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RESEARCH ARTICLE

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External finance and agricultural productivity growth

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Abstract

We propose a new method to estimate the impact of external finance on productivity. Using a nested constant elasticity of substitution production function, finance has an indirect influence on productivity through its effect on capital augmenting-technological change and depends on the elasticity of substitution between equity and debt, as well as on the quantity and price of external finance and net value added. We develop and test a theoretical model using Farm Accountancy Data Network regional data covering all EU Member States and different subsamples by EU regions, size of farms, and farm types. In the 2004–2018 period, land, labor, and capital complemented each other but had a decreasing or stagnating productivity, reaffirming the importance of external finance to improve productivity. Results suggest that external finance and productivity follow an inverted U-shaped curve, with a positive impact on less capitalized farms with lower debt-to-equity ratios, while capital-intensive farms are not benefiting from excess finance. Rethinking the general assumption that agricultural growth has a positive and linear effect with access to credit lead to different

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Abbreviations: 2SLS, two-stage least squares; 3SLS, three-stage least squares; CD, Cobb–Douglas; CES, constant elasticity of substitution; CRS, constant return to scale; DEA, data envelopment analysis; DIDID, differences-in-differences-in-differences; EU, European Union; FADN, Farm Accountancy Data Network; GMM, generalized method of moments; HAC, heteroscedasticity and autocorrelation consistent; NUTS, nomenclature of territorial units for statistics; OLS, ordinary least squares; PSM, propensity score matching; SFA, stochastic frontier analysis; SGLS, system generalized least squares; SOLS, system ordinary least squares; TFP, Total Factor Productivity.

strategies in the use of external finance. [EconLit Citations: G30, O16, O33, Q14].

KEYWORDS
agricultural productivity, CES function, external finance, factor-augmenting technical change, financial frictions, GMM regression

1 | INTRODUCTION

In addition to their own equity, farms depend heavily on debt and external finance to fund new investments and current operations (Cadot, 2013; Martins et al., 2022; Mugera & Nyambane, 2015; Ruml & Parlasca, 2022; Sabasi et al., 2021), for example, for purchasing high-tech machineries or obtain seeds and fertilizers on credit. A farm's demand for external finance depends on key factors, such as the availability of internal liquidity, technological changes in production methods, and on risks associated with agricultural production (Sabasi et al., 2021). The impact of finance on productivity and economic growth seized the attention of economic theory as early as Schumpeter's *Theory of Economic Development* (1983[1912]). However, despite the extensive research on finance and growth, economic theory and empirical literature did not fully disentangle the dynamics through which finance and growth operate, especially in the agricultural sector.

Before the 2008 financial crisis, there was huge enthusiasm for finance as the main driver for economic growth in both theoretical and empirical literature. The general assumption was that the growth of the financial sector has a positive and linear effect on productivity and economic growth (Beck & Levine, 2004; Beck et al., 2000; King & Levine, 1993; R. Levine et al., 2000; Rajan & Zingales, 1998). For the agricultural sector, a number of studies have identified financing as an important factor to ease farms' access to agricultural inputs and physical capital, improving farms' productivity and performance (Bhattacharyya & Kumbhakar, 1997; Blancard et al., 2006; Ciaian et al., 2012; Färe et al., 1990; Katchova, 2005; Lee & Chambers, 1986). After 2008, the interest in the macroeconomic impact of finance grew more intensively, aiming to critically understand the channels through which finance affects productivity and growth. New evidence of negative effects appeared. A number of studies have found that increasing levels of credit can have negative impacts on economic growth (Arcand et al., 2015; Cecchetti & Kharroubi, 2015; Law & Singh, 2014). Other studies have found that financial frictions have an indirect and negative impact on productivity growth (Caggese, 2019; O. Levine & Warusawitharana, 2021). Financial frictions have two interpretations. The first considers financial frictions as the spread between the rate of return on capital earned by businesses and the return earned by depositors (Hall, 2013). The second approximates financial frictions to financial transaction costs incurred by businesses (Claessens et al., 2010). In either case, financial frictions cause net losses to the return on investments, potentially turning them negative. Moreover, in agricultural economics, the majority of the studies focused on the issue of access to credit and agricultural performance in single, less-developed countries (e.g., Belek & Jean Marie, 2021; Guirkinger & Boucher, 2008; Narayanan, 2016; Nordjo & Adjasi, 2019; Sekyi et al., 2017). Less studies have focused on the intensive and semi-intensive agricultural sectors of countries with developed financial markets, such as the EU or the United States.

Most of the literature on the impact of finance on growth describe the production technology using Cobb–Douglas (CD) functional forms and Hicks-neutral representation of technological change. CD production functions assume the elasticity of substitution between production factors constant and equal to one, which has very limited empirical support but can fit a wide range of data, even when its essential assumptions are violated (Gechert et al., 2019; Miller, 2008; Shaikh, 1974). In this paper, we propose a two-level nested constant elasticity of substitution (CES) production function to estimate the impact of external finance on productivity growth, through estimating the endogenous factor-augmenting technical change of external finance. This method was originally developed in energy economics, and can significantly improve financial economic models. By contrast to CD production functions, CES allows one to empirically estimate nonunitary elasticity of substitution and factor-augmenting technical change, both important parameters for understanding the demand for production factors relative to their productivity and price, as well as the magnitude and direction of endogenous factor-augmenting technical change. Our analysis provides a more dynamic picture of the impact of finance on agricultural productivity, proposing a method to explain how external finance can affect agricultural productivity through indirect effects on capital augmenting-technological change but without imposing *ex-ante* the direction of the productivity impact of external finance.

We use regional-level data from the farm accountancy data network (FADN) for all the Member States of the European Union (EU) for the period from 2004 to 2018. In our findings, the impact of external finance varies across different EU regions, size of farms, as well as types of farms. The results suggest that external finance has a positive impact on productivity in less capitalized farms, while capital-intensive farms are not benefiting from excess finance. With this study, we aim to provide three main contributions to the literature on agricultural finance and productivity. First, we introduce a novel method to study the impact of finance on productivity that accounts for the dynamics of change in the quantities and prices of external finance. Second, we estimate the elasticity of substitution between land, labor, and capital, and between equity and external finance in the whole EU agricultural sector, testing also the validity of a CES against a CD elasticity of substitution. Third, we estimate the factor-augmented technical change of EU farms testing for the potential presence of Hicks-neutral technical change, including the endogenous factor-augmented technical change of external finance.

The remainder of the paper is structured as follows. Section 2 provides a review of the literature on the impact of external finance on agricultural productivity growth, and estimation methods used to measure the relationship between finance and productivity. Section 3 discusses our theoretical model in detail and Section 4 describes the data used and the econometric estimation strategy. Results are presented in Sections 5 and 6 concludes highlighting policy implications.

2 | FINANCE AND AGRICULTURAL PRODUCTIVITY

2.1 | Literature review

There is a growing and ongoing interest in the impact of external finance on productivity, with both theoretical and empirical applications. In this section, we discuss how finance can influence farms' performance and productivity, and we present an overview of the empirical literature and the methods used to study the impact of finance on productivity. The literature of reference for this study spans from macroeconomics, firm-level and farm-level analyses. Looking beyond agricultural economics is useful to disentangle the channels linking finance to productivity. Moreover, most of the relevant methodologies have been developed in the general and financial economics literature.

An extensive body of literature has identified access to credit and external finance to be crucial for improving farms' performance and productivity (Bhattacharyya & Kumbhakar, 1997; Blancard et al., 2006; Ciaian et al., 2012; Färe et al., 1990; Lee & Chambers, 1986). Generally, external finance can improve farms' productivity through three main channels. First, long-term financing can allow farms to expand their production capacities through new investments in modern equipment, technologies, or other fixed assets. Second, short-term financing can ease farms' liquidity constraints allowing to meet short-term obligations or current operational expenses (e.g., purchase of seeds and fertilizers, wages, rent, etc.), hence maintaining the productivity and competitiveness of the farm. Finally, short-term financing can also support the resilience capacity of farms to mitigate unexpected losses due to external shocks. In the absence of short-term finance, losses caused by external risks can deplete farms' internal financial resources that would have been used for current operational expenses, or invested in future capital assets (e.g., modern equipment; Amin, 1974).

