

Skill complementarity in production technology: new empirical evidence and implications

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Abstract

Matched worker-firm data from Danish manufacturing reveal that 1) industries differ in within-firm worker skill dispersion, and 2) the correlation between within-firm skill dispersion and productivity is positive in industries with higher average skill dispersion. We argue that these patterns are a manifestation of technological differences across industries: firms in the “skill complementarity” industries profit from hiring workers of similar skill level, whereas firms in the “skill substitutability” industries benefit from hiring workers of different skill levels. An empirical method we devise produces a robust classification of industries into the distinct complementarity and substitutability groups. Our study unveils hitherto unnoticed technological heterogeneity between industries within the same economy, and demonstrates its importance. Specifically, we show through simulations on a simple general equilibrium model that failing to take technological heterogeneity into account results in large prediction errors.

It is now well known that worker wages differ within firms, even controlling for observed worker characteristics (Lazear and Shaw, 2009; Skans, Edin and Holmund, 2009), and that inter-firm differences in within-firm wage dispersion (WFWD) are persistent (Iranzo, Schivardi and Tosetti, 2008). As wages are fundamentally determined by skill level, why do firms systematically differ in the skill mix of the workers they employ? Empirical studies on the relationship between WFWD and firm performance report diverging results. Some studies find a positive link (Iranzo, Schivardi and Tosetti, 2008; Lee, Lev and Yeo, 2008; Lallemand, Plasman and Rycx, 2009; Arranz-Aperte, 2014), others negative (Grund and Westergaard-Nielsen, 2008), yet other studies find a curvilinear relationship (Mahy, Rycx and Volral, 2011b) or non-robust, weak or no significant relationship at all (Hunnes, 2009; Liu, Tsou and Wang, 2010), and some find that the WFWD-performance link is moderated by firms’ personnel policies and institutional environment (Jirjahn and Kraft, 2007; Mahy, Rycx and Volral, 2011a).

In this paper, we propose that the link between worker skill dispersion and firm performance varies by

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industry and depends on the prevailing production technology in a given industry. We present empirical evidence that supports this proposition and illustrate its economic implications with policy simulations.

Our study is motivated by observing differences in WFWD between industries in the Danish manufacturing sector over the period 1995-2007. In some industries, such as transportation equipment, office machinery and chemical products, the industry-average WFWD conditional on age, experience, education and occupation is relatively small, about a third of the average wage. In others, such as publishing and printing or apparel, the industry average WFWD is close to half of the average wage. Overall, a simple analysis of variance reveals that industry-level factors account for 37% of the observed variation in WFWD.

We argue that one reason for the variation in WFWD by industry is technological differences in terms of the degree of complementarity between contributions of workers of different skill levels.¹ Our argument draws on the concepts of complementarity and substitutability (cf. [Milgrom and Roberts, 1990](#), p. 516): two production inputs are complements/substitutes/neutral to each other if the marginal product of one increases/decreases/stays constant with the level of the other. Holding the average skill level constant, the marginal product of a higher-skill worker is impaired by the lower skill of the other workers in the same firm if the production technology features skill complementarity. Conversely, in a firm operating under skill substitutability, the marginal product of labor of high-skill workers decreases with the skill level of the other workers. Therefore, holding the total labor costs fixed, firms operating in “complementarity” industries would gain from employing workers of similar skill level, to whom they would pay similar wages, whereas firms in the “substitutability” industries would profit from skill differences between the workers. Differences in WFWD by industry would then reflect the optimal staffing choices in terms of workforce skill composition given the prevailing production technology.

Consistently with the above argument, we observe in our data a positive correlation between WFWD and total factor productivity (TFP) in industries with relatively high average WFWD. We obtain the same pattern when we use other wage-based measures of skill and when we augment our data with measures of complementarity computed from employee surveys. Generally, industries with relatively low complementarity scores have higher average within-firm skill dispersion and a more strongly positive correlation between skill dispersion and TFP.

Inter-industry differences in the degree of skill complementarity were first documented by [Bombardini, Gallipoli and Pupato \(2012\)](#), and the findings above are consistent with the presence of such differences. Yet, little is known about which industries belong in the “complementarity” or “substitutability” groups, since there is no natural threshold in any empirical measure of skill complementarity that separates complementarity from substitutability. It turns out that knowing if a technology features complementarity or substitutability is more important than the degree of it, since the consequences for labor demand, wages and firm personnel policies depend on the sign of complementarity much more than on its degree. We therefore attempt to classify industries

¹In this study, we focus on performance effects of within-firm differences in worker skill levels, that is, whether it is better to employ two workers who are different in their individual productivities, or two equally productive workers. We do not consider differences in worker types (e.g., workers with or without a college degree, or engineers/managers vs. production workers), although we do account for worker type in calculating some of our several measures of skill level. The details of this approach are discussed in Section ??.

into the complementarity and substitutability groups using a specially designed procedure.

