AESTIMATIO, THE IEB INTERNATIONAL JOURNAL OF FINANCE, 2012. 4: 28-51

Fixed Capital Depreciations and TFP Growth: Evidence from Firm's Economic Balances

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▸ RECEIVED: 22 JULY 2011
▸ ACCEPTED: 8 JANUARY 2012

Abstract

By exploring evidence on the value of fixed assets, this paper uses firm-level data sets from manufacturing on capital depreciations spanning the period 1990-2008 from a group of OECD countries, along with panel data to investigate their association with total factor productivity (TFP), since different capital depreciation profiles imply different rates of capital accumulation and, therefore, different estimates of TFP. Our empirical findings, based on panel cointegration and error correction methodologies, indicate the presence of a positive relationship between capital depreciations and TFP. This result implies either the presence of strong institutions reducing levels of corruption, the presence of production embodying high technological achievements reducing the cost of capital maintenance, that the effectiveness of policy making minimizes the impact of uncertainty on investments, or the absence of certain distortions stemming from government financing policies, such as special tax credits to corporate investments and subsidies to investment loans.

Keywords:

TFP, Fixed capital depreciations, Firm level data, Panel data cointegration, Panel data error correction.

JEL classification:

E22, C23

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Depreciación del capital fijo y productividad total de los factores: **evidencia a partir los balances económicos de las compañías**

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Resumen

Mediante el análisis de la evidencia sobre el valor de los activos fijos, este artículo utiliza conjuntos de datos sobre depreciación de capital —a nivel de compañía manufacturera, para un grupo de países de la OCDE y en el periodo 1990-2008— junto con datos panel, para investigar su asociación con la productividad total de los factores (TFP), ya que diferentes perfiles de depreciación de capital implican diferentes tasas de acumulación de capital y, por tanto, diferentes estimaciones de la productividad total de los factores. Los resultados empíricos obtenidos, basados en metodologías de cointegración y corrección del error con datos de panel, indican la presencia de una relación positiva entre la depreciación del capital y la productividad total de los factores. Este resultado implica bien instituciones fuertes que reducen el nivel de corrupción, una producción que incorpora logros relacionados con la alta tecnología que reducen el coste de mantenimiento del capital, decisiones de política eficaces que minimizan el impacto de la incertidumbre en las inversiones, o ausencia de ciertas distorsiones derivadas de las políticas gubernamentales de financiación, tales como créditos fiscales especiales para las inversiones empresariales y las subvenciones a préstamos de inversión.

Palabras clave:

Productividad total de los factores, depreciación del capital fijo, datos a nivel de empresa, cointegración con datos de panel, corrección del error con datos de panel.

1. Introduction

The role of fixed capital stock depreciations has been established in the literature on investment theory and economic growth by Hulten and Wykoff (1981), Hulten (1990) and Jorgenson (1996). The role of TFP accounting in growth is extremely important, considering that it determines the trend of knowledge, skills, public services and technology, which are factors crucially associated with the growth pattern of modern economies. At the same time, developments in TFP are a crucial issue for researchers and entrepreneurs, given that TFP growth has slowed down, especially in advanced economies.

According to the OECD (1993, 2001), advanced industrial countries impose different criteria for determining fixed capital stock depreciations vis-à-vis developing countries. Consequently, imposing a unified depreciation rate is not a valid assumption, since capital stock is highly affected by differences in the cost of its maintenance as well as by differences in new capital investments across countries (and/or industries). In other words, how fixed capital stock is generated from investment differs to a great extent across countries. Studies in the relevant literature (Easterly and Rebelo, 1993; Nehru and Dhareshwar, 1993) that impose uniform depreciation rates across countries seem to account for growth incorrectly, which, in turn, generates misleading implications for investment and growth theories (Pritchett, 2000). In addition, Howitt (1998), Musso (2004) and Mukoyama (2008) argue that faster depreciation expenses lead to a more rapid replacement of capital stock and, therefore, to more investments in fixed capital, which in turn implies higher levels of TFP, given that the new investments are characterized by higher levels of quality embodied in the newer capital goods. In other words, there is a positive relationship between depreciation expenses and TFP.