Some empirical studies have looked at the relationship between finance and productivity at the aggregated macroeconomic level. Among these studies, Beck et al. (2000), using cross-country instrumental variable estimators in a CD production function setting, found that increasing credit supply in an economy is positively correlated with total factor productivity (TFP) and GDP growth. Evans et al. (2002) estimated the impact of human capital (measured as educational attainment) and financial development (measured as credit to gross domestic product [GDP]) on macroeconomic growth using a translog production function and panel data for 81 countries. They found that financial development has a positive impact on aggregate economic growth. More studies focused on the firm level. For instance, Gatti and Love (2008) used a CD model with ordinary least squares (OLS) and two-stage least squares estimators on cross-sectional data of Bulgarian firms and found that access to credit had a positive impact on TFP. Franklin et al. (2015) using a CD model found that the reduction in credit supply following the 2008 financial crisis has reduced capital intensity, labor productivity, and wages in the United Kingdom. Ferrando and Ruggieri (2018) found that, during the period 1995–2011, financial constraints, such as difficult access to finance and financial pressure, had a negative impact on the TFP of EU firms. Such negative impact is stronger in small, young, and private firms, and increased during the financial crisis. Manaresi and Pierri (2018) used fixed-effects panel methods to find that an expansion in credit supply had a positive impact on the productivity of Italian firms for more than 10 years. Caggese (2019) developed a theoretical model that explains how financial frictions can affect innovation decisions and, therefore, decrease competitiveness of Italian manufacturing firms. Thus, negatively affecting productivity growth at the firm level, as well as aggregate productivity. Similarly, O. Levine and Warusawitharana (2021) also explained how financial frictions have negative impact on productivity growth through reducing firms' investments in innovation, by using a CD specification with the Arellano–Bond estimator on a large dataset of European firms.

By building on these macroeconomics and firm-level studies, our paper aims to contribute to the following agricultural finance and economics literature. Concerning the EU agricultural sector, Zhengfei and Lansink (2006) studied the impact of debt on the productivity growth of the Dutch agricultural sector. They first computed Malmquist productivity growth indexes and used system generalized method of moment (GMM) regression to examine the impact of short- and long-term debt on productivity and profitability. Their results showed that the debt-to-asset ratio has no impact on the profitability of Dutch farms, but long-term debt has a positive effect on their productivity. Blancard et al. (2006) focused on French agriculture finding that large farms have facilitated access to finance more than small ones, and that access to financial markets allows better productive choices. Davidova and Latruffe (2007) found that highly indebted Czech farms are less efficient because they cannot have access to additional credit to finance their working capital or to apply new production methods. Finally, Ciaian et al. (2012) studied agricultural productivity at the farm level in six central and eastern European countries using semiparametric propensity score matching (PSM), finding that credit is associated to higher TFP and to lower labor inputs.

Outside the EU, Griffin et al. (2020) studied the impact of credit constraints on new farmers and ranchers in the United States using PSM, showing that difficult credit access is associated with lower production levels. Hartarska et al. (2015) found in the United States a positive relation between credit supplied by private landers and the agricultural GDP growth per rural resident with fixed-effects panel data methods. Butler and Cornaggia (2011) found that agricultural production of energy crops across US counties increased in areas with relatively strong access to finance during the period from 2000 to 2006, by using a differences-in-differences-in-differences (DIDID) approach. Similarly, Sabasi et al. (2021) found that increased access to credit is positively correlated with a higher level of productivity in US farms using state-level data for the period 1966–2003. Mugera and Nyambane (2015) found that short-term debt has a positive impact on the technical efficiency of Broadacre farms in Western Australia, but that long-term debt has no impact on productivity. They used data envelopment analysis (DEA) and stochastic production frontier on a 10-years unbalanced panel dataset. Finally, Tothmihaly and Ingram (2019) did not find a statistical correlation between access to credit and technical efficiency in Indonesian cocoa farms using stochastic frontier analysis (SFA).

Overall, the majority of the reviewed empirical literature suggested a positive impact of external finance on productivity growth, however, a number of studies highlighted the negative impact of high debt ratios and financial frictions on productivity (Caggese, 2019; Davidova & Latruffe, 2007; O. Levine & Warusawitharana, 2021).

2.2 | Theoretical background

The review of the literature in the previous section highlights three main modeling approaches for studying the impact of external finance on productivity, namely, growth accounting approaches, frontier approaches, and matching techniques. Growth accounting approaches are methods used to estimate the contribution of factors of production to economic growth. Generally, growth accounting methods assume perfect substitution between factors of production (CD function), and a Hicks-neutral technological change, such that the marginal rates of substitution of labor and capital do not change. These assumptions imply that changes in total output are not correlated with changes in the quantities of factors of production (Solow, 1957). However, empirical evidence does not support these assumptions, showing that technological progress is not necessarily neutral and can increase the relative demand for one factor of production while reducing the demand and the compensation for other factors (Acemoglu, 2003). Frontier approaches can be either parametric (e.g., SFA) or nonparametric (e.g., DEA) methods to estimate technical efficiency and its determinants. Similar to growth accounting approaches, frontier approaches assume Hicks-neutral technological change, thus implying that productivity is not affected by changes in the relative quantities of production factors. Finally, matching techniques (such as PSM and difference-in-differences) are statistical methods to estimate the treatment effect of a given factor (e.g., external finance) on an outcome (e.g., total output or labor productivity) by comparing the productivity of those who received external finance (treated group) against those who did not receive finance (nontreated group; Ciaian et al., 2012; Griffin et al., 2020). A major limitation of matching techniques is the use of discrete variables as indicators for external finance, by constructing an ordinal or categorical variable to denote the amount of finance received. This method ignores the differences and fluctuations in the amount of external finance received within each group.

In addition to the CD production function, the translog functional form has been also used in productivity analysis (Berndt & Christensen, 1973; Jin & Jorgenson, 2010). The translog function is more flexible than the CD and CES, as it does not assume constant return to scale (CRS) or CES between production factors. Despite the theoretical advantages of the translog function, it is not widely applied to estimate the impact of finance on productivity growth because of the excessive number of parameters to be estimated, which would require imposing further constraints for feasible application. To our knowledge, the only study that applied the translog function in the context of finance and growth was Evans et al. (2002), but they still assumed constant returns to scale and perfect substitution between production factors. Another form of translog functions is the Kmenta approximation. We discuss its advantages and limitations in Section 4.

Moreover, it is worth noticing that, except for the recent studies by Caggese (2019) and O. Levine and Warusawitharana (2021), the vast majority of the studies on finance and productivity ignored the cost of external finance (or interest expenses).

Our methodological contribution consists of proposing a theoretical model that explains how external finance affects productivity through the indirect impact on capital augmenting-technological improvements, without imposing the direction of the impact of external finance on productivity a priori. This method has been previously applied in agricultural, environmental and R&D economic modeling, and widely used for computable general equilibrium models (Carraro & De Cian, 2013; Dudu & Smeets Kristkova, 2017; Khafagy & Vigani, 2022; Smeets Kristkova et al., 2017; Van der Werf, 2008).

Production functions attempt to explain the relationship between physical outputs and physical inputs (factors of production). In a neoclassical production function, the quantity of capital stock represents heterogeneous capital goods, such as different types of tractors, seeds, fertilizers, and so forth.[1] Since we are trying to understand the impact of external finance on productivity, our model assumes that capital stock can be represented by two types of capital goods: (1) capital goods that are financed internally by the farms' equity, and (2) capital goods that are financed externally by debt. Distinguishing between the two responds to the fact that the availability and price of both are heterogeneous across different farming systems. Accordingly, access to external finance or availability of internal equity will determine the quantity as well as the quality of capital goods that are used in production. In other words, access to external finance allows farms to use improved seeds and fertilizers, new agricultural machineries, or replace old ones, which directly affect the productivity of farms.

The original two-level CES function proposed by Van der Werf (2008) and Henningsen et al. (2019) uses different nesting orders for capital, labor, and energy inputs. In our model, the lower level combines equity (internal finance or capital) and credit or debt (external finance) to form a composite input representing the net value added. The net value-added composite input is the net return on capital (equity and debt) after paying for wages and rent. The lower level is then combined with labor and land in the upper level. Since we want to understand the impact of external finance on productivity growth, we must treat debt as a separate input. This assumption is reasonable since not all EU farms have equal access to external finance as the price of external finance and the rate of return on total capital differs across and within regions. Moreover, our nesting structure allows us to distinguish between the elasticity of substitution of internal and external finance, between the elasticity of substitution of equity-debt, labor and land, and to estimate the factor-augmented technical change for labor and land as well as internal and external finance (equity and debt) separately.

Furthermore, because of financial frictions, the impact of external finance on productivity remains subject to the technological progress of capital, so that financing facilitates the exploitation of technological opportunities. In our model the impact of finance is not linear and depends on the elasticity of substitution between equity and external finance, as well as the quantity and price of external finance and total capital. These dynamics are not linear, since the elasticity of substitution between external finance and equity is determined by the changes in prices and quantities of net value added, equity, and external finance, in the first place.

