Scientific Research Publishing

Theoretical Economics Letters, 2023, 13, 1780-1801
https://www.scirp.org/journal/tel
ISSN Online: 2162-2086
ISSN Print: 2162-2078

Whither Greece? Productivity before and after the Subprime Crisis

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How to cite this paper: Tsionas, M. G., Vidali, M. E., Leledakis, G. N., & Tasiopoulos, A. E. (2023). Whither Greece? Productivity before and after the Subprime Crisis. *Theoretical Economics Letters, 13,* 1780-1801.
https://doi.org/10.4236/tel.2023.137103

Received: October 16, 2023
Accepted: December 26, 2023
Published: December 29, 2023

Abstract

This paper employs a stochastic production frontier model with time-varying inefficiency to assess the performance and productivity growth of 9054 Greek firms from 1996 to 2017. Various forms of capital are incorporated, extending beyond physical capital and labor, to estimate productivity growth and disentangle its components. Our results indicate that, despite a significant decrease in productivity growth after 2007, it remains positive on average, albeit with notable variations among firms. These findings offer valuable insights to inform future policy decisions in Greece, which may have implications for other nations as well.

Keywords

Productivity Growth, Production Functions, Stochastic Frontiers

1. Introduction

The global financial crisis that began in 2007 triggered by the collapse of the U.S. subprime mortgage market, resulted in one of the worst post-war economic recessions worldwide. Although public finances were severely impacted, several countries managed to ensure their sustainability and recovery. However, Greece experienced a decade-long recession of unprecedented magnitude and duration among modern developed economies, losing approximately 20% of real per capita Gross Domestic Product (GDP) between 2007 and 2017 (see Avramidis et al., 2021; Chodorow-Reich et al., 2019; Giannoulakis & Sakellaris, 2021; Gourinchas et al., 2017).

Greece faced three quasi-simultaneous and interlinked shocks: a sovereign debt crisis, a banking crisis, and a sudden stop (see the seminal paper of Gourinchas et al., 2017, which provides the first systematic analysis of the Greek economic crisis). Consequently, the Greek economy became even less competitive than other European Union (EU) and Organization for Economic Cooperation and Development (OECD) countries, which led to low productivity (see Alogoskoufis & Featherstone, 2021; Chodorow-Reich et al., 2019; Genakos, 2018; Katsoulakos et al., 2017; Pelagidis & Mitsopoulos, 2014). Therefore, the Greek economic crisis presents a unique opportunity to examine the factors that influence productivity and economic growth in a small open economy operating within a currency union during a crisis of unparalleled magnitude and duration.

This paper addresses the following question: How severely was productivity impacted in the aftermath of the crisis? This inquiry holds particular significance for investors, business professionals, and policymakers since enhancing productivity is essential for a country's economic growth, which, in turn, leads to economic recovery. While there is a growing body of literature that measures productivity at the firm level and elucidates its importance for economic growth (see, for example, Bournakis & Mallick, 2018; Li & Liu, 2011; Rath, 2018), to the best of our knowledge, there is limited empirical evidence available for Greece (see Belegri-Roboli & Michaelides, 2006; Bournakis, 2011; Halkos & Tzeremes, 2007; Voutsinas & Tsamadias, 2013). However, none of these studies offer evidence regarding productivity growth in the aftermath of the crisis.

The aim of this paper is threefold: First, to measure productivity at the firm level and identify its primary drivers. Second, to assess productivity growth and its underlying sources, revealing valuable policy-related insights that could contribute to sustained growth in Greece. Finally, to investigate the role of firm size. In particular, we utilize detailed firm-level data and differentiate between various forms of capital, including financial capital services, which represents a novel approach in applied modeling. We adopt a stochastic production frontier model with time-varying inefficiency, enabling us to disentangle the components and gain a comprehensive understanding of the factors influencing productivity changes among 9054 Greek firms from 1996 to 2017[1].

Related to our work is the study of Genakos (2018), which investigates the role of managerial practices in understanding productivity differences across firms and across countries and notes that "*it is almost as if there are two types of firms inside Greece* (i.e. "*two Greeces*"): *one that is outdated, inefficient, and ignorant of its own quality of management and one that is up-to-date, efficient and is trying to improve itself and achieving world standards*" (p. 888). His paper does not directly measure the productivity in Greece, though. In our paper, management is more related to efficiency or efficiency change.

The term "Total Factor Productivity (TFP) growth", first introduced by Solow

[1]See Bournakis and Mallick (2018) for a comprehensive discussion of the most up to date approaches in measuring firm level total factor productivity. They conclude that "*each method deals with a different challenge in estimating the production function. The approach of each methodology relies on different assumptions whose empirical verification is always subject to data scrutiny*" (p. 582).

(1957), also called "the Solow residual", is defined as the growth rate of output that cannot be explained by the changes of traditional inputs (labor and capital). However, this index does not allow for efficiency change which if there exists, it contributes to productivity change. The study of Kumbhakar et al. (2000) was the first to address the estimation and decomposition of TFP change within a stochastic frontier framework that permits efficiency change which is a fundamental assumption in this paper (see Cornwell et al., 1990; Kumbhakar, 1990). Assuming that technical inefficiency remains constant over time implies that firms or economies never learn. This assumption may be unrealistic in a competitive market or in a long panel framework. To account for time-varying technical inefficiency, one must make assumptions about the functional form of this term (see Kumbhakar, 1990; Battese & Coelli, 1992; Lee & Schmidt, 1993; Kumbhakar & Wang, 2005).

We use two popular approaches, as introduced by Kumbhakar (1990) and Battese and Coelli (1992). Our findings indicate that, on average, productivity growth remains positive, although it has decreased significantly since the subprime crisis. This outcome is primarily attributed to technical change. The role of efficiency change also appears to be significant, but its magnitude depends on the specific model used for efficiency estimation. Furthermore, we observe substantial variations in productivity among different firm size categories, indicating that larger firms generally exhibit higher average productivity. However, in the aftermath of the crisis, these differences are nearly eradicated.

In conclusion, despite a significant decline in productivity resulting from the shock of the financial crisis, it has managed to remain in positive territory. This suggests that certain policies have been effective in maintaining positive productivity growth. However, it is worth noting that these results have led to the narrowing of the productivity gap among firms that previously contributed to productivity growth and, consequently, economic growth in the past. In our view, these findings indicate that if policymakers were to tailor their reforms to the specific needs of different firm size categories, productivity growth could potentially act as a catalyst for economic growth and expedite the path to economic recovery.

The remainder of this paper is organized as follows. Section 2 presents the model specification and the method we use to estimate productivity growth and its component. In Section 3, we describe the data and Section 4 presents the results. Our concluding remarks are presented in Section 5.

