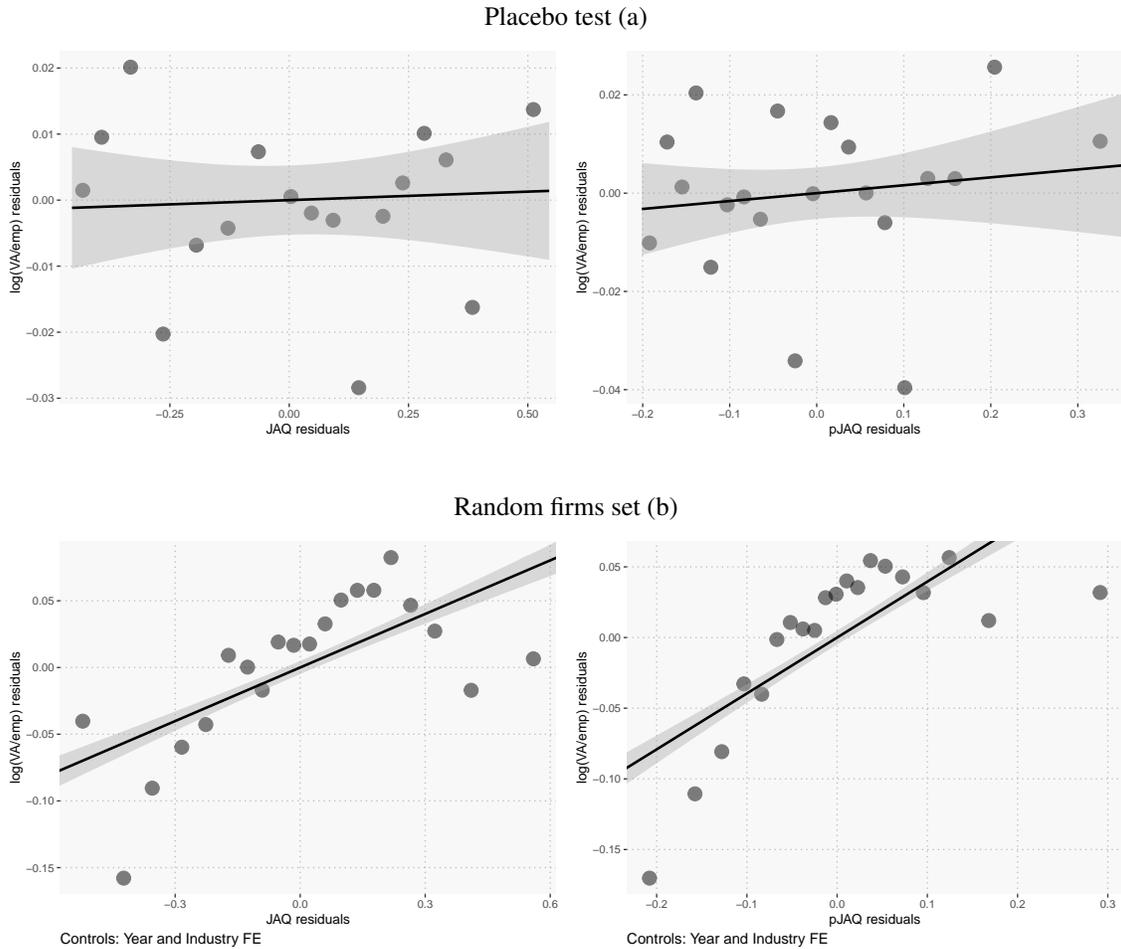


Figure 10: Addressing the circularity issue

Panel (a) shows partial regression plots of placebo productivity on JAQ in the left-hand chart and $pJAQ$ on the right-hand chart, controlling for a constant. Placebo productivity is a noise variable obtained by randomly reshuffling the original log value added per employee across firms. Panel (b) shows partial regression plots of productivity, as measured by log value added per employee, against job allocation quality, as measured by JAQ^R in the left-hand chart and by $pJAQ^R$ in the right-hand chart. JAQ^R and $pJAQ^R$ are measures of job allocation quality and workers' suitability to their actual job respectively obtained by estimating a ML algorithm on a 10% randomly chosen sample of firms, controlling for year and industry fixed effects. All the regression lines are shown together with the respective 95% confidence intervals (shaded area). The points shown in the two graphs represent the residuals of the partial regression plots and are computed as follows: residuals are first split into 20 equal-sized bins on the horizontal axis; each point in the figure represents the points in a bin, and its coordinates are determined by the average coordinates of the points in that bin. The regression line shown is fitted on the residuals and not on binned points.

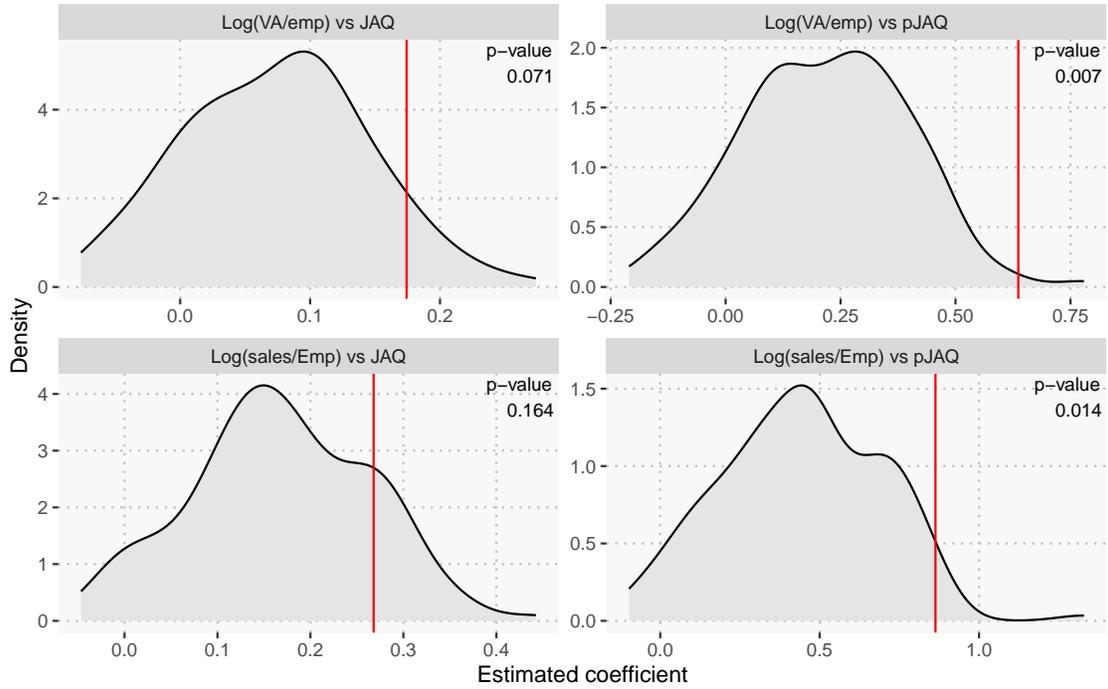


Figure 11: Monte Carlo distribution of JAQ^R coefficient in productivity regressions

Each panel in the figure plots the Monte Carlo distribution of the coefficients estimated regressing log value added per employee (top panel) and log sales per employee (bottom panel) on JAQ^R (left column) or $pJAQ^R$ (right column), controlling for 2-digit industry and year fixed effects. The Monte Carlo simulation is performed by training our ML algorithm on 150 randomly drawn learning samples, estimating JAQ^R and $pJAQ^R$ from each of them, and finally estimating the corresponding 150 above-described regressions. The vertical line in each graph indicates the JAQ and $pJAQ$ coefficient estimated in the corresponding productivity regression, where JAQ and $pJAQ$ are obtained using the top decile of the firms' productivity distribution as learning sample, while the p-value in each graph is the probability of observing a higher value under the relevant Monte Carlo distribution.

