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ORIGINAL ARTICLE

Skill heterogeneity and market labour income inequality

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Abstract
Occupational choice models predict that, ceteris paribus, countries with higher dispersion of skill will have higher market labour income inequality. However, an extended conclusion from empirical research is that cross-country variations in dispersion of skill explain little of the variation in income inequality. This paper identifies factors related to production and organization technologies that moderate the relationship between dispersion of skill and dispersion of income in occupational choice equilibrium outcomes and that, if not properly accounted for, can bias the results of the empirical studies that explain dispersion of income as a function of dispersion of skill. In particular, comparing equilibrium outcomes from occupational choices in economies that differ in the distribution of skill *and* in the efficiency of supervision hierarchies, the paper can explain why the US and Sweden have similar labour productivity, but income inequality is higher in the US than in Sweden, and why productivity is lower and income inequality is higher in Spain than in Sweden.

Keywords Income inequality · Labour income · Occupational choice · Distribution of skills · Scale economies of skills · Organizational size diseconomies

JEL Classification J24 · J31 · J21 · D31 · D21 · E24 · I24

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1 Introduction

Income inequality is increasing around the world, while cross-country differences in the distribution of income persist over time.[1] This paper, first, theoretically explains how the distribution of skill in the working population determines the distribution of market labour income in the economy; and second, it identifies factors that can moderate the across-country association between dispersion of skill and dispersion of income and that will be relevant to properly assessing the strength of that association in empirical research. The analysis is based on market equilibrium outcomes in economies where individuals with different general skills make occupational choices and firms are internally organized as supervision hierarchies.

If the market income of individuals is positively correlated with their respective skill—as would be expected if more skilled people are also more productive—ceteris paribus, market labour income inequality would be unequivocally higher in countries with high dispersion of skill than in countries with low dispersion. Within countries, there is evidence that individuals who are more skilled (more intelligent, more educated and/or more experienced in their work) earn higher salaries and that the price/return to skill implicit in the relationship between labour income and skill differs across countries (Autor 2014; Hanushek et al. 2015; Katz and Autor 1999). Research has also empirically investigated the relationship between dispersion of skills and dispersion of wages in cross-country data, particularly with data on cognitive skills from the International Adult Literacy Survey, IALS (Blau and Kahn 1996, 2005; De Gregorio and Lee 2002; Devroye and Freeman 2001; Freeman and Schettkat 2001; Leuven et al. 2004), and with data from the Program for the International Assessment of Adult Competencies, PIAAC (Broecke et al. 2018; Jovicic 2016; Machin et al. 2016; Paccagnella 2015). Although some evidence of a positive association between dispersion of skill and dispersion of income has been reported, the most accepted conclusion from this research is that differences in dispersion of skill contribute little to explaining cross-country differences in income inequality.[2] Since differences in the price of skill will imply differences in income inequality for a given distribution of skill, research shifts to explain differences in the price of skill (and in income inequality) as the result of differences in the supply and demand of skill (Broecke et al. 2017) and of cross-country differences in labour market regulations and institutions, such as collective bargaining, minimum wage, firing restrictions, unemployment benefits and so on (Blau and Kahn 1996; Broecke et al. 2015; Howell and Huebler 2005; Koeniger et al. 2007; Checchi and Garcia-Peñalosa 2010; Salvedra and Checchi 2014).[3]

This paper models and estimates the distribution of labour income in the market equilibrium of an occupational choice economy (Lucas 1978; Rosen 1982; Garicano 2000) and explains observed differences in income inequality across economies as the result of differences among them in the distribution of skill and in parameters of the production and organization-of-firms technologies that determine the occupational

[1] See the data reported in the recently released World Inequality Report 2018 https://wir2018.wid.world.

[2] Exceptions to the main result from IALS data are Juhn et al. (1993) and Nickell (2004).

[3] Occupational mobility (Kambourov and Manovskii 2009), labour income tax policies (Guvenen et al. 2014) and labour regulations (Flinn 2002) are also relevant factors in explaining wage inequality.

choice equilibrium. The main interest is in investigating how the distribution of skill and the parameters of the production and organization technology of firms interact in the joint determination of inequality, with the only regulation being a minimum wage. The results should contribute to better understanding some results found through empirical research on how much the differences in dispersion of skill contribute to explaining differences in dispersion of market labour income. More particularly, the results of the research will indicate to what extent the association between dispersion of skill and income inequality found in empirical research could be explained by differences in production and organization technologies across economies with similar labour institutions and regulations.

The proposed occupational choice model solves for the price of skill as a market equilibrium outcome; as such, it depends on the dispersion of skill and on other parameters of the model, different from labour market institutions (the occupational choice model includes a minimum wage that also affects the equilibrium price, but the other parameters continue to be relevant). Since countries' economies can differ in other parameters of the model, in addition to the dispersion of skill, the analysis of the link between dispersion of skill and dispersion of income should be done in a broader general framework that contemplates *all* the exogenous parameters of the model at the same time. One of the ways the paper does so is by comparing the equilibrium outcomes of four economies proxy of Spain, USA, Germany, and Sweden that, according to the PIAAC data, have different distributions of skill (mean and dispersion), and other sources indicate that they may have different efficacy of the supervision hierarchy of firms, too. The results suggest that the higher dispersion and the lower mean of the distribution of skill in the US, compared with those of Sweden, can explain why, with actual data, the Swedish economy is equally productive and more equal in the distribution of labour income than the US economy. They also indicate that to explain why the US is more productive and has similar income inequality to Spain, it is necessary to allow for differences in organizational technologies between the two countries, in addition to the higher dispersion of skill in the US observed in the PIAAC data.

Occupational choice models (Lucas 1978) differ in their assumptions about the internal organization of firms, a *supervision* hierarchy (the role of entrepreneurs-managers is to supervise the work of employees) in Rosen (1982) and a *knowledge* hierarchy (managers dedicate their time and skill to help employees in solving complex problems) in Garicano (2000). Medrano-Adan et al. (2018) model the distribution of labour income, including the salaries of employees, the income of the solo self-employed and the profits of entrepreneur-managers using an occupational choice model with supervision hierarchy. Garicano and Rossi-Hansberg (2006) apply the knowledge hierarchy model to explain some of the patterns observed in the changes in wage inequality attributed to the use of computers that reduce employment in occupations intensive in routine tasks and increase it in occupations intensive in cognitive skills (Bresnahan et al. 2002; Autor et al. 2008; Acemoglu and Autor 2011; Goos et al. 2014), which causes the return to cognitive skills to increase over time (Beaudry et al.

2016).[4] This paper models the occupational choice equilibrium with supervision hierarchies to investigate the more specific topic of the relationship between dispersion of skill and dispersion of income across economies, how such a relationship can be moderated by other variables of their respective production and organization technology, and how all these interrelationships should be accounted for in explaining evidence found in research on the determinants of labour income inequality.

The rest of the paper is organized as follows. Section 2 models the occupational choice equilibrium. Section 3 shows how to use the equilibrium conditions to calibrate the parameters of the model and define the base case economy. Section 4 compares the market equilibrium outcomes on production efficiency and income inequality in economies with different dispersion of skill. Section 5 extends the comparisons to economies with different dispersion of skill *and* different organizational size diseconomies. Section 6 focuses on reconciling the theory with evidence on the association between the distribution of skill and the distribution of income, mainly with PIAAC-OECD data. The conclusion section summarizes the main results and outlines extensions for future research.

2 Economy model

2.1 Distribution of general skills

The general skill, q, is distributed among the population according to a lognormal distribution (the log of q will be normally distributed with mean λ and standard deviation σ).[5] The first and second moments of the distribution depend on λ and σ as follows: $E[q] = e^{\lambda+\frac{\sigma^2}{2}}$ and $\text{var}[q] = e^{2\lambda+\sigma^2}\left(e^{\sigma^2} - 1\right)$. However, the median depends only on λ, $Median[q] = e^{\lambda}$, and the coefficient of variation $CV = \sqrt{\left(e^{\sigma^2} - 1\right)}$, and the ratios between quantiles, $\frac{Quantile[q_2]}{Quantile[q_1]} = e^{\sqrt{2}\,\sigma(InverseErfc[2q_1]-InverseErfc[2q_2])}$ depend only on σ.

2.2 Supervision hierarchies

In occupational choice models, would be entrepreneur-managers compete for the control of the resources of the economy offering salaries to attract employees whose labour services will be combined with capital services to produce goods and services that will

[4] See Garicano and Rossi-Hansberg (2015) for a review of the contributions of the knowledge hierarchy as a model of organization of firms to explain selected macroeconomic outcomes, including wage inequality. Salas-Fumás et al. (2014) and Medrano-Adan et al. (2019) apply the supervision hierarchy model to study the relationship between size and productivity of firms.

[5] Lucas (1978) solves the market equilibrium from occupational choices assuming that all individuals have the same operational skill and differ in entrepreneurial skill, with differences modelled by a Pareto distribution. In our model, individuals differ in general skill that can be applied to perform operational and managerial-entrepreneurial tasks. Therefore, it is more realistic to assume a bell-shaped distribution of the general skill, skewed to the right, as the log normal one, to capture the longer upper tail of the distribution where entrepreneurs will come from.

be sold in the market. The internal organization of the production team, including an entrepreneur manager and the employees under her direction, matters for the overall production efficiency. Rosen (1982) assumes a hierarchical organization, with the entrepreneur-manager supervising the work of employees in each operational job; the result of this supervision will determine the quantity and quality of labour input that will be combined with capital services in the final production of output.

