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RESEARCH ARTICLE

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Foreign labor, peer-networking and agricultural efficiency in the Italian dairy sector

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Abstract

While the presence of immigrants in the agricultural sector is widely acknowledged, the empirical evidence on its economic consequences is lacking, especially from a microeconomic perspective. Using the Farm Accountancy Data Network panel data for Italian dairy farms in the period 2008–2018, the present study investigates the relationship between foreign workforce and farm– technical efficiency, considering the workers' country of origin. We rely on different peer-network theories, and using a stochastic frontier analysis accounting for the endogeneity of immigrant labor force. Results point to the general positive contribution of immigrants on Italian farms' efficiency, while unpaid family labor exerts a null-to-negative influence. We detected an important effect of peer-working, namely complementary task specialization and conformity behavior, with diverse groups of workers associated to different efficiency levels. The evidence of the positive correlation between immigrants and the efficiency of the agricultural sector has significant implications

Abbreviations: CAP, Common Agricultural Policy; ELA, European Labour Authority; EPSR, European Pillar of Social Rights; EU, European Union; FADN, Farm Accountancy Data Network; GI, geographical indication; HAC, Heteroskedasticity Autocorrelation Consistent; IIAF, Intensity of Immigrant workforce per Area-of-origin per Farm; ITIF, Intensity of Total Immigrant workers per Farm; IV, instrumental variables; LSIA, immigrant farmworkers according to their area-of-origin; LSTI, Lagged difference Share of Total Immigrant working on the farm; MS, Member States; PDO, protected designation of origin; SFA, stochastic frontier analysis; TE, technical efficiency.

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for the design of immigration policies and the access to domestic agri-food markets, especially for those sectors in higher labor demand, as well as speeding up the process of economic and social integration of the labor force. [EconLit citations: Q12, Q18, J61, C23, C26].

KEYWORDS
agribusiness, food systems

1 | INTRODUCTION

Since the conclusion of the Second World War, the European agricultural sector has undergone significant structural transformations, evolving from a system dominated by family and subsistence farms to one characterized by industrialized production and a high demand for labor (Molinero-Gerbeau, 2021). At present, the domestic supply of agricultural labor is inadequate in numerous Member States (MS) of the European Union (EU), largely due to a notable shift of workers towards secondary and tertiary sectors, resulting from lower remuneration and longer working hours (Coopmans et al., 2020). There is an increasing number of farmers exiting the farming business[1] and a lack of successors replacing retiring farmers (Christiaensen et al., 2021). Workers from outside the EU are therefore necessary to guarantee a sufficient agricultural labor supply, representing a crucial source of flexible, adaptable, and frequently cheaper labor replacing domestic shortages[2] (Antonioli et al., 2023; Baldoni et al., 2017; Malchow-Møller et al., 2013; Peri & Rutledge, 2020). Moreover, given that labor shortages may result in reduced production capacity, high labor productivity is essential to maintain high levels of food security (Antonioli et al., 2023).

In this paper, we estimate technical efficiency (TE) through stochastic frontier analysis (SFA), adopting a novel econometric approach that accounts for potential endogeneity of the immigrant labor input in the estimation of translog production functions (Karakaplan & Kutlu, 2019). The analysis is performed at the micro-level using the Italian Farm Accountancy Data Network (FADN) panel data set[3] for the period 2008–2018. Italy is one of the most important EU MS producing agricultural goods and it is the only EU MS reporting farm-level data on the employment of foreign workers and their origin. We focus on the dairy sector as it produces some of the most important staple goods for domestic consumption, as well as protected designation of origin (PDO)—hence exclusively "Made in Italy"—products exported all over the world (e.g., Parmigiano Reggiano cheese). The Italian dairy sector has undergone a shift in the composition of its workforce over the past few decades, with a growing proportion of foreign workers replacing Italian nationals. The nonseasonal nature of the sector, in contrast to other agricultural sectors such as arable and fruit crops, has resulted in a relatively low turnover of farmworkers.

[1]According to the Farm Structure Survey (FSS) of Eurostat, the number of farms in the EU decreased by about 37% (ca. 5.3 million farms across the MSs) in the period between 2005 and 2020. The vast majority (about 87%) were small farms under 5 hectares. Italy recorded one of the largest reductions with a loss of about 0.6 million farms (34%). However, due to different coverage rates in different countries, as well as the raising of the size threshold for what is considered a farm, these figures are indicative rather than precise.

[2]Contract/outsourcing work is also flexible and often cheaper, potentially competing with agricultural immigrant labor. However, this is not the case for the Italian dairy sector in our data set where the median (mean) share of contract/outsourcing working hours on total farm working hours is 0.7% (1.7%) compared to immigrant working hours that represent the 32.3% (34.5%).

[3]The FADN contains microeconomic data based on harmonized bookkeeping principles across the EU member states. Data are collected through national surveys in each member state, and covers commercial agricultural holdings. The data are representative for the region, economic size and type of farming. The authors are grateful to the CREA-PB of Rome (Italy) for providing the data. More details available at: https://agriculture.ec.europa.eu/data-and-analysis/farm-structures-and-economics/fadn_en.

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The stability of the workforce throughout the year allows to better capture the influence of immigrant workers on farm performance. While these issues have been frequently debated in political and academic forums, the challenges became apparent to the general public as a result of the Covid-19 pandemic, with shortages of staple food products in supermarkets (e.g., fresh produce, wheat flour) due to mobility restrictions that reduced the availability of foreign[4] seasonal workers (Fernández-Reino et al., 2020; Hobbs, 2020; Kalantaryan et al., 2020; Ker & Cardwell, 2020; Larue, 2020; Orden, 2021). The recent report of the European Parliamentary Research Service (2021) emphasizes the current needs of foreign employment in the EU agriculture, highlighting that several MSs employ large numbers of immigrant agricultural workers. The European Commission (2020) recognizes the fundamental role of immigrant agricultural workers due to the severe lack of farmworkers in MSs such as Italy, Spain and Germany, particularly during the pandemic crisis (The Economist, 2020b).

Academic research on immigrant farmworkers in the EU is scant and mainly confined to macro-level studies (e.g., Devadoss & Luckstead, 2008; Partridge et al., 2008). However, recent applications (e.g., Antonioli et al., 2023; Baldoni et al., 2017, 2021) have demonstrated that micro-level analyses are more suited to understand the dynamics of foreign labor in the domestic farming sector. The work of Baldoni et al. (2017, 2021) on the role of immigrants in the Italian agricultural sector is a key example of a micro-level analysis on farm productivity effects of foreign workers. In particular, Baldoni et al. (2021) identify an inverted-U-shaped relationship between the rate of foreign workers and farms' productivity, suggesting that a culturally diversified workforce contributes positively to farm productivity up to a saturation point where the social distance between workers becomes too large and inverts the relationship. The study by Antonioli et al. (2023) focuses on the cost structure of the foreign agricultural labor, concluding that the lower unit labor cost of foreign work enhances the competitiveness of Italian dairy farms. We add to this stream of literature by explicitly accounting for the origin of the foreign workforce; this to disentangle whether when the concentration of immigrants sharing a cultural background is higher on the farm (i.e., peer-network), the farm's performance, by means of technical efficiency (TE), increases. While productivity measures the output produced for each unit of input used, TE measures the maximization of the farm's output with the given set of inputs; hence, assessing to what extent the farm over- or under-utilizes the set of inputs. Therefore, TE and productivity are two complementary indicators of a farm's performance.