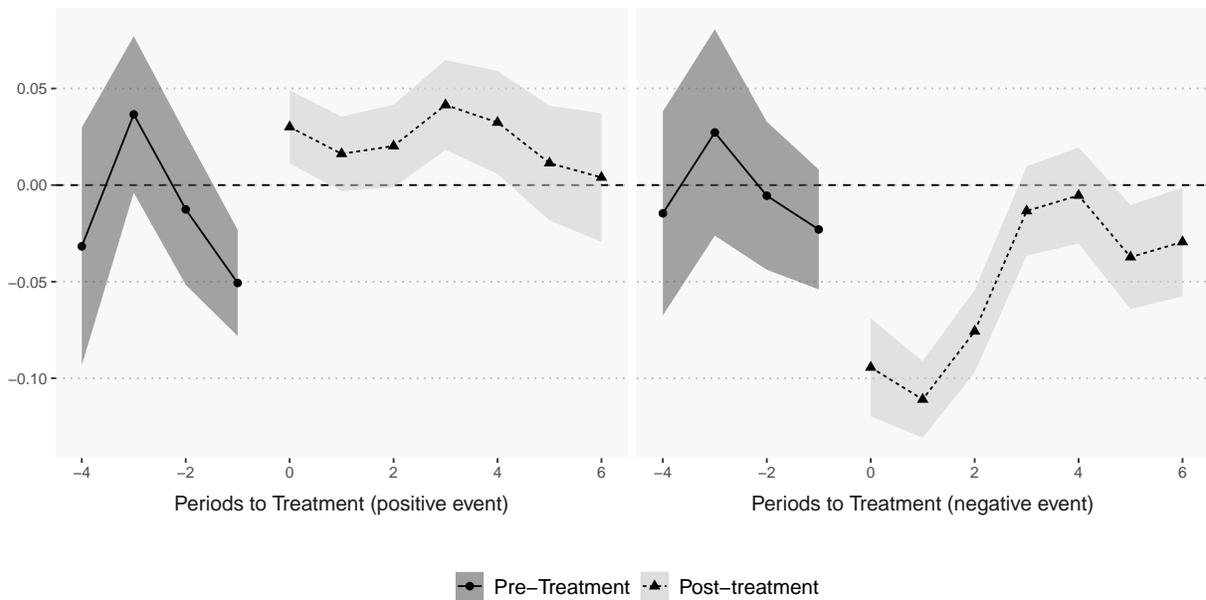


Figure 12: Response of rank-and-file workers' *JAQ* to positive (left) or negative (right) managerial turnover events

The figure shows the behavior of the *JAQ* of rank-and-file workers around managerial turnover events, respectively associated with a persistent increase in the *JAQ* of the relevant firm's management (left panel) and with a persistent decrease in the *JAQ* of the relevant firm's management (right panel). The event study coefficients are estimated using the method proposed by Callaway and Sant'Anna (2021).

Table 1: Descriptive statistics

This table reports the summary statistics of the individuals included in the main sample and in the learning sample. Our total sample includes firms active at some point between 2001 and 2010, reporting a yearly median number of employees between 30 and 6000, and positive total assets and sales. Since information about a worker's specific occupation is not always available, we restrict the sample to firms with at least 10 workers for whom we do observe the current occupation. The main sample contains 5,901,551 observations at the individual level and the learning sample 66,684 observations.

| | Mean | P50 | P10 | P25 | P75 | P90 | SD |
|---------------------------------|---------|---------|---------|---------|---------|---------|---------|
| Panel A: Main sample | | | | | | | |
| Labor income (TSEK 2019) | 351.991 | 324.377 | 168.806 | 258.118 | 409.305 | 541.715 | 197.704 |
| University degree | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.34 |
| Age | 40.64 | 40.00 | 25.00 | 31.00 | 50.00 | 58.00 | 11.96 |
| Female | 0.34 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.47 |
| Immigrant | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.34 |
| Mobility (lives where born) | 0.65 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.48 |
| Labor market experience | 19.66 | 19.00 | 3.00 | 9.00 | 29.00 | 39.00 | 12.84 |
| Tenure | 5.29 | 4.00 | 0.00 | 1.00 | 8.00 | 13.00 | 5.14 |
| # industries worked in | 2.28 | 2.00 | 1.00 | 1.00 | 3.00 | 4.00 | 1.26 |
| # jobs held | 2.29 | 3.00 | 1.00 | 2.00 | 4.00 | 5.00 | 1.69 |
| # unemployment days since '92 | 181.90 | 0.00 | 0.00 | 0.00 | 224.00 | 599.00 | 338.90 |
| Panel B: Learning sample | | | | | | | |
| Labor income (TSEK 2019) | 474.627 | 415.484 | 270.307 | 333.533 | 535.107 | 724.454 | 301.928 |
| University degree | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.41 |
| Age | 43.24 | 43.00 | 29.00 | 35.00 | 52.00 | 58.00 | 10.88 |
| Female | 0.31 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.46 |
| Immigrant | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.35 |
| Mobility (lives where born) | 0.62 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.49 |
| Labor market experience | 21.36 | 21.00 | 5.00 | 11.00 | 31.00 | 39.00 | 12.28 |
| Tenure | 7.81 | 6.00 | 0.00 | 2.00 | 12.00 | 20.00 | 6.54 |
| # industries worked in | 2.71 | 3.00 | 1.00 | 1.00 | 4.00 | 5.00 | 1.49 |
| # jobs held | 3.29 | 3.00 | 1.00 | 2.00 | 4.00 | 6.00 | 1.92 |
| # unemployment days since '92 | 164.37 | 0.00 | 0.00 | 0.00 | 192.00 | 530.00 | 321.09 |

Table 2: Average employees' characteristics for selected occupations

The table shows the average employees' characteristics (rows) for a pool of selected jobs (columns). Jobs are labeled by their ISCO code, as follows: directors and chief executives (121); production and operations managers (122); other specialist managers (123); managers of small enterprises (131); legal professionals (242); office secretaries and data entry operators (411); machinery mechanics and fitters (723); chemical-processing-plant operators (815); manufacturing labourers (932). The jobs included in the table are selected to provide information on the following broad occupation classes: 1) managers (121, 122, 123, 131), 2) professionals (242), 3) technicians and clerks (411), 4) skilled manual workers (723), 5) machine operators and assemblers (815), and 6) elementary occupations (932). For each job, the average characteristics are obtained averaging over the subset of the 1000 employees (990 and 998, for jobs 242 and 723, respectively) with the highest predicted conditional probability for the corresponding job, $P(j|X)$, as estimated by the ML algorithm. While occupation class 1 includes all managerial positions, for other occupation classes we select jobs with the highest average predicted probability, $P(j|X)$. For numerical variables, standard deviations are reported in parentheses; for categorical ones (Education level, Education type, Education orientation) the table shows the most frequent code with relative share in square brackets.