In Rosen's model, the joint production of a full-time employee with general skill q_i and an entrepreneur of skill q that dedicates a fraction of her working time t_i to the supervision of the employee will produce an intermediate output of operational skill equal to $l_i = (t_i q)^{\beta} q_i^{1-\beta}$, where β, between zero and 1, is a parameter of the supervision technology: higher is β indicates relatively more intensity of supervision in the joint production. The entrepreneur decides how much supervision time is allocated to each employee so that the total intermediate input operational skill, $\sum_i l_i$, is maximized, subject to the total working time constraint, $\sum_i t_i = 1$ (total working time is normalized to one for all those occupied). In the optimal solution, the allocation of the supervision time is proportional to the skill of the respective employee. The optimal allocation of the supervision time (proportional to the skill of the respective employee) results in a total amount of intermediate operational skill input equal to $L = q^{\beta} Q^{1-\beta}$, where $Q = \sum_i q_i$. The supervision hierarchy in Rosen's model converts the general skills of employees into a homogeneous commodity of operational skill that is perfectly interchangeable across firms.

2.3 The production and profit functions

The entrepreneur-manager combines labour and capital inputs to produce output to be sold in the market at a competitive price normalized to one. The entrepreneur of skill q contributes to the final output produced in two ways: through the supervision of the operational employees and through the "quality" of the entrepreneurial decisions, captured directly by her level of skill and considered an indivisible and nonreproducible factor. Better or worse entrepreneurial decisions affect the productivity of labour and capital inputs and the quality of decisions, which is assumed to be proportional to the level of skill q and will be one component of the Total Factor Productivity (TFP) term of the production function. Assuming a Cobb–Douglas production function with constant returns to scale in labour and capital services, the total output produced will be equal to:

$$Y = \theta q L^{1-\mu} K^{\mu} = \theta q \left(q^{\beta} Q^{1-\beta}\right)^{1-\mu} K^{\mu} = \theta q^{1+\beta(1-\mu)} Q^{(1-\beta)(1-\mu)} K^{\mu} \quad (1)$$

where Y is the total output produced; K is the quantity of capital services; μ is the elasticity of output to the capital service input, and θ is a positive parameter of the general production technology. The returns to scale in the inputs operational skill and capital are given by $(1-\beta)(1-\mu)+\mu$, lower than 1 if $\beta > 0$. The returns to scale decrease with β, the parameter that captures a feature of the internal organization of firms, namely, the relative intensity of the supervision input of the entrepreneur in the joint interaction with employees at the job level. Since higher β implies lower scale economies in production, the parameter β is interpreted as a measure of organizational size diseconomies.

The output is sold in a competitive market at a normalized price of 1, and there is a perfectly elastic supply of capital services at a unit price of c. Operational skills will be traded in the market at a unit price w that will be determined as an equilibrium value from supply and demand.

An entrepreneur of skill q solves for the profit-maximizing input quantities of capital services and operational skills,

$$\Pi(q) = Max_{Q,K}\theta q^{1+\beta(1-\mu)} Q^{(1-\beta)(1-\mu)} K^{\mu} - cK - wQ \tag{2}$$

The solution to the problem gives the maximum profit as a function of the entrepreneur's general skill q,

$$\Pi^{*}(q) = \beta(1-\mu)\left(\theta\left(\frac{\mu}{c}\right)^{\mu}\right)^{\frac{1}{\beta(1-\mu)}} \left(\frac{(1-\mu)(1-\beta)}{w}\right)^{\frac{1-\beta}{\beta}} q^{\frac{1+\beta(1-\mu)}{\beta(1-\mu)}} \tag{3}$$

Solo self-employed individuals have access to the same production technology. They differ from entrepreneur-managers in that the self-employed do not hire employees, so labour input/operational skills are limited to the general skills of the particular person. It is assumed that the lack of specialization (the solo self-employed perform operational and entrepreneurial functions) may penalize the total productivity of the self-employed with a parameter factor $k \leq 1$. Then, the production function of the solo self-employed is given by

$$Y = k\theta q q^{1-\mu} K^{\mu} = k\theta q^{2-\mu} K^{\mu} \tag{4}$$

The maximum net revenue of a solo self-employed with skill q is given by:

$$R^{*}(q) = (1-\mu)\left(k\theta\left(\frac{\mu}{c}\right)^{\mu}\right)^{\frac{1}{1-\mu}} q^{\frac{2-\mu}{1-\mu}} \tag{5}$$

A person with skill q working as an employee will earn a salary equal to

$$S = wq \tag{6}$$

2.4 Minimum salary

Let us denote by $S_{\min}$ the legally established minimum salary that an employer must pay to a hired employee. For a market price per unit of skill w, employers will only hire individuals with skills above the value q_0, given by $q_0 = \frac{S_{\min}}{w}$. Those individuals with skills lower than q_0 will either be unemployed or work as solo self-employed, as assumed here. They will be named "involuntary solo self-employed" (ISSE). Other solo self-employed individuals who have the skill to be hired as employees but prefer working as solo self-employed will be labelled "voluntary solo self-employed" (VSSE).

2.5 Market equilibrium conditions

The market equilibrium from occupational choices requires that two conditions be satisfied: every individual in the economy is choosing the occupation with the highest compensation (given her skill), and there is a price of skill for which the aggregate entrepreneur's demand for operational skills equals the supply of operational skills from those who choose to work as an employee.

From the assumptions above, the market equilibrium is characterized by

$$q_0 = S_{\min} \big/ w^* \tag{7}$$

$$w^* q_1 = (1-\mu)\left(k\theta\left(\frac{\mu}{c}\right)^{\mu}\right)^{\frac{1}{1-\mu}} q_1^{\frac{(2-\mu)}{(1-\mu)}} \tag{8}$$

$$\left(k\theta\left(\frac{\mu}{c}\right)^{\mu}\right)^{\frac{1}{1-\mu}} q_2^{\frac{(2-\mu)}{(1-\mu)}} = \beta(1-\mu)\left(\theta\left(\frac{\mu}{c}\right)^{\mu}\right)^{\frac{1}{\beta(1-\mu)}} \left(\frac{(1-\mu)(1-\beta)}{w^*}\right)^{\frac{(1-\beta)}{\beta}} q_2^{\frac{1+\beta(1-\mu)}{\beta(1-\mu)}} \tag{9}$$

$$\begin{aligned} &\frac{1}{2}\left(\frac{k^{\frac{1}{1-\mu}}}{\beta}\right)^{\frac{1}{1-\beta}} q_2^{\frac{-1}{\beta(1-\mu)}} e^{\lambda\left(1+\frac{1}{\beta(1-\mu)}\right)+\frac{\sigma^2}{2}\left(1+\frac{1}{\beta(1-\mu)}\right)^2} \\ &\left(1 + Erf\left[\frac{\lambda + \sigma^2\left(1+\frac{1}{\beta(1-\mu)}\right) - \ln[q_2]}{\sigma\sqrt{2}}\right]\right) \\ &\quad = \frac{1}{2} q_2^{\frac{-1}{\beta(1-\mu)}} e^{\lambda+\frac{\sigma^2}{2}} \left(Erf\left[\frac{\lambda+\sigma^2-\ln\left[S_{\min}\big/ w^*\right]}{\sigma\sqrt{2}}\right] - Erf\left[\frac{\lambda+\sigma^2-\ln[q_1]}{\sigma\sqrt{2}}\right]\right) \end{aligned} \tag{10}$$

Equation (7) determines the minimum level of skills to be hired as an employee, q_0. Equation (8) solves for the skill that makes an individual indifferent between working as an employee and as voluntary solo self-employed. Equation (9) determines the level of skill that makes an individual indifferent between working as voluntary solo self-employed and as an entrepreneur-manager. Finally, Eq. (10) sets the condition of supply $\int_{q_0}^{q_1} q\, dG(q)$ equal to the demand $\int_{q_2}^{\infty} Q(q; w^*) dG(q)$ of operational skills of employees from the profit maximizing quantity of operational skill by an entrepreneur of skill q. Appendix A of the supplementary online material provides more details on functional forms of quantities of inputs and output quantities, income distribution, etc.

3 Calibration of the parameters

This system has no closed-form solution, so to analyse the properties of the equilibrium, it must be solved numerically for calibrated values of the exogenous parameters (λ, σ, β, θ, μ, k, c and S_{min}). The calibration process consists of exogenously fixing some parameters to values that can be reasonably justified and letting the others be estimated from equilibrium conditions of the model and the observed values on some endogenous variables.

The values of four parameters (λ, θ, μ, c) are set exogenously. The proportionality parameter in the production function θ and the arbitrary location parameter of the distribution of skills λ are normalized to 1 and 2, respectively. The user cost of capital $c = 0.12$ is set equal to the sum of an estimated depreciation rate of capital of 0.08 and an estimated average real rate of return on capital of 4%, data for Spanish nonfinancial corporations (Salas-Fumás, 2022). The elasticity of output to capital services μ is set equal to the estimate of the share of the cost of operating capital assets over gross value added (from profit maximization conditions), $\mu = \frac{cp_K K}{pY} = 0.25$ (same source of data). From the production function above, the scale economies of the production function are given by $(1-\beta)(1-\mu)+\mu$. They have been calibrated to be equal to 0.8 in the US economy (Guner et al. 2008). The average size of Spanish firms with employees is smaller than the average size of firms with employees in the US, so we set the scale economies parameter to 0.7. Solving for β in $(1-\beta)(1-0.25)+0.25 = 0.7$, the result is $\beta = 0.4$.

The remaining parameters (σ, k and $S_{\min}$) are obtained from the market equilibrium conditions together with the conditions that the resulting sizes of the occupational groups coincide with those observed in the Spanish economy.