The correlation between agricultural employment and the area of origin of immigrants is often neglected in the literature, while it is analyzed in other economic sectors through either the "ethnic niching" theory (among others, Buchholz, 2021; Diodato et al., 2022; Esther Yoona Cho, 2017; Spindler-Ruiz, 2021) and peer-network models (Bandiera et al., 2009; Mas and Moretti, 2009). According to these strands of literature, the integration process of immigrants is often driven by co-ethnic social networks. This results in ethnic employment niches (Docquier & Rapoport, 2012; Martin & Portes, 1998; Model & Waldinger 1997; Nathan, 2015; Waldinger, 1994), which persist, and accumulate over time (Spindler-Ruiz, 2021). These networks are sources of knowledge exchanges, strengthening the vocation of the group to work in a certain sector (Iskander et al., 2010; Kerr, 2008). Moreover, immigrants are more likely to find employment in sectors affected by domestic labor shortages (Deng, 2020; Fairlie & Meyer, 1996; Fong & Shen, 2011; Schrover, 2001), a character of the EU agriculture. Immigrants' networks together with economic structural change and the local labor market's characteristics, can lead to the concentration of certain groups of immigrants in specific sectors, defined by Wilson (2003) as the "[…] labour specialization involving the tendency of members of a specific ethnic group to be over-represented in an activity" (p. 431). The degree of foreigners' labor specialization may affect the performance of the sector in which they are employed, promoting a higher production efficiency (Buchholz, 2021; Ottaviano & Peri, 2005).

The remainder of the paper is structured as follows. Section 2 discusses the EU law and agricultural policy frameworks governing the immigration of foreign workers. Section 3 provides the theoretical background of the formation of ethnic employment niches and connects it to the current situation of the employment of immigrants in

[4]Migrants and immigrants are considered alike since information about their permanent residence is not available.

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the Italian agricultural sector. Section 4 describes the data and the econometric strategy. Section 5 describes and discusses the results obtained by the econometric models; and, finally, Section 6 concludes with policy implications.

2 | THE EU POLICY BACKGROUND ON IMMIGRANT WORKERS

The EU's *acquis communautaire* contains several regulations concerning the participation of foreign workers in the domestic labor market. As declared in the Stockholm Program, the multi-year EU Justice and Home Affairs program for the period 2010–2014: "[…] in the context of the important demographic challenges that will face the Union in the future with an increased demand for labour […] immigration can contribute to increased competitiveness and economic vitality," fostering "[…] the creation of flexible admission systems [that] enable migrants to take full advantage of their skills and competence." Extra-EU nationals are protected by the Seasonal Workers Directive of 2014 (European Union, 2014), which grants equal treatment in terms of employment, free movement within the EU and some social benefits. However, the European Parliament called on MSs for a more thorough implementation of the existing EU legislation and on the Commission to propose long-term solutions against abusive practices on immigrant workers. The more recent resolution on the protection of seasonal workers adopted in June 2020 states that "[…] labour mobility should not only be free but also fair" (see par. A; European Parliament, 2020).

Regarding agriculture, the new Common Agricultural Policy (CAP) 2023–2027 introduced the "social conditionality" requirement, to avoid exploitative situations within the EU's agricultural labor market, especially concerning immigrants (European Parliament, 2021). With the social conditionality, the CAP income support payments are conditional on farmers' complying with EU social and labor standards from the EU Directive 2019/1152 (on the transparent and predictable working conditions), Directive 89/391/EEC (on health and safety) and Directive 2009/104/EC (on the use of equipment). If these conditions are not met, the farmer is subjected to an administrative penalty. This represents a key step in the evolution of the CAP, as the support is no longer exclusively linked to the productive and environmental aspects of agriculture, but also to the respect of workers' rights (Ó Conchúir, 2021). The Farm to Fork strategy published on May 20, 2020, emphasized the importance of social fairness along the food chain "[…] especially when it comes to precarious, seasonal and undeclared workers." (European Commission, 2020c, p. 11).

Despite the above-mentioned EU-level initiatives, immigration in Europe is still mainly managed through national immigration policies, fragmenting the rules for entering the European job market(Federico & Baglioni, 2021; Fernández-Reino et al., 2020).

3 | THEORETICAL BACKGROUND

The linkage between immigrant workforce and farms' performance is frequently explained by the cost theory: immigrant workforce is a cheaper input allowing farms to expand production by reducing the marginal cost of labor, hence there is imperfect substitutability between domestic and foreign workers (e.g., Antonioli et al., 2023). This mechanism has been empirically illustrated by the work of Malchow-Møller et al. (2013), showing that Danish farms with higher rates of immigrant workers are larger in terms of workforce, revenues and value added, with productivity levels at least equal to other farms. In line with Devadoss and Luckstead (2008), they also conclude on the complementarity of the foreign labor input to both capital and native workforce (e.g., through their knowledge about different production techniques), which potentially boosts farms' productivity.

An alternative explanation of the performance of different sources of agricultural labor comes from the family farm theory developed by Allen and Lueck (1998). They describe how the composition of the labor force employed on a given farm significantly impacts its performance according to two hypotheses: (i) technological-scale economies are exhausted before exhausting the capacity of available family labor; and (ii) the labor force different from

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family labor suffers from higher supervision costs. This hinges on the diverging incentives notion. That is, the effort of hired workers is a fraction of that of family members, requiring labor supervision, hence increasing costs. However, when hired farmworkers are employed in specialized and productive tasks—as for dairy farms—workers' specialization may overcompensate the (potential) side effects of moral hazard and supervision costs. In their study on five EU Members States, Kloss and Petrick (2019) find perfect substitution between hired and family labor in Italian arable farms, while hired workers are more productive in West Germany and France because of their involvement in highly productive tasks. This also applies to Italian dairies, where hired workers are employed for specialized and productive tasks while family members usually have a management role.

Moreover, a number of theories have been developed linking the origin of workers to the economic efficiency. Waldinger (1994) developed the "ethnic niching" theory, defining an ethnic niche as (p. 27) "[…] an instance of the embeddedness of economic actions within social relations that generate trust, establish expectations, and create norms." In other words, ethnic niching refers to the ability of an immigrant network to meet the labor demand by exploiting its social capital. Waldinger (1994) and Martin and Portes (1998) explain how immigrant networks are critical for organizing the information flow between those already settled and newcomers, especially regarding the access to the labor market.[5] Moreover, immigrant employment niches tend to acquire the cultural heritage of the predominant ethnic group(s) because of cumulative causation: ethnic networks perpetuate over time as successful immigrant pioneers introduce and refer newcomers in their own economic sector, extending access to the economic sector to other peers, forming and improving its social capital (Spindler-Ruiz, 2021).

In addition to this social capital perspective, there are economic mechanisms that play an equally important role in the formation of employment niches. Buchholz (2021) develops the complementary task specialization theory which explains how foreign-born employees may generate positive externalities thanks to skills developed at the native country, before immigrating. Therefore, the success of an employment niche is also related to pre-migratory abilities (Schrover, 2001). According to this theory, even among individuals with the same education and skills, workers from different origin are imperfect substitutes, reducing potential replacement or competition between them. Indeed, as argued by Ottaviano and Peri (2005), in specific sectors immigrants bear diverse knowledge and abilities with respect to local workers, increasing farm performance via "fine-grained" specialization. In sectors with a high turnover of employees—such as the Italian (and European) farming sector (Bogoeski & Costamagna, 2022; Corrado et al., 2017; Gertel & Sippel, 2014; Kalantaryan et al., 2020; Palumbo et al., 2022), employing people of the same origin facilitates the exchange of knowledge, improving human capital and avoiding transactional and training costs (Spindler-Ruiz, 2021).

The peer-network model developed in the 2000s further describes the relationship between social ties and efficiency. By assuming that neither the production technology nor the compensation scheme entail externalities onto co-workers, Bandiera et al. (2009) show that working along with socially-tied people increases (decreases) the worker's productivity, if the peers are more (less) productive workers—that is, conformity behavior. Mas and Moretti (2009), by assuming that the behavior of the workers does generate externalities onto co-workers, explains that the presence of highly-productive workers has positive spill-over effects on the productivity of others. This effect is stronger when the social interaction between co-workers is stronger. Socially-tied foreign workers sharing the same origin can therefore be more efficient via network effects that reinforce the abilities across the members of the network. However, this is particularly true when positive skills and abilities are embedded in the group, while the opposite may occur if the group is not familiar with the job (Bandiera et al., 2009; Mas & Moretti, 2009; Spindler-Ruiz, 2021).