While current literature treats external finance as a perfect substitute of equity, we show how the elasticity of substitution between equity and finance tends to be below one, and accordingly, different levels of capitalization have different productivity responses to finance, leading to an inverted U-shape relationship between farms' productivity and external finance. We identify three different stages for the impact of external finance on productivity. In the first stage farms have low levels of capitalization (low debt/capital and low capital/labor ratios), therefore external finance can significantly increase the productivity and competitiveness of farms, as it will be used to acquire state-of-the-art assets, increasing the capitalization of the farm business. In the second stage farms accumulated sufficient levels of capital, therefore external finance is used to maintain the operation of the already existing assets, such as restoration of depreciated assets, as well as financing working capital to reduce liquidity constraints and running of the assets. In this stage, finance is used to maintain the productivity or competitiveness of the farm. In the third stage farms have reached very high levels of capitalization (overcapitalization). The available technological progress has been fully exploited, additional capital cannot longer lead to new productive investments and finance becomes a burden on productivity. If capital is not used to acquire additional technologies and/or production inputs, financial frictions become net costs reducing the productivity and competitiveness of farms.

This nonlinear mechanism is evidenced through an empirical application concerning all the EU regions for the period 2004–2018 and it is based on the estimation of a system of equations derived from the first-order condition of a two-level CES production function using a GMM estimator to control for potential endogeneity.

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[1] The concept of capital in production functions has been subject to heated debates in the last century since Joan Robinson highlighted the difficulty to represent the quantity of capital stock by a single number which ignores the heterogeneity of capital goods (Robinson, 1953).

3 | THE MODEL

We assume that the production of a representative farm is a two-levels three-inputs nested CES production function with factor-specific technology parameters and CRS (Carraro & De Cian, 2013; Khafagy & Vigani, 2022; Smeets Kristkova et al., 2017; Van der Werf, 2008).

The CES production function has the following form:

$$Y_{i,t} = \left[\Phi_N (A_N N_{i,t})^{\frac{\sigma-1}{\sigma}} + \Phi_L (A_L L_{i,t})^{\frac{\sigma-1}{\sigma}} + \Phi_K (A_K K_{i,t})^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

such that

$$K_{i,t} = \left[\mathrm{B}_E (A_E E_{i,t})^{\frac{v-1}{v}} + \mathrm{B}_D (A_D D_{i,t})^{\frac{v-1}{v}}\right]^{\frac{v}{v-1}}. \tag{2}$$

In Equation (1), Y, N, L, and K denote quantities of gross value added, land, labor, and a composite input of capital (or net value added), respectively, for the ith farm at the year (t). Φ_N, Φ_L, and Φ_K are distribution parameters of land, labor, and capital, A_N, A_L, and A_K are factor-augmenting technology parameters that describe the productivity of the production factors, and σ is the elasticity of substitution between the three factors ($\sigma = 1$ is a CD production function, $\sigma > 1$ means factors are gross substitutes, and $\sigma < 1$ means gross complements). In Equation (2), K is a composite input in the lower nest that combines the net value added resulted from the components of capital, which are equity (E) and credit (D). B_E and B_D are the share of equity and credit in capital, and v is the elasticity of substitution between equity and credit, with similar characteristics as σ. The parameters σ and v reflect the relative extend to which factors of production can replace each other due to changes in their relative prices. The main parameters of interest here are A_E and A_D, which are factor-augmenting technology parameters that define the productivity of equity and credit, respectively. Substituting Equation (2) into Equation (1) gives us the nested CES function where equity (E) and credit (D) are in the lower nest forming the composite input K, and combining them with labor (L) and land (N) gives the final value added (Y).

From the CES function (1), we can determine how the production technology is represented, whether by input-specific technical change or by TFP (Hicks-neutral). In the case the production technology is represented by TFP, then we must have $A_N = A_L = A_K$ (Carraro & De Cian, 2013; Khafagy & Vigani, 2022; Van der Werf, 2008). Similarly, in Equation (2), we have Hicks-neutral technical change in the composite input of capital when $A_E = A_D$, or input-specific technical change when $A_E \neq A_D$.

The cost minimization problem of the two-level CES function can be denoted as a two-stage problem, where in the first stage we have the cost function of the composite input K, and in the second stage we have the cost function of the value added in the upper nest. The cost minimization problem of the two-level CES function is

$$\min C^K_{i,t} = P^E_{i,t} E_{i,t} + P^D_{i,t} D_{i,t}, \tag{3}$$

such that

$$\min C^Y_{i,t} = P^N_{i,t} N_{i,t} + P^L_{i,t} L_{i,t} + P^K_{i,t} K_{i,t}. \tag{4}$$

Replacing the price of the composite input ($P^K K$) in Equation (4) with the price of equity ($P^E E$) and credit ($P^D D$) in Equation (3) gives us the cost minimization problem of the nested CES function. Taking the first-order condition to solve the cost minimization problem and taking logarithms, the conditional factor demand equations can be expressed by linear relationships such as in the system of Equation (5)[2]:

$$\ln\left(\frac{N_{i,t}}{Y_{i,t}}\right) = \sigma\ln(\Phi_N) + (\sigma-1)\ln(A_N) + \sigma\ln\left(\frac{P^Y_{i,t}}{P^N_{i,t}}\right),$$

$$\ln\left(\frac{L_{i,t}}{Y_{i,t}}\right) = \sigma\ln(\Phi_L) + (\sigma-1)\ln(A_L) + \sigma\ln\left(\frac{P^Y_{i,t}}{P^L_{i,t}}\right),$$

$$\ln\left(\frac{K_{i,t}}{Y_{i,t}}\right) = \sigma\ln(\Phi_K) + (\sigma-1)\ln(A_K) + \sigma\ln\left(\frac{P^Y_{i,t}}{P^K_{i,t}}\right),$$

$$\ln\left(\frac{E_{i,t}}{K_{i,t}}\right) = v\ln(\mathrm{B}_E) + (v-1)\ln(A_E) + v\ln\left(\frac{P^K_{i,t}}{P^E_{i,t}}\right),$$

$$\ln\left(\frac{D_{i,t}}{K_{i,t}}\right) = v\ln(\mathrm{B}_D) + (v-1)\ln(A_D) + v\ln\left(\frac{P^K_{i,t}}{P^D_{i,t}}\right). \quad (5)$$

The first three equations are derived from the optimal demand for N, L, and K per unit of Y, and the last two equations are derived from the optimal demand for E and D per unit of K in the lower nest. The nesting structure is maintained through the last three equations in the system of Equation (5), where the last two equations represent the optimal demand for E and D per unit of K, while the third equation denotes the optimal demand for the composite input K per unit of gross value added Y (Van der Werf, 2008). Recalling that the prices of the input factors pf $(pf = pn, pl, pk, pe, pd)$ and N, L, E, and D denote the quantities of the input factors, then the prices of Y and K can be derived from the relative price of each input factor in the total cost of the composite input and the value added, such that

$$pk = \left[\left(\frac{pe\cdot E}{pd\cdot D + pe\cdot E}\right)\cdot pe\right] + \left[\left(\frac{pd\cdot D}{pd\cdot D + pe\cdot E}\right)\cdot pd\right],$$

$$py = \left[\left(\frac{pn\cdot N}{pn\cdot N + pl\cdot L + pk\cdot K}\right)\cdot pn\right] + \left[\left(\frac{pl\cdot L}{pn\cdot N + pl\cdot L + pk\cdot K}\right)\cdot pl\right] + \left[\left(\frac{pl\cdot K}{pn\cdot N + pl\cdot L + pk\cdot K}\right)\cdot pk\right]. \quad (6)$$

To estimate all the parameters of the CES function we need to impose additional restrictions or assumptions. The first three equations of the system of Equation (5) are underidentified, as we need to estimate three unknown parameters given two known variables for prices and quantities. Thus, we cannot separate the distribution parameters (Φ) and the productivity parameter (A) (first two terms on the right-hand side) because both will be calculated within the constant coefficient. Van der Werf (2008) suggests estimating the percentage changes in the factor-specific technology parameter by taking the first differences of the underidentified equations—that is, the first three equations in the system of Equation (5). By taking the first differences, we can drop the distribution parameters (Φ) from the system of equations, since it is assumed that the contribution of capital, labor, and land in production is constant in the short run. This assumption does not necessarily apply to the last two equations in the system, representing the factor demand for equity and debt, as their contribution to capital can substantially change in the short run. By log-transforming the conditional factor demand Equation (5), we obtain the corresponding linear relationships expressed in the following system of equations:

$$(n_{i,t} - y_{i,t}) = (\sigma-1)\alpha_N + \sigma(py_{i,t} - pn_{i,t}),$$

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[2] See Supporting Information Appendix 1 for the derivation of the conditional factor demands.