According to the Economically Active Population Survey (EAPS), INE, the occupied individuals in the private sector of the Spanish economy are distributed in occupational groups as follows: 80% employees, 12% solo self-employed and 8% entrepreneur-managers.[6] From other sources (IVIE 2008), there is evidence that solo self-employed individuals are segmented into two groups, one at the low end of the income distribution and another in the middle upper tail of the distribution. The actual numbers are unknown, but for calibration purposes, we assimilate the involuntary solo self-employed with what the Global Entrepreneurship Monitor, GEM-Spain (2014), identifies as necessity entrepreneurs. From the proportion of necessity entrepreneurs in the total of entrepreneurs, the 12% solo self-employed of EAPS are split into 4 percentage points involuntary and 8 percentage points voluntary self-employed. With

[6] An entrepreneur who hires and manages employees can be the owner of the business, or a professional manager with delegated strategy formulation and organizational functions. The occupational statistics distinguish between employees and the self-employed; the latter are further divided into self-employed without employees and self-employed with employees (employers). The top professional managers are included among salaried employees. According to the model, top managers and employers perform the same managerial functions and therefore they are included in the same occupational group.

this information, the conditions on the sizes of occupational groups are as follows:

$$\int_{0}^{q_0} dG(q) = 0.04, \quad \int_{q_0}^{q_1} dG(q) = 0.8, \quad \int_{q_1}^{q_2} dG(q) = 0.08 \tag{11}$$

where $\int_a^b dG(q) = \int_a^b \frac{1}{\sigma q \sqrt{2\pi}} \mathrm{e}^{-\frac{(-\lambda + \ln(q))^2}{2\sigma^2}} dq$, for any $a, b > 0$.

Individuals with skills lower than q_0 will work as involuntary solo self-employed, and according to the data, they are 4% of all occupied (first Eq. 11). Individuals with skills betweenq_0 and q_1 will choose to work as employees; they are 80% of all occupied (second Eq. 11). Individuals with skills between q_1 and q_2 will choose to work as voluntary solo self-employed; they are 8% of the population (third Eq. 11). The remaining individuals, 8%, will work as entrepreneur-managers.

There are seven equations, the market equilibrium conditions (7–10) plus the conditions on sizes of occupational groups (11), and seven unknowns, the exogenous parameters of the model (σ, k and S_{min}) and the endogenous variables w, q_0, q_1 and q_2. The unique solution is summarized in Table 1.

Table 1 Calibration: data targets and values of exogenous and endogenous parameters

Inputs to the market equilibrium conditions	
Predetermined parameters	
Position parameter of the distribution of skill	$\lambda = 2$
Position parameter of the production function	$\theta = 1$
Calculated parameters	
Elasticity of output to capital input (Spanish NFC)	$\mu = 0.25$
User cost of capital (Spanish NFC)	$c = 0.12$
Shares of occupational groups (Spanish EPA and GEM)	Employees = 0.8 (80%) Directors = 0.08 (8%) Voluntary SSE = 0.08 (8%) Involuntary SSE = 0.04 (4%)
Outputs from the market equilibrium conditions	
Organizational size diseconomies	$\beta = 0.400$
Standard deviation of the distribution of skill	$\sigma = 0.391$
Relative TFP of solo self-employed	$k = 0.665$
Minimum wage	$S_{min} = 50$
Threshold values of skills	$q_0 = 3.725$, $q_1 = 10.895$, $q_2 = 12.796$

The profits of entrepreneur-managers, the income of the solo self-employed and the salaries of employees in operational jobs, from Eqs. (3), (5) and (6), are given by:

$$\Pi^*(q) = 0.00339 q^{13/3}, \quad q \geq q_2 = 12.796 \tag{12}$$

$$R^*(q) = 0.56\, q^{7/3}, \quad q \leq q_0 = 3.725 \quad \text{or } q_1 = 10.895 \leq q < q_2 = 12.796 \tag{13}$$

$$S^*(q) = 13.42\, q, \qquad q_0 = 3.725 \leq q < q_1 = 10.895 \tag{14}$$

4 Comparison of equilibrium outcomes in economies with different dispersion of skill

This section compares the market equilibrium outcomes—output produced and labour income distribution—in economies with different dispersion of general skill with the rest of parameters of the model at their base case values. The exposition will be divided into two parts: the overall effects on market equilibrium outcomes of differences in the dispersion of skill and the decomposition of effects from changes in the price of skill and changes in the sizes of occupational groups.

4.1 Overall effects of skill dispersion

Table 2 shows selected occupational equilibrium outcomes for different values of the dispersion of skill parameter. Since the value of σ affects the mean value of the distribution, the value of λ is adjusted so that the expected skill $E[q]$ is the same in all columns (from $E[q] = e^{\lambda + \frac{\sigma^2}{2}}$, $\lambda = \ln(E[q]) - \frac{\sigma^2}{2}$). Figure 1 shows two graphical representations of income as a function of skill, one for $\sigma = 0.39$ (low σ) and the other for $\sigma = 0.43$ (high σ).

Higher values of σ imply higher dispersion in the distribution of skill, regardless of the measure of dispersion used (Table 2, first block of data). The GINI index of the distribution of skill in the base case is 0.218 and rises to 0.239 for $\sigma = 0.43$ (high σ). In a hypothetical economy where the labour income of individuals was proportional to their level of skill, the GINI index of the income distribution would be equal to the GINI index of the distribution of skill. In the occupational choice economy, income will be proportional to the level of skill only for the group of operational employees ((14); Fig. 1A); the income of solo self-employed and entrepreneur-managers is an increasing and convex function of skill ((12), (13); Fig. 1A). Overall, the distribution of labour market income is (much) more unequal than the distribution of skills.

From Table 2, economies with higher dispersion of skill, ceteris paribus, will have more individuals working as employees and fewer entrepreneur-managers and solo self-employed than economies with lower dispersion of skill. Therefore, the ratio of employees to entrepreneur-managers (average size of firms) will increase with the dispersion of skill. To explain these changes in the size of occupational groups in

Table 2 Equilibrium in the base-case economy and in economies with different dispersion of skills (adjusting λ to keep the E[*skill*] constant)

		Base case		High σ	
Distribution of skills					
Lambda, λ	2.008	2.000	1.992	1.984	1.975
Sigma, σ	0.37	0.39	0.41	0.43	0.45
E(*skill*)	7.98	7.98	7.98	7.98	7.98
var(*skill*)	9.38	10.50	11.69	12.97	14.33
CV(*skill*)	0.38	0.41	0.43	0.45	0.47
GINI skill	0.207	0.218	0.229	0.239	0.250
P90/P10 skill	2.587	2.723	2.866	3.017	3.176
P50/P10 skill	1.608	1.650	1.693	1.737	1.782
Endogenous variables					
Occupational groups and output					
Employees	78.3%	80.0%	81.6%	83.0%	84.4%
Entrepreneurs-managers	8.6%	8.0%	7.4%	6.8%	6.3%
Voluntary solo self-employed	9.0%	8.0%	7.2%	6.4%	5.7%
Involuntary Solo Self-employed	4.1%	4.0%	3.9%	3.7%	3.5%
Average firm size (Span of control)	9.10	10.00	11.01	12.14	13.42
Price operational skills	12.81	13.42	14.10	14.84	15.66
Total Output	177.56	188.23	199.92	212.75	226.83
Income per capita (IPC)					
IPC Employees	90.6	95.1	100.0	105.5	111.4
IPC Entrepreneurs-managers	549.7	634.1	734.3	853.7	996.6
IPC Voluntary solo self-employed	160.9	174.8	190.5	208.5	229.0
IPC Involuntary solo self-employed	9.8	8.7	7.6	6.7	5.8
Functional distribution of output					
Gross capital income	25.0%	25.0%	25.0%	25.0%	25.0%
Employees	40.0%	40.4%	40.8%	41.2%	41.5%
Entrepreneurs-managers	26.7%	26.9%	27.2%	27.4%	27.7%
Voluntary solo self-employed	8.1%	7.4%	6.8%	6.3%	5.8%
Involuntary solo self-employed	0.2%	0.2%	0.1%	0.1%	0.1%
Income inequality					
GINI all	0.401	0.416	0.431	0.444	0.458
GINI employees	0.139	0.149	0.160	0.171	0.182
GINI entre-managers	0.424	0.445	0.466	0.486	0.506
GINI solo self-employed	0.329	0.349	0.369	0.388	0.406
P90/P10 employees	1.979	2.086	2.202	2.328	2.464
P50/P10 employees	1.454	1.492	1.533	1.575	1.619

Table 2 (continued)

		Base case		High σ	
P90/P10 all	3.075	3.163	3.245	3.320	3.388
P50/P10 all	1.608	1.650	1.693	1.737	1.782
%Income low 10%	2.7%	2.6%	2.5%	2.4%	2.3%
%Income top 10%	37.5%	38.8%	40.0%	41.1%	42.2%
% Income top 1%	14.1%	15.4%	16.8%	18.2%	19.7%