| | Jobs | | | | | | | | |
|--------------------------------|------------------|------------------|-------------------|--------------------|-------------------|-------------------|-------------------|-------------------|--------------------|
| | 121 | 122 | 123 | 131 | 242 | 411 | 723 | 815 | 932 |
| Characteristics | | | | | | | | | |
| $P(j X)$ | 0.63 (0.03) | 0.683 (0.038) | 0.656 (0.032) | 0.683 (0.073) | 0.998 (0.001) | 0.848 (0.052) | 0.931 (0.018) | 0.896 (0.032) | 0.837 (0.062) |
| Age | 50.22 (7.26) | 49.54 (6.88) | 46.61 (6.72) | 44.11 (9.76) | 32.85 (5.16) | 51.62 (8.93) | 40.13 (10.50) | 45.10 (9.47) | 44.24 (10.90) |
| Female | 0.01 (0.11) | 0.07 (0.26) | 0.28 (0.45) | 0.55 (0.50) | 0.48 (0.50) | 1.00 (0.00) | 0.00 (0.00) | 0.04 (0.19) | 0.07 (0.26) |
| Lives where born | 0.46 (0.50) | 0.48 (0.50) | 0.49 (0.50) | 0.68 (0.47) | 0.42 (0.49) | 0.67 (0.47) | 0.85 (0.36) | 0.88 (0.33) | 0.76 (0.43) |
| Immigrant | 0.21 (0.41) | 0.09 (0.29) | 0.14 (0.35) | 0.07 (0.25) | 0.08 (0.28) | 0.10 (0.29) | 0.02 (0.13) | 0.07 (0.26) | 0.14 (0.35) |
| Education level [share] | 4.00 [0.86] | 4.00 [0.52] | 4.00 [0.82] | 2.00 [0.71] | 4.00 [1.00] | 2.00 [0.80] | 2.00 [0.99] | 2.00 [0.77] | 2.00 [0.54] |
| Education type [share] | 2.00 [0.53] | 6.00 [0.96] | 2.00 [0.94] | 0.00 [0.40] | 1.00 [1.00] | 2.00 [0.85] | 6.00 [0.99] | 6.00 [0.69] | 0.00 [0.55] |
| Education orient. [share] | 340a [0.49] | 521b [0.22] | 340a [0.88] | 010a [0.21] | 380a [1.00] | 346x [0.32] | 525c [0.77] | 010a [0.23] | 010a [0.46] |
| Unemployment days | 22.17 (84.20) | 23.68 (84.56) | 45.92 (111.13) | 153.74 (261.94) | 51.60 (114.13) | 64.26 (199.56) | 92.87 (258.25) | 33.95 (135.74) | 125.26 (304.29) |
| Tenure | 7.09 (5.14) | 11.46 (5.80) | 7.03 (5.13) | 5.72 (4.74) | 3.23 (2.16) | 10.50 (5.61) | 8.04 (5.48) | 14.50 (4.26) | 12.37 (5.87) |
| Experience | 24.20 (7.85) | 25.99 (8.01) | 20.98 (7.83) | 25.03 (10.37) | 6.90 (4.99) | 30.86 (9.80) | 21.33 (10.68) | 26.67 (9.90) | 26.29 (11.58) |
| N. industries of employment | 2.80 (1.53) | 2.24 (1.19) | 2.74 (1.34) | 2.20 (1.17) | 2.59 (1.04) | 1.81 (0.96) | 1.76 (0.88) | 1.30 (0.69) | 1.54 (0.85) |
| Military service | 0.23 (0.21) | 0.07 (0.11) | 0.17 (0.17) | 0.26 (0.16) | 0.20 (0.22) | 0.04 (0.09) | 0.01 (0.05) | 0.03 (0.07) | 0.05 (0.10) |
| Experience in job | 3.12 (1.79) | 5.05 (1.45) | 4.74 (1.89) | 2.38 (1.44) | 3.52 (1.63) | 5.88 (1.53) | 6.65 (1.62) | 6.55 (1.13) | 5.47 (1.59) |

Table 3: Labor earnings, separations and match quality

This table displays the relationship between the log of labor earnings and match quality in columns (1) to (4), and between a separation indicator (which equals 1 if a worker changes employer between time $t - 1$ and t and 0 otherwise) and match quality in columns (5) to (8). Match quality is measured by $eJAQ$ in Panel A and by $epJAQ$ in Panel B for workers in the main sample. The worker controls (used in the ML algorithm) are age, gender, an indicator for immigrant status, residence municipality, a mobility indicator equal to one for workers employed in a county different from the county of birth, education level (basic, high school, vocational, or university), education subject (no specialization, law, business and economics, health and medicine, natural sciences, teaching, engineering, social sciences, services, or other specializations), labor market experience (measured as years since graduation), tenure at the current firm, number of firms and number of two-digit industries where an individual previously worked, total number of unemployment days since 1992 (when the unemployment data starts in LISA), years of experience in each occupation, years of experience in each 2-digit industry, and years of experience in each decile of the distribution of firms' number of employees or total assets. The firm controls are firm age, size (measured by the number of employees), sales, and total assets, as well as ownership categories measured by indicators for the firm being a state-owned firm, a listed firm, or a family firm. Standard errors clustered at worker level are shown in parentheses.

| | Log(labor earnings) | | | | Separation indicator | | | |
|-----------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Panel A | | | | | | | | |
| <i>eJAQ</i> | 0.0240*** (0.0004) | 0.0266*** (0.0004) | 0.0174*** (0.0004) | 0.0272*** (0.0013) | -0.0125*** (0.0003) | -0.0119*** (0.0004) | -0.0270*** (0.0005) | -0.0103*** (0.0024) |
| Panel B | | | | | | | | |
| <i>epJAQ</i> | 0.0497*** (0.0011) | 0.0574*** (0.0012) | 0.0539*** (0.0014) | 0.0649*** (0.0074) | -0.0697*** (0.0011) | -0.0582*** (0.0012) | -0.1723*** (0.0017) | -0.0878*** (0.0133) |
| Year and job FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Worker controls | ✓ | ✓ | | | ✓ | ✓ | | |
| Industry FE | | ✓ | | | | ✓ | | |
| Firm controls | | ✓ | | | | ✓ | | |
| Worker FE | | | ✓ | ✓ | | | ✓ | ✓ |
| Firm FE | | | | ✓ | | | | ✓ |
| Observations | 5,901,551 | 3,909,445 | 5,901,551 | 5,526,718 | 4,484,975 | 3,415,510 | 4,484,975 | 4,262,039 |