$$(l_{i,t} - y_{i,t}) = (\sigma - 1)\alpha_L + \sigma(py_{i,t} - pl_{i,t}),$$

$$(k_{i,t} - y_{i,t}) = (\sigma - 1)\alpha_K + \sigma(py_{i,t} - pk_{i,t}),$$

$$(e_{i,t} - k_{i,t}) = v(\beta_E) + (v - 1)\alpha_E + v(pk_{i,t} - pe_{i,t}),$$

$$(d_{i,t} - k_{i,t}) = v(\beta_D) + (v - 1)\alpha_D + v(pk_{i,t} - pd_{i,t}), \tag{7}$$

where small letters denote the first difference of the log-transformed variables. The unequal productivity parameters for equity and debt rise from different prices of equity and debt, as well as from the change in quantities. Equity is usually recapitalized by retained earnings or the owner's savings, and it increases at a slower rate. The rate of change in the quantity of debt may also be slower in farms with prior access to credit instruments, however, debt may increase or decrease substantially through access to new credit instruments or at the end of credit contracts. As such, the rate of change in debt is likely to fluctuate more than the rate of change of equity. Furthermore, in perfect competition, the price of capital P^K will be equivalent to the nominal lending interest rate, or rental cost of capital P^D, such that $P^K = P^E = P^D$. However, the ability to estimate the productivity of equity and credit separately comes from the existence of imperfect competition which derives endogenous price markups based on different degrees of monopoly and different profitability levels, so that $P^K \neq P^E \neq P^D$, and the P^K is determined by the P^E, P^D and the portion of capital that is financed by equity and debt, as illustrated in Equation (6). Nonconstant price markup (μ) can be calculated following Raurich et al. (2012), Chen and Yu (2022), and Koppenberg and Hirsch (2022) as follows:

$$\mu = \frac{P^Y Y}{P^N N + P^L L + P^D K}, \tag{8}$$

where the rental market price of capital is equivalent to the nominal lending interest rate P^D. Furthermore, from the conditional factor demand of debt in the system of Equation (7), we can see how the productivity of debt is a function of the elasticity of substitution between debt and equity, the difference between the quantity of debt and quantity of capital, as well as the difference between the price of debt and price of capital. That is,

$$\alpha_D = \left(\frac{1}{v - 1}\right)(d_{i,t} - k_{i,t}) - \left(\frac{v}{v - 1}\right)(\beta_D) - \left(\frac{v}{v - 1}\right)(pk_{i,t} - pd_{i,t}). \tag{9}$$

The elasticity of substitution between equity and external finance (v) can be represented by a function of the ratio of price of external finance (PD, interest rate) to price of equity (PE, rate of profit or return on equity)—similar to financial frictions—and equity to external finance (leverage ratio). Denoting the leverage ratio as $h = \frac{E}{D}$ and the financial frictions as $f = \frac{PD}{PE}$, then the elasticity of substitution (v) is

$$v = \frac{dh/h}{df/f}, \tag{10}$$

such that (dh/h) is the rate of change in leverage ratio and (df/f) is the rate of change in financial frictions.

From Equation (9), we can draw the dynamics of productivity growth of debt in relation to the elasticity of substitution between equity and debt, and in relation to the change in the quantity and price of debt relative to the change in the quantity of net value added associated with capital (k) and price of capital as a whole. These dynamics are not linear, since the elasticity of substitution between debt and equity is determined by the changes in prices and quantities of net value added, equity, and debt, in the first place. More specifically, we can have four cases.

First, if ($v = 1$) we have a CD elasticity of substitution where equity is perfectly substituted by debt. In this case, there is no particular advantage for debt and capital exhibits a neutral augmented technical change, such that ($\alpha_D = \alpha_E = 0$).

Second, if ($v = 0$) we have a Leontief technology where there is no substitution between debt and equity. In this case, the impact of debt on productivity growth is due only to the change in the net value added relative to the change in the quantity of debt, such that, ($\alpha_D = k_{i,t} - d_{i,t}$).

Third, the more likely realization is that ($v < 1$). In this case, we have complementarity instead of substitution between debt and equity and the impact of debt on productivity growth is due, once again, to the relative change in the net value added to the change in the quantity of debt, and also to the change in the contribution of debt in total capital (β_D), and the difference between the price of net value added and the price of debt ($pk_{i,t} - pd_{i,t}$). In this third case, two alternatives arise based on whether ($k_{i,t} > d_{i,t}$) or ($k_{i,t} < d_{i,t}$).

If ($k_{i,t} > d_{i,t}$), then the impact of debt on productivity growth depends on the change in net value added relative to the change in the quantity and price of debt. Since (v) is a function of interest and profitability rates (prices of debt and equity), then if the interest rate does not increase substantially, (v) will be positive ($0 < v < 1$) and the increase in net value added will be reflected as an increase in the productivity of debt. However, if the increase of debt price is substantially greater than the increase in net value added, then the price of equity will consequently decrease leading to a negative elasticity of substitution ($v < 0$). In this case, we can have a negative productivity impact on debt even if net value-added increases more than the quantity of debt itself.

On the other hand, if ($k_{i,t} < d_{i,t}$), then we will have a negative impact of debt on productivity growth if the price of debt is constant or if it increases, since the price of equity will decrease and the elasticity of substitution will be negative. We can have a positive impact of debt on productivity in this case only if the price of debt decreased at a higher rate than the negative change in net value added and the decrease in the price of equity. This proposition is in line with the O. Levine and Warusawitharana (2021) model, which suggests that the impact of finance on productivity is positive when the cost of finance (financial frictions) is low, however, an increase in the cost of finance will reduce firms' expenditure on innovation and thus negatively affects their productivity. Finally, if ($v > 1$), then we have a high elasticity of substitution between debt and equity, and debt is better be replaced with equity. In this fourth case we have the opposite dynamics from when debt and equity are complementary factors ($v < 1$). Such that, if ($k_{i,t} > d_{i,t}$) then there is a higher probability to have a negative impact of debt on productivity growth. Whereas, if ($k_{i,t} < d_{i,t}$), then there is a higher probability to have a positive impact of debt on productivity growth. This is a very rare scenario because it requires that the rate of change of the quantity of debt is higher than the change in the quantity of equity, while at the same time, the rate of change in the price of equity is higher than the change in the price of debt. This may occur in one period or on the very short term, once a farm is granted a new credit contract to finance capital investments or working capital expenditures, but the following years of utilizing the same credit contract will be not reflected in the rate of change of the quantity of debt. Thus, the farm needs to be granted a new credit contract in addition to the existing one every year, to maintain a high rate of change of its debt quantity. Moreover, since equity is mainly financed by previous years' profits (retained earnings), and ($v > 1$) requires that the rate of growth of the return on equity is high. Thus, this growth in the price of equity in 1 year will be reflected in the growth rate of the quantity of equity in the following year, reducing the ratio between change of equity and change of debt and consequently decreasing the elasticity of substitution to below one again.

Understanding the dynamics between the rates of change in net value added and quantities and prices of debt and equity, and their impact on the elasticity of substitution, help us to draw the nonlinear impact of external finance on productivity. In particular, since the elasticity of substitution between equity and debt tends to be below one, we expect an inverted U curve with three different stages depending on the level of capitalization of the farm. This is illustrated by means of numerical examples using regional FADN data (see more details about the data in Section 4) which show a clear inverted U-shape relationship between productivity and capital intensity. In Figures 1 and 2, we fitted two-way quadratic predictions with confidence intervals for gross value added against capital, and for labor productivity (gross value added per labor input) against capital intensity (capital per labor input). The two-way quadric prediction produces predicted values after regressing the y variable (i.e., gross value added and labor productivity) against the x and the x^2 of the regressor variable (i.e., capital and capital intensity).