2. Model

We consider the following production frontier model $y_{it} = f\left(\boldsymbol{x}_{it}, t; \boldsymbol{\beta}\right)\exp\left(\varepsilon_{it}\right)$, where the error term $\varepsilon_{it} = v_{it} - u_{it}$ is the difference of v_{it} the two-sided error component, and u_{it}, the nonnegative time-varying technical inefficiency component. The output of firm *i* at time *t*, y_{it} is produced using a vector of inputs $x_{it} \in \mathbb{R}_{+}^{K}$ through a production function where *t* is the time trend used here as a proxy for technical change. A time-varying stochastic production frontier is assumed, originally proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977) in a cross-sectional framework:

$$\ln y_{it} = \beta_0 + \beta_{01} t + \frac{1}{2}\beta_{02} t^2 + \sum_{k=1}^{K} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{K} \beta_{kj} \ln x_{kit} \ln x_{jit} + \sum_{k=1}^{K} \beta_{1k} t \ln x_{kit} + v_{it} - u_{it} \quad (1)$$

for $i = 1, \cdots, N$, $t = 1, \cdots, T$.

We also assume that:

$$v_{it} \sim iid\ N\left(0, \sigma_v^2\right) \quad (2)$$

$$u_{it} = G(t) u_i \quad (3)$$

$$u_i \sim iid\ N^+\left(\mu, \sigma_u^2\right) \quad (4)$$

where $G(t) \geq 0$ is function of time *t*. For $G(t)$, we use two functional forms, one proposed by Kumbhakar (1990):

$$G(t) = \left(1 + \exp\left(\gamma t + \delta t^2\right)\right)^{-1} \quad (5)$$

and the other by Battese and Coelli (1992):

$$G(t) = \exp\left(\gamma\left(t - T\right)\right) \quad (6)$$

We estimate the parameters using maximum likelihood and obtain estimates for productivity change and its sources (detailed derivations are presented in the **Appendix A** and parameter estimates are available on request):

$$T\dot{F}P_{it} = TC_{it} + \left(e_{it} - 1\right)\sum_{k=1}^{K}\left(\frac{e_{itk}}{e_{it}}\right)\dot{x}_{kit} + TEC_{it} \quad (7)$$

where

$$\widehat{TC}_{it} = \hat{\beta}_{01} + \hat{\beta}_{02} t + \sum_{k=1}^{K} \hat{\beta}_{1k} \ln x_{kit} \quad (8)$$

$$\hat{e}_{itk} = \hat{\beta}_k + \hat{\beta}_{1k} t + \sum_{j=1}^{K} \hat{\beta}_{kj} \ln x_{jit} \quad (9)$$

$$\hat{e}_{it} = \sum_{k=1}^{K} \hat{e}_{itk} \quad (10)$$

The estimation of efficiency change (TEC) depends on the choice of $G(t)$ so, following Kumbhakar (1990) (Equation (5)), we obtain:

$$\widehat{TEC}_{it} = -\hat{u}_i\left(\hat{\gamma} + 2\hat{\delta} t\right)\exp\left(\hat{\gamma} t + \hat{\delta} t^2\right)\left(1 + \exp\left(\hat{\gamma} t + \hat{\delta} t^2\right)\right)^{-2} \quad (11)$$

If we adopt Battese and Coelli's (1992) approach (Equation (6)), we have:

$$\widehat{TEC}_{it} = -\hat{u}_i \hat{\gamma} \exp\left(\hat{\gamma}\left(t - T\right)\right) \quad (12)$$

where $\hat{u}_i = E\left(u_i \mid \boldsymbol{\varepsilon}_i\right)$ of the distribution of $u_i \mid \boldsymbol{\varepsilon}_i$, where $\boldsymbol{\varepsilon}_i = \left(\varepsilon_{i1}, \cdots, \varepsilon_{iT}\right)'$.

3. Data

The data is an unbalanced panel of 9054 firms for the period 1996-2017. We include companies from several sectors except for banks and financial institutions that are active in Greece during the period under investigation. The data was obtained from the database of ICAP, a Greek private research company that collects detailed business information, which includes accounts and ratios from the firms' annual financial statements[2]. We measure output y_{it} as the sum of final and semifinal products. The inputs include labor l_{it}, measured as the number of employees and different types of capital: Services from use of buildings, x_{1it}, the services of mechanical equipment x_{2it}, the services of intangible assets x_{3it}, materials x_{4it}, services of financial capital x_{5it} and other inputs x_{6it}. To the best of our knowledge, use of such detailed data at the firm level is quite novel. Summary statistics are presented in Table 1 and industry classification (SIC) in Table 2, respectively.

Table 1. Descriptive statistics.

Name	Variable	Mean	Std. Dev.	Min	5th Percentile	95th Percentile	Max
Output	y	2,065,497	17,700,000	1	6365.37	6,359,667	1,350,000,000
Labor	l	76.67	252.70	1	4	262	11,750
Buildings	x_1	2,682,159	15,300,000	64.56	33,874	8,687,617	1,900,000,000
Equipment	x_2	4,304,057	85,000,000	1	9495	9,899,002	6,920,000,000
Intangible	x_3	926421.4	22,200,000	1	1300	1,705,452	2,460,000,000
Materials	x_4	1,180,573	7,028,264	1	7111	4,236,906	467,000,000
Financial Capital	x_5	457264.7	3,945,121	1	89,508	1,403,137	443,000,000
Other Inputs	x_6	2,702,692	18,000,000	3	56,108	8,949,948	1,640,000,000

Note: All variables, except for l, are measured in euros. Labor is defined as the number of employees. We use a sample of 42,391 observations and 9054 firms.

Table 2. Industry classification.

Industry Title	Number of Firms
Agriculture, Forestry, and Fishing	360
Mining	35
Construction	219
Manufacturing	6365
Transportation, Communications, Electric, Gas, and Sanitary Services	64
Wholesale Trade	231
Retail Trade	1319
Services	461

Note: The total number of firms is 9054.

[2]Other recent studies used the same database (see Avramidis et al., 2021; Giannoulakis & Sakellaris, 2021).

4. Empirical Results

In this section, we present the results of our analysis. Using the method of maximum likelihood, we estimate the parameters of production frontier and derive the sources of productivity change and its components. As we described in Section 2, we use two different functional forms for $G(t)$ and hence, we have two models; Model 1 stands for the approach proposed by Kumbhakar (1990) and Model 2 stands for the approach proposed by Battese and Coelli (1992).

4.1. Full Sample

Table 3 presents the descriptive statistics of elasticities. We observe that elasticities are almost identical for both models. **Figure 1** shows the distribution of elasticities. The estimation of input elasticities suggests that labor, financial capital, and intermediate inputs (materials) are the most important, on average.

Figure 2 shows the distribution of scale elasticity, an initial measure for returns to scale. The distribution of both models that lies between .4 and 1.4. Scale elasticity, on the average, is less than zero and equal to .84. Since we are interested in testing whether the production function is characterized by constant returns to scale or decreasing returns to scale on average, we perform a Wald test and reject the null hypothesis of constant returns to scale in favor of the alternative hypothesis (p-value = .003). However, we observe that scale elasticity is above unity for 5.8% of firms of our sample suggesting increasing returns to scale (N = 521, RTS > 1).

The distribution productivity growth and its sources are depicted in **Figure 3** for the whole period for both models and **Table 4** reports the descriptive statistics.