Another growing strand of literature finds mixed results regarding the contribution to economic growth of large amounts of capital accumulation in the majority of developing countries. Elias (1992) argues that TFP contributions to growth are much lower for Latin American countries vis-à-vis the figures for Asian countries. Young (1995) supports the view that although fixed capital accumulation has been the dominant factor in Hong Kong, Korea and Taiwan, there is still a substantial TFP contribution to growth potentials. Pritchett (2000) shows that the majority of developing countries record negative figures for TFP growth, while Bu (2006) investigates the role of capital depreciations for developing countries and finds that in selected developing countries capital depreciations are faster than in other OECD economies, leading to a lower contribution of savings, investment and foreign aid to the growth process. In this case, there is a negative association between depreciation expenses and TFP.

Finally, a different group of studies makes use of disaggregated data to explore the role of TFP for the growth potential of firms and their impact on their stock prices. These studies have introduced equilibrium models to investigate optimal investment decisions (also associated with decisions on capital depreciation rates) of firms in response to changes in productivity (Gourio, 2007; Belo and Lin, 2010). However, none of these studies has directly estimated firm-level productivity. Others, such as the studies by Foster *et al*. (2008) and Hsieh and Klenow (2009), make use of plant-level data from China and India to measure the role of resource misallocation for TFP in China and India.

This paper goes a step further and attempts to close the gap in this literature by investigating with firm-level data on total fixed assets from a group of 25 OECD countries and using the panel cointegration and error correction to provide evidence about any possible impact of fixed capital stock accounting depreciation expenses on TFP, i.e. fixed capital depreciation values stemming directly from firm balance sheets. Next, provided that such a statistically significant association is present and given that the employment of firm-level data expressly takes into consideration the differentiation of the fixed capital depreciation profile, the empirical analysis will attempt to identify the sign between the two variables under study. The novelties of this study are: i) a unique feature of this data set that provides firm-specific observations for outputs and inputs, thus, allowing for the construction of a more reliable measure of firm TFP productivity. The reason is that the majority of papers using a firm-level base recognize the presence of high heterogeneity, i.e. in terms of productivity levels, technologies, age etc. This type of heterogeneity cannot be captured or evaluated under a macroeconomic approach as it aggregates different firms that share some characteristics and which are assumed to be influenced by economic forces in a similar way, ii) it makes use, for the first time in this literature, of panel data methodology to investigate the above association. There are at least three factors contributing to the extensive growth of panel data estimations: data availability, greater capacity for modeling the complexity of economic and financial trends, e.g. controlling the impact of omitted variables and uncovering dynamic relationships, than single cross-section or time series data estimations and challenging methodology (Baltagi, 2001; Hsiao, 2003), and, iii) obtaining depreciation data directly from balance sheets, which differentiates the accounting measurement of fixed capital depreciations from their economic measurement, which imposes a uniform pattern across firms. In other words, although the depreciation rate within the manufacturing sector follows a unified pattern, when it comes down to disaggregated manufacturing units, depreciation depends on the value of total fixed assets each and every firm holds. These non-uniform value (not rates) rules lead to different fixed capital accumulations and, therefore, to different estimates of TFP (Boucekkine *et al*., 2008). Firm-level estimations of fixed capital depreciations validate our empirical findings, in the sense that employing accounting measurement of depreciations increases firm efficiency (Kim and Moore, 1988). The assumption of common depreciation values across manufacturing firms may be wrong because of firm differences in the costs of capital maintenance and new capital investment. By assuming equal depreciation values across firms, nonetheless, conventional growth accounting studies could yield misleading results and suggest severe capital underutilization and mis-measurement of the stocks of capital.

The rest of the paper is organized as follows. Section 2 reviews the main literature on TFP and fixed capital stock depreciations, while Section 3 describes the data used in the empirical analysis, together with the methodological approach. Section 4 outlines the estimates and discusses the empirical findings, while Section 5 concludes and offers certain policy implications.

2. Measuring TFP and the Relationship between TFP and Fixed Capital Stock Depreciations: Evidence through Growth Accounting Modeling

TFP is not a variable that can be observed directly. It shows technological progress, or alternatively, in terms of real business cycle perception, technological shocks that drive the business cycle (Romer, 1990; Aghion and Howitt, 1998) or policies favoring the adoption of new technologies (Prescott, 1997). Economists have modeled it through the supply side of the economy. In particular, TFP estimates are obtained as the residuals between output growth and the weighted sum of labor, capital growth and human capital growth through a Cobb-Douglas production function with constant returns to scale:

$$Y = A\,K^{\alpha}\,L^{(1\text{-}\alpha)} \tag{1}$$

where α indicates the share of capital in income and (1-α) indicates the share of labor in income. Then from (1), changes in TFP are calculated as:

$$\Delta TFP = A/A = Y/Y - \alpha\,K/K\,(1-\alpha)\,L/L \tag{2}$$

where the dot-notation represents a time derivative and Δ denotes first differences. While there are different versions of this simple growth accounting model, this approach remains the workhorse of most *TFP* issues. Despite the simplicity of the approach, it has been widely used not only to decompose output growth, but also to explain cross-country differences in income per capita (Mankiw *et al.*, 1992; Hall and Jones, 1999; Easterly and Levin, 2001; Bosworth and Collins, 2003). Nevertheless, this methodology