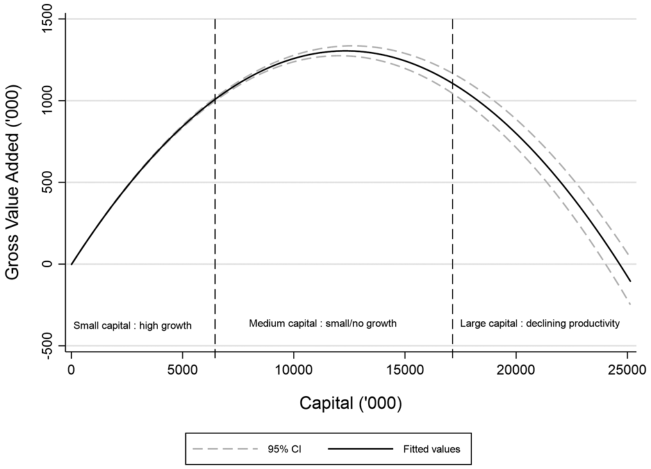

FIGURE 1 Two-way quadratic prediction—gross value added to capital

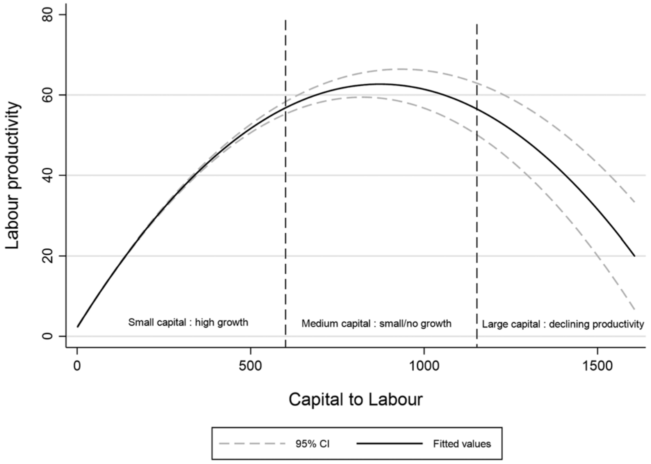

FIGURE 2 Two-way quadratic prediction—labor productivity to capital intensity

The first stage coincides with the raising parts of the curves in Figures 1 and 2. The farm has small capital stock and restricted access to credit reflected in a low level of capitalization (low debt/labor and low debt/capital ratios). The farm here is only able to maintain low production levels due to low-productive farming practices, and/or, low liquidity to finance its working capital. In this stage, external finance is used to buy and accumulate new assets, such as new machineries or farming technologies, which lead to increasing the capitalization of the farm business. These new assets can significantly increase the productivity and competitiveness of farms, such that ($k_{i,t} - d_{i,t} \gg pd_{i,t}$).

In the second stage, the farm will have a medium to a high level of capitalization. The farm here has accumulated sufficient production assets and technologies to produce at the highest available productivity level. In this stage, credit is used for reducing liquidity constraints by financing working capital and maintaining the production of existing assets. In other words, credit is used to maintain productivity or competitiveness, such that ($k_{i,t} - d_{i,t} \cong pd_{i,t}$).

In the third stage, the farm reaches a very high level of capitalization or even overcapitalization. Here, the farm is already operating using the most productive practices and technologies available and has a good liquidity position, financed either by external credit facilities or internal cashflow. In this stage, the farm will not benefit from additional credit at all as additional capital will not be reflected in additional net value added because there is no capacity to utilize this additional capital in productive outlets. On the contrary the extra credit will have a negative impact on productivity and will reduce the competitiveness of the farm, since ($k_{i,t} - d_{i,t} < pd_{i,t}$).

4 | DATA AND ESTIMATION STRATEGY

We use regional-level data from the FADN for all EU Member States covering the period from 2004 to 2018. Regions are classified according to the EU's nomenclature of territorial units for statistics (NUTS) 2 level of division. Data are described in Table 1, while Table 2 reports summary statistics.

A common method to estimate CES production functions is the Kmenta approximation. Kmenta (1967) introduced a linearized form of the standard two-input CES function using Taylor approximation around a unitary elasticity of substitution between inputs. The proposed linearization could be estimated using OLS regression as a restricted formula of the general translog function. However, the Kmenta approximation remains only an approximation of the CES function and can produce considerably biased estimates because it is strictly valid for elasticities of substitutions around unity (Hoff, 2004; Henningsen & Henningsen, 2011).

To overcome the limitations of the Kmenta approximation, we estimate the system of Equation (7) which is directly derived from the nested CES function. Estimations of systems of equations have been previously done using system ordinary least squares and system generalized least squares. However, the two estimators do not allow controlling for endogeneity problems and impose a restriction on the explanatory variables to be strictly exogenous. A strict exogeneity condition assumes that the explanatory variables are uncorrelated with the disturbance term (unobservable factors or errors) in all equations in the same time period. This is also referred to as explanatory variables being orthogonal to the errors. The exogeneity condition is often violated and for that, instrumental variables models provide more valid approaches.

Estimates of production function parameters must address endogeneity problems arising from the relationship between input demand and the unobserved productivity parameters. Endogeneity in production functions comes from the fact that the allocation of production inputs is based on their prices and the farmer's belief about the productivity of these inputs (Olley & Pakes, 1996). In our model, some of the covariates might violate the strict exogeneity condition and be correlated with the error term. Such covariates are differences in factor prices ($pk - pd$, $pk - pe$, *and* $py - pk$) and they might be endogenous because of the relationship between price levels and inputs and output quantities. The modern approach to system instrumental variables estimation is based on the principle of GMM, which uses fewer distributional assumptions than the alternative three-stage least squares approach. The GMM estimator is more efficient to estimate models with potential endogeneity problems by using internal instruments, such as lagged values of the explanatory variables. Therefore, to consider the potential endogeneity of the variables in the system of Equation (7), we used the two-steps GMM system estimator in STATA. In the first step the parameters are estimated using an initial weight matrix; in the second step the obtained parameters are used to compute a new weight matrix which serves to re-estimate adjusted parameters. This is opposed to the one-step GMM estimator where the parameters estimated are just the ones in the first step obtained with the initial weight matrix.

We used different internal instrumental variables to address the endogeneity of prices variables ($pk - pd$, $pk - pe$, *and* $py - pk$). As instruments, we used the lag of the first difference of prices to instrument the corresponding explanatory variables. A valid instrumental variable must be correlated with the endogenous variables and uncorrelated with the error term at the same time. It is difficult to find external instrumental variables in the FADN that explain the growth rates of prices and are not correlated with growth rates of quantities at the same time, as both variables are highly correlated by default. Several studies have used the lagged values of the endogenous variables as instruments, such as Acemoglu et al. (2008), Murtin (2013), Smeets Kristkova et al. (2017),

TABLE 1 Data description

Variable	Description
Quantities and prices	
Gross value-added quantity	Gross value added that will be distributed among the factors of production, before depreciation, subsidies, or taxes. Calculated as gross farm income divided by the price of gross value added.
Labor quantity	Total labor input expressed in time worked in hours.
Land quantity	Total utilized agricultural area in hectares. It includes land in owner occupation and rented land.
Net value-added quantity (composite input)	Calculated as gross value added minus wages and rent paid, divided price of capital.
Debt quantity	In Euros. Calculated as the average total liabilities.
Equity quantity	In Euros. Calculated as the difference between average farm capital and average total liabilities. Farm capital includes the value of livestock, permanent crops, land improvements, buildings, machinery and equipment, and circulating capital. It is only calculated if the value of buildings is recorded separately from the value of land capital.
Labor price	Calculated as: wages paid/paid labor input.
Land price	Calculated as: rent paid/rented utilized agricultural area.
Debt price	Calculated as the price of farm's debt: interest rate + depreciation rate. Interest rate is interest paid/average liabilities. The depreciation rate is depreciation/average farm capital. See Pietola and Myers (2000) for more discussion on the price of capital.
Capital price	Calculated as: net value added/average farm capital.
Equity price	Calculated as: (net value added − [debt price x quantity of debt])/average farm equity.
Data clustering	
Crops	If the farm is specialized in field crops, horticulture, wine grapes, or other permanent crops. On the basis of the "Type of Farming" FADN variable.
Livestock	If the farm is specialized in other grazing livestock, or granivores. On the basis of the "Type of Farming" FADN variable.
Dairy	If the farm is specialized in milk. On the basis of the "Type of Farming" FADN variable.
Small-scale farms	On the basis of FADN economic size categorical variable in which the standard output of farms is ≤25,000 EUR.
Medium-scale farms	On the basis of FADN economic size categorical variable in which the standard output of farms is ≤100,000 EUR.
Large-scale farms	On the basis of FADN economic size categorical variable in which the standard output of farms is ≥100,000 EUR.
Northern region	If the farm is in Denmark, Ireland, the United Kingdom, Finland, or Sweden.
Southern region	If the farm is in Italy, Greece, Spain, Portugal, Cyprus, Malta, or France.
Central and eastern region	If the farm is in the Czech Republic, Hungary, Poland, Slovakia, Slovenia, Croatia, Estonia, Latvia, Lithuania, Bulgaria, or Romania.
Western region	If the farm is in Germany, Austria, Belgium, Luxembourg, or the Netherlands.