Scholars already pointed to the existence of certain ethnic employment niches within the Italian farming sector. In Italy, nearly half of the Italian total agricultural workforce is foreign. About 40% of the immigrant farm workers in Italy are estimated to be irregular—that is, outside the regulatory immigration rules, and, hence, suffering from

[5]For further empirical applications see Clark and Drinkwater (2002), Samaluk (2016) and Sanders and Nee (1987).

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irregular working conditions regarding payment of wages or social security. According to CREA (2019), for the year 2017 about 15% of the total agricultural workforce in Italy is composed of employees from Eastern European countries, especially from Romania (10% of the total agricultural workforce). After the EU accession in 2007, Romanian farmworkers gradually substituted workers from North Africa, who nowadays account for about 5% of the total agricultural workforce, followed by Asian farmworkers (4.5%). Asian immigrants are often employed in livestock farming (e.g., Indian-Punjab milkers in the Po Valley) (Azzeruoli, 2017; Lum, 2012), African workers in greenhouse operations and fruit and vegetable picking and East Europeans as shepherds or in the horticultural sector (Corrado et al., 2017).

These specializations are reflected also in the FADN data set (see Figure 1): Asian workers are prevalent in the dairy sector, covering half of the total foreign working hours, in the COP (cereal, oleaginous and protein crops) and the granivores sectors. Employees from African countries are mostly employed in horticultural farms, but also in the olives and dairy sectors, while workers from Eastern European countries—that is, Albania, North Macedonia, Poland, Romania and Slovakia—are mainly employed in the grazing livestock sector (particularly Romanians), in fruit (Romanians, Polish and Slovaks) and horticultural farms (Romanians and Albanians), vineyards (Romanians and North Macedonians), olive production (Albanians and Romanians), and in the field crops sector (Albanians and Romanians).

In terms of geographical distribution, the *Italian Ministry of Labour and Social Policies* reports that in 2017 almost one-third of migrant agricultural workers were in the North-Eastern Italian regions, possibly as a consequence of their specialization in livestock farming, which is characterized by less seasonality compared to other sectors such as the fruit and vegetable sector, leading to a higher stabilization of immigrant workers with less precarious contracts (Huffman & Evenson, 2001; Ministero del Lavoro e delle Politiche Sociali, 2018; Nori & Farinella, 2020). Indeed, as presented in Table 1, the dairy sector is the second most important in terms of intensity of immigrant farmworkers, with an average share of working hours in total agricultural working hours of 9.3% for the period 2008–2018.

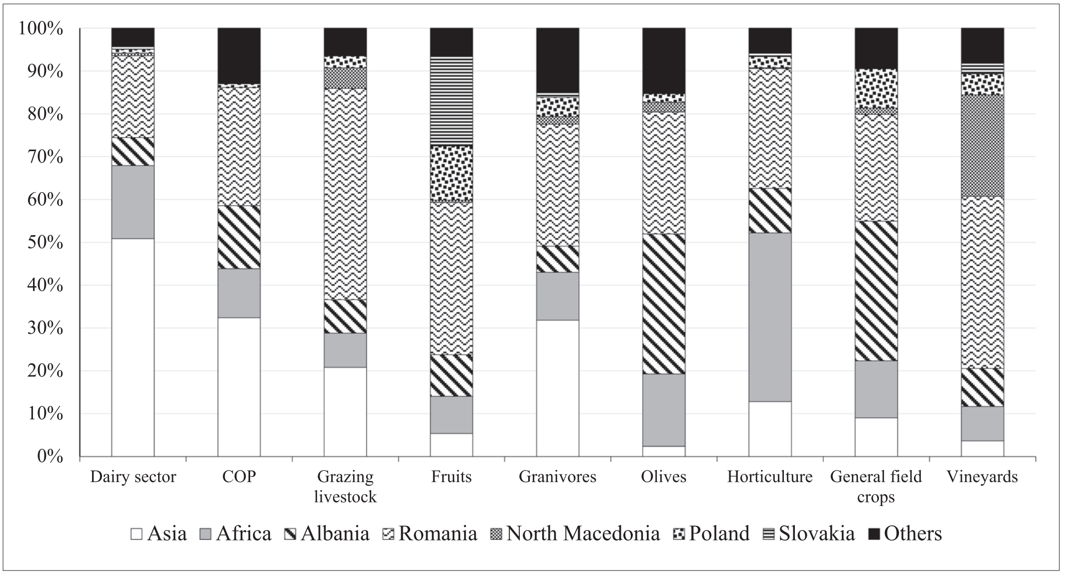

FIGURE 1 Average share of immigrant working hours by area of origin (Asia, Africa, Albania, Romania, Macedonia, Poland, Slovakia, Others). Farm Accountancy Data Network (FADN) Sample for the Italian Farming Sector, 2008–2018. COP stands for "Cereal, Oleaginous and Protein crops." The category "Others" refers to immigrants whose area of origin is different from those enlisted. *Source*: Authors' elaboration on FADN data set.

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TABLE 1 Share of immigrant working hours in total agricultural working hours (excluding unpaid working hours) per farming sector in the Italian FADN sample 2008–2018.

Sector	Share of immigrant working hours
Horticulture	9.5%
Dairy sector	9.3%
Fruits	8.8%
Granivores	6.6%
Grazing livestock	5.2%
General field crops	4.2%
Vineyards	4.2%
Olives	2.8%
COP	1.4%
Total	5.8%

Source: Authors' elaboration on FADN data set.

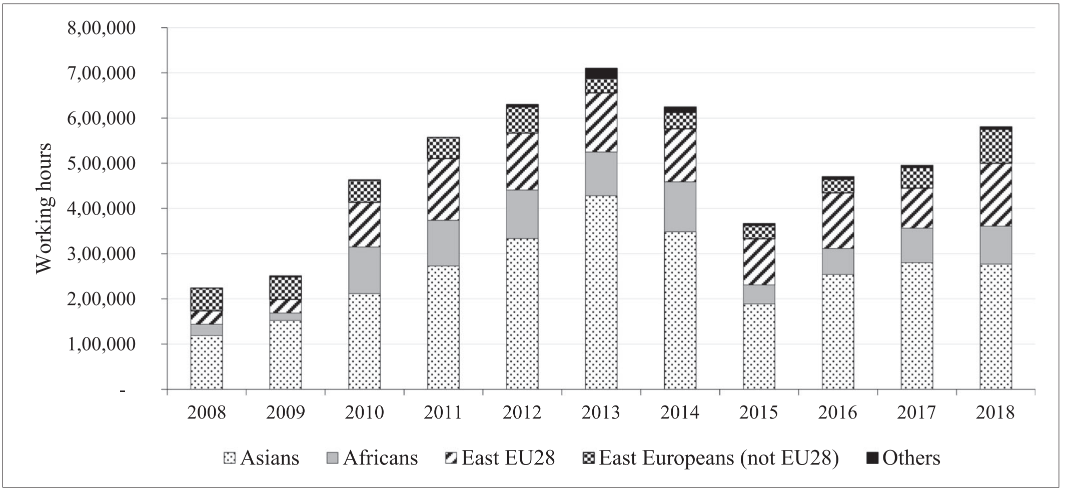

FIGURE 2 Average immigrant employees working hours by region of origin (Asia, Africa, East European Union countries, East European countries, other immigrants), Farm Accountancy Data Network (FADN) sample for the Italian Dairy Sector, 2008–2018. The category "Others" refers to immigrants whose area of origin is different from those listed. *Source*: Authors' elaboration on FADN data set.

Moreover, the Italian livestock sector is characterized by aging farmers, low intergenerational succession and a low level of attractiveness for new entrants (Ballarino & Panichella, 2021; Coopmans et al., 2021; Duval et al., 2021), featuring a shortage of labor supply that allowed foreign farmworkers to settle in. Asians make up more than 50% of the total dairy foreign workers in Italy, followed by 21% of East-Europeans from EU countries, 17% of Africans, 10% of non-EU East Europeans (e.g., Albania, Moldova, Ukraine and North Macedonia), and the remaining 3% comes from other European countries. Figure 2 highlights the significant and increasing role of migrants in Italian dairy farming. As one can see, the majority of foreign work hours are from Asian employees.