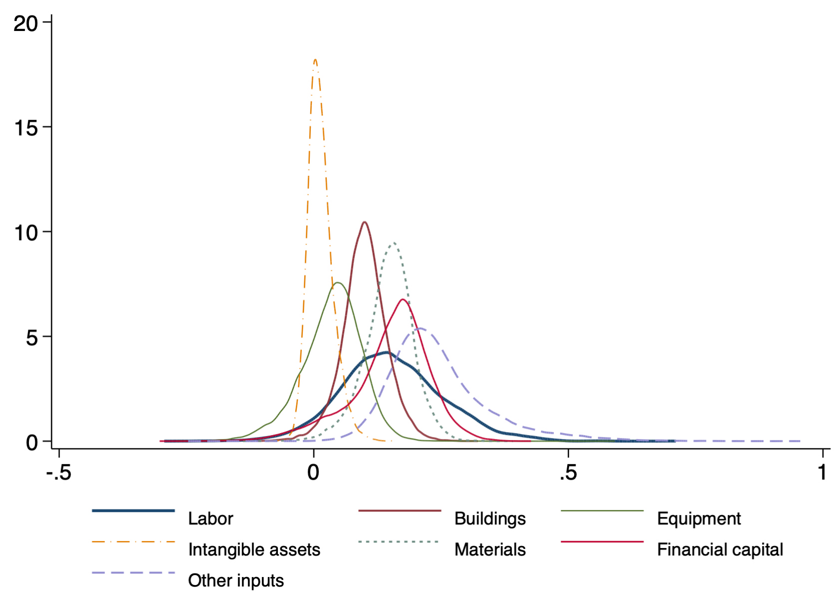

Figure 1. Elasticities. Note: This figure shows the distribution of input elasticity for each input. We use a sample of 42,391 observations.

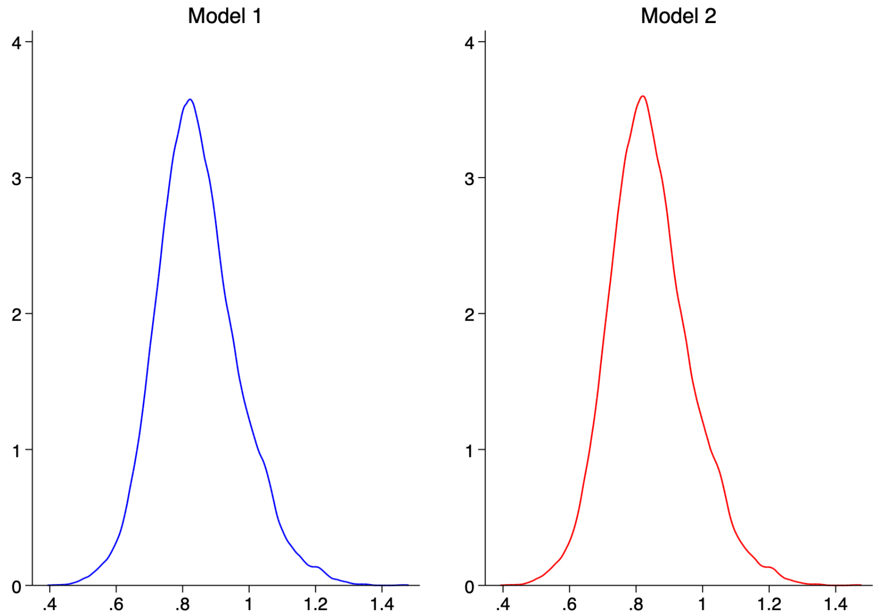

Figure 2. Returns to scale. Note: This figure shows the distribution of Returns to scale for each model. We use a sample of 42,391 observations.

Table 3. Summary elasticities.

		Mean	Std. Dev.	5th Percentile	95th Percentile
e_l	Model 1	.158	.101	0	.331
	Model 2	.154	.101	−.004	.327
e_{x_1}	Model 1	.102	.042	.032	.170
	Model 2	.100	.044	.028	.171
e_{x_2}	Model 1	.033	.058	−.071	.118
	Model 2	.035	.059	−.070	.121
e_{x_3}	Model 1	.012	.025	−.023	.057
	Model 2	.013	.025	−.022	.059
e_{x_4}	Model 1	.147	.048	.064	.221
	Model 2	.148	.048	.064	.221
e_{x_5}	Model 1	.149	.078	−.003	.257
	Model 2	.150	.079	−.004	.259
e_{x_6}	Model 1	.246	.098	.121	.437
	Model 2	.245	.099	.119	.438

Note: The elasticities of output with respect to each of the inputs are estimated according to Equation (9) and then we take sample means for all years and firms. We use a sample of 42,391 observations and 9054 firms.

Table 4. Decomposition analysis.

		Mean	Std. Dev.	5th Percentile	95th Percentile
Scale	Model 1	−.001	.013	−.012	.008
	Model 2	−.001	.013	−.012	.008
TC	Model 1	.036	.026	.001	.094
	Model 2	.035	.018	.010	.071
TEC	Model 1	−.002	.010	−.018	.012
	Model 2	−.020	.012	−.041	−.004
TFP	Model 1	.033	.036	−.017	.105
	Model 2	.014	.025	−.023	.055

Note: The TFP growth rate and its components are based on Equations (7) to (12). Analytical calculations are provided in the appendix. The estimates are averaged across firms and years. We use a sample of 33,231 observations.