TABLE 2 Summary statistics

Variable	N	Mean	Standard Deviation	Minimum	Maximum
$e-k$	10,361	−0.021	2.425	−32.787	30.258
$d-k$	10,361	−0.015	2.970	−32.342	30.089
$k-y$	10,361	0.037	3.037	−30.318	32.515
$l-y$	10,361	0.029	1.097	−10.324	11.840
$n-y$	10,361	0.032	1.109	−10.314	11.852
$pk-pe$	10,361	0.021	2.480	−21.127	20.971
$pk-pd$	10,361	0.060	2.354	−16.802	18.874
$py-pk$	10,361	0.001	2.654	−18.622	19.022
$pl-py$	10,361	−0.001	1.534	−18.709	17.607
$pn-py$	10,361	0.008	1.474	−16.198	18.399

Jetter and Parmeter (2018), and Khafagy and Vigani (2022), however, using lagged endogenous explanatory variables as instruments is not without limitations (Bellemare et al., 2017; Reed, 2015). Reed (2015) suggests that using lagged explanatory variables is an effective strategy when they are correlated with the simultaneously determined explanatory variable, and are not included in the main estimating equation. Bellemare et al. (2017) argued that using lagged explanatory variables does not necessarily mitigate endogeneity problems, as it may only channel the endogeneity effects of the previous time period. They suggest that the use of lagged explanatory variables is only valid either if (1) there is no correlation between the dependent variable and the lagged explanatory variable or (2) there is no correlation between the dependent variable and its lagged value (no temporal dynamics in the dependent variable).

We chose lagged internal instruments of growth rates of prices that are correlated with the endogenous variables, and we tested the validity of the instruments using Hansen's $J\ \chi^2$ for testing the overidentifying restrictions. We used only the first-order lag to maintain a sufficient number of observations for all regions included in the examined time period, and there is no economic reason to assume that higher-order lags would explain the values of endogenous variables better than the first-order lag, especially that the endogenous variables here are first-differenced (Smeets Kristkova et al., 2017, p. 395). We also tested for Bellemare et al.'s (2017) validity conditions for the whole dataset using fixed-effect panel regression on each equation of the system of Equation (7). We found that the first condition applies to our instrumental variables, that is, lagged growth rates of the prices of debt, labor, land, and net value added (composite input) are not correlated with the dependent variables in their equations. These tests indicate that our lagged instrumental variables are valid.

Because we are dealing with an unbalanced panel dataset consisting of a large number of regions for 15 years, it is fair to assume that the residuals may exhibit clustering. For this reason, we specified a weight matrix that accounts for arbitrary correlation among observations within the same region, and that assumes independent moment equations. In this way, the GMM command in STATA computes a weight matrix that does not assume that errors are independent within each farm's observations (clusters), and we kept the default weight matrix (unadjusted) which assumes that the weight matrix has independent and identically distributed moment equations. We applied our estimations using the Newey and West algorithm to obtain consistent standard errors in the presence of heteroscedasticity and autocorrelation in the data.

Finally, we use Wald tests to examine if our estimations demonstrate a CD production technology (Carraro & De Cian, 2013; Smeets Kristkova et al., 2017), such that the elasticity of substitution is equal to one. In these tests, rejecting the null hypothesis does not support the existence of a CD technology and confirms the assumption of a CES technology. We used Wald tests also to test for the assumption of Hicks-neutral technical change. The system of equations derived from the FOC allows one to estimate the total magnitude and direction of factor-augmented technical change and to test for the presence of Hicks-neutral technical change by testing if labor- and capital-augmented technical changes are equal. We therefore test whether $\alpha_N = \alpha_L = \alpha_K$ and $\alpha_E = \alpha_D$.

5 | RESULTS

We present the results for the two-steps GMM estimations of the system of Equation (7) for different economic sizes (Table 3), EU regions (Table 4), and types of farms (Table 5). For all the estimations in each table, Hansen's *J* test for overidentifying restrictions supports our models' specification and the instruments used to account for potential endogeneity, as we cannot reject the null hypothesis that the overidentifying restrictions are valid (*p* value of the χ^2 is >0.05).

We start first by analyzing the results of the upper nest of the production function—that is, the first three equations in the system of Equation (7)—representing labor, land, and capital. In all the estimations, the results suggest that the upper nest of our production function has a CES technology specification rather than a CD technology. This is shown from the parameters of the elasticity of substitution (σ, first rows of Tables 3–5) and the Wald tests (last rows), which suggest rejecting the null hypothesis that the technology specification in our data is a CD technology. Furthermore, the Wald tests also reject the null hypothesis of the presence of Hicks-neutral technical change and support the assumption of factor-augmented technical change in some estimations, and confirms the presence of Hicks-neutral technical change assumption in most of the estimations. In particular, the Wald tests reject the null hypothesis for Hicks-neutral technical change in the estimations of the medium-size farms (Table 3), and the eastern and central, and western EU regions (Table 4). This confirms different levels of marginal productivity between labor, capital, and land in these estimations. However, the Wald tests support the presence of a Hicks-neutral technical change in the remaining estimations, namely, in EU28, small and large farms (Table 3), northern and southern EU regions (Table 4), and crop, dairy, and livestock farms (Table 5).

The results highlight the presence of complementarity between the three production factors of EU agriculture. Indeed, in all the reported estimates in Tables 3–5, the elasticity of substitution between labor, land, and capital (σ) is below one or negative and always statistically significant either at 1%, 5%, or 10% probability levels. As mentioned earlier, the parameter sigma (σ) (as well as nu (ν) below) reflects the relative magnitude to which one factor will be replaced by another because of a change in their relative prices. Our findings here suggest that land, labor, and capital in EU agriculture complement production factors that can hardly be substituted one for the other, at least in the short run, which may reflect the decline in the process of replacing labor with agricultural mechanization during the last decade. These results are in line with previous findings by Dudu and Smeets Kristkova (2017) and Khafagy and Vigani (2022), who found that the elasticity of substitution between land, labor, and capital in the EU is below one.

The second parameters of interest in the upper nest of the CES function are alphas (α), which represent the productivity growth—or technological change—of each production factor. Overall, Tables 3–5 indicate that in the EU the agricultural productivity of production factors has declined or stagnated during the examined period. This is indicated by the fact that the factor-specific productivity parameter (α) of land, labor, and capital is either negative or statistically insignificant. These results are in line with Khafagy and Vigani (2022), who found that technological change in the EU agricultural sector declined between 2004 and 2015. However, it is worth noting that the magnitude of productivity decline varies across regions, types of farms, and economic sizes. Specifically, the factors' productivity growth is negative and statistically significant at the EU28 aggregate level, as well as, medium-size farms (columns 1 and 3 of Table 3, respectively), and eastern and central, and western regions (columns 3 and 4 of

TABLE 3 External finance and technical change using two-steps GMM estimates of the system of equations with Newey–West HAC errors (EU28, by economic size)

	EU28 **(1)**	**Small** **(2)**	**Medium** **(3)**	**Large** **(4)**
(σ) Elasticity of substitution	**0.327*****	**0.780*****	**0.224*****	**0.614*****
(labor, land, and capital)	(0.063)	(0.236)	(0.063)	(0.169)
(α) Labor	**−0.044*****	−0.279	**−0.054*****	−0.011
	(0.009)	(0.290)	(0.014)	(0.013)
(α) Land	**−0.044*****	−0.292	**−0.047*****	−0.020
	(0.009)	(0.298)	(0.014)	(0.014)
(α) Capital	**−0.055****	−0.279	**−0.082*****	0.064
	(0.022)	(0.353)	(0.026)	(0.055)
(v) Elasticity of substitution	**−1.248*****	**0.071*****	**−0.370*****	**−0.157*****
(equity and debt)	(0.339)	(0.026)	(0.069)	(0.049)
(α) Equity	−0.002	0.015	0.011	0.014
	(0.006)	(0.025)	(0.007)	(0.012)
(α) Debt	−0.011	**0.095****	0.015	**−0.041*****
	(0.010)	(0.039)	(0.016)	(0.016)
Number of observations	10,361	1499	3920	4942
Instrumental variables for prices	$L \cdot pk$, $L \cdot pl$, $L \cdot \beta e$	$L \cdot pk$, $L \cdot pl$, $L \cdot pnL \cdot pe$, $L \cdot pd$	$L \cdot pk$, $L \cdot pl$, $L \cdot pe$	$L \cdot py$, $L \cdot pl$, $L \cdot pe$, $L \cdot pd$, $L \cdot \beta d$
Hansen's J test (χ^2)	0.5	12.5	0.6	3.4
Hansen's J test (p value)	0.49	0.13	0.43	0.34
v (equity and debt)				
Test of C–D (χ^2)	44.1	1242.1	398.4	549.2
Test of C–D (p value)	0.00	0.00	0.00	0.00
Test of neutral TC (χ^2)	0.8	4.9	0.1	12.4
Test of neutral TC (p value)	0.36	0.03	0.79	0.00
σ (land, labor, and capital)				
Test of C–D (χ^2)	114.5	0.9	150.9	5.2
Test of C–D (p value)	0.00	0.35	0.00	0.02
Test of neutral TC (χ^2)	0.4	0.1	7.1	3.4
Test of neutral TC (p value)	0.81	0.95	0.03	0.18