Table 4: Job allocation quality, market competition and firm ownership

This table shows regressions of measures of job allocation quality (*JAQ*) and of workers' suitability to their actual job (*pJAQ*) on the Lerner index of market competition in columns 1 to 4, and on a family firm status dummy in columns 5 to 8. The Lerner index for each firm is defined as $1 - \text{profits/sales}$ lagged by 2 years and averaged across all firms in the same 2-digit industry, excluding the firm itself. All specifications include year and industry dummies (where industries are manufacturing, real estate, renting and business activities, and wholesale and retail). The specifications of the even-numbered columns control for the share of employees with a college degree, and include the following additional controls (whose coefficients are not shown for brevity): log employment, log capital, log firm age, indicator for listed firms, years of managerial experience averaged over employees in the firm.

| | <i>JAQ</i> | | <i>pJAQ</i> | | <i>JAQ</i> | | <i>pJAQ</i> | |
|---------------------------------|---------------------|---------------------|---------------------|---------------------|----------------------|---------------------|----------------------|----------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Lerner index (2-year lagged) | 0.003*** (0.000) | 0.003*** (0.000) | 0.003*** (0.000) | 0.002*** (0.000) | | | | |
| Family firm | | | | | -0.026*** (0.007) | -0.008 (0.007) | -0.024*** (0.003) | -0.008*** (0.003) |
| Share emp. w/ college | | 0.070*** (0.019) | | 0.110*** (0.011) | | 0.112*** (0.020) | | 0.125*** (0.011) |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Industry dummies | | ✓ | | ✓ | | ✓ | | ✓ |
| Firm controls | | ✓ | | ✓ | | ✓ | | ✓ |
| Observations | 33,254 | 33,254 | 33,254 | 33,254 | 29,947 | 29,541 | 29,947 | 29,541 |
| No. Firms | 6,269 | 6,269 | 6,269 | 6,269 | 6,372 | 6,294 | 6,372 | 6,294 |
| y Mean | 0.496 | 0.496 | 0.211 | 0.211 | 0.483 | 0.484 | 0.210 | 0.210 |
| y St. Dev. | 0.296 | 0.296 | 0.128 | 0.128 | 0.300 | 0.299 | 0.131 | 0.130 |

Table 5: Firm performance and JAQ

This table displays results from regressions of firm productivity and profitability on *JAQ* and control variables. Panel A refers to our baseline specification. The results in Panel B control for firms' occupation structure (the fraction of workers in firm *f* assigned to job *j* in year *t*) and firm controls (age, family firm status, state-owned status, listed firm status, an indicator for the presence of a human resources (HR) manager, its log number of employees and its log of total assets). Panel C adds controls for worker characteristics (listed in the notes to Table 3). Standard errors clustered at firm level are shown in parentheses.

| | Log(sales/emp) (1) | Log(VA/emp) (2) | OROA (3) | Log(sales/emp) (4) | Log(VA/emp) (5) | OROA (6) |
|---------------------------|-----------------------|---------------------|-------------------|-----------------------|---------------------|----------------------|
| Panel A | | | | | | |
| <i>JAQ</i> | 0.366*** (0.023) | 0.195*** (0.014) | -0.005 (0.005) | 0.102*** (0.014) | 0.080*** (0.010) | 0.005 (0.005) |
| log(cap/emp) | | | | 0.413*** (0.012) | 0.237*** (0.009) | -0.020*** (0.002) |
| log(emp) | | | | 0.003 (0.007) | -0.005 (0.005) | -0.003* (0.002) |
| Share emp w/ college | | | | 0.108*** (0.031) | 0.337*** (0.022) | 0.013 (0.010) |
| Industry dummies | | | | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 48,116 | 47,743 | 48,116 |
| No. Firms | 7,875 | 7,827 | 7,875 | 7,875 | 7,827 | 7,875 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.306 | 6.140 | 0.079 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.793 | 0.534 | 0.179 |
| Panel B | | | | | | |
| <i>JAQ</i> | 0.169*** (0.017) | 0.116*** (0.012) | 0.005 (0.005) | 0.080*** (0.017) | 0.067*** (0.013) | 0.012* (0.007) |
| Industry dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Size-industry bin dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm controls | | | | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 29,947 | 29,742 | 29,947 |
| No. firms | 7,875 | 7,827 | 7,875 | 6,372 | 6,339 | 6,372 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.339 | 6.173 | 0.089 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.790 | 0.527 | 0.183 |
| Panel C | | | | | | |
| <i>JAQ</i> | 0.091*** (0.017) | 0.062*** (0.012) | 0.004 (0.005) | 0.044*** (0.018) | 0.045*** (0.014) | 0.010 (0.007) |
| Industry dummies | | | | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Workers X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm Z | | | | ✓ | ✓ | ✓ |
| Size-industry bin dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 29,947 | 29,742 | 29,947 |
| No. firms | 7,875 | 7,827 | 7,875 | 6,372 | 6,339 | 6,372 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.339 | 6.173 | 0.089 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.790 | 0.527 | 0.183 |

Table 6: Firm performance and worker suitability

This table displays results from regressions of firm productivity and profitability on firm-level $pJAQ$ (defined as the average of worker-level $pJAQ$ for a given firm) and control variables. Panel A refers to our baseline specification. The results in Panel B control for firms' occupation structure (the fraction of workers in firm f assigned to job j in year t) and firm controls (age, family firm status, state-owned status, listed firm status, an indicator for the presence of a human resources (HR) manager, its log number of employees and its log of total assets). Panel C adds controls for worker characteristics (listed in the notes to Table 3). Standard errors clustered at firm level are shown in parentheses and three stars denote statistical significance at the one percent level.

| | Log(sales/emp) (1) | Log(VA/emp) (2) | OROA (3) | Log(sales/emp) (4) | Log(VA/emp) (5) | OROA (6) |
|----------------------|-----------------------|---------------------|-------------------|-----------------------|---------------------|----------------------|
| Panel A | | | | | | |
| $pJAQ$ | 0.995*** (0.064) | 0.724*** (0.036) | 0.000 (0.014) | 0.289*** (0.040) | 0.266*** (0.028) | 0.025* (0.014) |
| log(cap/emp) | | | | 0.412*** (0.012) | 0.235*** (0.009) | -0.020*** (0.002) |
| log(emp) | | | | 0.005 (0.007) | -0.003 (0.005) | -0.003* (0.002) |
| Share emp w/ college | | | | 0.088*** (0.031) | 0.317*** (0.022) | 0.011 (0.010) |
| Industry dummies | | | | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 48,116 | 47,743 | 48,116 |
| No. firms | 7,875 | 7,827 | 7,875 | 7,875 | 7,827 | 7,875 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.306 | 6.140 | 0.079 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.793 | 0.534 | 0.179 |
| Panel B | | | | | | |
| $pJAQ$ | 0.545*** (0.050) | 0.385*** (0.033) | 0.021 (0.014) | 0.242*** (0.048) | 0.217*** (0.034) | 0.039** (0.019) |
| Industry dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Size-industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm controls | | | | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 29,947 | 29,742 | 29,947 |
| No. firms | 7,875 | 7,827 | 7,875 | 6,372 | 6,339 | 6,372 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.339 | 6.173 | 0.089 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.790 | 0.527 | 0.183 |
| Panel C | | | | | | |
| $pJAQ$ | 0.261*** (0.056) | 0.190*** (0.037) | 0.029* (0.017) | 0.150*** (0.055) | 0.156*** (0.038) | 0.042* (0.022) |
| Industry dummies | | | | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Workers X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm Z | | | | ✓ | ✓ | ✓ |
| Size-industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 29,947 | 29,742 | 29,947 |
| No. firms | 7,875 | 7,827 | 7,875 | 6,372 | 6,339 | 6,372 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.339 | 6.173 | 0.089 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.790 | 0.527 | 0.183 |