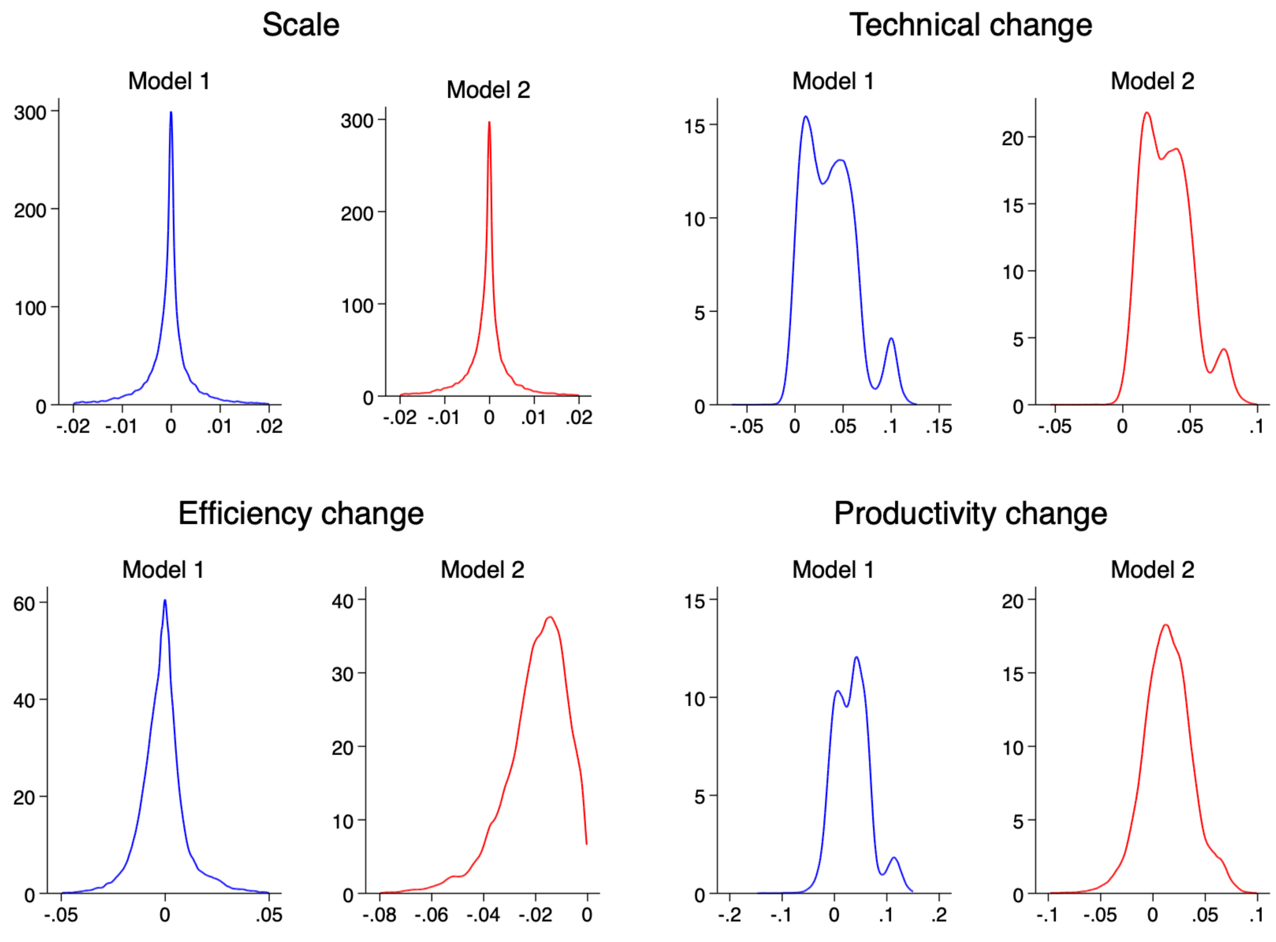

Figure 3. Productivity change and its sources. Note: This figure shows the distribution of productivity change and its sources for each model. We use a sample of 33,231 observations.

The upper left panel of **Figure 3** illustrates the scale component, representing scale economies. On average, it falls slightly below zero, but its impact is minimal. The term $\sum_{k=1}^{K}\left(\frac{e_k}{e}\right)\dot{x}_k$ which presents the use of inputs is positive indicating an expansion in input use over the period. However, since the average scale elasticity is below unity, its effect on productivity change is negative but very modest. Additionally, we note that the scale component is positive for a group of firms, suggesting a positive contribution to productivity change. Throughout the period, the primary driver of TFP growth is the distribution of Technical Change (TC), as shown in the upper right panel. The TC distribution exhibits multiple modes, and its values range from slightly below zero to nearly 10%, indicating the presence of firm clusters with varying growth rates. The distribution of efficiency change (TEC) is concentrated around the mean in Model 1, while in Model 2, the distribution is truncated below zero. On average, productivity growth stands at approximately 3%, with values ranging from just below zero to almost 10%, as depicted in the lower right panel of **Figure 3**.

4.2. Role of Financial Crisis

Our next objective is to assess the extent to which productivity change was impacted by the financial crisis. Given that the recession in Greece endured longer than in other European or OECD countries, primarily due to the sovereign debt crisis, we divide the period from 1996 to 2017 into two subperiods. The first subperiod spans from 1996 to 2007, characterized by a period of economic growth in Greece, and the second subperiod covers the crisis from 2008 to 2017. We will examine productivity change and its underlying sources during these two distinct timeframes[3].

The distribution of productivity growth and its sources can be found in **Figure 4**, while **Table 5** provides descriptive statistics. Since 2008, both models consistently demonstrate a leftward shift in the distribution of productivity growth. For Model 1, the range spans from −5% to 7%, while for Model 2, it extends from −5% to 5%. **Table 5** reveals a decrease in productivity growth between the pre- and post-crisis periods. In Model 1, the estimated decline in productivity is approximately 77%, and in Model 2, it is estimated at around 85%. Surprisingly, despite the challenges faced since 2008, productivity growth has managed to remain positive on average.

In terms of efficiency change, Model 1 indicates a leftward shift in the distribution of TEC, transitioning from positive to negative values, suggesting a decline in efficiency change. On the other hand, for Model 2, the distribution post-crisis remains largely consistent with the pre-crisis distribution.

Consequently, both models concur that TC is the primary driver of positive productivity growth, although it is notably lower in the post-crisis period, averaging around 2% as opposed to 6% during the pre-crisis period. The pre-crisis

[3]For robustness, we also split the sample into two different subperiods, 1996-2008, 2009-2017 and also, 1996-2009, 2010-2017. The results are qualitatively similar. See **Appendix B**, **Table B1** and **Table B2**.