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has certain inherent shortcomings, which have raised some concerns about the validity of the residual approach as an adequate measurement for technical progress. These shortcomings are related to the issues of labor hoarding, excess capacity, input quality and data measurement problems. Unlike most of the previous studies of *TFP*, which use aggregate data, this paper uses firm-level data to gain a better understanding of developments within the firm. The firm-level approach improves growth accounting, in terms of labor hoarding, because over time firms ignore the impact of the business cycle since during recessions they are reluctant to lose the majority of their staff, while during booms they do not begin hiring as quickly and, thus, the labor figures from the balance sheet reflect the role of the business cycle more closely. In terms of input quality, such as higher educational levels for the labor force, growth accounting does not capture the full extent of labor inputs, while labor data from firm balance sheets are adjusted for actual hours worked and, thus, offset the effects of labor hoarding that generate biased *TFP* estimations (Bils and Cho, 1994). Moreover, firm-level data improve the estimations of income accounting through better measures of the fixed capital employed by firms. In other words, disaggregated fixed capital data stemming directly from balance sheets better reflect the adoption of different technology profiles or research and development activities embodied in that fixed capital data (Foster *et al*., 2001; Sakellaris and Wilson 2004; Syverson, 2010).

We also assume that capital accumulation (K) follows:

$$K = qI - \delta K \tag{3}$$

where I is the aggregate investment, q is the investment-specific level of technology and δ is the depreciation rate, which is time varying. Equations (2) and (3) yield:

$$A/A = Y/Y - \alpha(qI/K - \delta) - (1-\alpha)\ L/L \tag{4}$$

From (4) we obtain: $\partial(A/A)/\partial\delta = \alpha$, which is positive and implies a positive association between fixed capital stock depreciations and *TFP*. We need to empirically test the presence of such a positive relationship between the two variables under investigation and across firms in case different capital depreciation profiles imply different rates of capital accumulation. As a result, accounting for the different values of depreciation in constructing capital stock series would necessarily lead to comparatively different estimates of *TFP* growth. Our empirical approach relies on reported (accounting) depreciations, which could contrast the rationale of growth accounting.

2.1 An Alternative Measurement of TFP

For the sake of robustness, a latent variable approach can also be applied. In particular, the state-space model is employed, which allows *TFP* to vary over time

(Durbin and Koopman, 2001). The Kalman filter can be defined as a dynamic time-series model in which an observable variable can be expressed as the sum of a linear function of some observable and unobservable variables plus an error. Furthermore, the unobservable variables evolve according to a stochastic difference equation. The paths of these observable and unobservable variables are inferred from the data.

Although this methodology has been widely used in economics, very few studies use this tool to estimate productivity issues. The first contribution in this area was introduced by Harvey and Wren-Lewis (1986), who propose this approach to model TFP in an employment-output equation, while Slade (1989) considers a translog production function for a micro-level application to the US primary-metals industry. Another empirical example has been illustrated by Esposti (2000), who follows a similar methodology and, using data from the Italian agriculture industry, attempts to identify technical progress induced by R&D and extension expenditure. The most innovative application to be estimated using the Kalman filter technique was introduced by Jorgenson and Jin (2008), who consider a dual approach for a translog production function, assume that technological change is not observable and model it as a latent variable with production function elasticities. Chen and Zadrozny (2009) make a recent contribution to the literature by considering both productivity and capital as unobservable. Finally, Fuentes and Morales (2011) is the most recent empirical application of the Kalman filter approach to measuring *TFP*.