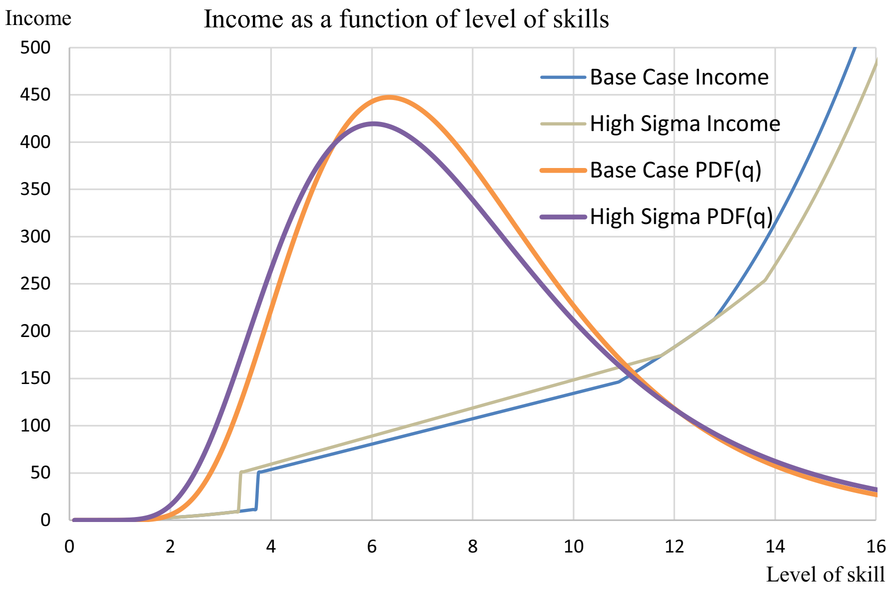
The parameters different from those of the distribution of skill are kept at their base case values in Table 1: $\beta = 0.4$, $\theta = 1$, $c = 0.12$, $\mu = 0.25$, $k = 0.665$, $S_{\min} = 50$)

the equilibrium, notice that higher dispersion of skill implies a higher density of individuals in the upper tail of the distribution who will work as entrepreneurs.[7] Then, higher dispersion of skill implies fewer but more skilled entrepreneurs (6.8% of people with an average skill of 16.94 in the high dispersion economy as opposed to 8% with an average skill of 15.47 in the base-case economy) and a more than proportional increase in demand for operational skill, which pushes up the equilibrium price of operational skill (from 13.42 to 14.84). The higher price of skill will, in turn, induce individuals to revise their occupational choices. First, the profits of entrepreneurs will decrease so that some of these entrepreneurs (the initially less skilled) will change occupation to work as solo self-employed. Second, with the higher price of skill some solo self-employed, those with lower skill will earn higher salary as employees and will also change occupation.

Labour productivity, measured by total output produced, will be 13.03% higher in the high dispersion of skill economy than in the low dispersion economy.[8] On average, the per capita income of employees, voluntary solo self-employed and entrepreneurs will also increase with higher dispersion of skill. The increase in total output is explained by the more than proportional contribution to output of the increase in the average skill of entrepreneurs in the high dispersion economy. Employees earn a higher average salary in the new equilibrium for two reasons: because the price of skill is higher, and because their average skill increases as the result of changes in the composition of the occupational groups (due to a higher σ). However, the contribution from the increase in the price of skill is much more important than the contribution from the increase in the average skill. In the case of voluntary (involuntary) solo self-employed individuals, the higher (lower) average income is explained by higher (lower) average skill in the market equilibrium with high dispersion. In the group of entrepreneur-managers, even though the higher price of skill has a negative effect on the level of profits, the profit per capita increases because the average skill of entrepreneur-managers is higher, which compensates for the higher price of operational skill.

[7] For instance, in the low-σ economy (σ= 0.39), 2.4% of individuals have a level of skill higher than 16 as opposed to 3.4% (40% more) in the high-σ economy (σ= 0.43).

[8] Additionally, output per average skill is 13% higher in the economy with high dispersion of skill (26.68 in the economy with σ = 0.43 as opposed to 23.60 in the economy with σ = 0.39).



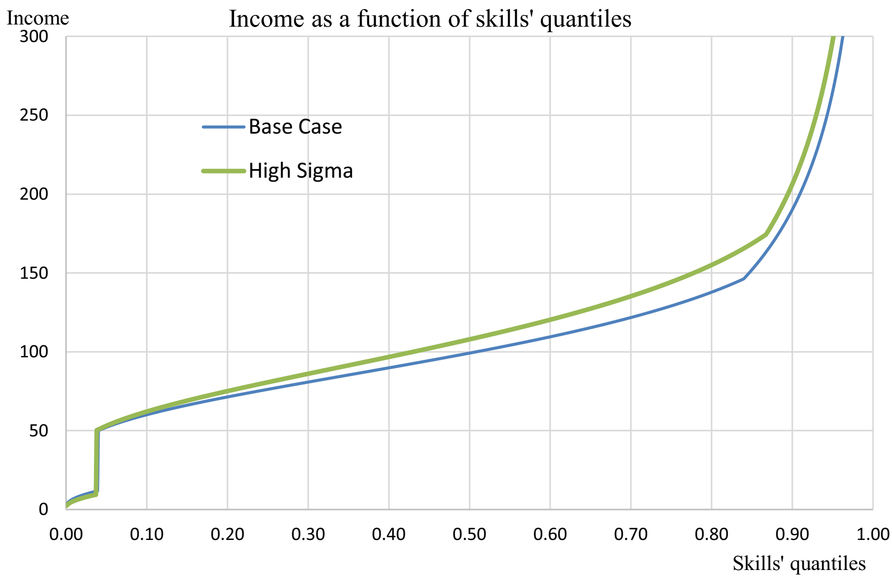


Fig. 1 Effect of a change in skill dispersion on labour income. *Notes* Top figure: labour income as a function of the level of skills in the population. Bottom figure: labour income as a function of the quantiles of the distribution of skills in the population. In both figures, blue lines correspond to the base case, low dispersion of skills $\sigma = 0.39$ ($\lambda = 2$), and green lines correspond to the scenario with high dispersion of skills, $\sigma = 0.43$ ($\lambda = 1.98$). The rest of the parameters are set at their base case values: $\theta = 1$, $c = 0.12$, $\mu = 0.25$, $\beta = 0.4$, $k = 0.665$, and $S_{\min} = 50$

The functional distribution of total output (in capital and labour income, separated into income of employees, solo self-employed and entrepreneur-managers) varies little across economies with different dispersion of skill (bottom block of variables on income inequality in Table 2) and not at all in the case of the share of gross capital income in total output because this share is always equal to the elasticity of output to the capital input.[9]

The inequality in the distribution of labour income is higher in economies with higher dispersion of skill than in economies with lower dispersion, regardless of the measure of income inequality considered. The particular way of organizing production and determining the compensation of individuals in each occupational group (from the occupational choice equilibrium) explains the jump in the GINI index from the 0.218 value for the distribution of skill to the 0.416 GINI index value for the distribution of skill income (base case). In the high-dispersion economy ($\sigma = 0.43$), the GINI index of the distribution of skill is 0.239, and the GINI of the distribution of labour income is 0.444. Proportionately, the 9.94% increase in the GINI of skill from 0.218 (base case) to 0.239 (high dispersion of skill) results in a less than proportional increase (of 6.72%) in the GINI index of the distribution of income, from 0.416 to 0.444.

Higher dispersion of skill results in higher dispersion of income within all occupational groups. The overall GINI index calculated as the sum of the weighted GINI index within each occupational group—with weights equal to the respective share of labour income—is equal to 0.276 in the base case and equal to 0.305 for $\sigma = 0.43$ (high σ). The weighted GINIs are closer to the GINI of the respective distribution of skill than to the GINI indexes of 0.416 and 0.444 of the distribution of labour income. The incremental inequality in the distribution of labour income, with respect to the inequality if income was proportional to skill, can then be attributed to inequality in the distribution of income across occupational groups.

The ratios of percentile incomes, P90/P10, P90/P50 and P50/P10, are higher in the high dispersion economy than in the low dispersion economy for both the income within the group of employees and the income of the total population. The concentration of income at the top of the distribution increases with the dispersion of skill, but the share of income in the bottom 10% is similar in the two economies. Notice that the P50/P10 ratio of incomes for the entire population is the same as the P50/P10 ratio of skill from the distribution of skill (first block of data in Table 2). The explanation is that individuals in the P50 and P10 of the distribution of labour income are both employees; in the calculation of the ratio of incomes P50/P10, the price of skill in the numerator and in the denominator cancel out, and the ratio of incomes coincides with the ratio of skills. This coincidence does not occur between the ratio P90/P50 of skill and the ratio P90/P50 of labour income because the person in the P90 of the distribution of income is not an employee but a voluntary solo self-employed with

[9] The net capital income will be distributed among the investors that finance the productive capital assets of firms. Entrepreneur-founders of firms that finance all the productive capital, in addition to managing the business will earn a total income equal to economic profits plus the capital income net of depreciation. All individuals of the economy can hold shares of firms, although it is well known that shareholdings are highly concentrated across economies (World Inequality Report). The occupational choice models do not consider the distribution of shares and wealth in the population, and this is why the analysis here is restricted only to labour income inequality.

income equal to a power function of skill (Fig. 1A). Differences in the occupation of the person in the P90 of the income distribution across economies may distort the conclusion about the association between dispersion of skill and income inequality.

4.2 Comparison of the values of the two distribution functions

The comparison of Fig. 1A, B provides further insights into the explanation of the differences in the distribution of income across economies with different distributions of skills. In Fig. 1A, the variable on the horizontal axis is the level of skill and that on the vertical axis is the level of income for the given skill and occupation, Eqs. (12–14). In Fig. 1B, the horizontal axis changes to the quantiles of the distribution of skill. The income for a given quantile value depends on the skill of the individual and on the density of individuals with that skill. Differences in the skill distribution functions imply that the same skill will correspond to a different quantile and, possibly, to a different occupation.[10]

From Fig. 1A, an employee of a given skill in the low dispersion economy would earn a salary lower than that of an employee with the same skill in the high dispersion one (for instance, the employee with skill $q = 6$ would earn 80.5 in the low skill dispersion economy, as opposed to 89.1 in the high dispersion one); the explanation is the higher price of operational skill in the latter than in the former. The solo self-employed of a given skill will earn the same in the two economies (the solo self-employed with skill $q = 12$ would earn 183.2 in both economies). Finally, because of the higher price of skill, the profit of an entrepreneur-manager of a given skill will earn a lower income (profit) in the high dispersion economy (an entrepreneur with skill $q = 18$ would earn 933.8 in the low skill dispersion economy and 803.01 in the high dispersion economy). The employees of the low dispersion of skill economy will be attracted to migrate to work as employees in the high dispersion economy; the solo self-employed will be indifferent between the two economies; and the entrepreneur-managers will prefer continuing in the low dispersion-low price of skill economy.