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Azzeruoli (2017) analyzed the Italian dairy sector focusing on two geographical indication (GI) cheeses, Parmigiano Reggiano and Grana Padano. These GI cheeses are produced exclusively in Italian northern regions, where many Asian farmworkers also reside. Azzeruoli (2017) argues that the concentration of Punjabi milkers in the area is not a simple replacement for the lack of local workforce, but it is also the result of the transformation of the supply chain and the development of specific immigrant recruiting systems.

Nevertheless, despite the evidence and the ethnic concentration in specific agricultural tasks, the literature does not offer sufficient empirical contributions that further deepen the topic. Considering the whole spectrum of Italian firms, the recent contributions of Brunello et al. (2020) and Vittori et al. (2023) conclude that employing low-skilled immigrants leads to lower labor costs, as wages are negatively affected while the effect on productivity is either negative or nonsignificant.

Baldoni et al. (2021) investigate the relationship between farms' productivity (defined as the total factor productivity, obtained as a ratio of output quantity index to an input quantity index) and the immigrant workforce composition, considering diversity in the workers' origin as a factor shaping the farm performance. They find a positive relationship as long as the share of foreign workforce is fairly high and the ethnic composition fairly homogeneous. Antonioli et al. (2023) and Malchow-Møller et al. (2013), for the Italian dairy and Danish farming sector, respectively, found that farms employing immigrants benefit from a cheaper labor source, boosting their competitiveness. Malchow-Møller et al. (2013), assessing the linkage between immigrant workforce, job creation and farms' revenue, found positive effects, providing evidence that foreign workers represent cheaper inputs, substituting unskilled native workers. In terms of labor productivity, Baldoni et al. (2017) and Malchow-Møller et al. (2013) (measuring labor productivity as farm net value added per annual working unit and as revenue and value added per employee, respectively) found no statistically significant effects. However, these studies used the aggregate volume of foreign workforce, without considering the heterogeneity of their origin.

We add to this recent stream of literature first by deepening the understanding on whether immigrant farmworkers improve the farm's TE; second, we disentangle whether specific immigrants' groups have a different influence on the dairy farms' efficiency.

4 | DATA AND ECONOMETRIC STRATEGY

We use data from the Italian FADN, which provides farm-level accountancy data, including the hours worked by type of labor—that is, family and hired labor, seasonal or permanent—and the nationality of employees (not available in other EU country-specific FADN data sets). For the analysis, we extracted the farm category "specialist milk"[6] for the period 2008–2018, constituting an unbalanced panel of 2888 single dairy farms with 10,142 observations.

To estimate the impact of different groups of immigrant workers on Italian dairy farms' TE, we estimate a simultaneous equation model composed of the stochastic frontier production function (1) and the (in)efficiency Equation (2). TE assesses the capacity of the farm to obtain the maximum output from the set of inputs available to the farmer (Coelli et al., 2005). The maximum output a farm can achieve is represented by an upper-bound frontier measuring the relative TE in using the factors of production (Guesmi et al., 2018; Koppenberg & Hirsch, 2022; Lakner et al., 2017; Mishra et al., 2018; Vigani & Dwyer, 2020). A positive influence of foreign workers on TE indicates higher human capital due to skills, expertize or specialization, highlighting the effect of immigrant workers in the Italian dairy sector.

[6]This is as the European Commission defines those farms having ¾ of total grazing livestock as dairy cows (see the EC regulation 1242/2008 and the repealing delegated regulation 1198/2014).

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4.1 | Endogenous SFA estimation

A key concern is the potential endogeneity of the foreign workforce due to sector-specific labor demand and supply shocks. Such shocks can affect the movement of foreign workers and induce a selection towards certain countries of origin and specific skill sets. This can introduce potential simultaneity with estimates affected by the correlation between the inefficiency term u_{it} and the share of employed immigrants (Card, 2001; Card et al., 2012; Peri, 2012). Addressing this potential bias is particularly important in the case of the Italian dairy sector; the sharp decrease in the domestic agricultural workforce can facilitate the substitution with foreign farm workers.

In the econometric procedure, we test for endogeneity with the Durbin–Wu–Hausman test, with no endogeneity hypothesis under the null—that is, rejection of the null would indicate the presence of endogeneity. Subsequently, to reduce the potential endogeneity bias, we combine the estimation of the TE with instrumental variables (IV) techniques, following the method proposed by Karakaplan and Kutlu (2017a), an extension of Kutlu (2010), and Karakaplan and Kutlu (2017b). Endogeneity in production functions is not a new concern (Olley & Pakes, 1996), but only recently gained special attention in SFA applications (Karakaplan & Kutlu, 2019; Latruffe et al., 2017); up to the authors knowledge, the approach proposed here has not yet seen applications in the agricultural sector. The econometric strategy allows for consistent estimates of the SFA via the maximum likelihood estimation accounting for the correlation between the two-sided error terms, v_{it} and u_{it}, in (1), and not only between regressors in the frontier and the *iid errors* as in other empirical applications (Dong et al., 2016; Latruffe et al., 2017; Shee & Stefanou, 2014; Tran & Tsionas, 2013). Furthermore, the likelihood function allows for a farm-specific random component, i.e. individual effects accounting for farm's characteristics that may correlate with the concentration of immigrants (e.g., farm size, managerial attitudes towards immigrants and managerial quality, among others).

The Karakaplan and Kutlu (2017a) strategy is a generalization of the well-known Battese and Coelli (1995) estimator, conveying robust standard errors via one- instead of two-steps estimation of the control function, avoiding the need for bootstrapping and computationally intensive methods and researcher' subjective decisions (Amsler et al., 2017; Amsler & Prokhorov 2016; Tran & Tsionas, 2015).

Accordingly, the stochastic frontier model is

$$y_{it} = x'_{yit}\beta + v_{it} - u_{it};\ x_{it} = Z_{it}\delta + \varepsilon_{it}, \tag{1}$$

$$u_{it} = h\left(x'_{uit}\varphi_u\right)u_i^*, \tag{2}$$

where y_{it} is the logarithm of output at the tth observation ($t = 1, 2, ..., T$) for the ith farm ($i = 1, 2, ..., N$)*;* x'_{yit} is a vector of both exogenous and endogenous variables, including inputs—land, labor, capital and intermediate inputs -; and x_{it} is a kx1 vector of endogenous variables, $Z_{it} = z'_{it} \otimes I_p$ where z_{it} is a px1 vector of all exogenous variables, that is, IVs. v_{it} and ε_{it} are two-sided error terms, and $u_{it} \geq 0$ is the one-sided inefficiency term, and φ_u is a vector of variance parameters.

In (2), the inefficiency term u_{it} is explained by a set of shifters, differing from inputs and outputs and exogenous to the production frontier (Belotti & Ilardi, 2018). Here, the share of immigrant workers is included in the model, and IVs will be used to estimate their unbiased effects on the technical efficiency. Since farms cannot exceed the ideal output, any deviation represents the (individual) farm's inefficiency (u_{it}) in the use and allocation of inputs. The focus on a single sector—that is, dairy farming—allows for assuming a similar production technology (Battese & Coelli, 1995; Kumbhakar, 1987). Such assumption is also consistent with our sample, as the FADN contains only commercial farms. $h_{it} = h\left(x'_{uit}\varphi_u\right) > 0$, with x_{uit} being a vector of all endogenous variables excluding the constant. That is, to say, the inefficiency term is a function of the endogenous variables, hence v_{it} and u_{it} can be correlated

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with x_{it}. Following the Cholesky decomposition of the variance-covariance matrix of $(v_{it}, \tilde{\varepsilon}'_{it})'$, the stochastic frontier in (1) can be specified as[7]:

$$y_{it} = x'_{yit}\beta + (x_{it} - Z_{it}\delta)'\eta + e_{it}, \tag{3}$$

where $e_{it} = w_{it} - u_{it}$, where $\tilde{\varepsilon}_{it}$ and $\tilde{w}_{it} \sim N(0,1)$ are independent, with $w_{it} = \sigma_{v\sqrt{1-\rho'\rho}}\tilde{w}_{it} = \sigma_w \tilde{w}_{it}$, where ρ is the correlation vector between v_{it} and $\tilde{\varepsilon}_{it}$; the term $(x_{it} - Z_{it}\delta)'\eta$ serves as the bias-correction term, with $\eta = \sigma_w \Omega^{-1/2}\rho/\sqrt{1-\rho'\rho}$, where Ω is the variance–covariance matrix of ε_{it}, thus conditionally independent from the regressors given x_{it} and z_{it}.