The application of our classification procedure to the data reveals two distinct groups of industries, one featuring complementarity and the other substitutability between workers of different skill levels. Examples of the complementarity industries are chemicals and rubber and plastics. Foundries and transport equipment are examples of the substitutability industries. Our classification results – most importantly, the complementarity/substitutability industry groupings – are robust to the choice of empirical specification in terms of measures of skill and skill complementarity, as well as estimation technique. Also, consistent with the definition of complementarity/substitutability and our preliminary evidence, the correlation between skill dispersion and firm TFP is positive in the substitutability group and is negative in the complementarity group.

The coexistence within the same economy of two industry groups, radically different in the workforce skill composition their production technologies optimally require, has important implications. First, inasmuch as a firm’s workforce skill distribution matters beyond the average, choosing the right skill mix is important for gaining and sustaining competitive advantage. Consequently, personnel management policies may also be affected by the extent of complementarity. Our results may thus be helpful in explaining why some firms prefer to hire similarly skilled workers, while others do not (the point also made by [Prat \(2002\)](#)), and why firms in some industries train workers rather selectively, whereas others spread their training budgets more evenly across their workforce ([Konings and Vanormelingen, 2015](#)).

Second, complementarity shapes productivity differences between industries, under a given distribution of skill within the labor force, and consequently affects resource allocation domestically as well as international trade flows. For instance, [Grossman and Maggi \(2000\)](#) theory predicts that countries with more homogenous ability distribution will export more goods produced by technologies featuring stronger complementarity, a prediction empirically confirmed by [Bombardini, Gallipoli and Pupato \(2012\)](#). Turning to inter-sectoral productivity differences, [Wingender \(2015\)](#) argues that the relatively high elasticity of substitution between high- and low-skilled workers in agriculture leads to an overrepresentation of skilled workers in non-agriculture, and is behind the large agricultural productivity gap in developing countries, where skilled labor is in limited supply.

While not the first to find differences in the degree of complementarity between industries (the first, to our knowledge, are [Bombardini, Gallipoli and Pupato \(2012\)](#)), our study is the first attempt to classify manufacturing industries into the distinct complementarity and substitutability groups using individual worker and firm data. [Iranzo, Schivardi and Tosetti \(2008\)](#), who used matched worker-firm data similar to ours, and whose empirical approach we take as the starting point, estimated a single complementarity parameter for all industries, thereby assuming all industries to be technologically similar. As we show in this paper, one consequence of this assumption are potentially large prediction errors of the models simulating the economic outcomes of policies or natural events (for example, migration) that affect workforce skill distribution.

To illustrate how large these errors could be, we devise a stylized general equilibrium model of an economy with perfectly competitive labor and product markets, and two types of labor, A (low skill level) and B (high skill level), employed in two sectors, one featuring skill complementarity, the other substitutability. Under this

setting – later referred to as the “true model” – we simulate the effects of an exogenous ten-percent increase in the supply of one type of labor on the wages of both types and on labor productivity in each sector. For comparison, we perform the same simulations under the (incorrect) assumption that the two sectors are identical in terms of skill complementarity – later referred to the “false model”.

The true model correctly predicts a decrease in wages of the relatively abundant type and an increase in wages of the relatively scarce type. It also predicts that labor productivity will grow in the sector that benefits from changes in workforce diversity, and will decrease in the other sector – again, an intuitively appealing prediction. Yet, depending on the assumed degree of complementarity, common across the two sectors, the false model predicts milder or sharper wage and labor productivity effects than does the true model, with the prediction error of up to 2 percentage points. Generally, the false model produces inaccurate predictions for the effects of changes in workforce composition on labor market outcomes, such as wages and skill premium, with errors commensurate to the magnitude of the correctly estimated effects for a wide range of underlying parameter values. With these illustrations, and informed by our empirical results, we call for taking technological heterogeneity between industries fully into account in policy analysis.

In addition to the labor and trade literatures cited above, our study also speaks to the large literature on workforce diversity (e.g., [Shore et al., 2011](#); [Kahane, Longley and Simmons, 2013](#); [Parrotta, Pozzoli and Pytlikova, 2014](#)). We complement the existing research, much of which focusses on diversity in nominal characteristics, such as age, ethnicity, education, or professional background, by examining the effects of diversity in skill levels. Our findings reveal the importance of production technology in the “business case for diversity” ([Smedley, 2014](#)), a currently under-researched issue. Our empirical framework can be employed to capture the relationship between firm performance and diversity in terms of other, not necessarily cardinally measurable, characteristics (e.g., gender), thus further contributing to this thriving research area.

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