FONDAZIONE ARISTIDE MERLONI

ECONOMIA MARCHE **Journal of Applied Economics**

Vol. XLII, No.1, Marzo 2023

Linking the labour share of income to market imperfections: Microeconomic evidence from Italy

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abstract

In the last 15 years or so, the Italian labour share of income has not displayed a clear pattern; this is partly due to the fact that different organizations compute it in different ways, making it difficult to draw a clear picture of this important labour indicator. Additionally, microeconomic evidence on product market power is still limited. In this study, we aim to shed light on the recent dynamics of the labour share in Italy and to better understand how such dynamics relate to the changes in market imperfections. Using firm-level data on a large sample of manufacturing firms for the years 2010-2018, we show that the observed trend in the revenue-based labour share, which is more reassuring than the trend in the value-added labour share, is associated with a muted increase in the markups which, however, is more than offset by the rise in the parameter of labour market power. Also, variations in the labour share are driven by within-firm variations and are mostly explained by the wage share component. Finally, some inter-regional disparities emerge.

JEL Classificazione: *D33, J42, L11*

Keywords: *labour share, market power, markup*

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Acknowledgments

I would like to thank Prof. Stefano Schiavo and Prof. Mauro Caselli (University of Trento) for the useful comments and suggestions, and Fondazione Caritro (Trento) for financially supporting me during the main phases of the research that led to this output.

1. Introduction

The labour share of income is a key labour market indicator which has long been object of debate both outside and inside the academic arena. In particular, in recent years, several researchers have attempted to shed light on what is often defined as "the secular decline" in the US labour share, which contrasts with the historical stylized fact of stable labour share highlighted by Kaldor (1957). Many possible explanations have been put forward, such as the decrease in the relative price of investment goods due to information technology (e.g., Karabarbounis and Neiman, 2014), the introduction of labour-market institutional reforms leading to a reduction in the bargaining power of labour (e.g., Bental and Demougin, 2010), the change in the industry composition to the detriment of manufacturing (e.g., Armenter, 2015), the rapid expansion of trade and international outsourcing (e.g., Elsby, Hobyn and Sahin, 2013), and the increasing importance of intangible capital, associated with lower expenditures on labour (e.g., Koh, Santaeulàlia-Llopis and Zheng, 2020).

However, an emerging strand of literature underlines the fact that these hypotheses are supported by mixed empirical evidence, and more importantly, that they assume there is a trade-off between labour and capital (namely, that firms have replaced expenditures on labour inputs with expenditures on capital inputs), which does not always occur. Instead, this fast-growing strand of literature focuses on the role played by rises in product market power, and in particular by corporate price-cost margins, or markups[1]. Specifically, De Loecker, Eeckhout and Unger (2020), who employ the methodology proposed by De Loecker and Warzynski (2020) to estimate firm-level, time-varying markups, document a significant increase in product market power across US non-financial corporations over the last few decades, which seems to be mainly attributable to what Autor et al. (2020) define "superstar firms". Moreover, they link such an increase to both to the decline in the labour share and to other worrying trends, such as the decrease in labour force participation, the rise in wage inequality, and a slowdown in business and labour dynamism.

Since the working-paper version of De Loecker and co-authors' study was made public, a considerable number of studies have estimated firm-level markups using methodologies that imply the estimation of a production function and linked them with other relevant variables, including the labour share. As an illustration, the IMF (2019) shows that the (firm-revenue-weighted) average

[1] The markup is the ratio between the price applied by a firm and corresponding the marginal cost. Unlike its definition, the computation is not straightforward, as marginal costs are not observable. Since the publication of the seminal paper by Hall (1986), who suggests measuring the marginal cost using the observed change in input cost corresponding to the variation of output from one year to the next, a large strand of literature has estimated markups drawing upon Hall's methodology, or applying an extension or refinement of the latter (e.g., Domowitz, Hubbard and Petersen, 1988; Morrison, 1988; Roeger, 1995; Klette, 1999; Crafts and Mills, 2005). An important methodological advancement is made by De Loecker and Warzynski (2012), who develop a method that, unlike prior work, produces firm-level estimates of markups and controls for unobserved productivity shocks.