The maximization of the likelihood function is then used for the panel configuration of the stochastic production function, with the likelihood function of panel i defined as $\ln L_i = \ln L_{i,\ y|x} + \ln L_{i,x}$. The inclusion of the bias correction term in the log-likelihood function solves the problem of inconsistent estimates due to endogeneity, and the efficiency term $EFF_{it} = \exp(-u_{it})$ can be correctly predicted as

$$\exp\left(-E\left[u_{it}|e_i\right]\right) = \exp\left(-h_{it}\left(u_{i*} + \frac{\sigma_{i*}\phi\left(\frac{u_{i*}}{\sigma_{i*}}\right)}{\Phi\left(\frac{u_{i*}}{\sigma_{i*}}\right)}\right)\right)x'_{yit}\beta + (x_{it} - Z_{it}\delta)'\eta + e_{it},$$

where ϕ is the standard normal probability density function and Φ the standard normal cumulative distribution function.[8]

4.2 | Econometric specification

For each dairy farm, the empirical specification of the production function in (1) is given by the output variable (Y_{it}) defined as the farm's "total output" (i.e., farm's total sales plus other activities), while the independent variables include "total intermediate consumption" (i.e. total specific costs and overheads arising from production—MC_{it}), farm non-land fixed assets (i.e. the sum of the values of buildings and fixed equipment belonging to the holder, machinery, and the value at closing valuation of breeding livestock) (K_{it}), farm labor as "total labor input" (expressed on average number of hours, full-time person equivalent—AWU_{it}), and farmland as the total utilized agricultural area of the holding (UAA_{it}).[9] To adjust for inflation, inputs have been deflated by their relative annual nominal input price indexes, while the output variable is deflated by the relative annual output price index[10] (Table 1).

To avoid restrictions on production and substitution elasticities (Hirsch et al., 2019), a translog production function is specified. This is a flexible functional form that represents adequately the production-possibility set, that is, an ith order differential approximation of the real set of production possibilities (Sauer et al., 2006):

$$Y_{it} = \beta_0 + \sum_{n=1}^{N}\beta_n X_{in} + \frac{1}{2}\sum_{m=1}^{M}\sum_{l=2}^{L}\beta_{ml}X_{im}X_{il} + \sum_{t=1}^{T}\tau_t t, \tag{4}$$

[7]See Karakaplan and Kutlu (2017a) for extended calculus.

[8]$u_i^* \sim N^+(\mu, \sigma_u^2)$, where u_i^* is the farm-specific random component, independent from both v_{it} and ε_{it}. See Karakaplan and Kutlu (2017a) for extended calculus and Kutlu et al. (2019) for the generalization of the above-described panel model. The Stata command "xtsfkk" is used for estimating the model.

[9]According to the FADN classification: SE275 (*MC*); SE010 (*AWU*); SE025 (*UAA*); SE131 (*Y*); SE455 + SE450 (*K*). Document available at: https://circabc.europa.eu/sd/a/16d411ec-33fe-404b-ab4c-efcfdbbf9935/RICC%20882%20rev9.2%20Definitions%20of%20Variables.

[10]Retrieved from Eurostat, "Price indices of the means of agricultural production, input (2010 = 100)—annual data (Nominal, Eurostat)", "Input 1" for variable costs and "Input 2" for quasi-fixed costs (available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apri_pi10_ina&lang=en), and from "Price indices of agricultural products, output (2010 = 100)—annual data", product "Cows' milk" (available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apri_pi10_outa&lang=en).

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where X is a vector of factors of production defined above, after their logarithmic transformation (small letters stand for the log-transformed variables): $X = mc, \quad k, \quad awu, \quad uaa$, and τ_t are year fixed effects (Hirsch et al., 2019; Kumbhakar et al., 2015). Equation (4) translates into the empirically estimable model as follows:

$$y_{it} = \beta_0 + \beta_1 awu_{it} + \beta_2 k_{it} + \beta_3 uaa_{it} + \beta_4 mc_{it} + \beta_5 mc_{it} k_{it} + \beta_6 mc_{it} awu_{it} + \beta_7 mc_{it} uaa_{it} + \beta_8 k_{it} awu_{it} + \beta_9 k_{it} uaa_{it} + \beta_{10} awu_{it} uaa_{it} + 0.5\beta_{11} mc_{it}^2 + 0.5\beta_{12} uaa_{it}^2 + 0.5\beta_{13} k_{it}^2 + 0.5\beta_{14} awu_{it}^2 + \sum_{t=1}^{T} \tau_t + v_{it} - u_{it}. \tag{5}$$

To estimate the effect of immigrant labor, Equation (2) is estimated accounting for the share(s) of employed immigrants. More specifically, we include the shares of the three main areas-of-origin of the immigrant labor force employed in the Italian dairy sector, namely Asia, East-EU28 and Africa. These three groups account for about 90% of the total hours worked by immigrants in the sample.

According to the family farm theory described in Section 3, we also include the share of unpaid (family) working hours. To account for differentials between Italian regions, regional dummies R_k are included. This accounts for regional unobservable characteristics (e.g., different immigrant concentrations, presence of NGOs helping immigrants, different regional policies and initiatives related to immigrants amongst other socioeconomic factors). We estimate three different specifications of the system of Equations (1)-(2), in which (2) is modeled as a function of three different sets of explanatory factors, particularly regarding immigrant workforce (from more to less aggregated shares in terms of areas-of-origin), tracking their effect on the inefficiency term. More specifically, we defined (2) as a function of farm-specific random effects only (6.1), adding the shares of unpaid and (overall) migrant labor and further socioeconomic factors (6.2), and, finally, adding areas-of-origin specific shares of immigrant labor (i.e., Asian, African and Eastern EU-28) (6.3). The three model specifications are defined as follows:

$$u_{it} = \gamma_0 + a_i + \varepsilon_{it} \tag{6.1}$$

$$u_{it} = \gamma_1 + a_i + \delta_1 \textit{share unpaid labour}_{it} + \delta_2 \textit{share migrant labour}_{it} + \sum_{l=1}^{L} \delta_l \vartheta_{il} + \sum_{k=1}^{K} \delta_k R_k + \varepsilon_{it} \tag{6.2}$$

$$u_{it} = \gamma_2 + a_i + \delta_3 \textit{share unpaid labour}_{it} + \delta_4 \textit{share Asian labour}_{it} + \delta_5 \textit{share African labour}_{it} + \delta_6 \textit{share Eastern EU28 labour}_{it} + \sum_{l=1}^{L} \beta_l \vartheta_{il} + \sum_{k=1}^{K} \theta_k R_k + \varepsilon_{it}, \tag{6.3}$$

where a_i are farm-specific random effects (e.g., managerial ability, farmers' attitude towards foreigners, amongst others), ϑ_{il} is a vector of control variables including the farm's economic size (i.e. large and small farms), and its location (i.e. mountain and lowland farms); finally, δ, β, θ are parameters to estimate. According to previous empirical works, size can positively affect a farm's efficiency level due to scale economies (Alvarez & Arias, 2004; Skevas et al., 2018; Wilson et al., 2001; Zhu & Lansink, 2010). Indeed, estimations show decreasing returns to scale for the whole sample (i.e., RTS < 1, between 0.75 and 0.85, see Supporting Information S1: Table A2 of the appendix), but the positive and significant coefficient of larger farms indicates that they might benefit from scale economies. In contrast, farms located in disadvantaged or marginal areas, such as mountains, suffer of lower efficiency due to the unfavorable location and environmental conditions (Bojnec & Latruffe, 2013; Brummer, 2001; Davidova & Latruffe, 2007; Hadley, 2006).