In Fig. 1B, the income associated with each quantile of the distribution of skill is higher in the high dispersion than in the low dispersion economy (with the exception of a few quantiles at the bottom end of the distribution). The differences have to do with the higher density of skill at both ends of the distribution in the distribution with high dispersion than in that of low dispersion, which implies that the same quantile of the distribution of income is associated with individuals with different skills, and possibly different occupations, in one economy and the other. For example, a person in quantile 95 in the high dispersion economy has a level of skill of 14.76, while a person in the same quantile in the low dispersion economy has a skill level of 14.05. Both of them are entrepreneurs, but the former, more skilled, earns higher income (297.2) than the latter (264.80), despite the higher price of operational skill in the high dispersion economy. However, an entrepreneur with skill 15.0 would prefer the low dispersion economy because the lower price of skill implies higher profit (423.8 instead of 364.4).

[10] For instance, an individual with skill level 3.5 corresponds to the 2.8 percentile in the low sigma distribution and the 4.5 percentile in the high sigma one. In the former, he would be involuntary solo self-employed (in equilibrium) while he would be an employee in the latter.

A person in quantile 40 will have a level of skill of 6.69 in the low dispersion of skill economy and of 6.52 in the high dispersion economy. However, despite the lower skill, the latter earns a higher salary (96.75) than the former (89.84) because of the higher price of operational skill (14.84 versus 13.42) in the high dispersion economy. In quantile 70, the employee in the high dispersion economy earns a higher salary than the employee in quantile 70 of the low skill economy (135.3 versus 121.8) because the latter has a higher skill (9.11 versus 9.07) and because the equilibrium price of operational skill in the economy is also higher (14.84 versus 13.42).

Figure 1B also explains why the concentration of income in the top 1% of the distribution of income is higher in the economy with high dispersion of skill than in the base case. In the two economies, the individuals at the top of the distribution are entrepreneur-managers, but entrepreneur-managers in the top 1% of the income distribution in the high dispersion economy are more skilled (mean skill of 23.1) than those in the top 1% of the low dispersion economy (mean skill of 21.1). The higher concentration of skill implies an even higher concentration of income-profit (note that the mean skill of individuals in the top 1% in the high dispersion economy is approximately 9.6% higher than the mean skill of the individuals in the top 1% in the low dispersion economy, but they receive 18.3% more of the total output produced, 18.2 versus 15.4).

4.3 Decomposition: effects of price of skill and of sizes of occupational groups

Differences in the dispersion of skill result in equilibrium outcomes with different prices of skill and with different sizes of occupational groups. We now separate the two effects in the changes in the equilibrium outcomes, total output, and GINI index by exogenously setting the equilibrium price of skill of the high dispersion of skill economy ($w = 14.84$) in the low dispersion economy and examining what happens with the sizes of occupational groups. This exercise allows us to understand (and highlight) the influence of the organization of work on the effect on income inequality from changes in the dispersion of skills.

With the price of skill $w = 14.84$ and the individuals not allowed to change their occupation, including the entrepreneurs not allowed to dismiss any employee, the sizes of groups and the total output produced in the base case economy would not change. However, the distribution of income would change towards a more equal one: with the higher price of operational skill entrepreneurs see their profit-income reduced, while the income of employees goes up (the income of the solo self-employed is not affected). The transfer of income from entrepreneurs to employees implies a reduction in the GINI index, in the base case economy, from 0.416 to 0.362.

The assumptions that entrepreneurs are not allowed to dismiss any employee and that no one is allowed to change occupation are not realistic. Since the price of skill is set to a value higher than the equilibrium price (14.84 instead of 13.42), there will be relatively low-skilled entrepreneurs in the low dispersion economy that will stop hiring employees and become solo self-employed. More specifically, the level of skill from which individuals will choose to work as entrepreneur-managers will be the same as that of the equilibrium in the high dispersion of skill economy (13.80), but the number of entrepreneurs with skill above this threshold will be determined from the low dispersion of skill distribution. The calculation gives a share of individuals occupied as entrepreneur-managers in the low dispersion economy with the price of skill of the high dispersion economy of 5.5%, compared with 8.0% in the equilibrium of the low dispersion economy and 6.8% in the high dispersion economy. Moreover, those who continue as entrepreneurs will hire fewer employees. From the demand side of the market, aggregate demand for operational skills would diminish from 5.67 (in the low dispersion equilibrium) to 3.86 (aggregate demand decreases from 5.67 to 4.21 because of the higher skill price and from 4.21 to 3.86 because of the reduction in the number of entrepreneurs).

On the other hand, there would also be changes from the supply side of the market. Some individuals who chose to work as solo self-employed at the lower equilibrium price of skill will prefer working as operational employees at the higher price. Actually, 86.0% of the individuals would want to work as employees; 6.3% would work as voluntary solo self-employed, and 2.2% would do so as involuntary solo self-employed. Aggregate supply of operational skills increases from 5.67 to 6.21.

Overall, at the nonequilibrium skill price of 14.84, the aggregate demand of operational skill would be 3.86 and the aggregate supply would be 6.21, resulting in an excess supply of 2.35 (1.81 comes from the demand reduction and 0.54 from the supply increase). The question is to determine who will be finally hired as an employee to supply the operational skill input that the entrepreneurs demand. Since the operational skills supplied by the employees are perfect substitutes and the price of skill is given, for a given level of demand for operational skill, the entrepreneur is indifferent (same cost) between hiring fewer more skilled employees and hiring a larger number of less skilled ones. However, from the social welfare point of view, the alternative of entrepreneurs hiring more low-skilled employees is preferred. The reason is that the fewer and relatively highly skilled persons who do not work as employees will occupy themselves as relatively highly productive solo self-employed.

In particular, the proportion of persons occupied as employees is 62.3% when the hired employees come from the low skill end of the distribution and 43.3% when hired from the high skill end. The solo self-employed with relatively high (low) skill are 6.27% (44.96%) when employees are drawn from the low-skilled group and 29.97% (2.22%) when drawn from the high-skilled group. The respective total output and GINI indexes of income inequality are 162.7 and 0.517 if the employees are hired from the high-skilled group and 182.5 and 0.356 when hired from the low-skilled group. If those who find a job as employees are randomly chosen from the supply of employees, the proportion of persons occupied as employees (62.2%), the output (172.4) and the Gini index (0.422) would be in between the two extreme cases above.

In summary, imposing the equilibrium skill price of the high skill dispersion economy in the low skill dispersion economy reduces the total output and the number of individuals occupied as employees and as entrepreneurs. The effect on income inequality is ambiguous: the GINI index decreases if the hired employees come from the low skill end of the distribution and increases otherwise. In any case, the results from the decomposition exercise suggest that higher dispersion of skill increases the equilibrium price of operational skill, which in turn contributes to reducing overall labour income inequality (lower GINI). On the other hand, higher dispersion of skill changes the sizes of occupational groups in a way that overall income inequality increases. Therefore, the higher equilibrium price of skill in the high dispersion economy than in the low dispersion economy moderates the increase in income inequality from higher dispersion of skill.

The supervision hierarchy, through the joint production of employees and entrepreneur-managers at the job level, equalizes the operational skill of all employees, and therefore, the productivity of one unit of operational skill is the same across all employees. If low-skilled individuals had to work as solo self-employed individuals, their productivity would be much lower than working as employees. From a social welfare point of view, it is preferred to have more skilled individuals working as solo self-employed individuals, with or without employees, and less skilled individuals working as employees.

The minimum salary does just the opposite: it excludes low-skilled individuals from finding a job as employees. Although the minimum salary is often defended as a public policy that reduces income inequality, the calculations from the occupational choice equilibrium without a minimum wage show the opposite: Without a minimum wage, total output in the equilibrium increases 1%, from 188.23 to 190.04, and the GINI index decreases from 0.416 to 0.406. The reason is that the income as solo self-employed of those who lose their job as employees is significantly lower than their salary as employees. The choice between the minimum salary and regulations that raise the price of operational skill as alternatives to reduce income inequality falls outside the scope of the paper, but it may be a topic for future research.

5 Combining differences in the distribution of skill and differences in organizational size diseconomies

Differences in the distribution of skill, i.e., differences in λ and σ, are two sources of heterogeneity across countries (PIAAC data) but are not the only sources. This section extends the comparative analysis of income inequality allowing for differences in the parameters σ (dispersion of skill), λ (related to the mean of skill in the distribution) and β, organizational size diseconomies, across four economies, including the base case, Spain, with different distribution of skill according to the PIAAC data, and with different organizational size diseconomies, according to differences in their observed respective distribution of firm sizes. The PIAAC arbitrarily measures the cognitive skill of individuals on a scale from 0 to 500. In the base case, the units of the scale were rescaled for a value of $\lambda = 2$ (recall that in the lognormal distribution, $Median[q] = e^{\lambda}$ and $\sigma = \frac{1}{2.5631} \ln\left(\frac{q90}{q10}\right)$). The PIAAC gives the q90/q10 ratios of skills for each of the 22 countries. With $\lambda = 2$, the calibrated value of σ for the base case economy (Spain) was 0.39. With the PIAAC data on the median and quantile ratios of skill for the 22 countries, we estimate λ and σ and normalize them for the values of $\lambda = 2$ and $\sigma = 0.39$ of the base case economy (see supplementary material for more details). Finally, we select the values of λ and σ for the countries US, Germany, and Sweden to be used as representatives of the differences in the distribution of skill across economies.