markup based on a sample of 27 countries increased by 6% during the period 2000-2015, and that this rise has contributed to the recent contraction of firms' labour shares. In particular, for the overall sample, the average increase in markups since 2000 is associated with a 0.2% decrease in the labour share, whereas for the sample of top decile firms, the average increase in markups is associated with a 1% decrease in the labour share, a result which reinforces the "superstar firms" hypothesis. Similarly, the cross-country, firm-level study by Diez, Leigh and Tambunlertchai (2018) on the relationship between markup and investment, innovation, and labour share respectively finds that the association between the markup and the labour share is generally negative. Additionally, Mertens (2019), who extends De Loecker and Warzynski's (2012) framework to incorporate frictions in the labour market, finds that 70% of the labour share decline that occurred between 1995 and 2014 in the German manufacturing sector is explained by a decrease in the output elasticity of labour, while the remaining 30% is attributable to firms' increasing labour and product market power, and then to market distortions. At the same time, some studies focusing on the OECD countries and Europe indicate that also there, labour share on average has recently fallen, but not as remarkably as in the US, and, importantly, with relevant differences across countries, some of which (e.g., the United Kingdom and France) have experienced even an increase since 2000 (see for instance: Schwellnus, Kappeler and Pionnier, OECD, 2017; McKinsey Global Institute, 2019; Schwellnus et al., OECD, 2018).

A European Union country which represents an interesting case study in this regard is Italy: Italy is an advanced economy which, especially in recent years, has exhibited a mixed economic performance, including an ambiguous trend in the labour share, which is also affected by the level of analysis and the definition considered. In this regard, if we first compute the labour share (for instance, from 1995 onwards) using aggregate data from Istat Statistics, and then employing information from Ilostat, we can notice that the two series differ not only in terms of the absolute level but, more importantly, also in terms of the trend (in particular, during the period 1995-2018 the Istat-based labour share shows an average positive trend, while the Ilostat indicator does not display a clear prevailing direction). The main source of such a divergence seems to lie in the way the two indexes are computed; hence, as Torrini (2016) stresses, it is important to properly clarify how a certain labour share indicator has been built.

Interestingly, some studies have attempted to link changes in the labour share in Italy with the trends in product market power. Torrini (2016), who explores the long-run trends and recent patterns in labour, profit and housing rent shares in this country, hypothesizes that the trend reversal in the labour share observed at the beginning of the new millennium after a long period of slowdown is mainly attributable to a compression in corporate markups, and to the difficulty experienced by the Italian firms in being rewarded for their innovation in a more competitive environment. Nonetheless, the author does not empirically examine the labour share-markup nexus. Microeconometric evidence of a negative relationship between product market power and the labour share in Italy has been provided by Dall'Aglio et al. (2015) and Perugini et al. (2017), who estimate the labour share at the firm level for a large sample of Italian companies (and also for companies from other five EU countries in Perugini et al., 2017), and investigate its main determinants. Both these studies find a significant and negative coefficient for product market power, which, however, is not estimated using a production function, but is simply proxied by the return on sales and the ratio between sales minus variable costs and sales, respectively. Moreover, although a few recent contributions have shed light on this topic (e.g., Mondolo, 2022; Ciapanna et al., 2022), microeconomic evidence on Italian markups is still limited.

In light of these considerations, we aim to provide further evidence on the recent trends in the labour share in Italy, and in particular on the relationship between the former and the markups.

To this end, we draw upon a recent extension of the methodology developed by De Loecker and Warzynski (2012), which presents the following main advantages. First, it allows us to obtain an accurate, firm-level and time-varying indicator of a company's competitive position in the product market; second, it makes it possible to perform various markup decompositions aimed to shed light on the mechanisms underlying the observed variations over time. Also, it permits to easily estimate a measure of labour market power as well, and thus to scrutinise the determinants, size and trend of market power in both the product and the labour markets. Concerning the labour share, we compute two indicators, namely the widely used value-added labour share (i.e., the ratio between cost of employees and value added) and the revenue-based labour share (i.e., the ratio between cost of employees and revenues); we mainly focus on the revenue-based labour share because, as we analytically and graphically show, it is linked to the markup by a specific relationship which also accounts for the role played by labour market power.

From our analysis on a large sample of Italian manufacturing firms observed during the years 2010-2018 it emerges that, in recent years, the value-added labour share has exhibited a mixed trend, while the revenue-based labour share has slightly increased despite an increase in the markups. The variation in the labour share is indeed explained also by two other variables, namely the output elasticity of labour and labour market power, and the growth in this latter variable has more than offset the (limited) rise in product market power and the decline in the output elasticity of labour. Additionally, the changes in the labour share are driven by within-firm changes, and the wage component is the one that mostly accounts for both the level and the trend in this variable. Finally, some inter-regional differences emerge, with the Mezzogiorno being the macroarea that has experienced the strongest rise in the labour share during the period under scrutiny.