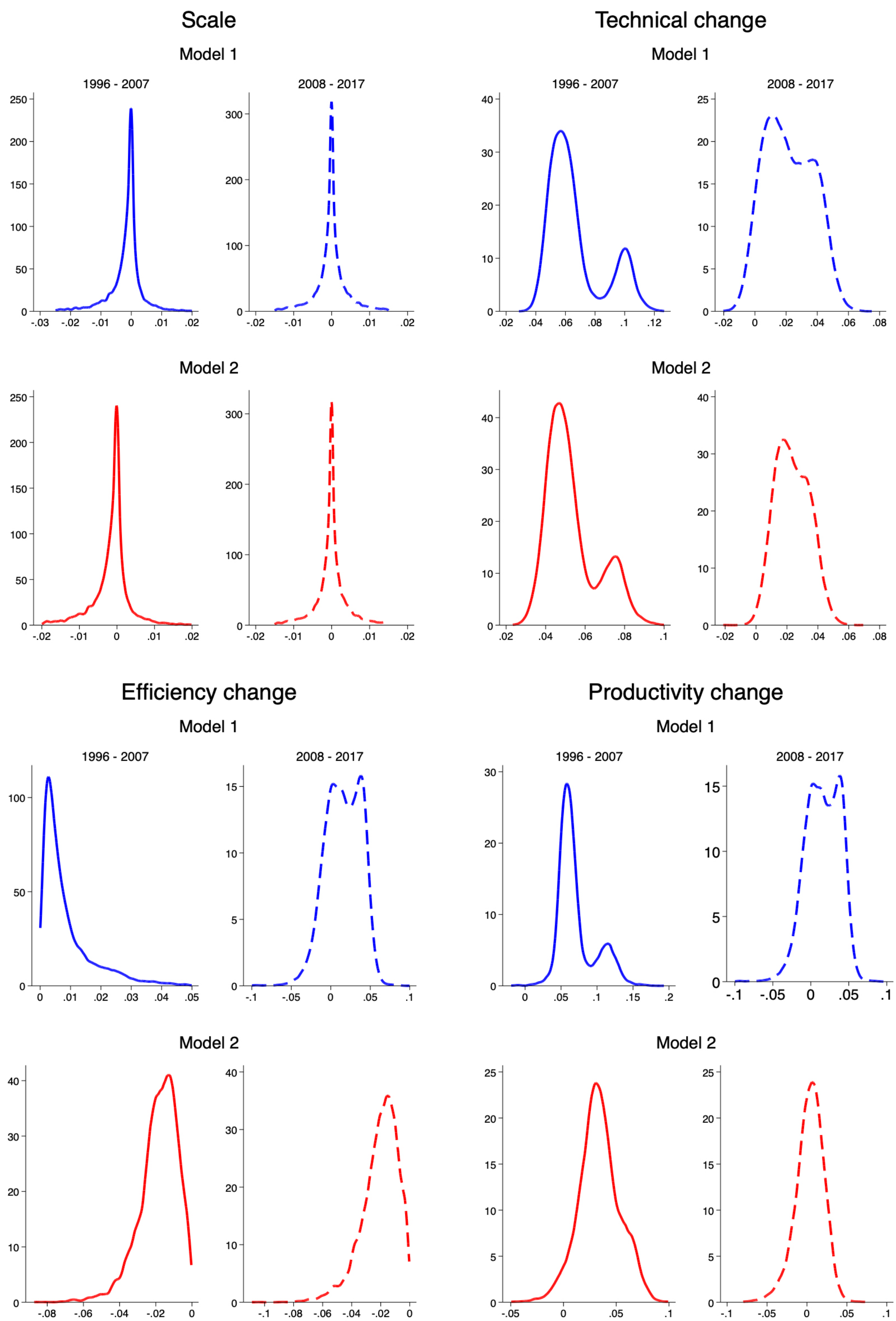

Figure 4. Productivity change and its sources before and after the sub-prime crisis. Note: This figure shows the distribution of productivity change and its sources for each model before and after the subprime crisis. We use a sample of 33,231 observations.

Table 5. Decomposition analysis before and after crisis.

		Period	Mean	Std. Dev.	5^{th} Percentile	95^{th} Percentile
Scale	Model 1	1996-2007	−.002	.012	−.015	.006
		2008-2017	−.001	.013	−.010	.009
	Model 2	1996-2007	−.002	.012	−.015	.006
		2008-2017	−.001	.013	−.010	.009
TC	Model 1	1996-2007	.066	.019	.045	.104
		2008-2017	.023	.016	−.001	.048
	Model 2	1996-2007	.054	.013	.039	.080
		2008-2017	.026	.011	.009	.044
TEC	Model 1	1996-2007	.007	.008	.001	.023
		2008-2017	−.007	.007	−.020	.001
	Model 2	1996-2007	−.018	.010	−.037	−.004
		2008-2017	−.020	.012	−.042	−.003
TFP	Model 1	1996-2007	.070	.027	.042	.124
		2008-2017	.016	.024	−.021	.048
	Model 2	1996-2007	.034	.021	.001	.068
		2008-2017	.005	.021	−.028	.033

Note: The TFP growth rate and its components are based on Equations (7) to (12). Analytical calculations are provided in the appendix. The estimates are averaged across firms and years. From 1996 to 2007, the sample size is 10,542 while, from 2008 to 2017, it is 22,689, respectively.

distribution of TC exhibits a distinctive minor mode at approximately 8% to 10%, depending on the model, indicating the presence of a group of firms with exceptionally high growth rates. While this group continues to grow in the aftermath of the crisis, the growth rate has slowed considerably, approaching 4%. Nevertheless, the bimodality of the TC distribution remains apparent.

4.3. Role of Firm Size

Finally, this paper addresses the question if there are differences in productivity and its sources across various firm size categories. We categorize firms based on the number of employees. Small firms are those with fewer than 50 employees, medium-sized firms fall within the range of 50 to 249 employees, and large firms consist of those with at least 250 employees. Both models (Table 6, Figure 5) are consistent with the result that the larger a firm is the greater its TFP growth on the average.

Table 6. Decomposition analysis across firm size.

		Firm Size	Mean	Std. Dev.	5th Percentile	95th Percentile
Scale	Model 1	Small	−.002	.015	−.016	.010
		Medium	0	.002	−.003	.001
		Large	.001	.005	−.002	.007
	Model 2	Small	−.002	.015	−.016	.010
		Medium	0	.002	−.003	.001
		Large	.001	.005	−.002	.007
TC	Model 1	Small	.034	.024	0	.072
		Medium	.041	.028	.001	.099
		Large	.049	.032	.004	.105
	Model 2	Small	.032	.016	.009	.060
		Medium	.039	.018	.012	.080
		Large	.046	.021	.016	.083
TEC	Model 1	Small	−.003	.009	−.018	.010
		Medium	−.002	.010	−.017	.014
		Large	0	.011	−.018	.017
	Model 2	Small	−.020	.012	−.042	−.003
		Medium	−.018	.011	−.038	−.004
		Large	−.017	.011	−.036	−.003
TFP	Model 1	Small	.029	.034	−.018	.081
		Medium	.039	.036	−.013	.113
		Large	.050	.041	−.011	.122
	Model 2	Small	.010	.025	−.026	.046
		Medium	.020	.023	−.015	.060
		Large	.030	.026	−.011	.072

Note: The TFP growth rate and its components are based on Equations (7) to (12). Analytical calculations are provided in the appendix. Our sample consists of 22,402 observations in the case of small firms, 8825 in the case of medium firms and 2004 in the case of large firms.

Table 6 provides the descriptive statistics. TFP growth (on average) ranges from almost 3% for small firms, increases to 4% for medium-sized firms, and reaches 5% for large firms. In Model 2, the corresponding values are 1%, 2%, and 3%, respectively. Thus, both models concur that, on average, there is a positive correlation between firm size and productivity growth. Figure 5 illustrates the distributions of productivity and its sources across firm sizes, following the structure of the previous figures. While the positive relationship between firm