The values of the organizational size diseconomies parameter are set to $\beta = 0.30$ for the US and $\beta = 0.35$ for Germany and Sweden, based on the observed differences in the distribution of firm size across the four countries (including the base case, Spain with $\beta = 0.40$). For example, the proportions of persons employed in firms with 250 or more employees in Spain, US, Germany, and Sweden are 0.313 (Eurostat), 0.540 (Bureau of Labor Statistics), 0.413 (Eurostat) and 0.443 (Eurostat), respectively. One of the points of this research is that countries will reasonably differ in variables other than dispersion of skill, and differences in the importance of large firms in the economies suggests that organizational size diseconomies will likely differ across countries, inversely with such importance.

Comparing the outcomes of economies that differ in the distribution of skill and in the organizational size diseconomies will provide insights into how the dispersion of skill interacts with characteristics of the internal organization of firms in explaining differences in labour income inequality. For that purpose, Table 3 shows some selected outcomes from the occupational choice equilibrium of the respective economy. Note that the minimum salary has been set so that the Kaitz ratio (minimum salary over average salary) is the same in the four economies (52.7%). The calculated equilibrium values in Table 3 are completed with actual values of the GINI index, productivity, and relative importance of large firms in Spain, US, Germany, and Sweden, from various sources (bottom of the Table).

In the column labelled US-like economy, the average span of control, the equilibrium price of skill and the total output are higher than in the base case. Moreover, the differences in these variables between the two columns are higher than in Table 2, when economies only differed in the dispersion of skill. The reason would be that lower organizational size diseconomies imply higher scale economies in the production function, and this is sufficient for firms demanding more operational skill and employing more employees, causing an increase in the equilibrium market price of operational skill. The combination of a more efficient supervision hierarchy (lower β) with a higher density of individuals in the upper tail of the distribution of skill (higher σ) reduces the equilibrium number of entrepreneurs and increases the number of employees in the new equilibrium. The more skilled entrepreneurs together with more effective supervision hierarchies complement each other, and the output produced increases by almost 50%.

Higher σ and lower β in the US-like economy imply higher income inequality than in the Spain-like economy in all but one of the indicators. The exception is the ratio P90/P10 from the distribution of income of all occupied individuals, which is lower in column two, 2.97, than in column one, 3.16. The equilibrium price of skill in column two is almost 70% higher than in column one. The higher dispersion of skill in the US-like economy implies that the skill of the person in P10 of the distribution of skill is lower in the US-like economy than in the Spain-like economy. The higher price of skill compensates for the lower skill, and the total salary of the person in the P10 of the distribution of skill is higher in the US-like economy than in the Spain-like economy. It turns out that the person in the P90 of the distribution of skill is an employee in the US-like economy and a solo self-employed in the Spain-like economy and that the two earn practically the same income. All these facts explain why the P90/P10 ratio of the distribution of income is similar in US-like and Spain-like economies.

Table 3 Scenario analysis of output and inequality from occupational choices equilibrium

	Spain-like economy	US-like economy	Germany-like economy	Sweden-like economy
Distribution of skills				
Lambda, λ	2.000	2.023	2.155	2.225
Sigma, σ	0.391	0.425	0.388	0.376
E(*skill*)	7.98	8.28	9.30	9.93
var(*skill*)	10.50	13.55	14.09	15.00
GINI skill	0.218	0.236	0.216	0.210
P90/P10 skill	2.723	2.971	2.706	2.623
P50/P10 skill	1.650	1.724	1.645	1.620
Size diseconomies				
β	0.40	0.30	0.35	0.35
ENDOGENOUS				
Occupational groups and output				
Employees	80.0%	85.5%	84.1%	84.0%
Entrepreneurs-managers	8.0%	3.8%	6.4%	6.8%
Span of control	10.00	22.46	13.07	12.32
Price operational skills	13.42	20.49	18.44	19.45
Total output	188.23	280.46	292.51	328.38
Income inequality				
GINI All	0.416	0.433	0.406	0.395
GINI employees	0.149	0.177	0.156	0.152
GINI entre-managers	0.445	0.576	0.482	0.469
GINI solo self-employed	0.349	0.718	0.476	0.424
P90/P10 employees	2.086	2.348	2.154	2.109
P50/P10 employees	1.492	1.513	1.497	1.488
P90/P10 all	3.163	2.971	2.803	2.769
P50/P10 all	1.650	1.724	1.645	1.620
% Income top 1%	15.4%	20.4%	16.6%	15.7%
Minimum wage	50.000	88.000	83.000	93.000
Mean wage	95.108	167.095	158.323	177.213

Table 3 (continued)

	Spain-like economy	US-like economy	Germany-like economy	Sweden-like economy
Observed data on productivity and inequality				
Labour productivity[a]	52.6	71	67	71.5
GINI[b]	0.501	0.506	0.495	0.432
% Employment in large firms[c]	0.313	0.54	0.413	0.443

For the four scenarios, $\theta = 1$, $c = 0.12$, $\mu = 0.25$, $k = 0.67$. The scenarios analysed differ in λ, σ, β and the minimum wage as follows: Spain-like economy ($\beta = 0.4$, $\lambda = 2.0$, $\sigma = 0.391$, $S_{\min} = 52.6$), US-like economy ($\beta = 0.3$, $\lambda = 2.023$, $\sigma = 0.425$, $S_{\min} = 88$), Germany-like economy ($\beta = 0.35$, $\lambda = 2.155$, $\sigma = 0.388$, $S_{\min} = 83$), and Sweden-like economy ($\beta = 0.35$, $\lambda = 2.225$, $\sigma = 0.376$, $S_{\min} = 93$)

The minimum wage values have been set so that the minimum to average ratios coincide in the 4 scenarios

[a]Source: OECD https://stats.oecd.org/Index.aspx?DataSetCode=PDB_LV

[b]Source: OECD Income Distribution Database https://stats.oecd.org/Index.aspx?QueryId=66600

[c]Source: EU data: https://ec.europa.eu/eurostat/databrowser/view/TIN00148/default/table, US data https://www.bls.gov/web/cewbd/table_f.txt

Additionally, notice that in the US-like economy, column two, the P90/P10 ratios of the distribution of skill and of the distribution of income coincide. This happens because in the market equilibrium of the US-like economy, those occupied in the P90 and in the P10 of the distribution are both employees in operational jobs, and the price of skill in the numerator and in the denominator of the ratio cancel out (as said before, in the Spain-like economy, a person in the P90 of the distribution of skill is a solo self-employed).

The last two columns show the equilibrium results in two economies labelled Germany-like and Sweden-like economies, respectively. Both have a higher β, higher λ and lower σ than that in the US (consistent with the PIAAC data). From the calculations in Table 2, it can be expected that the lower dispersion of skill in Germany and Sweden compared with that in the base case economy (Spain) would result in lower total output and less income inequality in the former countries than in the latter. The results in Table 3 show that inequality decreases but total output increases. The explanation is that the negative effect of lower dispersion of skill in total output is compensated by the positive effect on total output of lower β and higher average skill, λ.

The different outcomes of the Germany-like and Sweden-like economies, the latter with higher λ and lower σ than the former, provide information about the mixed effects of decreasing λ and increasing σ in countries' outcomes. In the market equilibrium, the Sweden-like economy produces more output and has lower income inequality than the German-like economy. When comparing the equilibrium outcomes of Sweden with those of the base case, the results are mixed. For example, the average span of control, the price of skill and the total output are higher in the Sweden-like economy than in the Spain-like economy. However, the overall income inequality is lower in Sweden than in Spain when measured by the Gini index but higher when measured by the concentration of income in the top 1% of the distribution.

The actual GINI indexes of income inequality shown at the bottom of Table 3 are higher than those calculated from the market equilibrium. However, keep in mind that the market labour income used in the calculation of the actual GINI includes labour and nonlabour income (for example, capital income) and that capital income is more concentrated in fewer people than labour income. The US economy has the highest GINI index, from real data and from the calculations behind the values in Table 3, followed by Spain. Sweden is the country with the lowest income inequality among those compared. The US is the country with the highest share of employees in large firms, and Spain has the lowest share. Overall, the differences in equilibrium outcomes across the simulated economies follow a similar pattern as that observed from actual data.

The comparison of equilibrium outcomes across economies that differ in several exogenous parameters and not only in dispersion of skill introduces more "noise" in the sign of the correlations between exogenous dispersion of skill and endogenous dispersion of labour income across economies than when the differences are restricted to the dispersion of skill.

5.1 Equal organizational size diseconomies than the base case for all countries

Although the main interest of the paper is in studying the relationship between dispersion of skill and dispersion in labour income, to complete the exposition, we present additional results that contribute to better understanding how differences in the organizational size diseconomies affect the equilibrium outcomes. For that purpose, the simulated economies in Table 3 are modified so that the parameter of organizational size diseconomies is set equal to 0.4 (the base case) in all of them (keeping the rest of parameters unchanged).

Solving for the new market equilibrium, it is possible to compare the new output produced and resulting income inequality for each country, with their respective values in Table 3 (complete results presented in Table B.1 of Appendix B-online supplementary material-). With $\beta = 0.4$, total output produced decreases (up to 19.3% in the case of the United States and more than 8% in Germany and Sweden). Income inequality measured in terms of the GINI Index increases in the labour income distribution of all occupied (up to 0.15 points in the United States economy and 0.08 points in the other two). However, income inequality within each occupational group decreases, and the concentration of income in the top 1% also decreases (2.6 percentage points in the US and 1.3 percentage points in the other two countries). To explain these results, first notice that higher organizational size diseconomies imply a higher number of entrepreneur-managers and a lower number of employees in the occupational choice equilibrium. Then, the average skill of entrepreneurs, the average profit per firm, and the average productivity of their employees all decrease. The equilibrium price of operational skill decreases as β increases. The results of Sect. 4.2, decomposition effects, show that a higher price of skill contributes to reducing overall income inequality for a given distribution of skill. Since higher β implies a lower price of skill in the equilibrium, higher β will increase inequality through the lower price of skill channel. Moreover, even though inequality within the occupational groups decreases with higher organizational size diseconomies, the fact that the proportion of individuals in the groups with higher within income inequality (entrepreneurs and solo self-employed) increases also contributes to higher overall income inequality.