The balance of this study is organized as follows. Section 2 presents the analytical framework. Section 3 illustrates some basic descriptive statistics and some decompositions of the labour share for the selected sample of Italian manufacturing firms. Section 4 illustrates how changes in the revenue-based labour share are associated with changes in the markup and in two other variables. Section 5 concludes.

2. Analytical framework

2.1 Data

The data used to calculate the labour share of income and the markups come from the commercial database AIDA by Bureau van Dijk and cover the years 2010-2018. We retrieve information on revenues, labour costs, number of employees, the book value of the capital stock, expenditures on intermediate inputs (i.e., materials), the industrial sector of activity and the year of birth of the firm. We merge these firm-level data with industry-level deflators of value added, intermediate inputs and tangible assets compiled by the National Statistical Office (Istat) and OECD-Stan. The raw data require intensive cleaning to net out the influence of measurement error and extreme values, and we exclude firms that remain in the sample for less than five consecutive years. The resulting dataset contains 287,630 observations, corresponding to 36,360 firms.

2.2 Estimation of the markups

We estimate the parameter of corporate markup drawing upon De Loecker and Warzynski' s (2012) methodology. This approach assumes that firms minimize costs and at least one input (materials) is adjusted freely, while the other factors (capital and labour) may show frictions in their adjustment. Unlike previous contributions, this framework requires neither assumptions on demand and how firms compete, nor the computation of the user cost of capital, and provides firm-level, time-varying estimates while controlling for unobserved productivity.

By combining the optimal input demand conditions obtained from cost minimization with the standard definition of markup (i.e., price over marginal cost), De Loecker and Warzynski show that the price-cost margin can be identified as the ratio of the output elasticity of materials and its revenue share:

$$\mu_{it} = \frac{\theta_{it}^{M}}{\alpha_{it}^{M}}, \qquad (1)$$

where μ_{it} is the markup of firm i at time t, θ_{it}^{M} is the output elasticity of materials and α_{it}^{M} is the revenue share of materials, also known as cost share or expenditure share of materials.

If $\mu_{it} = 1$, the firm operates in a product market characterized by perfect competition; if $\mu_{it} > 1$, there is imperfect competition in the product market and the firm owns some degree of product market power, namely, it charges a price that is higher than the marginal cost.

We also estimate a measure of labour market imperfections, that we label φ, as the ratio between the average labour cost paid by firms (w), which we observe in the data, and the marginal revenue product of labour (MRP^{L}):

$$\varphi_{it} = \frac{w_{it}}{MRP_{it}^{L}} \qquad (2)$$

The parameter φ captures the wedge between the cost of an additional unit of labour and the revenue it generates (both in nominal terms); therefore, it is a measure of (labour) market power on the side of firms' employees. If $\varphi = 1$, the wage is equal to the marginal revenue product of labour and the labour market is competitive. On the other hand, any departure from unity signals frictions, stemming from either the existence of labour market power owned by the firms, resulting in $\varphi < 1$ and implying that the marginal revenue of labour is higher than the wage, or from some degree of market power by firms' employees ($\varphi > 1$).

As Mertens (2019, 2020) and Caselli, Nesta and Schiavo (2021) demonstrate, φ can be expressed in terms of the ratio of the output elasticity of materials over the revenue-based materials share and the output elasticity of labour over the revenue-based labour share:

$$\varphi_{it} = \frac{\frac{\theta_{it}^{M}}{\alpha_{it}^{M}}}{\frac{\theta_{it}^{L}}{\alpha_{it}^{L}}} \qquad (3),$$

where $\frac{\theta_{it}^{M}}{\alpha_{it}^{M}}$ represents the markup, θ_{it}^{L} is the output elasticity of labour and α_{it}^{L} is the revenue-based labour share of firm i at time t. Even though we focus on the markups, we also account for labour

market power since the latter is strictly related to both product market power and the labour share, as we show in Section 4.
While the revenue shares can be easily computed using data from firms' balance sheets, the output elasticities need to be estimated. In the Appendix, we briefly illustrate how we estimate a firm-level production function that permits us to uncover the parameters θ_{it}^{M} and θ_{it}^{L} and then to compute our indicators of market imperfections.