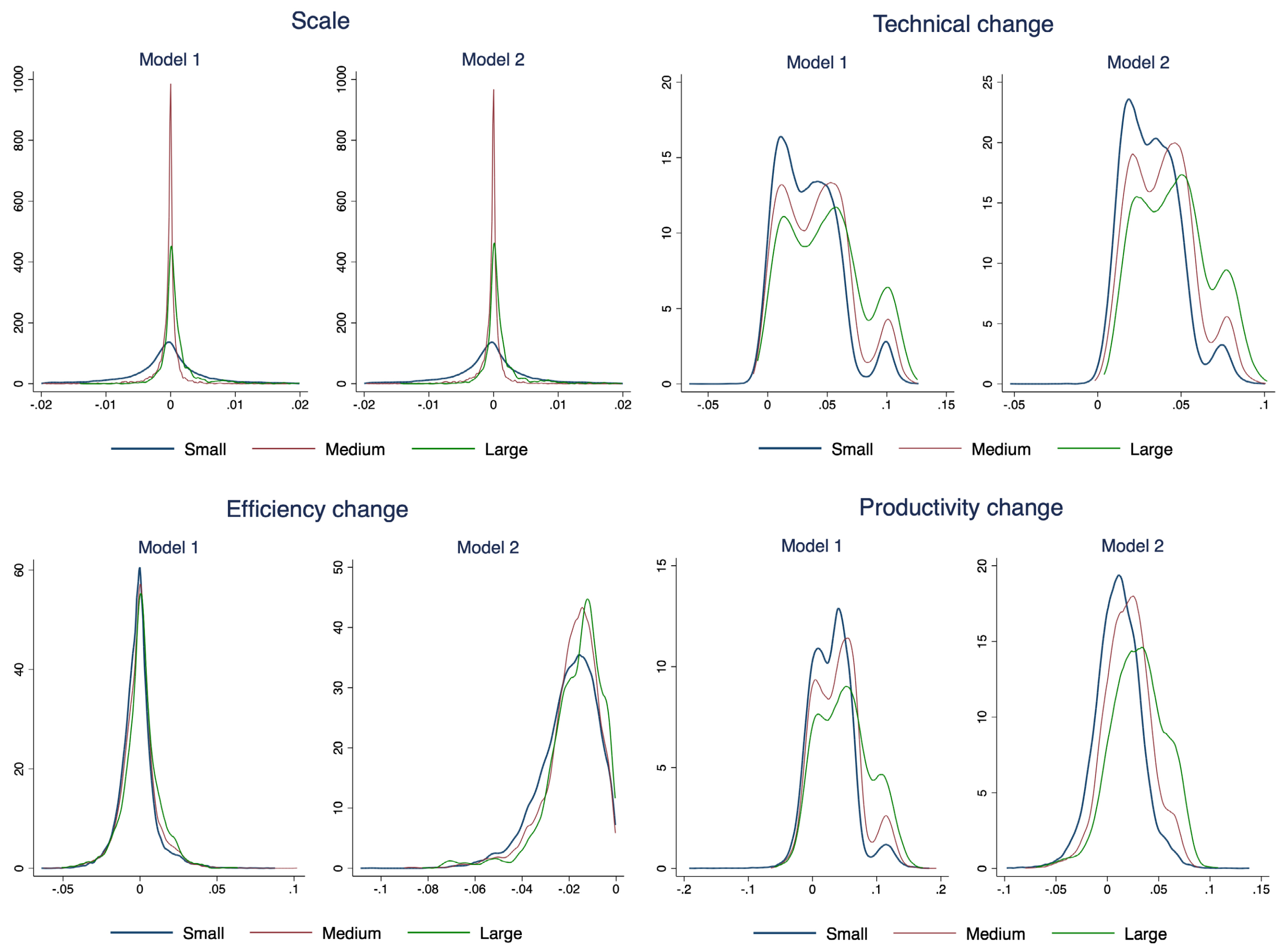

Figure 5. Productivity and its sources across firm size. Note: This figure shows the distribution of productivity change and its sources for each model across firm size. We use a sample of 33,231 observations.

size and productivity is evident, **Figure 5** also reveals that there is a group of small and medium-sized firms outperforming some large firms in terms of productivity growth. This may be occurred because small and medium enterprises *can be in growing industries or at a catching up stage* (see Tsionas & Mallick, 2019).

Regardless of the size of the firm, TC is the main source of growth. We observe that there are substantial differences in TC among firm size categories and both models support that the larger the firm the larger the TC, on the average. Conversely, the Scale component, while exhibiting a small negative effect for small and medium-sized firms, approaches zero and even becomes slightly positive for large firms (.1%). This minor positive shift is a direct result of the larger firms having a total elasticity greater than unity and their tendency to expand the use of inputs over the examined period. The variance in the scale component's impact between large firms and those of smaller sizes can be attributed to the fact that medium and small-sized firms, despite expanding input usage over time, exhibit diminishing returns to scale in their performance. In terms of TEC, we observe that the larger the firm, the lower its inefficiency. The extent of these differences among firm size categories depends on the model employed. According to Model 1, inefficiency decreases from .3% for small firms to .2% for medium-sized firms and approaches almost zero for large firms. In contrast, the corresponding figures for Model 2 are 2%, 1.8%, and 1.7%.

Another aspect we examine is how firm size influenced TFP growth during both the pre- and post-crisis periods. **Figure 6** displays the distributions of productivity and its sources for different firm sizes before and after the subprime crisis, while **Table 7** provides the corresponding descriptive statistics. The evidence from **Figure 6** suggests that the distribution of productivity growth for all firm sizes has shifted to the left since the subprime crisis. This indicates that, on average, productivity growth worsened after the crisis, although it still remains positive for all firm sizes. Additionally, the bottom right panel of **Figure 6** vividly illustrates that before 2008, significant differences existed in the distribution of productivity growth among firm size categories, implying that the distinct growth experiences have been partially equalized in the aftermath of the crisis. However, the positive correlation between firm size and productivity growth persists in each subperiod, especially in the case of Model 2. Here, the smaller the firm, the greater the negative impact of the crisis on productivity growth. Specifically, small firms experienced an average loss of 89.3% in their growth rate, medium-sized firms lost 77.5%, and large firms lost 75%. In Model 1, the pattern is less clear, with corresponding rates of 78.5%, 76.3%, and 77.3%. Both models indicate that regardless of firm size, there was a reduction of at least 3/4 of the post-crisis productivity growth rate compared to the pre-crisis period.

As we described above, in both periods, the primary factor contributing to productivity growth is TC. The decline in TC since the crisis is distributed fairly evenly among firms of various sizes, accounting for approximately 65% according to Model 1 and 52% according to Model 2. In the top right panel of **Figure 6**, significant differences in the distribution of TC among firm size categories before 2008 are prominently visible. Following the subprime crisis, the distributions are nearly identical, indicating that although firms continue to grow at varying rates, these rates have significantly decreased, erasing the disparities among firm size categories. This finding suggests that TC is one of the factors contributing to the absence of substantial differences in terms of productivity growth in the aftermath of the crisis. Furthermore, the two models yield different results regarding the impact of TEC on productivity during the pre-crisis period. Model 1 estimates that the average TEC is around .7% for all firm sizes, while Model 2 suggests it's approximately −.17%. Model 1 indicates that TEC is not influenced by firm size, even before 2008, whereas Model 2 suggests that firm size has a small positive effect on TEC. Nevertheless, it is evident from both models that TEC deteriorates after the crisis for all firm sizes. As for the scale component, the results in each period are qualitatively similar to those presented in **Table 6** and **Figure 5**.