6 Reconciling the theory with the empirical evidence

This section will examine possible reasons why differences in the dispersion of skill (apparently) contribute so little to explaining cross-country differences in wage and income inequality, particularly in empirical studies with PIAAC data (Paccagnella 2015; Pena 2016; Broecke 2016; Broecke et al. 2017, 2018).

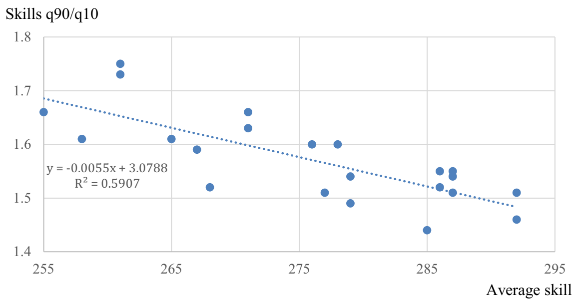
6.1 Measurement issues

The first issue is how close the cognitive skill measured by the PIAAC and other related studies is to the general skill in the theoretical model. Although it is reasonable to assume that literacy and numeracy skills will be part of the general skills, differences in work experience and in other ‘soft’ skills will also affect the correspondence between cognitive skills and usable occupational skills in operational and entrepreneurial-managerial jobs. In fact, the PIAAC data for Spain report a ratio of percentiles of skills q50/q10 equal to 1.34, while the q50/q10 of the distribution of skill with the calibrated Spanish data within the group of employees is 1.49. Then, the dispersion of skills from the calibrated lognormal distribution is greater than the dispersion in cognitive skills in the PIAAC survey data. The heterogeneity in experience and in noncognitive skills may partly explain the difference.

Another relevant issue for the proper calibration of the results from empirical studies is the nature of the jobs occupied by the individuals in the percentiles of the income distribution when calculating the wage ratios. The PIAAC database includes salaries and wages and does not consider entrepreneurial income. Databases with wages/salaries of employees may include employees who occupy jobs where they perform operational tasks, together with employees who perform intermediate or high management tasks. The theoretical model considers that professional managers hired by the business owners and entrepreneur-owners who perform the same managerial function with similar skill earn similar labour income (the manager-owner may earn additional income in the form of dividends if she holds shares in the firm).

Individuals in P50 and P10 of the income distribution in the PIAAC study will likely be working as operational employees; individuals in the same percentiles of the income distribution in the occupational choice equilibrium will also, in general, work employees. Therefore, the comparison between the P50/P10 ratio calculated from the market equilibrium and the ratio calculated from the PIAAC database will involve individuals within the same occupational group of employees. The individual in the percentile P90 of the income distribution in the PIAAC study could be occupied as an operational employee or as a manager (top or intermediate manager). If this was

Fig. 2 Correlation between the mean and dispersion of cognitive skills (PIAAC data). *Notes* q90/q10 is the ratio between the 90th and the 10th percentiles of skills. *Data source*: Data from Broecke et al. (2018) on the mean and dispersion of cognitive skills for 22 OECD countries



the case, the numerator of the ratio P90/P50 includes the income of an individual who occupies a managerial job, while the income in the denominator corresponds to that of an operational employee. The two could have been hired and contracted as employees, but according to the model, the compensation will be determined differently: the operational employee's salary will be proportional to skills, and the manager will receive a compensation increasing and convex with the level of skill.

6.2 Omitted variable biases

The theory predicts that inequality in the distribution of income will depend on other factors, different from the dispersion of skills. The omission of these other factors in the explanation of dispersion of income as a function of dispersion of skill will give biased results if the omitted variables are also correlated with the dispersion of skills. For example, Fig. 2 shows that the average and dispersion of skill are negatively correlated in the PIAAC data. If the average skill was positively correlated with the dispersion of income, then the omission of average skill in the estimation of the correlation between dispersion of skill and dispersion of income would result in a downwards biased estimated correlation.

The occupational choice models imply that in the market equilibrium, the distribution of market labour income depends on variables in addition to those of the distribution of skill, namely, the production technology, the organization technology, the user cost of capital and, in our analysis, the regulated minimum salary. More formally, if the chosen income inequality variable in cross-country data was the ratio P90/P10, as is the case in the studies with the PIAAC data, the variation in the ratio of percentiles of income can be explained by an unknown function of the values of the exogenous parameters of the model as follows $P90/P10 = g\,(\beta, \lambda, \sigma, \mu, k, c, \theta, S_{\min})$. Omitting explanatory variables of income inequality, other than lambda, correlated with the explanatory variables included in the model will result in similar estimation biases as those mentioned above.

The PIAAC data provide information only on countries' data on skills and wages. To go deeper into the potential biases from omitted variables, the nonobserved values of the parameters of the model for the 22 OECD countries with PIAAC data are substituted by simulated values. Next, the measure of income inequality will be correlated with the measure of skill inequality and different combinations of other explanatory variables. The values of parameters λ and σ of the lognormal distribution of skills for the 21 countries (excluding Spain) are calculated proportionately to the values of λ = 2 and σ = 0.39, calibrated for Spain in Sect. 3 (see the online Supplementary Material for more details). The rescaling of the mean and dispersion values of the cognitive skills across countries takes into consideration the negative correlation of − 0.77 between the mean and dispersion of cognitive skills (Fig. 2). The values of the rest of the parameters are estimated by random draws from a uniform distribution with a central value equal to the respective value of the parameter calibrated for Spain.

Each of the 22 vectors of parameters represents a simulated economy. Each economy will have its own distribution of labour income calculated from the respective market equilibrium. Next, the measure of income inequality P90/P10 used in studies with PIAAC data is explained as a function of the exogenous parameters that characterize the respective economy. The results appear in Table 4 for different specifications of the empirical model.

The $R^2 = 0.061$ in model one implies a correlation of (σ, P90/P10) = 0.247) that is not significantly different from zero (p value = 0.2675). This result is consistent with the findings reported in papers that correlate dispersion of skill and dispersion of income with PIAAC data. The estimation of column two with all parameters of the model as explanatory variables has an R^2 close to one, as expected considering the way the data points are generated (the coefficient of determination is not equal to one

Table 4 Estimation of income inequality as a function of parameters of the model: Dependent variable P90/P10 of the income distribution

	Model 1	Model 2	Model 3	Model 4
σ	3.0243 (2.6521)	1.605 (1.216)	2.757*** (0.778)	5.6334 *** (0.831)
λ		− 0.327 (0.269)		0.128 (0.200)
β		5.093*** (0.470)	4.97*** (0.47)	4.36*** (0.54)
μ		− 2.72*** (0.64)	− 2.69*** (0.65)	− 2.13*** (0.635)
k		4.89*** (0.89)	4.59*** (0.875)	5.008*** (0.946)
$S_{\min}$		0.0012 (0.0099)	0.0039 (0.0098)	0.0064 (0.010)
c		0.215 (4.88)	1.71 (4.81)	5.077 (5.196)
θ		− 0.39 (0.437)	− 0.307 (0.44)	− 0.440 (0.49)
Constant	1.7783* (1.0111)	− 1.102 (1.39)	− 2.40** (0.90)	− 4.337*** (1.047)
R2	0.061	0.961	0.961	0.968
Observations	22	22	22	22

For models 1–3, the values of λ and σ are based on observed data for 22 OECD countries (source: Broecke et al. 2018), so that they are negatively correlated corr(λ, σ) = − 0.77. In model 4, λ and σ are resampled so that they are uncorrelated. The rest of the parameters are generated from independent uniform distributions (centered in the calibrated values of the respective parameters in the base case)

The values of the dependent variable, the ratio of the 90th and 10th percentiles of labour income P90/P10, are calculated from the equilibrium Eqs. (7–10), given the randomly generated values of the parameters (λ, σ, β, μ, k, $S_{\min}$, c, θ)

Standard errors in parenthesis

*, **, *** indicate significantly different from zero at $p < 0.10$, $p < 0.05$, $p < 0.001$

because the econometric model is a linear approximation of a nonlinear deterministic functional relationship). The estimated coefficients of the parameters of the distribution of skill, σ and λ are not statistically significant; the same is true for the coefficients of the explanatory variables minimum wage, cost of capital, and general TFP. The estimated coefficients of the other three explanatory variables are statistically significant, with a positive sign in the case of parameters β and k and a negative sign in the case of μ.

Column three reports the results of excluding the λ parameter, proxy for the mean of skill, from the list of the explanatory variables. The results in column four correspond to the estimation where the values of λ and σ are uncorrelated (in the other columns, their correlation is that observed in the PIAAC data, − 0.77). When λ is omitted as an explanatory variable and when its values are uncorrelated with the dispersion of skill, the estimated coefficient of the dispersion of skill variable is positive and statistically significant: income inequality increases with the dispersion of skill in the working population, as predicted from the model.