Note: Newey–West HAC standard errors are in parentheses. Bold values are statistically significant coefficients.
Abbreviations: GMM, generalized method of moments; HAC, heteroscedasticity and autocorrelation consistent.
$^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

TABLE 4 External finance and technical change using two-steps GMM Estimates of the system of equations with Newey–West HAC errors (by region)

	North (1)	**South** (2)	**East and central** (3)	**West** (4)
(σ) Elasticity of substitution	**0.795*****	**0.751****	**0.272****	**0.0421***
(labor, land, and capital)	(0.285)	(0.347)	(0.122)	(0.025)
(α) Labor	0.002	−0.023	**−0.107*****	**−0.030*****
	(0.191)	(0.068)	(0.027)	(0.007)
(α) Land	0.012	0.042	**−0.112*****	**−0.035*****
	(0.190)	(0.082)	(0.029)	(0.007)
(α) Capital	0.938	−0.268	**−0.171*****	**−0.064****
	(1.330)	(0.463)	(0.044)	(0.029)
(v) Elasticity of substitution	**−0.532*****	**0.124***	**0.539*****	**−0.047***
(equity and debt)	(0.181)	(0.065)	(0.095)	(0.028)
(α) Equity	0.008	0.030	0.026	0.026
	(0.018)	(0.021)	(0.068)	(0.019)
(α) Debt	**−0.149*****	**0.121*****	**0.134****	0.007
	(0.040)	(0.027)	(0.062)	(0.027)
Number of observations	1136	3050	2645	3530
Instrumental variables for prices	$L \cdot pk$, $L \cdot pl$, $L \cdot pnL \cdot pe$, $L \cdot pd$, $L \cdot \beta d$, $L \cdot \beta e$	$L \cdot py$, $L \cdot pk$, $L \cdot pd$	$L \cdot py$, $L \cdot pe$, $L \cdot pd$	$L \cdot py$, $L \cdot pl$, $L \cdot pe$
Hansen's J test (χ^2)	9.4	3.6	0.2	7.2
Hansen's J test (p value)	0.09	0.06	0.92	0.31
v (equity and debt)				
Test of C–D (χ^2)	71.2	181.9	23.4	1436.8
Test of C–D (p value)	0.00	0.00	0.00	0.00
Test of neutral TC (χ^2)	13.4	26.1	4.0	0.7
Test of neutral TC (p value)	0.00	0.00	0.05	0.41
σ (land, labor, and capital)				
Test of C–D (χ^2)	0.5	0.5	35.5	1496.4
Test of C–D (p value)	0.47	0.47	0.00	0.00
Test of neutral TC (χ^2)	0.6	0.4	4.7	16.5
Test of neutral TC (p value)	0.75	0.82	0.09	0.00

Note: Newey–West HAC standard errors are in parentheses. Bold values are statistically significant coefficients.

Abbreviations: GMM, generalized method of moments; HAC, heteroscedasticity and autocorrelation consistent.

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

TABLE 5 External finance and technical change using two-steps GMM Estimates of the system of equations with Newey–West HAC errors (by type of farm)

	Crop **(1)**	**Dairy** **(2)**	**Livestock** **(3)**
(σ) Elasticity of substitution	**0.311****	**0.360****	**0.359*****
(labor, land, and capital)	(0.149)	(0.174)	(0.108)
(α) Labor	−0.008	**−0.072*****	**−0.083***
	(0.009)	(0.022)	(0.044)
(α) Land	−0.008	**−0.071*****	**−0.083***
	(0.010)	(0.020)	(0.044)
(α) Capital	−0.034	−0.047	−0.099
	(0.027)	(0.051)	(0.069)
(v) Elasticity of substitution	**0.363*****	**−0.129***	**−0.209***
(equity and debt)	(0.069)	(0.073)	(0.113)
(α) Equity	0.030	0.009	0.012
	(0.021)	(0.021)	(0.022)
(α) Debt	**0.074****	−0.007	−0.022
	(0.030)	(0.031)	(0.032)
Instrumental variables for prices	$L \cdot py$, $L \cdot pe$, $L \cdot pd$	$L \cdot pk$, $L \cdot plL \cdot pe$, $L \cdot pd$	$L \cdot pk$, $L \cdot pl$, $L \cdot pn$, $L \cdot pe$, $L \cdot pd$, $L \cdot \beta d$, $L \cdot \beta e$
Number of observations	5002	1675	2352
Hansen's *J* test (χ^2)	0.2	5.1	8.4
Hansen's *J* test (*p* value)	0.63	0.08	0.14
v (equity and debt)			
Test of C–D (χ^2)	85.7	242.2	113.5
Test of C–D (*p* value)	0.00	0.00	0.00
Test of neutral TC (χ^2)	2.2	0.3	1.7
Test of neutral TC (*p* value)	0.14	0.57	0.20
σ (land, labor, and capital)			
Test of C–D (χ^2)	21.4	13.5	34.9
Test of C–D (*p* value)	0.00	0.00	0.00
Test of neutral TC (χ^2)	1.1	0.3	0.1
Test of neutral TC (*p* value)	0.58	0.86	0.95

Note: Newey–West HAC standard errors are in parentheses. Bold values are statistically significant coefficients.

Abbreviations: GMM, generalized method of moments; HAC, heteroscedasticity and autocorrelation consistent.

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 4). livestock and dairy farms, only labor and land have negative and statistically significant factor-specific productivity parameters, while capital-specific productivity is not statistically significant. Finally, all three factors of production have no statistically significant productivity parameters in small and large farms, northern and southern regions, as well as crop farms.

The focus of our analysis is on the lower nest of the CES function, regarding the elasticity of substitution between equity and debt (v), and the productivity parameters of equity and debt (α equity and α debt). The elasticity of substitution between debt and equity in all the estimations is below one or negative. The negative sign can be due to negative net value added and price of equity in some farms (Hicks, 1970; Sato & Koizumi, 1973; Stern, 2011). This implies that, overall, external finance, represented by debt, complements owners' equity, but it does not substitute it. We have explained earlier in Section 3 the tendency of elasticity of substitution to be below one. This is because, above unity elasticity of substitution requires that the rate of change of the quantity of debt is higher than the change in the quantity of equity, and simultaneously, the rate of change of the price of equity is higher than the change in the price of debt. As long as future equity is financed by previous profits, the rate of change of the quantity of equity will increase when the rate of change of the price of equity increases in the previous year, thus returning the elasticity of substitution to below one again.

The Wald test for the presence of CD technology rejects the CD hypothesis that the elasticity of substitution is not different from one, and indicates that the estimations of equity and debt are better modeled by the CES function. Furthermore, the Wald tests reject the null hypothesis of the presence of Hicks-neutral technical change in the estimations and support the assumption of factor-augmented technical change, in the estimations of small and large farms, northern, southern, eastern, and central regions. However, we cannot reject the hypothesis of Hicks-neutral technical change at the EU28 level, medium farms, western regions, crop, dairy, and livestock farms. The presence of a Hicks-neutral technical change in the equity and debt equation indicates that there are no

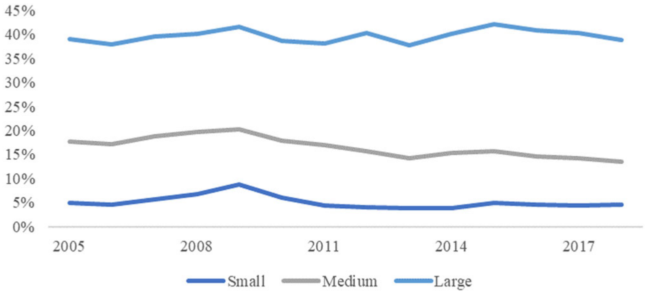

FIGURE 3 Debt-to-capital ratio by economic size

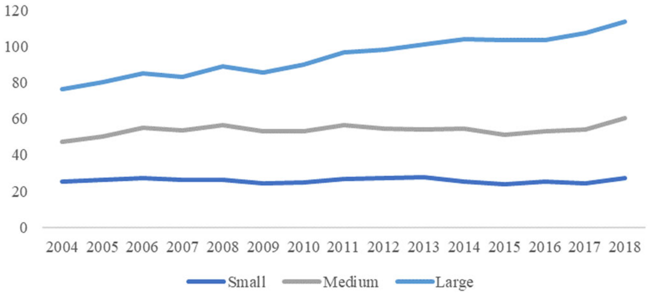

FIGURE 4 Capital-to-labor ratio by economic size (in euros)