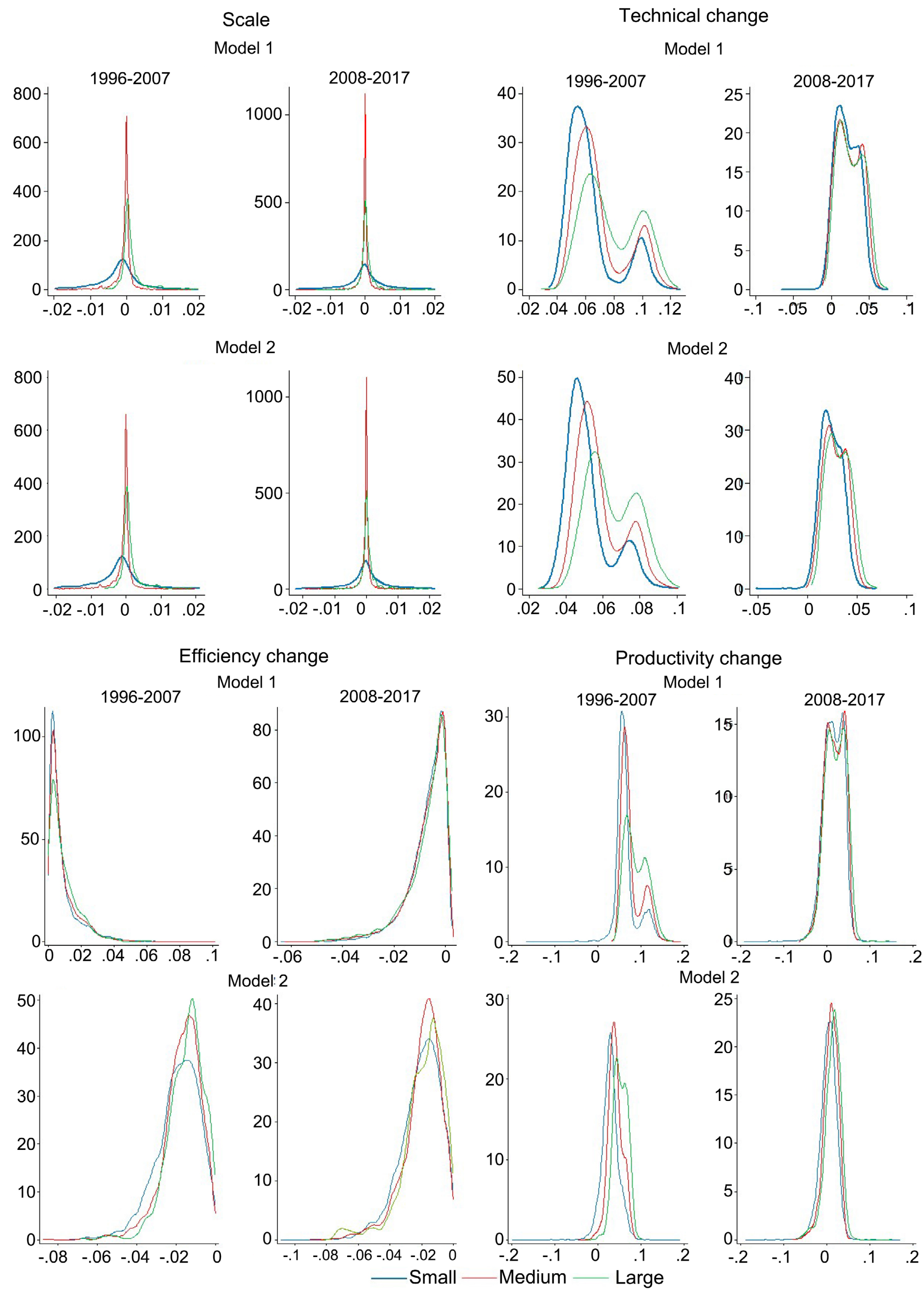

Figure 6. Productivity change and its sources before and after the subprime crisis across firm size. Note: This figure shows the distribution of productivity change and its sources for each model across firm sizes before and after the subprime crisis. We use a sample of 33,231 observations.

Table 7. Decomposition analysis across firm size before and after crisis.

		Period	Firm Size	Sample Size	Mean	Std. Dev.	5th Percentile	95th Percentile
Scale	Model 1	1996-2007	Small	6443	−.004	.015	−.020	.007
			Medium	3210	−.001	.004	−.005	.001
			Large	889	.002	.004	−.002	.009
		2008-2017	Small	15,959	−.0008	.015	−.013	.011
			Medium	5615	−.0002	.002	−.002	.001
			Large	1115	.0009	.006	−.002	.004
	Model 2	1996-2007	Small	6443	−.004	.015	−.021	.007
			Medium	3210	−.001	.003	−.005	.001
			Large	889	.002	.004	−.002	.009
		2008-2017	Small	15,959	−.0008	.015	−.013	.011
			Medium	5615	−.0002	.002	−.002	.001
			Large	1115	.0009	.006	−.002	.005
TC	Model 1	1996-2007	Small	6443	.062	.017	.044	.101
			Medium	3210	.070	.018	.049	.105
			Large	889	.078	.019	.052	.109
		2008-2017	Small	15,959	.022	.015	−.002	.046
			Medium	5615	.024	.016	−.0006	.050
			Large	1115	.026	.017	.002	.053
	Model 2	1996-2007	Small	6443	.051	.012	.037	.077
			Medium	3210	.058	.012	.042	.081
			Large	889	.065	.013	.047	.087
		2008-2017	Small	15,959	.025	.011	.008	.041
			Medium	5615	.028	.011	.011	.046
			Large	1115	.031	.012	.014	.050
TEC	Model 1	1996-2007	Small	6443	.007	.008	.0008	.023
			Medium	3210	.007	.007	.001	.023
			Large	889	.008	.007	.0007	.023
		2008-2017	Small	15,959	−.007	.007	−.020	.0007
			Medium	5615	−.007	.007	−.020	.0007
			Large	1115	−.007	.008	−.022	.0007
	Model 2	1996-2007	Small	6443	−.019	.011	−.039	−.004
			Medium	3210	−.017	.010	−.034	−.004
			Large	889	−.015	.009	−.029	−.002
		2008-2017	Small	15,959	−.021	.012	−.043	−.003
			Medium	5615	−.019	.011	−.039	−.004
			Large	1115	−.019	.013	−.040	−.003

Continued

TFP	Model 1	1996-2007	Small	6443	.065	.027	.038	.121
			Medium	3210	.076	.025	.050	.125
			Large	889	.088	.025	.054	.132
		2008-2017	Small	15,959	.014	.025	−.022	.047
			Medium	5615	.018	.022	−.018	.050
			Large	1115	.020	.023	−.016	.054
	Model 2	1996-2007	Small	6443	.028	.022	−.003	.061
			Medium	3210	.040	.017	.015	.069
			Large	889	.052	.016	.026	.077
		2008-2017	Small	15,959	.003	.023	−.030	.031
			Medium	5615	.009	.017	−.021	.034
			Large	1115	.013	.019	−.019	.040

Note: The TFP growth rate and its components are based on Equations (7) to (12). Analytical calculations are provided in the appendix.

5. Concluding Remarks

We estimate a stochastic production frontier model with time-variant inefficiency that allows us to estimate productivity change and disentangle its sources. Utilizing detailed firm-level data for Greece, our findings reveal that, on average, productivity growth remains positive, albeit significantly reduced since the subprime crisis. This is primarily driven by technical change, though the role of efficiency change is also substantial, depending on the specific efficiency estimation model used. These results challenge the conventional belief that the crisis severely damaged the productive foundations of the Greek economy, demonstrating that there is still potential for both efficiency enhancements and technical advancements. Even in the aftermath of the crisis, there exists a group of firms that exhibit growth. Additionally, our research demonstrates the significant influence of firm size on productivity growth, although this impact appears to weaken in the post-crisis period. We observe a partial elimination of differences in growth experiences among firm size categories.