3. An overview of the labour share based on microdata

This section provides some descriptive analysis of the labour share in the Italian manufacturing sector drawing upon our sample of manufacturing companies observed during the period 2010-2018.
Table 1 reports some basic descriptive statistics of both the revenue-based labour share and the value-added labour share, as well as their two main components based on the decomposition of the numerator (cost of employees), namely, the wage share and the security share. We see that the average revenue-based labour share calculated for the whole sample amounts to 25%. Thus, it is quite conform to the usual manufacturing characteristics that the largest share of total sales is represented by costs for materials, whereas labour costs generally represent about one-third of total revenues. On average, the wage share and the social security share represent about 72% and 21.5% of the labour share, respectively, while the residual part consists in the share of other labour costs. The value-added labour share has a mean equal to 0.7, but exhibits a large degree of heterogeneity.

We expect that the various manufacturing sectors use different combinations of inputs and also present different average levels of labour share. Accordingly, in Table 2 we report the average revenue-based labour share per sector, together with the material share. We observe that the mean labour share ranges between 0.18 in Chemical and pharmaceutical products to 0.27 in Basic metals and fabricated metal products. Generally, the sectors characterized by relatively low labour share exhibit relatively high levels of material share.

Table 1. *Labour share and its components, basic descriptive statistics (whole sample)*

	#obs	mean	std. dev.	p1	p25	p50	p75	p99
revenue-based labour share	287,618	0.246	0.119	0.067	0.158	0.225	0.310	0.625
revenue-based wage share	287,456	0.177	0.087	0.047	0.114	0.162	0.223	0.460
revenue-based social security share	287,456	0.053	0.028	0.009	0.033	0.048	0.068	0.140
value-added labour share	287,618	0.696	0.707	0.245	0.574	0.703	0.810	1.147
value-added wage share	287,456	0.501	0.503	0.173	0.505	0.585	0.585	0.841
value-added social security share	287,456	0.150	0.154	0.030	0.117	0.150	0.180	0.285

Table 2. *Revenue-based labour share and material share by sector*

Sector	#firms	#obs.	abour share	naterial share
All manufacturing	36,360	287,630	0.246	0.601
Food products, beverages and tobacco	3,485	27,357	0.184	0.68
Textiles, wearing apparel, leather and related products	4,032	31,523	0.261	0.598
Wood and paper products, and printing	3,476	27,381	0.238	0.609
Chemical and pharmaceutical products	1,364	11,038	0.178	0.675
Rubber and plastics products, and other non-metallic mineral products	1,805	14,105	0.236	0.613
Basic metals and fabricated metal products, except machinery and equip.	11,229	90,047	0.27	0.562
Computer, electronic and optical products	959	7,507	0.256	0.588
Electrical equipment	1,337	10,582	0.235	0.627
Machinery and equipment n.e.c.	3,790	30,127	0.238	0.613
Transport equipment	610	4,891	0.237	0.62
Furniture; other manufacturing; repair and installation of mach. and equip.	4,273	33,072	0.26	0.59

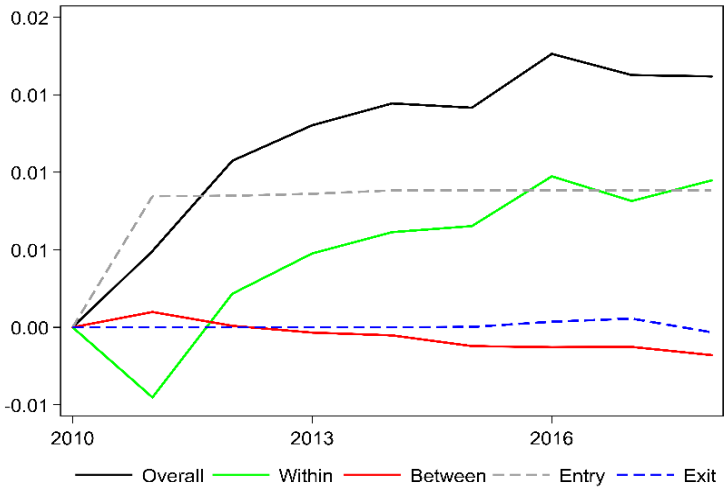
We now look at the recent dynamics of the labour share. As in the case of the aggregate labour share, when we interpet this indicator, we have to pay attention to the way it has been computed. As Figure 1 shows, the average value-added labour share (left panel) and the revenue-based labour share (right panel) of our sample differ not only in level, but also in terms of trend. In particular, the value-added labour share increased between 2010 and 2012, fell from 2012 and 2016 and then slightly increased again, whereas the revenue-based labour share, which peaked in 2016, exhibits a positive average growth.