In (6.1) we do not parametrize inefficiency u_{it} with any determinant, obtaining first estimates without controlling for the presence of endogeneity hence any type of labor-related variables. Specification (6.2) includes the shares of unpaid (family) labor and the share of overall immigrant labor on the total farm's working hours, hence without distinguishing between workers' cultural capital. Finally, specification (6.3) distinguishes between shares of Asian, African, and Eastern EU28 workers in total working hours of hired workers, allowing for insights on the effect of ethnical niching on farms' TE.

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4.3 | Instrumental variable strategy

We use two different instrumental variable strategies to account for the endogeneity of farms' shares of immigrant workforce. The first strategy is composed of a set of four instruments and it is based on the "shift-share" instrument by Bartik (1991), which is defined as a function of the current immigrants' national inflows rates and past local shares to predict for changes in the local- and sector-specific labor market. The Bartik instrument combines aggregate shocks with measures of local shock exposure, building a hypothetical and exogenous projection of regional employment growth that would have happened if regional industry growth rates reflect that of the country (Broxterman & Larson, 2020). Thus, the instrument assumes that national shocks affect regional ones based on the initial state of the economy, and the region's industry composition determines the local sensitiveness to such changes. We therefore exploit Bartik's logic to instrument the (endogenous) share of immigrant workers at the farm level, by interacting total national immigrants with regional immigrants and their share over the total regional agricultural employment in previous out-of-sample periods, and the farm-specific shares of immigrant labor.

Because Bartik's instrument addresses static sources of endogeneity only, Jaeger et al. (2018) introduced the dynamic shift-share instruments. Indeed, adjustments in the labor market are a function of lagged inflows of immigrants, leading to an omitted variable bias that can be addressed by the inclusion of lagged immigrant inflows, instrumented with the lagged version of the conventional shift-share instrument. Therefore, we include lagged shares of on-farm immigrant workers combined with the canonical shift-share approach (see models EN(5) and EN(6) in Table 2). As justified by the variation of immigrant inflows in terms of origins and volumes (see Figure 2), exclusion restrictions are more plausible in settings where immigrant inflows are dynamic over time, as it is for many European countries. Moreover, Goldsmith-Pinkham et al. (2020) pointed out that at the macro-level if the shares are correlated with unobserved local conditions the Bartik's instrument may not be fully exogenous, even if national inflow rates of immigrants are not related to the local conditions. However, this is not the case in our analysis as we combine out-of-sample national shares of immigrants with farm-level share of immigrants' hours worked.

Following Card, (2001) observation that newcomers tend to settle where earlier enclaves of co-national immigrants already reside, we use the Intensity of Total Immigrant workers per Farm (ITIF):

$$ITIF_{it} = M_G^{2008-2018} * \lambda_{Gc}^{2007} * \delta_{Gc}^{2010} * \tau_{iG,t-s}^{2008-2018}, \tag{7.1}$$

where G is the total inflow of immigrants, $M_G^{2008-2017}$ is the inflow of migrants on the Italian territory during the period 2008–2018, calculated as the difference between the total immigrant population in Italy in 2018 and that of 2008; λ_{Gc}^{2007} is the share of immigrants residing in region c in the total resident population in the out-of-sample year, 2007; δ_{Gc}^{2010} is the share of foreign workers employed in agriculture in region c in the total agricultural workforce in 2010; and, $\tau_{iG,t-s}^{2008-2018}$ represents the share of hours worked by immigrant on the farm at time $t - s$, with s indicating the first lagged share available in the FADN panel.

Likewise, three more area-specific[11] IVs measuring the intensity of immigrant workforce per area-of-origin per farm (i.e., Asia, East-EU28, and Africa) (hereafter IIAF) can be retrieved:

$$IIAF_{it} = M_g^{2008-2018} * \lambda_{gc}^{2007} * \delta_{gc}^{2010} * \tau_{ig,t-s}^{2008-2018} \tag{7.2}$$

where all elements are similar to those in (7.1), the specific area of origin are g = Asia, East-EU28, and Africa. The instruments need to be correlated with the presence of immigrant farmworkers but must be uncorrelated to the

[11]The FADN does not provide the same degree of specificity regarding the workers' country-of-origin, being the latter sometimes at the aggregated level (i.e., Africa and Asia) and some other at single-country level, whereas the other data sources used for the specification of the IV works at single-country level. Because of this, we rely on the United Nations M49 specification for matching the two sources of information (see https://unstats.un.org/unsd/methodology/m49/) and always refer to Asia, Africa and East-EU28 aggregations.

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TABLE 2 Stochastic frontier analysis results on inefficiency: exogenous and endogenous models (EX and EN), IV Strategy and IV Tests.

	Model 1	Model 2		Model 3		
y_{it}	EX(1)	EX(2)	EN(3)	EX(4)	EN(5)	EN(6)
Stochastic frontier						
$\beta_1 awu_{it}$	0.248***	0.240***	0.234***	0.239***	0.236***	0.236***
	(0.012)	(0.011)	(0.014)	(0.011)	(0.014)	(0.014)
$\beta_2 k_{it}$	0.199***	0.208***	0.210***	0.207***	0.212***	0.212***
	(0.007)	(0.006)	(0.008)	(0.006)	(0.008)	(0.008)
$\beta_3 uaa_{it}$	0.130***	0.130***	0.130***	0.131***	0.132***	0.132***
	(0.008)	(0.007)	(0.009)	(0.007)	(0.009)	(0.008)
$\beta_4 mc_{it}$	0.434***	0.416***	0.427***	0.416***	0.426***	0.425***
	(0.007)	(0.007)	(0.008)	(0.007)	(0.008)	(0.008)
$\beta_5 mc_{it} k_{it}$	−0.017***	−0.018***	−0.020***	−0.018***	−0.021***	−0.021***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)
$\beta_6 mc_{it} awu_{it}$	−0.059***	−0.053***	−0.059***	−0.054***	−0.063***	−0.061***
	(0.017)	(0.016)	(0.020)	(0.016)	(0.020)	(0.020)
$\beta_7 mc_{it} uaa_{it}$	0.039***	0.031***	0.034***	0.030***	0.032***	0.032***
	(0.009)	(0.009)	(0.011)	(0.009)	(0.011)	(0.011)
$\beta_8 k_{it} awu_{it}$	−0.009***	−0.009***	−0.004	−0.009***	−0.004	−0.004
	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)	(0.004)
$\beta_9 k_{it} uaa_{it}$	−0.000	−0.000	0.0004	−0.000	0.0005	0.0006
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)
$\beta_{10} awu_{it} uaa_{it}$	−0.211***	−0.194***	−0.200***	−0.192***	−0.194***	−0.194***
	(0.022)	(0.021)	(0.026)	(0.021)	(0.026)	(0.026)
$0.5\beta_{11} mc_{it}^2$	0.042***	0.041***	0.040***	0.042***	0.040***	0.040***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$0.5\beta_{12} k_{it}^2$	0.024***	0.025***	0.023***	0.025***	0.023***	0.023***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)
$0.5\beta_{13} awu_{it}^2$	0.211***	0.186***	0.171***	0.187***	0.170***	0.170***
	(0.027)	(0.025)	(0.032)	(0.025)	(0.032)	(0.032)
$0.5\beta_{14} uaa_{it}^2$	0.028***	0.031***	0.032***	0.031***	0.032***	0.032***
	(0.005)	(0.005)	(0.006)	(0.005)	(0.006)	(0.006)
Constant	12.77***	12.81***	13.10***	12.81***	13.08***	13.09***
	(0.148)	(0.143)	(0.251)	(0.143)	(0.251)	(0.251)
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

(Continues)