Table 7: *JAQ* and productivity with AKM selection strategy

The table reports the estimated relationship between productivity and the three firm-level measures of job allocation quality, when the ML algorithm is estimated on the subsample of firms within the top-decile of the residuals' distribution of an AKM model. JAQ^{AKM} and $pJAQ^{AKM}$ are the two resulting job-allocation quality measures. Panels A and B respectively replicate panels A in Table 5 and Table 6. Standard errors clustered at firm level are shown in parentheses.

| | Log(sales/emp) (1) | Log(VA/emp) (2) | OROA (3) | Log(sales/emp) (4) | Log(VA/emp) (5) | OROA (6) |
|----------------------|-----------------------|---------------------|-------------------|-----------------------|---------------------|----------------------|
| Panel A | | | | | | |
| JAQ^{AKM} | 0.238*** (0.037) | 0.127*** (0.024) | -0.007 (0.008) | 0.120*** (0.021) | 0.049*** (0.018) | -0.001 (0.009) |
| log(cap/emp) | | | | 0.423*** (0.015) | 0.265*** (0.012) | -0.015*** (0.004) |
| log(emp) | | | | 0.013 (0.010) | -0.012 (0.008) | -0.013*** (0.004) |
| Share emp w/ college | | | | 0.075* (0.041) | 0.344*** (0.031) | 0.014 (0.014) |
| Panel B | | | | | | |
| $pJAQ^{AKM}$ | 0.744*** (0.117) | 0.581*** (0.072) | 0.016 (0.031) | 0.393*** (0.068) | 0.222*** (0.060) | 0.038 (0.034) |
| log(cap/emp) | | | | 0.422*** (0.015) | 0.264*** (0.012) | -0.015*** (0.004) |
| log(emp) | | | | 0.016 (0.010) | -0.012 (0.008) | -0.014*** (0.004) |
| Share emp w/ college | | | | 0.047 (0.042) | 0.326*** (0.031) | 0.010 (0.014) |
| Industry dummies | | | | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 16,592 | 16,403 | 16,592 | 8,405 | 8,322 | 8,405 |
| No. Firms | 3,696 | 3,656 | 3,696 | 2,474 | 2,450 | 2,474 |
| LHS Mean | 7.264 | 6.147 | 0.069 | 7.282 | 6.185 | 0.083 |
| LHS St. Dev. | 0.828 | 0.603 | 0.208 | 0.797 | 0.594 | 0.224 |

Table 8: Role of management in the allocation quality of rank-and-file employees

This table displays results from regressions whose dependent variable is the job allocation quality of rank-and-file employees (*R&F-JAQ*) and whose explanatory variables are the allocation quality of managers (*M-JAQ*) and their experience in managerial jobs (Manager exp). In columns 1 to 3, *M-JAQ* and Manager exp refer both to top managers (CEOs and firm directors) and to middle managers, whereas in columns 4 to 6 they only refer to top managers. The regressions are based on data from 2003 to 2010. All specifications include year fixed effects; those in columns 2, 3, 5 and 6 include firm fixed effects, and those in columns 3 and 6 include industry fixed effects, municipality fixed effects and firm controls (age, family firm status, state-owned status, listed firm status, an indicator for the presence of a human resources (HR) manager, its log number of employees and its log of total assets). Standard errors are clustered at firm level and are shown in parentheses.

| | <i>R&F-JAQ</i> | | | | | |
|------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| <i>M-JAQ</i> | 0.191*** (0.007) | 0.115*** (0.006) | 0.062*** (0.008) | 0.115*** (0.007) | 0.062*** (0.006) | 0.019** (0.008) |
| Manager exp | | 0.018*** (0.002) | 0.019*** (0.002) | | 0.009*** (0.002) | 0.008*** (0.002) |
| Industry FEs | | | ✓ | | | ✓ |
| Municipality FEs | | | ✓ | | | ✓ |
| Year FEs | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm FEs | | ✓ | ✓ | | ✓ | ✓ |
| Firm controls | | | ✓ | | | ✓ |
| Observations | 36,230 | 36,230 | 22,830 | 22,821 | 22,821 | 14,149 |
| No. Firms | 7,680 | 7,680 | 6,084 | 6,454 | 6,454 | 4,712 |

Table 9: Role of management in firm productivity

This table displays the estimated relationship between productivity and the quality of managers' allocation. Productivity is measured either as log sales per employee or log value added per employee. The regressions are based on data from 2003 to 2010. All specifications include municipality and year fixed effects; those in columns 3 to 6 include industry fixed effects. The specifications in columns 5 and 6 also control for experience in managerial jobs. Standard errors are clustered at firm level and are shown in parentheses.

| | Log(Sales/emp) (1) | Log(VA/emp) (2) | Log(Sales/emp) (3) | Log(VA/emp) (4) | Log(Sales/emp) (5) | Log(VA/emp) (6) |
|------------------|-----------------------|---------------------|-----------------------|---------------------|-----------------------|---------------------|
| <i>M-JAQ</i> | 0.213*** (0.019) | 0.132*** (0.015) | 0.158*** (0.015) | 0.081*** (0.013) | 0.109*** (0.017) | 0.060*** (0.013) |
| Managers exp | | | | | 0.030*** (0.004) | 0.013*** (0.004) |
| Industry FEs | | | ✓ | ✓ | ✓ | ✓ |
| Year FEs | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FEs | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 35,971 | 35,823 | 35,971 | 35,823 | 35,971 | 35,823 |
| No. Firms | 7,592 | 7,559 | 7,592 | 7,559 | 7,592 | 7,559 |
| LHS Mean | 7.408 | 6.163 | 7.408 | 6.163 | 7.408 | 6.163 |
| LHS St. Dev. | 0.779 | 0.577 | 0.779 | 0.577 | 0.779 | 0.577 |

Table 10: Decomposing the impact of managerial turnover

The table shows the impact of positive and negative managerial turnover events on the allocation of employees staying in the firm. The coefficients in columns 1 and 2 measure the estimated average treatment on the treated (ATT) for the outcome variable shown at the beginning of the respective row of the table at the event time (standard errors in parentheses) using the Callaway-Sant'Anna method, for positive and negative managerial turnover events, respectively. Internal reallocation is the number of workers that switch jobs within the same firm as a fraction of the total number of employees remaining in the firm in the same year. Firings is the fraction of workers fired at the time of managerial turnover out of the total number of previous year's employees. Hirings is the fraction of workers hired at the time of managerial turnover out of the total number of employees in the same year. $R\&F-JAQ$ is the average allocation quality of rank-and-file employees. $\Delta R\&F-JAQ^{TO}$ is the change in the allocation quality of rank-and-file employees net that of rank-and-file workers who stay in the firm (defined by applying equation (3) to rank-and-file workers rather than managers). $R\&F-JAQ^s$ is the fraction of correctly allocated rank-and-file employees among those retained by the firm when the event occurs. $\Delta R\&F-JAQ^s$ is the change in the allocation quality of rank-and-file employees who stay in the firm.