From now on, we focus on the revenue-based labour share. In order to shed light on the mechanisms underlying the observed dynamics, we first decompose the overall trend in its within-firm, between-firm, entry and exit components using Foster, Haltiwanger and Krizan's (2001) decomposition. From Figure 2, we see that the increase occurred between 2010 and 2011 is mainly attributable to firm entry, and that the within-firm component contributed negatively. Conversely, from 2011, the overall trend in the labour share was driven by the within-firm component, while the contribution of new firms becomes negligible.

Figure 1. *Value-added labour share and revenue-based labour share (weighted averages), 2010-2018*

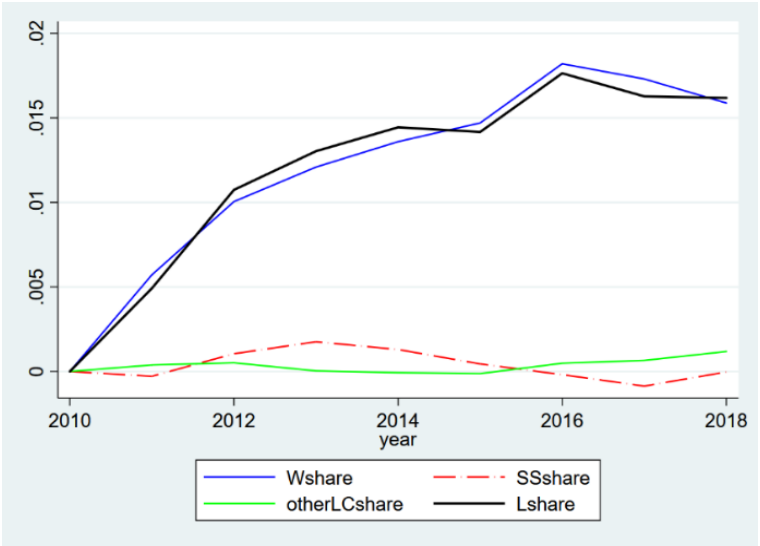
Note: *we did not plot the two labour-share series in the same figure in order to obtain a clear view of the trends in both the variables (which present a significantly different range of values)*

Figure 2. *FHK decomposition of the revenue-based labour share, 2010-2018 (2010 = 0)*



Then, we perform an additional decomposition which is based on the disaggregation of the (gross) total cost of employees in three parts, namely: net wages, social contributions and other labour costs (including the severance pay). As **Figure 3** reveals, the average overall trend is mainly attributable to its largest component, i.e., the wage share, while the social security share declined between 2013 and 2017. The fall in the social security share was accompanied by a (limited) decrease in the social security contribution rate (i.e., the ratio between social security contributions and total cost of employees).

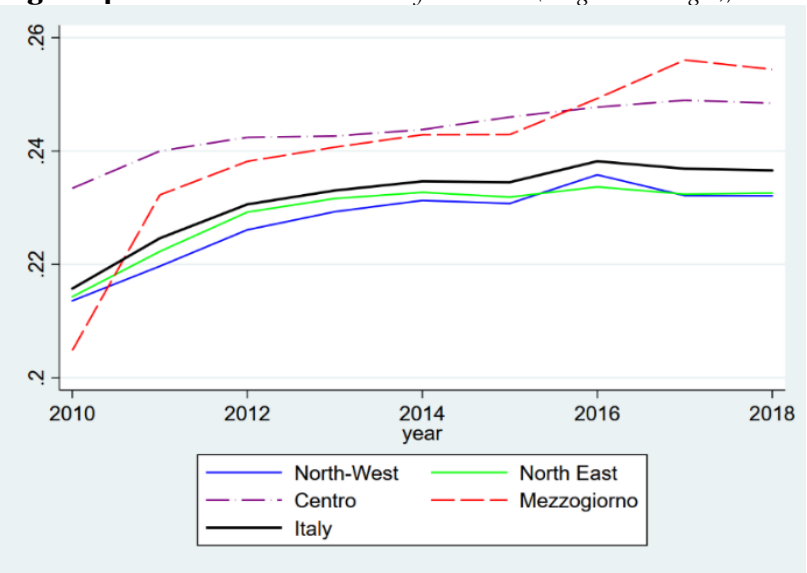
Figure 3. *Contributions of wage share, social security share and share of other labour costs to revenue-based labour share (2010 = 0)*