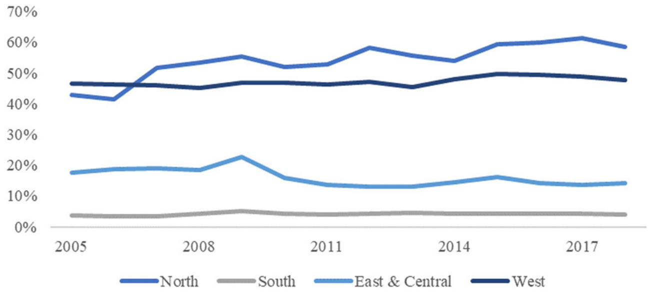

FIGURE 5 Debt-to-capital ratio by EU macroregion

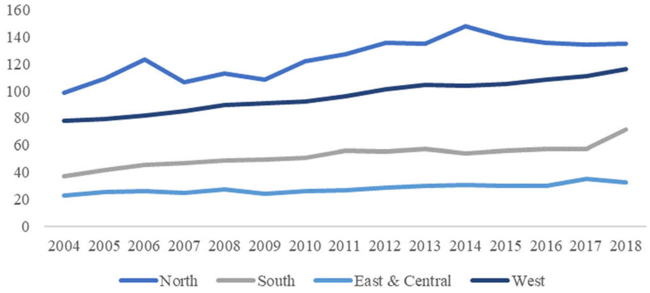

FIGURE 6 Capital-to-labor ratio by EU macroregion (in euros)

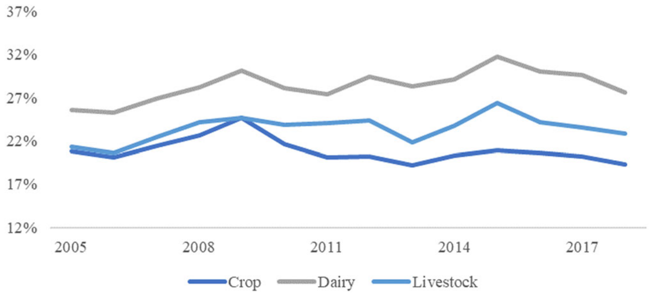

FIGURE 7 Debt-to-capital ratio by type of farm

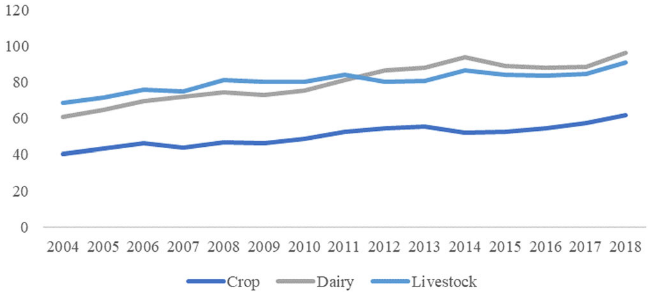

FIGURE 8 Capital-to-labor ratio by type of farm (in euros)

different levels of marginal productivity between equity and debt, and that their productivity is driven by the overall productivity of capital.

The main parameter of interest here is alpha (α) debt, which denotes the growth in productivity of external finance. Interestingly, the results show a positive and statistically significant growth in the productivity of debt in small farms, south, eastern and central regions, and crop farms. Except for crop farms, in these estimations, positive productivity parameters are recorded without neutral technical change, indicating that in these estimations, external finance has a positive marginal productivity distinguished from equity or total capital. This fact becomes particularly meaningful when compared with the levels of debt-to-capital and capital-to-labor ratios in Figures 3–8. As one can see, the positive productivity impact of external finance occurs in the low-capitalized farms and regions, which coincide with small farms (Figures 3 and 4), farms in southern and east-central EU (Figures 5 and 6), and crop farms (Figures 7 and 8). This confirms the predictions of the theoretical model developed in Section 3 that when farms have low levels of capitalization—that is, first stage, additional finance can boost the productivity and competitiveness of farms through access to new production techniques, and improve farms' liquidity. Thus, the rate of change in the quantity of debt has a significant positive impact on farms with low capital intensity and low debt-to-capital ratios. These results are in line with Zhengfei and Lansink (2006), who found that debt has a positive impact on the productivity growth of arable farms in the Netherlands. Our results also support the findings of Ciaian et al. (2012) who found that access to credit increases the TFP of eastern and central Europe farms.

On the other hand, the results indicate that external finance has a negative and statistically significant impact on the productivity of large and northern regions farms, which are the ones with large to medium capitalization levels as shown in Figures 3–8. This further support our theoretical prediction that in farms already relying on capital-intensive farming additional finance has negative rather than positive impacts on productivity, most likely because the productivity advantage of capital is already utilized. Accordingly, with the overall decline in productivity in agriculture, additional external finance in these farms does not contribute positively to productivity.

Finally, the statistically insignificant coefficient of alpha (α) debt in medium-size farms, and farms in the western region confirms the presence of an inverted U-shape between capital intensity and external finance on productivity. These farms have already sufficient access to external finance and a sufficient level of capitalization as indicated by Figures 3–6. Thus, finance here maintains its level of productivity and competitiveness. Moreover, the coefficient of productivity growth of debt in dairy and livestock farms is not statistically significant, reflecting also the overall stagnation of the productivity of capital, as indicated by the presence of Hicks-neutral production technology, as well as the sufficient levels of capitalization of dairy and livestock farms as indicated in Figure 8.

6 | CONCLUSION

In this paper, we proposed a novel method for estimating the impact of finance on agricultural productivity while distinguishing between internally and externally financed capital (equity and debt) in a two-level nested CES production function. In particular, we are able to estimate the impact of external finance on agricultural productivity while accounting for gross and net value added, amounts of debt and equity, and financial frictions in addition to other production factors, namely, labor and land.

Both the theoretical model and empirical findings show the tendency of the elasticity of substitution between debt and equity to be below one, indicating the existence of a complementary relationship between equity and external finance instead of substitution. This suggests that access to credit alone is not sufficient for an EU farm to improve its production capacity, but it is important in combination with the assets already owned by the farm generating a synergetic effect.

Because equity and finance are complements, the impact of external finance on productivity differs in relation to levels of capitalization. This is empirically shown by (a) a positive productivity impact of finance in less capital-intensive farms, such as small-scale farms, southern, eastern and central regions, and crop farms, (b) a negative impact in high capital-intensive farms, such as large-scale and northern region farms, and (c) no impact on productivity growth in farms with medium-levels of capital-intensity, such as medium-scale farms, western region, and livestock, and dairy farms. Considering the financial development of EU agricultural businesses, we can derive three consecutive situations: (i) farms with a low level of capitalization: credit is used to build assets and increasing the capitalization of the farm business. The new assets significantly boost the farms productivity and competitiveness; (ii) farms with medium/high level of capitalization: credit is useful if the farm already has sufficient assets and the extra credit is used for reducing liquidity constraints and running the assets. In other words, credit is used to maintain the productivity or competitiveness; (iii) farms with very high levels of capitalization (over-capitalization): they do not benefit from credit, on the contrary the extra credit has a negative impact on productivity, reducing competitiveness.

This suggests that the farming business development is strongly influenced by capitalization and credit. Once a certain level of assets has been built, then credit becomes pivotal to maintain the productivity. Therefore, external finance is not only a tool for the development of the farming sector, but also for maintaining its competitiveness. But when a maximum capitalization point is reached, extra credit becomes detrimental and reduces productivity. This because the technological frontier has been reached, therefore credit cannot be used to acquire additional innovation and the accumulation of debt increases financial frictions to the point exceeding the marginal increase of value added.

However, the cycle starts over again when new technologies are available, shifting the technological frontier. When new technologies are available, the highly capitalized farms have a competitive advantage in using credit for productive investments over the low-capitalized farms. For example, technological improvements can be built on farms using initial debt for the investment. Once the new technology is up and running additional credit is necessary for keeping the technology constantly updated reducing the obsolescence rate, maintaining in this way the acquired competitiveness. However, without technological progress additional creation of capital makes the business unmanageable and loses productivity until new technologies appear on the markets.

This mechanism is even more important considering that agricultural production factors (land, labor, and capital) in the EU are complements, not substitutes, and that, from the empirical results, in the period 2004–2018 the productivity of all production factors stagnated (north, south, and crops) or even declined (east and central, livestock). Therefore, improving the EU's agricultural productivity does not only necessitate an efficient governance of credit markets, but also needs to consider the productive development of land and labor through supporting the health of soils (and of agroecosystems more widely) and skilled labor.

CONFLICT OF INTEREST

We confirm that this study is original and has not been published yet, and that the authors have no potential conflict of interest in the subject of the research. I would also like to state our ability to share the data and estimations codes. The study uses open-source regional data of the Farm Accountancy Data Network (FADN) available at https://ec.europa.eu/agriculture/rica/database/consult_std_reports_en.cfm

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SUPPORTING INFORMATION

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