| | Positive event (1) | Negative event (2) |
|------------------------|-----------------------|-----------------------|
| Internal reallocation | -0.049*** (0.015) | 0.146*** (0.017) |
| Firings | 0.044*** (0.016) | 0.056*** (0.019) |
| Hirings | -0.154*** (0.021) | 0.007 (0.019) |
| $R\&F-JAQ$ | 0.03*** (0.01) | -0.094*** (0.013) |
| $R\&F-JAQ^s$ | -0.017 (0.012) | -0.081*** (0.014) |
| $\Delta R\&F-JAQ$ | 0.084*** (0.02) | 0.005 (0.026) |
| $\Delta R\&F-JAQ^{TO}$ | 0.067*** (0.015) | 0.002 (0.013) |
| $\Delta R\&F-JAQ^s$ | 0.039** (0.015) | -0.104*** (0.018) |

Appendix

JAQ of All Trades: Job Mismatch, Firm Productivity
and Managerial Quality

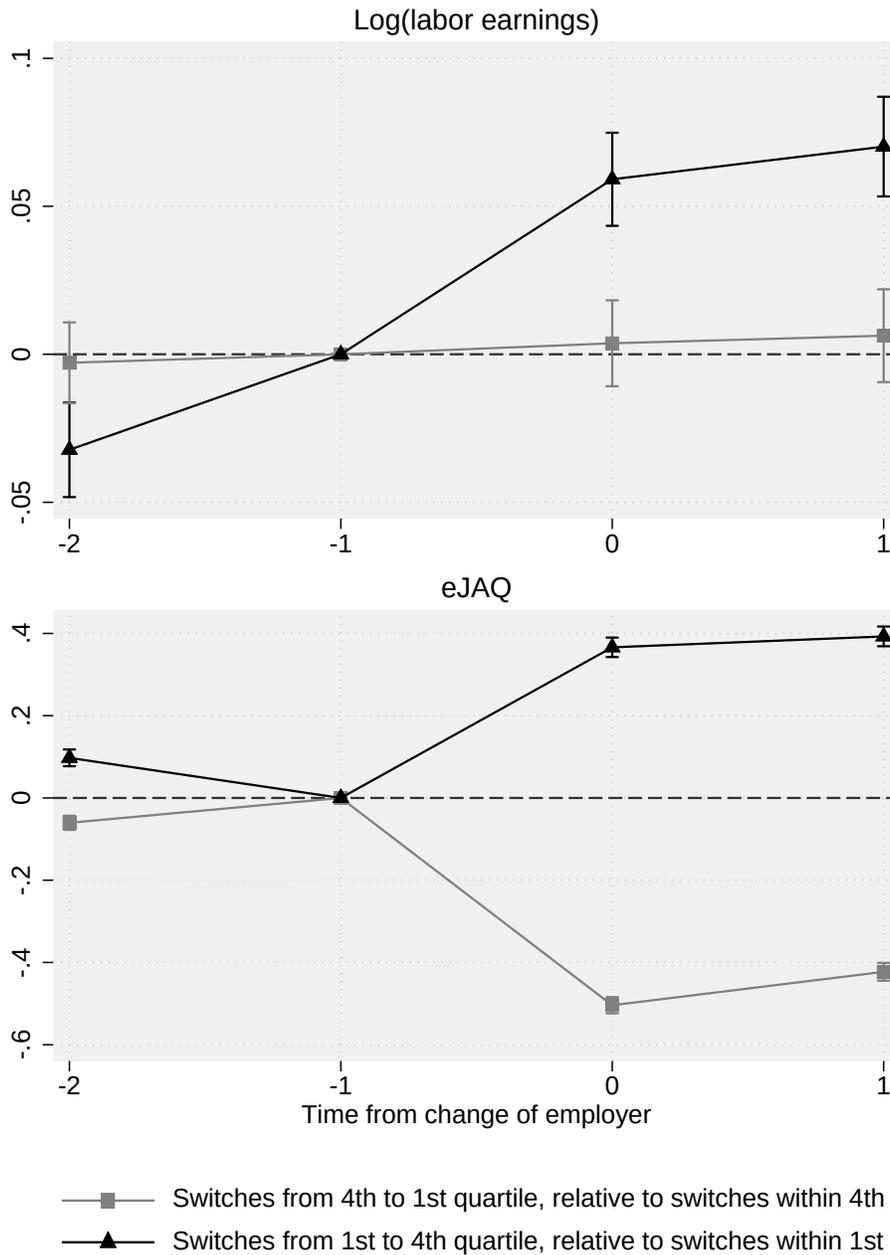


Figure A1: Response of earnings and $eJAQ$ to employer switches

The graphs show the coefficient estimates and the 95% confidence intervals of two distinct event studies: the first plots changes of log labor earnings (top graph) or $eJAQ$ (bottom graph) from 2 years before to 1 year after a switch from an employer belonging to the first quartile of the co-worker $eJAQ$ distribution to one in the fourth quartile, relative to the changes occurring around switches across two employers in the first quartile of the co-worker $eJAQ$ distribution; the second plots changes of log labor earnings (top panel) or $eJAQ$ (bottom panel) from 2 years before to 1 year after a switch from a firm in the fourth quartile of the co-worker $eJAQ$ distribution to one in the first quartile, relative to switches across two employers belonging to the fourth quartile.