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TABLE 2 (Continued)

y_{it}	Model 1 EX(1)	Model 2 EX(2)	EN(3)	Model 3 EX(4)	EN(5)	EN(6)
Inefficiency						
Unpaid family hours on total labor		0.594***	0.426**	0.631***	0.303	0.308
		(0.145)	(0.184)	(0.146)	(0.190)	(0.190)
Hired immigrant hours on total labor		0.232	−0.431*	0.502**	−1.091***	−0.989***
		(0.167)	(0.242)	(0.212)	(0.371)	(0.361)
Asian immigrant hours on total hired labor				−0.336***	0.204	0.117
				(0.113)	(0.158)	(0.152)
African immigrant hours on total hired labor				−0.005	0.366***	0.333***
				(0.080)	(0.117)	(0.114)
East-EU immigrant hours on total hired labor				−0.048	0.280**	0.237**
				(0.078)	(0.113)	(0.110)
Large farm (Dummy)		−0.288***	−0.282***	−0.283***	−0.283***	−0.281***
		(0.042)	(0.052)	(0.042)	(0.052)	(0.052)
Mountain Farm (Dummy)		0.604***	0.596***	0.594***	0.594***	0.595***
		(0.083)	(0.101)	(0.083)	(0.101)	(0.101)
Regional fixed effects		Yes	Yes	Yes	Yes	Yes
Constant $\ln(\sigma_u^2)$	−0.792***	−1.901***	−1.935***	−1.934***	−1.821***	−1.826***
	(0.044)	(0.184)	(0.222)	(0.185)	(0.227)	(0.227)
Constant $\ln(\sigma_v^2)$	−2.86***	−2.83***	0.11***	−2.83***	−2.76***	−2.76***
	(0.184)	(0.019)	(0.051)	(0.019)	(0.021)	(0.021)
Endogeneity test			30.85***		41.29***	41.92***
Errors i.i.d.						
F test of excluded instruments			1388.16***		108.29***	182.58***
HAC Estimates						
F test of excluded instruments			181.31***		19.31***	41.96***
IVs						
ITIF (intensity total immigrant per farm)			Yes		Yes	Yes
LSTI (lagged share total immigrant per farm)			Yes		Yes	Yes
IIAF (Asia) (intensity immigrant per area-of-origin per farm)					Yes	
LSIA (Asia) (lagged share immigrant farmworkers per area-of-origin)						Yes
IIAF (Africa) (intensity immigrant per area-of-origin per farm)					Yes	

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TABLE 2 (Continued)

y_{it}	Model 1 EX(1)	Model 2 EX(2)	 EN(3)	Model 3 EX(4)	 EN(5)	 EN(6)
LSIA (Africa) (lagged share immigrant farmworkers per area-of-origin)						Yes
IIAF (East-EU28) (intensity immigrant per area-of-origin per farm)					Yes	
LSIA (East-EU28) (lagged share immigrant farmworkers per area-of-origin)						Yes

Note: y_{it} is farm total output, mc_{it} farm total intermediate consumption, k_{it} farm non-land fixed assets, awu_{it} farm total labor input, and UAA_{it} the total utilized agricultural area of the holding (see Section 4.2 for further details). Standard errors in parentheses.

Abbreviations: FE, fixed effects; LSIA, Lagged difference Share of Immigrant farmworkers according to their Area-of-origin; LSTI, Lagged difference Share of Total Immigrant.

*Significant at the 10% level.

**Significant at the 5% level.

***Significant at the 1% level.

Source: Authors' elaboration.

farms' (in)efficiency level, thus exogenous to any specific and unobserved demand-pull factors which may attract immigrants, for instance a higher demand of agricultural labor in specific areas of Italy combined with an insufficient domestic supply.

The second IV strategy is based on Malchow-Møller et al. (2013) and Arellano and Bover (1995), and inspired by the "static" criticism raised in Jaeger et al. (2018), consisting of exploiting lagged differences of the share of foreign farmworkers per farm and per area-of-origin. We therefore obtain one IV measuring the Lagged difference Share of Total Immigrant working on the farm (hereafter LSTI) (7.3) as well as three more IVs measuring the Lagged difference Share of Immigrant farmworkers according to their Area-of-origin (hereafter LSIA) (7.4):

$$LSTI_{it} = \Delta\tau_{iG,t-s}^{2008-2018}, \tag{7.3}$$

$$LSIA_{it} = \Delta\tau_{ig,t-s}^{2008-2018}. \tag{7.4}$$

Note that this second set of IVs is not used as a stand-alone IV set, but always combined with some IVs from the first IV set described above to add dynamics and avoid the "static" drawback asserted by Jaeger et al. (2018). The validity of the IVs is tested by using a battery of tests.

5 | RESULTS

We first check whether the production function is monotonically increasing in all inputs—that is, the output does not decrease when inputs increase—as well as the (quasi)concavity—that is, decreasing marginal rates of technical substitution since input sets are convex (Henningsen & Henning, 2009; Kumbhakar et al., 2015; O'Donnell & Coelli, 2005; Sauer et al., 2006). Given a general production function $y = f(X, \beta)$ where X and β are vectors of input quantities and parameters to estimate, respectively, monotonicity requires all marginal products f_i to be positive: $f_i(X, \beta) = \frac{\delta f(X, \beta)}{\delta x_i} \geq 0 \ \forall i$. Therefore, we checked for monotonicity of the translog production function by:

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(i) predicting the output value for each input and for each farm using estimates from (5) hence verifying that there are no negative outputs; (ii) testing that the sum of all inputs' coefficients is statistically positive; and (iii) estimating both the restricted and the unrestricted translog functions and Wald test not rejecting the null that both models are equal (Henningsen & Henning, 2009). The results of these tests confirm the fulfillment of the monotonicity requirements: (i) for each input and farm there is no negative output; (ii) the sum of the inputs' coefficients is always positive; iii) the Wald test cannot reject the null hypothesis that the two models are equal. Regarding the quasi-concavity restriction, this is "[…] not always fulfilled in the real world and measuring TE generally assumes only that producers maximize output given their input quantities but not that producers maximize their profit" (Henningsen & Henning, 2009, p. 219). Therefore, there is no technical rationale for restricting the production function to be quasi-concave, as non-quasi-concave points may resemble profit-maximizing behavior when there are restrictions to input usage (e.g., protected areas), or prices are not all exogenously given. Moreover, such a restriction may hamper the maximization of the likelihood function because of complex calculus, causing convergence problems (Henningsen & Henning, 2009). Therefore, without imposing any quasi-concavity condition on the estimated production function, we perform the standard test for quasi-concavity, i.e. that the Hessian matrix is negative semidefinite (Hirsch et al., 2019; Kumbhakar et al., 2015). The results of the test fulfill the quasi-concavity requirement for 98% of observations.[12]

Table 2 reports the results of the different specifications of the SFA. Note that the model estimates inefficiency (see Section 4.1) and not TE, therefore positive (negative) coefficients in the inefficiency equation in Table 2 should be interpreted as having a negative (positive) effect on TE. While model 1 reports estimates of the production function, models 2 and 3 contain different specifications of the latter. The inefficiency equation of Model 2 is parametrized with both family and hired immigrant labor, and with control variables (farm size and mountain farms), while groups of immigrants variables are included in model 3. Models EN(3), EN(5) and EN(6) control for the endogeneity of the immigrant variables, using different sets of IVs (see last rows of Table 2 for more details). All tests reject the null hypothesis of "no endogeneity" and the sets of IVs used are strong instruments—either assuming *iid errors* or relying on Heteroskedasticity- and Autocorrelation-Consistent (HAC) standard errors—according to the general rule of thumb that F-statistic of the first-stage regression must be larger than a value of 10 (Bellemare, 2015; Karakaplan & Kutlu, 2017a; Latruffe et al., 2017). The battery of additional statistical tests performed delivers satisfactory results, ensuring the validity of the IVs used (see Table 2 and Supporting Information S1: Table A.2 in the Appendix). Assuming standard *i.i.d.* errors, the Anderson LM test rejects the null of under-identification (i.e., the matrix is not full rank) and the Cragg–Donald Wald *F* statistic[13] is relatively higher than the Stock and Yogo critical values, rejecting the null hypothesis of weakly-identified equation (i.e., excluded instruments are weakly-correlated with the endogenous regressors); finally, the Sargan statistic fails to reject the null of the instruments' validity (i.e., uncorrelated with the error term, excluded instruments are correctly not included in the estimated equation). However, due to the long time series of the panel data set, further tests (Baum et al., 2007) are assessed: the Kleibergen–Paap LM statistic and Kleibergen–Paap Wald statistic for under-identification, Kleibergen–Paap Wald *F* statistic for weak-identification, and the Hansen *J* statistic for overidentification test of all instruments, all ensuring the instruments are valid (for further details on the whole set of tests, see Baum et al., 2007). Therefore, in what follows we focus the discussion on the models EN(3), EN(5) and EN(6) that correct for the potential endogeneity bias.