Also, the national picture may hide relevant within-country heterogeneity. Hence, in **Figure 4** we plot the labour share of the four Italian macro-areas (i.e., North-West, North-East, Centro and

Mezzogiorno), as well as the average Italian one (black solid line). We notice that the labour share in in the Mezzogiorno is the one that experienced the strongest growth during the period under scrutiny and, from 2015, is also the largest one among the four macroareas. From the medium-term analysis (1995-2018) of the trend in the labour share based on Istat aggregate data, it emerges that, in the Mezzogiorno, this labour outcome rapidly grew especially between the beginning of the 2000s and 2010. Brunello, Lupi and Ottone (2001) report that the labour share had already increased particularly fast in this region during the seventies, mainly as a consequence of the elimination of the institutions that allowed the presence of significant wage differentials.

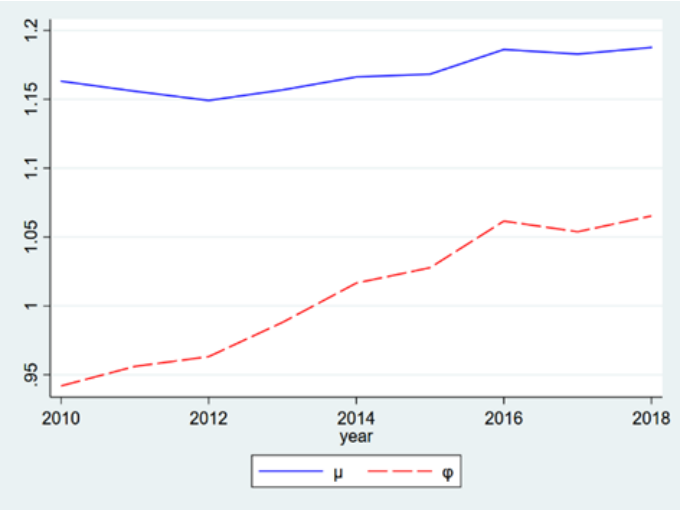
Figure 4. *Revenue-based labour share by macroarea (weighted averages), 2010-2018.*



4. Linking the labour share with market imperfections

Before focusing on the markup-labour share nexus, it can be useful to have a look at the trend in product market power (proxied by corporate markups) and how the latter co-moves with labour market power. **Figure 5** documents the evolution of the average indicators of product and labour market power weighted by firms' employment shares. The markup μ declined from 2010 to 2012 and then reversed its trend, but it increased by only 2% between 2010 and 2018. This upward trend since 2012 also holds after excluding firms with relatively high markups (above the 90th percentile), suggesting that it is not mainly driven by firms in the right part of the distribution. During the same period, the indicator of labour market frictions φ experienced a 13% growth, which corresponds to a shift of labour market power away from firms and towards workers. In a companion work (Mondolo, 2022), we conduct a more in-depth analysis of these market imperfections and provide some explanations for the reassuring but somehow unexpected finding concerning the rise in bargaining power.

Figure 5. *Average weighted markup and labour market power, 2010-2018*



The evolution of product and labour market power help explain the trend in the labour share of income. Drawing upon Mertens (2019), we show that a rising (falling) revenue-based labour share is associated with increasing (decreasing) output elasticity of labour, decreasing (increasing) product market power, and increasing (decreasing) labour maker power detained by workers[2]. Specifically:

$$\alpha_{it}^{L} = \varphi_{it}\, \theta_{it}^{L}\, \frac{1}{\mu_{it}} \qquad (5)$$