The nonstatistical significance of the coefficient of the dispersion of skill variable (σ) in Model 1 is the consequence of omitting the other relevant explanatory variables (especially λ, negatively correlated with σ), i.e., biases from omitted variables. The nonstatistical significance of the estimated coefficient of σ in Model 2 is a consequence of the negative correlation, − 0.77, between σ and λ (the multicollinearity among the explanatory variables increases the estimated standard error of the estimator). The small sample may also have an effect on the estimated results. Online Appendix C shows the results of replicating the same estimations as those in Table 4 but with vectors of parameter values generated for 200 simulated economies instead of the 22 for which PIAAC data are available. In all specifications, the estimated coefficient of the explanatory variable σ is positive and significantly different from zero. The main differences between the estimations in Table 4 and those in Online Appendix C are in the estimated standard errors, not in the estimated values of the coefficients. In conclusion, the apparent independence between dispersion of cognitive skills and dispersion of wages in the PIAAC data could be attributed to misspecification of the econometric model with the omission of other relevant explanatory variables, including not accounting for the high (negative) correlation between mean and dispersion of cognitive skills in the PIAAC data, aggravated by the small sample of countries included in the analysis.

The empirical studies on the association between dispersion of skill and income inequality are concerned not only about the possible biases in the estimation of the coefficient of the explanatory variable with cross-country data but also about the evaluation of the explanatory power of the distribution of skill variable. The supplementary materials show the results of simulations that inform about the contribution to the explanation of the variance of the income inequality variable of the different explanatory variables of the model. When dispersion and mean of skill are treated as independent variables, the dispersion of skill variable is the main explanatory variable of income inequality, measured by the GINI index and by the concentration of income in 1% of the distribution, with more than 80% of the dependent variable explained by the σ of the distribution of skill. When λ and σ are negatively correlated, as in the PIAAC data, the proportion of variance of income inequality explained by the dispersion of skill variable decreases to 28%. The reduction in the explanatory power of the dispersion of skill is compensated by an increase in the explanatory power of the mean of skill (negatively correlated with dispersion) and of the organizational size diseconomies parameter.

7 Conclusions

This paper examines the determinants of market labour income inequality at the individual level, with special attention given to the relationship between the distribution of general skills in the working population and market labour income inequality. It does so by analysing the properties of market equilibrium outcomes in economies where individuals with different general skills make occupational choices of working as employees, solo self-employed and entrepreneurs who perform supervision and direction functions. Then, the labour income distribution includes the earnings of individuals in all these occupations. The results indicate that in samples of economies where the distributions of skill in the working population have similar dispersion but different means and all the rest are equal, a positive cross-country association should be observed between the mean of skills and average labour productivity, but the correlation of average skill with income dispersion would be expected to be low. On the other hand, differences in dispersion of skill with similar means are expected to be highly correlated with dispersion of income (especially concentration of income in the top 1%), as well as with average labour productivity. The positive correlation between dispersion of skill and dispersion of income is the net effect of an increase in income inequality due to differences in the size and composition of occupational groups in the low and high dispersion economies and a decrease in income inequality from the higher equilibrium price of skill in the high dispersion of skill economy than in the low dispersion of skill economy.

The comparison of the distribution of income in two economies that differ only in the dispersion of skills helps to better understand the efficiency and distributional effects of dispersion in cognitive skills. First, the economy with greater dispersion will produce more output because those occupied as entrepreneur-managers are more skilled than the entrepreneur-managers in the economy with less dispersion of skills and because there are more individuals working as operational employees and fewer involuntary solo self-employed individuals. Second, the economy with greater dispersion of skills concentrates a higher proportion of individuals in the two tails of the distribution than the economy with low dispersion. The greater dispersion of skills is sufficient for higher income inequality in the market equilibrium, although the dispersion in the distribution of market labour income increases proportionately more because of the more than proportional increase in the profits-income of the fewer but more skilled entrepreneur-managers at the top of the distribution.

The PIAAC data indicate that the mean and the dispersion of measured cognitive skills are negatively correlated, i.e., countries with higher mean (lower) have lower (higher) dispersion. This fact will necessarily complicate the explanation of cross-country differences in productivity and income inequality. Moreover, if the educational system of the country can modulate the distribution of cognitive skills in the population, some countries seem to opt for educational systems that sacrifice the mean for more dispersion (such as the US), while others sacrifice dispersion for a higher mean (northern European countries). This clearly opens a new avenue of research and policy debate about the relationships between countries' educational systems, the productivity of their economies and their respective market labour income inequality.

The educational system and its influences on the distribution of cognitive skills is one of the many elements of the market and production environment that can affect the efficiency and inequality of market economies. Previous research has highlighted the relevance of labour market institutions such as collective bargaining, protection of employees' rights, costs of hiring and firing as determinants of the prices of skill across economies. This paper shows that the price of skill is determined differently within each occupational group and that in all cases, the prices will depend on the parameters of the production technology, the internal organization of firms and the market prices of other inputs (cost of capital). Therefore, it is not necessary to have heterogeneity of labour market institutions across countries to have differences in prices of skill and for having different effects of these prices on income inequality. Except for minimum wage regulation, this paper does not consider other institutional or regulatory constraints in the functioning of markets. The consequences observed from the introduction of a minimum wage (benefiting some occupational groups but penalizing others) illustrate the relevance of considering general equilibrium effects in the assessment of the effects of market regulations, taxes, and subsidies that alter the market equilibrium. Moreover, the results from the decomposition of differences in income inequality in economies with different dispersion of skill suggest a new line of research about the benefits and costs of introducing a minimum wage and of increasing the price of operational skill as income redistribution mechanisms.

Future research should also extend the analysis presented here to solve for the market equilibrium and study the determinants of income inequality with more general production technologies than the Cobb–Douglas production function. On the empirical side, research should advance in developing country-level data on proxy variables of organizational size diseconomies, the capital intensity of the production technology, the efficiency of the solo self-employed and, together with data on skills, re-estimate the models on the determinants of productivity and income inequality with the real data. None of these variables is accounted for in the papers on determinants of wage inequality referenced in the introduction of the paper, so the theoretical results are difficult to relate to the existing empirical evidence. With proxy values on these variables, it will also be possible to extend the paper from an emphasis on explaining differences in productivity and income inequality across countries in a given moment of time to incorporate into the analysis the evolution of productivity and inequality for a single country over time. Particularly worthwhile will be the exploration of the trade-offs between efficiency and distributional concerns under changes in production and organization technologies, for example, those caused by intensification in the use of computers to perform routine tasks. On the policy side, it may be worthwhile to compare, in a cost–benefit way, alternatives to the minimum salary to reduce income inequality. The minimum salary forces low skilled-low productive individuals to work as (involuntary) solo self-employed; the results of the paper suggest that total output would increase with public policies (for example taxes that increase the price of skill) that favour low skilled individuals working as employees, and middle skilled individuals working as voluntary solo self-employed.

A third line of future research is replicating the results on the relation between dispersion of skills and income inequality in occupational choice models with knowledge hierarchies (Garicano 2000) instead of the supervision hierarchies of Rosen (1982) (considered in our analysis). The main and most relevant difference in the predictions from the two theories is that under the supervision hierarchy, there is perfect substitutability among employees in operational jobs, and therefore, the composition of employees in terms of modified operational skill is the same across firms. On the other hand, in the market equilibrium of the knowledge economy, the composition of skills of employees will not be homogeneous across firms; rather, more skilled employees will tend to be employed in firms with more skilled managers. We conjecture that replacing the knowledge hierarchy in place of the supervision hierarchy would not change the prediction of a positive association between dispersion of skills and income inequality; in fact, it could be expected to be stronger since higher dispersion of skill would increase even more the income inequality within the group of employees.[11]

Considering other related applied research, knowledge and supervision hierarchy both explain the empirical finding of Smeets and Warzynsky (2008) that managers' compensation increases with their span of control. However, the supervision hierarchy could not explain the evidence of Iranzo et al. (2008) of a positive association between the dispersion of skill of employees (production and nonproduction) and the productivity of their respective firms. Santamaria (2022) reports evidence that in larger cities, there are more qualified managers, average income is higher, and income is distributed more unequally than in smaller cities. Moreover, she provides her own evidence of a negative correlation between the size of cities and the average span of control of managers. Higher dispersion of skill in larger cities than in small cities would be a sufficient condition for an occupational choice model with supervision hierarchies to explain this evidence (more skilled managers, higher average income, and higher income inequality in larger than in smaller cities). However, the positive association between dispersion of skill and size of the city would predict a positive correlation between size of the city and average span of control of managers, contrary to the reported evidence. Santamaria (2022) reconciles the evidence and the theory with an occupational choice model and knowledge hierarchies whose technology differs horizontally, i.e., is different (more complex) in larger cities than in smaller ones.

[11] Empirical research sorts out evidence in support of predictions from the two organizational hierarchy models. Gould (2002, 2005), Ingram and Neumann (2006) and Capatina (2014) provide evidence indicating the level of skill is becoming more important than the firm or the job position to explain differences in wages among employees. Mueller et al. (2017a, b), using UK data, find a firm size effect on average wages but no firm size effect at all on wages in the lower levels of the organizational hierarchy, where jobs are mainly operational. The within firm wage inequality is higher in larger than in smaller firms because large firms pay higher salaries to employees in higher (managerial) levels of the hierarchy, which is consistent with the convexity of the relationship between compensation and skill in management positions, predicted by the hierarchy supervision model. This evidence complements the research that compares the within and between firms' decompositions of wages' inequality (Card et al. 2013; Boddin and Kroeger 2021), calling into attention the relevance of separating operational from managerial jobs when performing the decomposition.

To explain all the evidence about differences in income distribution across cities of different sizes with an occupational choice model with supervision hierarchy, it would be necessary, for example, to combine differences in the dispersion of skill and higher organizational size diseconomies in larger cities than in smaller cities.

The interest of future research comparing the predictions from occupational models with knowledge and supervision hierarchies goes beyond the study of the determinants of income inequality and extends to many other relevant fields of study.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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