Across the three models, a higher share of hired immigrant hours on total labor has a negative and statistically significant effect on inefficiency, therefore a positive and statistically significant effect on TE. In line with previous studies which found a positive correlation between foreign work and competitiveness (Antonioli et al., 2023; Baldoni et al., 2017; Buchholz, 2021; Malchow-Møller et al., 2013; Ottaviano & Peri, 2005, 2021; Vittori et al., 2023). On the contrary, models EN(3), EN(5) and EN(6) show the negative-to-null influence of unpaid family

[12]Note that the remaining 2% was not dropped and therefore included in the models' estimation.

[13]In case of one endogenous regressor this is equal to the *F*-statistic (Baum et al., 2007).

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labor on the efficiency of dairy farms; in line with the work of Kloss and Petrick (2019), where family farms are generally equal or less productive than those heavily relying on hired labor. Moreover, the fact that these family working hours are not remunerated indicates that farming might not be the primary activity of these individuals, suggesting a lower level of specialization compared to hired workers.

Regarding our variables of interest, models EN(5) and EN(6) show a statistically significant positive effect on inefficiency of African and Eastern-EU28 work (i.e. a negative effect on efficiency) and a statistically nonsignificant effect on inefficiency of Asian work.[14] These results suggest that foreign labor has an overall positive association with a farm's TE, given the always negative and statistically significant coefficient of the share of hired immigrant hours on total labor in all endogenous models, which is in line with the results of Baldoni et al. (2021).[15] Nevertheless, the labor supplied by different main groups of migrants differently affects TE, with negative-to-null influence depending on the immigrant group investigated. While from these results we cannot directly establish the presence of ethnic niches in the Italian dairy farming—that is, whether migrant workers of a particular origin strengthen the presence of migrants of the same origin because of their positive influence on the sector performance (Spindler-Ruiz, 2021)—the heterogeneous effect across migrants groups suggests that workers from different origins are imperfect substitutes. This might be due to the presence of different specialization degrees among foreign workers in the sector that have been developed in the country of origin (Buchholz, 2021). Results suggest that network effects among immigrants are at work, generating positive externalities for immigrant workers (conformity behavior), which maintains the efficiency level of Italian dairy farms (Bandiera et al., 2009).

6 | CONCLUSIONS AND POLICY CONSIDERATIONS

Our empirical analysis for the period 2008-2018 on Italian dairy farms, provides evidence of a general positive contribution of immigrant workers on the technical efficiency, an essential element of farms' competitiveness. The results support the idea that a higher share of foreign labor does not result in a simple upwards shift of the labor supply as it is suggested by neoclassical growth models (Malchow-Møller et al., 2013). On the contrary, there is a qualitative element, channeled through higher technical efficiency that differentiate foreign from family labor and affects the farm's economic performance.

These results may serve as useful evidence for the positive role of immigrant farmworkers in the EU agricultural economy, possibly helping their social and economic inclusion. European policies are increasingly addressing the growing presence and need of foreign workers in the agricultural labor market. A notable example is the recent creation of a European Labour Authority (ELA) under the new European Pillar of Social Rights (EPSR) as well as the new CAP 2023–2027, giving special attention to both employment and social inclusion (Schuh et al., 2019). Moreover, the finding of a negative-to-null effect of unpaid labor suggests that foreign employees could represent a viable complement and/or alternative to the declining family labor. The social conditionality established in the CAP can be a useful policy instrument to provide immigrant workers with fairer and better working conditions, recognizing their fundamental role in maintaining the performance of the Italian dairy sector. This should ensure their fair remuneration (Antonioli et al., 2023; Baldoni et al., 2021), as well as safety and healthy working conditions, which are often neglected (UN, 2020). This could help to promote their regularization and reduce unlawful working situations.

[14]Note that areas-of-origin related variables are not endogenous as the test fails to reject the null. Therefore we estimated an exogenous additional model with specific areas-of-origin as determinants of inefficiency besides the usual control variables and the regional Fixed Effect. Results hold, with positive and significant coefficient for unpaid labor, negative and significant coefficient for Asian workers, positive and nonsignificant effects for both African and Eastern EU-28 workers, negative and significant for large farms, positive and significant for mountain farms.

[15]Note that the share of hired immigrant hours on total labor measure the overall presence of immigrants on the farm, hence including a wide range of different immigrant groups.

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However, further research on this specific issue is needed for a more comprehensive conclusion on the substitutability or complementarity of immigrant to family work. A further qualitative differentiation of labor is given by peer-network effects. In fact, foreign labor influences the farm performance in different ways, depending on farmworkers' social capital, reflecting skills and experience. While explaining the reasons of such differences goes beyond the scope of this research, such outcome raises further important policy reflections. Many immigration policies across the globe select incoming foreigners based on their work profile, with high-income countries facilitating the inflow of high-skilled workers (Ruhs, 2013). For example, the failure of the "Pick for Britain" campaign in UK (BBC, 2020) shows how manual workers are not easily replaceable by the domestic workforce: during the COVID-19 pandemic, where workers' displacement was almost interrupted, labor costs rose by about 9%–15% in the United Kingdom, with a significant role played by unexperienced Britons (The Economist, 2020a).

Regarding the New Pact on Migration and Asylum, and particularly the "Talent Partnerships," our results hint at the inclusion of agricultural-specific sections intended to match labor needs in cooperation with third countries. This would facilitate the inflow of foreign workers with highly demanded skills and experience in specific sectors, improving the effectiveness and efficiency of the agricultural labor market. Moreover, employers are often facing bureaucratic barriers—which translates into higher transaction costs—for temporary visas and limited options for obtaining a permanent settled status (Chiaromonte & Federico, 2021). Reducing such bureaucratic and administrative burdens on agricultural employers may result in a more efficient immigration system overall. In the UK, farmers fear having to rely more on domestic workforce because of new restrictive immigration policies, and ask for an immigration policy that stops prioritizing better-qualified migrants, detrimental for the future of farming (The Economist, 2020a). This may apply in EU countries as well, as not considering soft skills and abilities valued by the hosting labor market can endanger the efficiency of the immigration system, eventually percolating into the socioeconomic sphere (Heckman & Kautz, 2012).

Despite the general shortage of agricultural workers in the EU, the Green Deal aims at shifting towards more sustainable agricultural systems (Luckstead et al., 2021), which are often labor-intensive (Duval et al., 2021; Hostiou et al., 2020; van der Ploeg et al., 2019), and, hence, potentially leading to an increase in labor costs (Martin & Calvin, 2010; Richards, 2018). Christiaensen et al. (2021) warn that decisions of closing borders to foreign workers should be coupled with broader reforms providing farmers with alternatives—for example, increasing educational attainment, facilitating technology adoption, occupational mobility and reducing income inequalities.

Immigrant agricultural workforce and farm performance is yet an emerging research strand in agricultural economics that needs further research efforts, especially covering different agricultural sectors in different MSs, as each country differs in terms of technology of production, workforce structure and legal framework, and factors that may affect the adoption of immigrants farmworkers, delivering a clearer picture of their current and future role in the EU farming system.

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