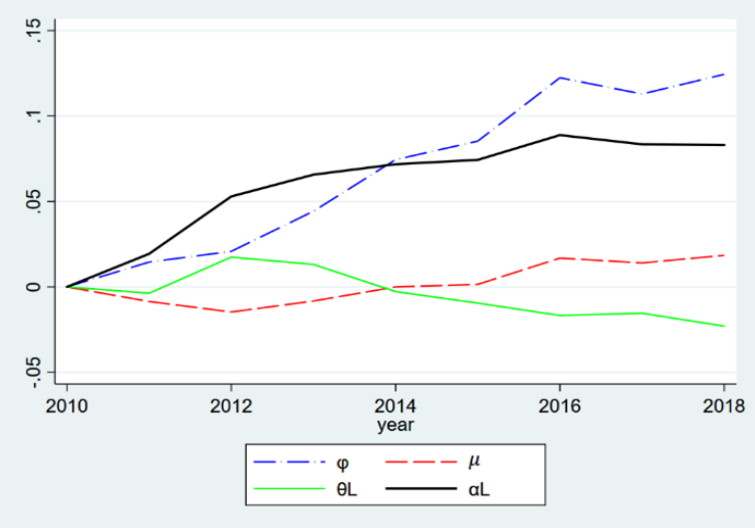
Taking the logs of equation (5) yields a simple linear expression that decomposes $log(\alpha_{it})$ into three additive terms:

$$log(\alpha_{it}^{L}) = log(\varphi_{it}) + log(\theta_{it}^{L}) - log(\mu_{it}) \qquad (6)$$

The dynamics of the labour share and its components are represented in Figure 6. Without claims on the direction of causality, we see that, in recent years, the (revenue-based) labour share slightly increased despite the (muted) rise of the markup and the contraction of the output elasticity of labour. The negative contribution of θ^{L} and μ to α^{L} is indeed more than offset by the positive trend in φ.

[2] In Mertens (2019), the indicator of labour market power φ is calculated as MRP_{it}^{L}/w_{it}, hence an increase in Mertens' φ corresponds to a shift of labour market power from the employees to the employers, namely to a rise in monopsony power. In equation (5), which can be recovered by simply rearranging the terms of equation (3), φ is computed as w_{it}/MRP_{it}^{L}, consistent with our definition of labour market power introduced in equation (2) and applied in the rest of this work.

Figure 6. *Decomposition of the revenue-based labour share based on Mertens (2019), 2010-2018 (2010= 1)*



Accordingly, as expected, product market power is negatively correlated with the labour share, while it is positively correlated with our measure of labour market power. A diminishing output elasticity of labour, which is also detected by Mertens in the German manufacturing sector, may reflect a change in the firms' production technology that boosts capital intensity and reduces the importance of labour to firms. Moreover, in line with Mertens, it is in contrast with the assumption of constant output elasticities of factors, thus stressing the need to choose a translog specification, rather than a Cobb-Douglas one (which does not allow elasticities to vary). Finally, the important role played by labour market power suggests that a proper assessment of the determinants of the labour share should account for imperfections in both the product and the labour markets.

5. Conclusions

In recent years, several papers have attempted to shed light on a number macroeconomic dynamics observed in some economies, especially in the US, which raise some concerns and which may be partly attributable to a rise in product market power. One of these worrying macrotrends is the decline in the labour share, which has been experienced also in several European countries, although with relevant differences both within the continent and with respect to the US. An interesting case study in this regard is represented by Italy, a country which has recently exhibited a mixed economic performance and has displayed an unclear trend in the labour share. Moreover, the latter is computed in different ways by different institutions, and this makes it difficult to obtain a clear picture. In addition, microeconomic evidence on product market power in this country is still limited. Accordingly, in this work we aim to provide additional evidence on this important labour indicator and in particular to analytically and graphically show how the latter relates to market imperfections. Hence, we add to the existing literature on the link between markups and labour share in Italy by focusing on the revenue-based labour share (rather than on the value-added one), by estimating the markups starting from the estimation of a firm-level production function and by

accounting for labour market power as well.

We show that, in recent years, the value-added labour share has exhibited a mixed trend, while the revenue-based labour share has slightly increased despite an increase in the markups. Indeed, the trend in the labour share is explained also by two other variables, namely the output elasticity of labour and labour market power, and the growth in bargaining power has more than offset the (limited) rise in product market power and the decline in the output elasticity of labour. Additionally, the changes in the labour share are driven by within-firm changes, and the wage component is the one that mostly accounts for both the level and the trend in this variable. Finally, some inter-regional differences emerge, with the Mezzogiorno being the macroarea that has experienced the strongest rise in the labour share during the period under scrutiny.