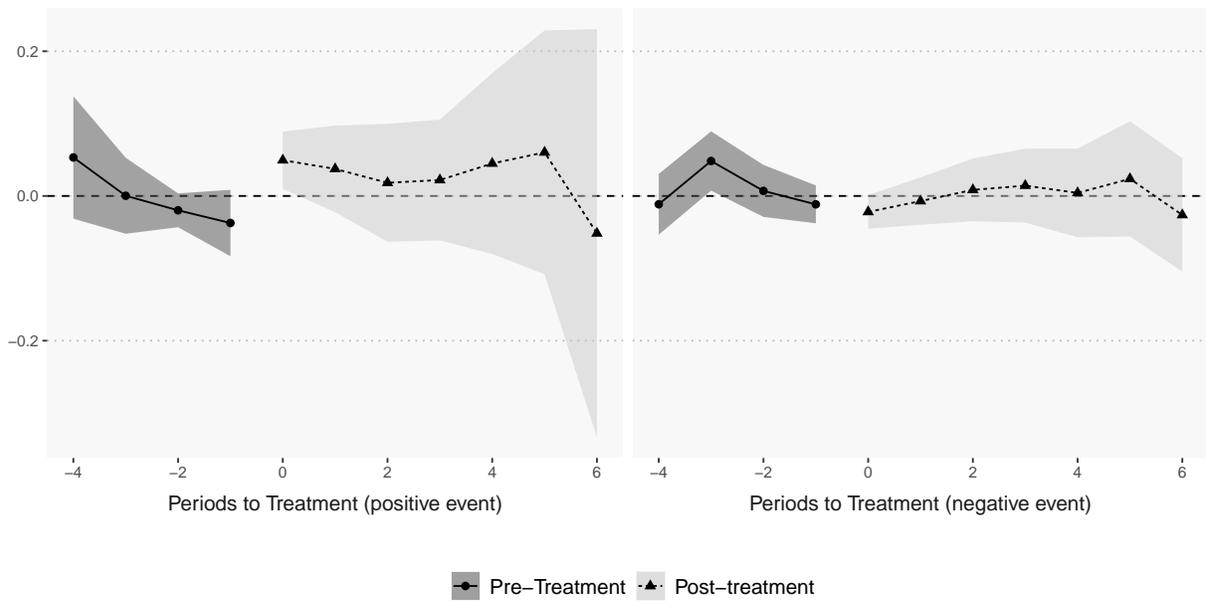


Figure A2: Response of rank-and-file workers' JAQ to positive (left) or negative (right) managers' death events
 The figure shows the event study estimated with the method by Callaway and Sant'Anna (2021) relating the JAQ of rank-and-file workers with managerial turnover events associated with the death of (at least) one of the members of the incumbent management. The left graph refers to positive events, i.e., events associated with an increase in managerial JAQ, whereas the right graph refers to negative events, i.e., those associated with a decrease in managerial JAQ.

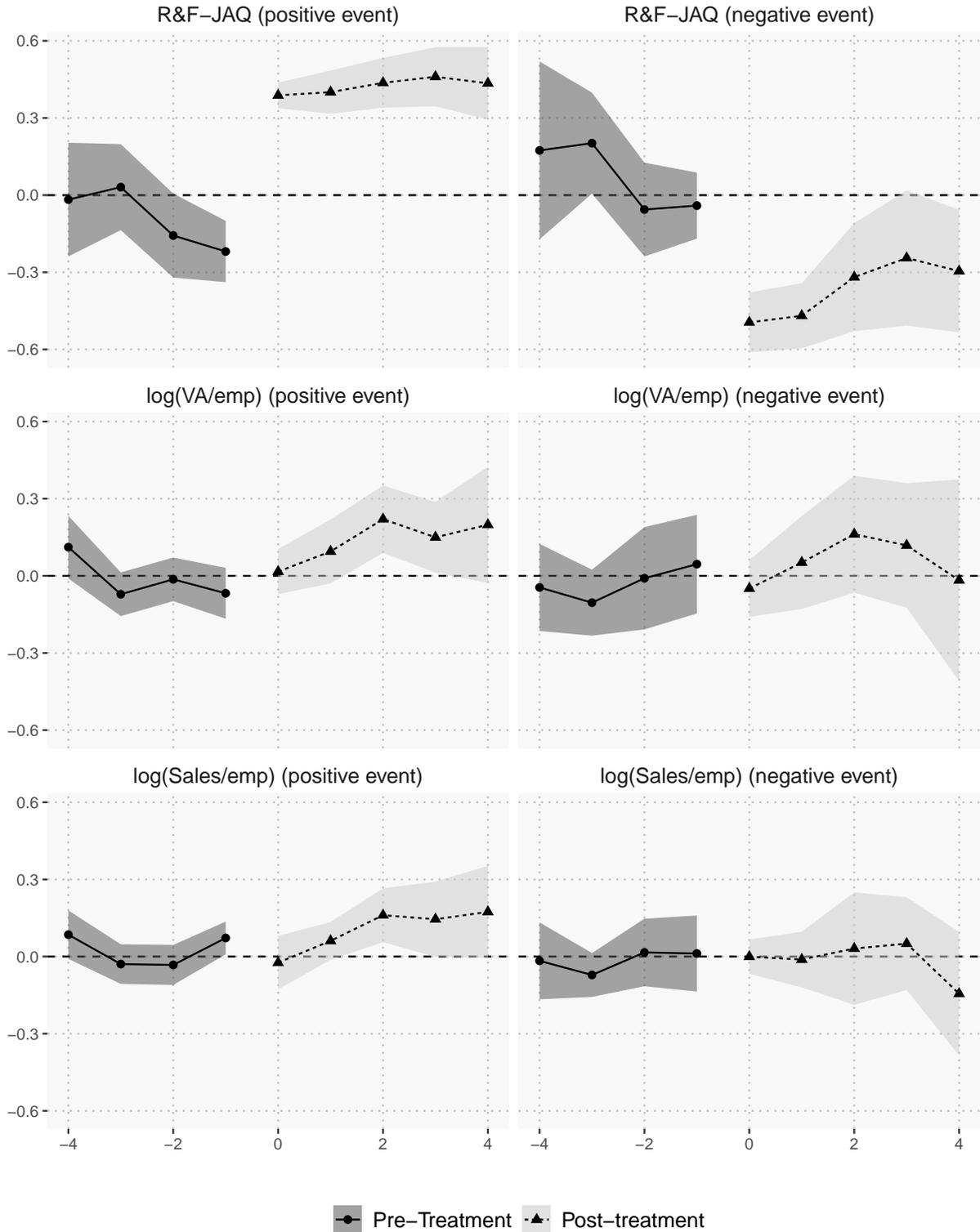


Figure A3: JAQ and productivity response to events leading to extreme $R\&F - JAQ$ changes

The left and right panels of this figure respectively show the response of rank-and-file workers' JAQ , $\log(VA/emp)$ and $\log(Sales/emp)$ to positive and negative managerial turnover events. The event study coefficients are estimated with the method by Callaway and Sant'Anna (2021). The managerial turnover events are defined as in Section 5, but are restricted to events associated with large impact effects on $R\&F - JAQ$, defined as those in the top quartile of positive events (left panel) and in the bottom quartile of negative events (right panel).

Table A1: Labor earnings, separations and match quality

This table displays the relationship between the log of labor earnings and match quality in columns (1) to (4), and between a separation indicator (which equals 1 if a worker changes employer between time $t - 1$ and t and 0 otherwise) and match quality in columns (5) to (8). Match quality is measured by *ecJAQ* for workers in the main sample. The worker controls (used in the ML algorithm) are age, gender, an indicator for immigrant status, residence municipality, a mobility indicator equal to one for workers employed in a county different from the county of birth, education level (basic, high school, vocational, or university), education subject (no specialization, law, business and economics, health and medicine, natural sciences, teaching, engineering, social sciences, services, or other specializations), labor market experience (measured as years since graduation), tenure at the current firm, number of firms and number of two-digit industries where an individual previously worked, total number of unemployment days since 1992 (when the unemployment data starts in LISA), years of experience in each occupation, years of experience in each 2-digit industry, and years of experience in each decile of the distribution of firms' number of employees or total assets. The firm controls are firm age, size (measured by the number of employees), sales, and total assets, as well as ownership categories measured by indicators for the firm being a state-owned firm, a listed firm, or a family firm. Standard errors are clustered at worker level and are shown in parentheses.