Compared to Genakos (2018), our results indicate although it may be true that there is "evidence demonstrating the low ranking of firms in the Greek economy compared with other EU and OECD countries" (Genakos, 2018: p. 896), it does not necessarily be true that productivity is low, especially as Genakos (2018) does not present direct productivity-related evidence. Our work contributes to this discussion by showing that, apart from the role of management, which in our paper is more related to efficiency and efficiency change, other factors are responsible for both: 1) the dramatic decline in productivity growth, and 2) the fact that this productivity growth is still positive (although unevenly distributed across firms) despite institutional rigidities and other exogenous factors (Bloom & Van Reenen, 2007, 2010). An interesting extension of this paper is the evaluation of productivity growth among different sectors. However, we leave an investigation of this important question to future research.

Acknowledgements

We would like to thank the participants at the 2019 Conference of the Association of Southern European Economic Theorists (ASSET) for their valuable comments and suggestions. Authors acknowledge financial support from the project co-financed by Greece and the European Union (European Social Fund), through the Operational Program "Human Resources Development, Education and Lifelong Learning 2014-2020" (MIS-5006583). All remaining errors and omissions are our own.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A: Productivity Change Decomposition

Assume the following production frontier $y_{it} = f\left(\boldsymbol{x}_{it}, t; \boldsymbol{\beta}\right)\exp\left(\varepsilon_{it}\right)$. By taking logs and differentiating with respect to time t we obtain:

$$\dot{y}_{it} = \frac{\partial \ln f\left(\boldsymbol{x}_{it}, t; \boldsymbol{\beta}\right)}{\partial t} + \sum_{k=1}^{K} \frac{\partial \ln f\left(\boldsymbol{x}_{it}, t; \boldsymbol{\beta}\right)}{\partial x_{kit}} \frac{\partial x_{kit}}{\partial t} - \frac{\partial u_{it}}{\partial t}$$

$$\dot{y}_{it} = TC + \sum_{k=1}^{K} \frac{\partial f\left(\boldsymbol{x}_{it}, t; \boldsymbol{\beta}\right)}{\partial x_{kit}} \frac{1}{f\left(\boldsymbol{x}_{it}, t; \boldsymbol{\beta}\right)} \frac{\partial x_{kit}}{\partial t} + TEC$$

$$\dot{y}_{it} = TC + \sum_{k=1}^{K} e_k \dot{x}_{kit} + TEC$$

where $e_k = \frac{\partial f\left(\boldsymbol{x}, t; \boldsymbol{\beta}\right)}{\partial x_k} \frac{x_k}{f\left(\boldsymbol{x}, t; \boldsymbol{\beta}\right)}$ are the elasticities of output with respect to each of the inputs[4], $\dot{x}_{kit} = \frac{\partial \ln x_{kit}}{\partial t}$. TC stands for technological change and TEC for Efficiency change. Following Kumbhakar and Lovell (2000: p. 283),

$$T\dot{F}P = \dot{y} - \sum_{k=1}^{K} s_k \dot{x}_k = TC + \sum_{k=1}^{K} \left(e_k - s_k\right) \dot{x}_k + TEC$$

By adding and subtracting the term $\sum_{k=1}^{K} \left(\frac{e_k}{e}\right) \dot{x}_k$, we obtain

$$T\dot{F}P = TC + \left(e - 1\right) \sum_{k=1}^{K} \left(\frac{e_k}{e}\right) \dot{x}_k + \sum_{k=1}^{K} \left(\left(\frac{e_k}{e}\right) - s_k\right) \dot{x}_k + TEC$$

where $e = \sum_{k=1}^{K} e_k$ is the scale elasticity and provides a measure of returns to scale characterizing the production frontier, $s_k = w_k x_i / E$, the observed expenditure share, $E = \sum_{k=1}^{K} w_k x_i$ the total expenditure and $w_k > 0$ for $k = 1, \cdots, K$ are the input prices. So, according to Kumbhakar and Lovell (2000: p. 284), we assume that $s_k = e_k / e$ and finally we obtain a measure that involves only quantity information (Equation (7)):

$$T\dot{F}P = TC + \left(e - 1\right) \sum_{k=1}^{K} \left(\frac{e_k}{e}\right) \dot{x}_{kit} + TEC$$

Appendix B: Robustness Tests of Productivity Change Decomposition

Table B1. Decomposition analysis before and after crisis. Cutoff 2008.

		Period	Mean	Std. Dev.	5th Percentile	95th Percentile
Scale	Model 1	1996-2008	−.002	.012	−.013	.005
		2009-2017	0	.013	−.010	.009
	Model 2	1996-2008	−.002	.013	−.014	.005
		2009-2017	0	.013	−.010	.009

[4]We suppress the indices *i* and *t*, for the elasticities and expenditure share, to keep the notation simple.

Continued

TC	Model 1	1996-2008	.062	.019	.041	.103
		2009-2017	.020	.014	−.002	.043
	Model 2	1996-2008	.052	.013	.036	.079
		2009-2017	.024	.010	.008	.041
TEC	Model 1	1996-2008	.006	.007	0	.021
		2009-2017	−.008	.007	−.021	0
	Model 2	1996-2008	−.018	.011	−.038	−.004
		2009-2017	−.020	.012	−.043	−.003
TFP	Model 1	1996-2008	.065	.027	.037	.121
		2009-2017	.012	.023	−.022	.043
	Model 2	1996-2008	.031	.022	−.001	.066
		2009-2017	.003	.021	−.029	.030

Note: The TFP growth rate and its components are based on Equations (7) to (12). Analytical calculations are provided in the appendix. The estimates are averaged across firms and years. From 1996 to 2008, the sample size is 13,061 while, from 2009 to 2017, it is 20,170, respectively.

Table B2. Decomposition analysis before and after crisis. Cutoff 2009.

		Period	Mean	Std. Dev.	5th Percentile	95th Percentile
Scale	Model 1	1996-2009	−.002	.012	−.013	.006
		2010-2017	0	.013	−.010	.009
	Model 2	1996-2009	−.002	.013	−.013	.006
		2010-2017	0	.013	−.010	.009
TC	Model 1	1996-2009	.060	.019	.040	.102
		2010-2017	.017	.013	−.003	.038
	Model 2	1996-2009	.049	.013	.033	.078
		2010-2017	.022	.009	.008	.038
TEC	Model 1	1996-2009	.005	.007	−.001	.020
		2010-2017	−.008	.007	−.022	−.001
	Model 2	1996-2009	−.019	.011	−.038	−.004
		2010-2017	−.021	.012	−.043	−.003
TFP	Model 1	1996-2009	.061	.027	.033	.119
		2010-2017	.008	.021	−.024	.037
	Model 2	1996-2009	.029	.022	−.003	.064
		2010-2017	.002	.020	−.031	.027

Note: The TFP growth rate and its components are based on Equations (7) to (12). Analytical calculations are provided in the appendix. The estimates are averaged across firms and years. From 1996 to 2009, the sample size is 15,579 while, from 2010 to 2017, it is 17,652, respectively.