Although this study has a descriptive stance, and does not make claims on the direction of causality in the labour share-markups nexus, we think that its preliminary results can serve as the starting point of future research. For instance, a similar analysis may be extended to other sectors and to a longer time-frame. Moreover, there is still limited microeconomic evidence on how and to what extent the recent rise in the markups partly explains the increase in wage inequality that has been observed also in Italy, or how markups are related to corporate investment rates.

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***Note:** the articles marked with an asterisk are quoted in the Appendix

Appendix

Estimation of the production function

In Section 2, following De Loecker and Warzynski (2012), we defined the firm-level markup as the ratio between of the output elasticity of materials and its revenue share:

$$\mu_{it} = \frac{\theta_{it}^{M}}{\alpha_{it}^{M}}, \qquad (1)$$

where μ_{it} is the markup of firm i at time t, θ_{it}^{M} is the output elasticity of materials and α_{it}^{M} is the revenue share of materials, also known as cost share or expenditure share of materials. While the expenditure share of materials can be easily computed using firm-level data that are generally available, the related output elasticity needs to be estimated.

In order to get unbiased estimates of θ_{it}^{M} at the firm-year level, we consider the following general production function Q for firm i at time t:

$$Q_{it} = Q_{it}(L_{it}, M_{it}, K_{it,} w_{it}), \qquad (2)$$

where L_{it}, M_{it} and K_{it} are the firms' inputs (i.e., labour, materials and capital, respectively) and w_{it} is firm's productivity. Unobserved productivity shocks are potentially correlated with input choices, and if not controlled for, can lead to inconsistent estimates of the production function. Accordingly, we employ the Wooldridge-Levinsohn-Petrin (WLP) estimator, as derived from Wooldridge (2009) and implemented in Petrin and Levinsohn (2012). The WLP estimator does not assume constant returns to scale, is robust to the Ackerberg, Caves and Frazer's (2015) criticism of Levinsohn and Petrin's (2003) estimator and is programmed as a simple instrumental variable estimator. The potential endogeneity issues related to the simultaneous determination of inputs and unobserved productivity are addressed by introducing lagged values of specific inputs as proxies for productivity. Specifically, the estimation strategy used in this paper consists in two steps.

First, we run:

$$q_{it} = g(l_{it}, k_{it}, m_{it}) + \epsilon_{it}, \qquad (3)$$

where we use a third-order polynomial on all inputs to remove the random-error term ϵ_{it} from the output and hence to obtain estimates of the expected output $\widehat{q_{it}}$. Then, we use a general production function of the following type:

$$\widehat{q_{it}} = f_s(l_{it}, k_{it}, m_{it}, \mathrm{B}) + \omega_{it} + \varepsilon_{it}, \qquad (4)$$

where $\widehat{q_{it}}$ is the natural log of real sales of firm i at time t, l_{it}, k_{it} and m_{it} are, respectively, the natural logarithms of the quantities of labour, capital and materials used by the firm and that get transformed into the output according to the production function f_s, B is the parameter vector to

be estimated in order to calculate the output elasticities, ω_{it} is the firm-level productivity term that is observable by the firm but not by the econometrician, and ε_{it} is an error term that is unobservable to both the firm and the econometrician. Productivity is, thus, assumed to be Hicks neutral and specific to the firm, as in the approach using inputs to control for unobservables in production function estimations (Ackerberg, Caves and Frazer, 2015; Levinsohn and Petrin, 2003; Olley and Pakes, 1996). We assume that labour is a variable input, and instrument current labour and materials and their interactions with the first and second lags of labour as well as the second lags of capital and materials. To control for time-variant shocks common to all plants, we add year fixed effects.

We adopt a translog specification, which, unlike the Cobb-Douglas, permits us to recover firm-level time-variant output elasticities. The production function is a revenue function, since data on firms' output prices are not available, and is allowed to change across different sectors, as implied by the subscript s. Leaving subscripts i and t aside for simplicity, the translog function f_s can be written as:

$$f_s = \alpha + \beta_L l + \beta_K k + \beta_M m + \beta_{L^2} l^2 + \beta_{M^2} m^2 + \beta_{K^2} k^2 + \beta_{KL} kl + \beta_{KM} km + \beta_{LM} lm \quad (5)$$

Thus, the parameter vector is made up of nine parameters for each sector.
The estimated parameters of the translog production function allow us to compute the output elasticity of materials. Using the estimates of the output elasticity and the calculated revenue shares of materials, we can now compute markups at the firm-year level based on Equation (1).