| | Log(labor earnings) | | | | Separation indicator | | | |
|-----------------|---------------------|---------------------|---------------------|---------------------|----------------------|----------------------|----------------------|----------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| <i>ecJAQ</i> | 0.041*** (0.001) | 0.039*** (0.001) | 0.026*** (0.001) | 0.026*** (0.002) | -0.022*** (0.000) | -0.022*** (0.001) | -0.045*** (0.001) | -0.019*** (0.004) |
| Year and job FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Worker controls | ✓ | ✓ | | | ✓ | ✓ | | |
| Industry FE | | ✓ | | | | ✓ | | |
| Firm controls | | ✓ | | | | ✓ | | |
| Worker FE | | | ✓ | ✓ | | | ✓ | ✓ |
| Firm FE | | | | ✓ | | | | ✓ |
| Observations | 5,901,551 | 3,909,445 | 5,901,551 | 5,526,718 | 4,484,975 | 3,415,510 | 4,484,975 | 4,262,039 |

Table A2: Firm performance and *cJAQ*

The table reports the estimated relationship between productivity and *cJAQ*. Panel A refers to our baseline specification. The results in Panel B control for firms' occupation structure (the fraction of workers in firm *f* assigned to job *j* in year *t*) and firm controls (age, family firm status, state-owned status, listed firm status, an indicator for the presence of a human resources (HR) manager, its log number of employees and its log of total assets). Panel C adds controls for worker characteristics (listed in the notes to Table 3). Standard errors are clustered at firm level and are shown in parentheses.

| | Log(sales/emp) (1) | Log(VA/emp) (2) | OROA (3) | Log(sales/emp) (4) | Log(VA/emp) (5) | OROA (6) |
|---------------------------|-----------------------|---------------------|---------------------|-----------------------|---------------------|----------------------|
| Panel A | | | | | | |
| <i>cJAQ</i> | 0.574*** (0.027) | 0.257*** (0.016) | -0.010** (0.005) | 0.158*** (0.016) | 0.088*** (0.012) | 0.005 (0.006) |
| log(cap/emp) | | | | 0.411*** (0.012) | 0.236*** (0.009) | -0.020*** (0.002) |
| log(emp) | | | | 0.001 (0.007) | -0.005 (0.005) | -0.003* (0.002) |
| Share emp w/ college | | | | 0.094*** (0.031) | 0.331*** (0.022) | 0.013 (0.011) |
| Industry dummies | | | | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 48,116 | 47,743 | 48,116 |
| No. Firms | 7,875 | 7,827 | 7,875 | 7,875 | 7,827 | 7,875 |
| LHS Mean | 7.306 | 6.140 | 0.079 | 7.306 | 6.140 | 0.079 |
| LHS St. Dev. | 0.793 | 0.534 | 0.179 | 0.793 | 0.534 | 0.179 |
| Panel B | | | | | | |
| <i>cJAQ</i> | 0.248*** (0.022) | 0.149*** (0.014) | 0.005 (0.006) | 0.140*** (0.021) | 0.097*** (0.016) | 0.022*** (0.008) |
| Industry dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Size-industry bin dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm controls | | | | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 29,947 | 29,742 | 29,947 |
| No. firms | 7,875 | 7,827 | 7,875 | 6,372 | 6,339 | 6,372 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.339 | 6.173 | 0.089 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.790 | 0.527 | 0.183 |
| Panel C | | | | | | |
| <i>cJAQ</i> | 0.167*** (0.022) | 0.094*** (0.015) | 0.003 (0.006) | 0.090*** (0.022) | 0.069*** (0.017) | 0.021** (0.008) |
| Industry dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Workers X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm Z | | | | ✓ | ✓ | ✓ |
| Size-industry bin dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,116 | 47,743 | 48,116 | 29,947 | 29,742 | 29,947 |
| No. firms | 7,875 | 7,827 | 7,875 | 6,372 | 6,339 | 6,372 |
| LHS mean | 7.306 | 6.140 | 0.079 | 7.339 | 6.173 | 0.089 |
| LHS SD | 0.793 | 0.534 | 0.179 | 0.790 | 0.527 | 0.183 |

Table A3: JAQ^R and productivity

The table reports the estimated relationship between productivity and the three firm-level measures of job allocation quality, when the ML algorithm is estimated on a random subsample of firms: JAQ^R (panel A), $pJAQ^R$ (panel B) and $cJAQ^R$ (panel C). The panels replicate panel C from Table 5, Table 6, and Table A2, respectively. The regressions include controls for firms' occupation structure (the fraction of workers in firm f assigned to job j in year t), firm controls (age, family firm status, state-owned status, listed firm status, an indicator for the presence of a human resources (HR) manager, its log number of employees and its log of total assets), and worker characteristics (listed in the notes to Table 3). Standard errors are clustered at firm level and are shown in parentheses.

| | Log(sales/emp) (1) | Log(VA/emp) (2) | OROA (3) | Log(sales/emp) (4) | Log(VA/emp) (5) | OROA (6) |
|---------------------------|-----------------------|---------------------|-------------------|-----------------------|---------------------|--------------------|
| Panel A | | | | | | |
| JAQ^R | 0.086*** (0.018) | 0.045*** (0.013) | 0.006 (0.006) | 0.065*** (0.018) | 0.042*** (0.015) | 0.016** (0.007) |
| Industry dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Workers X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm Z | | | | ✓ | ✓ | ✓ |
| Size-industry bin dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,519 | 48,172 | 48,519 | 29,988 | 29,804 | 29,988 |
| No. Firms | 7,865 | 7,820 | 7,865 | 6,338 | 6,308 | 6,338 |
| LHS mean | 7.374 | 6.211 | 0.085 | 7.410 | 6.246 | 0.095 |
| LHS SD | 0.822 | 0.590 | 0.188 | 0.820 | 0.585 | 0.194 |
| Panel B | | | | | | |
| $pJAQ^R$ | 0.161*** (0.051) | 0.071* (0.037) | 0.032* (0.019) | 0.171*** (0.045) | 0.087** (0.036) | 0.041* (0.021) |
| Industry dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Workers X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm Z | | | | ✓ | ✓ | ✓ |
| Size-industry bin dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,519 | 48,172 | 48,519 | 29,988 | 29,804 | 29,988 |
| No. Firms | 7865.000 | 7820.000 | 7865.000 | 6,338 | 6,308 | 6,338 |
| LHS mean | 7.374 | 6.211 | 0.085 | 7.410 | 6.246 | 0.095 |
| LHS SD | 0.822 | 0.590 | 0.188 | 0.820 | 0.585 | 0.194 |
| Panel C | | | | | | |
| $cJAQ^R$ | 0.122*** (0.022) | 0.060*** (0.016) | 0.005 (0.007) | 0.086*** (0.022) | 0.057*** (0.019) | 0.021** (0.009) |
| Industry dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Occupations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Workers X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Firm Z | | | | ✓ | ✓ | ✓ |
| Size-industry bin dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 48,519 | 48,172 | 48,519 | 29,988 | 29,804 | 29,988 |
| No. Firms | 7,865 | 7,820 | 7,865 | 6,338 | 6,308 | 6,338 |
| LHS mean | 7.374 | 6.211 | 0.085 | 7.410 | 6.246 | 0.095 |
| LHS SD | 0.822 | 0.590 | 0.188 | 0.820 | 0.585 | 0.194 |