Let the signal equation that describes output growth be:

$$\Delta y_t = TFP_t + a\ \Delta kk_t + \varepsilon_t \tag{5}$$

where y and kk denote the output per worker and capital per worker, respectively. Next, let the state equation be described as a pure $AR(q)$ linear Gaussian state-space representation defined as follows:

$$B(L)\ TFP_t = \gamma + u_t \tag{6}$$

where $B(L)$ represents a q-order polynomial on the lag operator L. Finally, let white noise disturbances be uncorrelated to each other:

$$\begin{bmatrix} \varepsilon_t \\ u_t \end{bmatrix} \sim NID \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{pmatrix} \sigma_\varepsilon^2 & 0 \\ 0 & \sigma_u^{\ 2} \end{pmatrix} \right] \tag{7}$$

The state-space methodology makes use of the Kalman filter, which is an updating algorithm for the linear projection of the state vector (the latent variables) based on observable variables that allow a likelihood function of the model based on the prediction error decomposition. After obtaining the likelihood function, the coefficients are estimated by numerical optimization methods. In addition, the filter requires startup conditions (parameter values) to achieve convergence. To this end, like the approach proposed by Chen and Zadrozny (2009), where initial conditions are needed for TFP growth, we make use of the estimates from a regression of the growth accounting model.

3. Data

The firm-level data sample, on an annual basis, covers a selected group of 25 OECD countries. Our sample comes from Bloomberg and by looking at the economic balances of each listed firm. Firms come from the manufacturing sector of each economy. The number of firms in each country along with the countries used is shown in Appendix A. If firms are missing values for any of our variables under investigation, they are dropped. This sector accounts for a large percentage of GDP activities in each country and in terms of value added. Data obtained from the United Nations Economic Outlook database confirm the above argument (see Appendix B). The number of firms in each country is allowed to differ. As a result, $4{,}030$ firms have been employed spanning the period 1990-2008. Variables such as output, fixed capital stock and labor are available from the accounting balance of each firm. In particular, output (Y) is measured as value added, capital (K) is measured as capital expenditures, while labor (L) is measured as the number of workers employed in each firm. Labor was not adjusted for changing skill composition due to data unavailability. Capital expenditures were based on fixed assets, which, in turn, contain land, buildings and structures, machinery equipment, office equipment and transport equipment. Depreciation expenses (D) are obtained from the same accounting balances and are considered to be accurate as they come from listed firms, whose balance sheets are under auditor scrutiny. Investment expenses (I) were also obtained from the financial reports provided by the firms and are related to cash flows generated by fixed capital stock purchases by the firm. We also include data on a number of control variables, such as the Consumer Price Index, budget deficits (*deficits*), *FDI* inflows (*FDI*), openness (TT) measured by the terms of trade, and, finally, financial development. The latter is proxied by two alternative indicators: i) the ratio of private credit offered by deposit money banks to GDP (*credit1*) and the ratio of the sum of demand, saving and time deposits at money banks and other financial institutions to *GDP* (*credit2*). This data set was also obtained from Bloomberg, except for the data on *FDI* that were obtained from the World Bank. Throughout the paper, lower case letters denote variables expressed in natural logarithms, while RATS (version 6.1) assists the empirical analysis.

4. Empirical Analysis

4.1. Panel Unit Root Tests

At the outset, the statistical properties of the value added series, the capital stock series, the labor series and depreciation expenses are examined by testing for the presence of unit roots. There are a variety of panel unit root tests, which include Maddala and Wu (1999), Breitung (2000), Hadri (2000), Choi (2001), Levin *et al*. (LLC, 2002) and Im *et al*. (IPS, 2003), among others.

The results in Table 1 indicate that the hypothesis that all the variables except *TFP* contain a unit root is accepted at the 1% confidence level in all tests, suggesting that these variables in our study are I(1). In other words, it seems that all tests lead to a clear acceptance of the I(1) null at the 5% level of significance for the first differences of the variables under study, which we take as a strong evidence in favor of the stationarity of those variables. In contrast, the *TFP* variable is seen to be an I(0) variable, i.e. the null hypothesis of stationarity is accepted at the level form of the variable. These results imply that in order to investigate the association between *TFP* and fixed capital depreciations, only short-run dynamics should be tested using panel causality tests.

Table 1. **Panel Unit Root Tests**

	IPS	LLC	Handri (hom)	Handri (het)	Fisher-ADF	Fisher-PP
Variables						
y	-1.68(3)	-1.32	11.27*	8.48*	-15.68	-21.26
Δy	-5.41(1)*	-9.53*	1.35	0.62	-94.55*	-132.48*
l	-1.43(3)	-1.62	9.55*	9.57*	-18.75	-31.44
Δl	-5.57(2)*	-8.75*	1.17	1.77	-118.33*	-147.89*
k	-1.47(3)	-1.62	19.85*	18.36*	-21.23	-25.48
Δk	-5.38(2)*	-9.37*	1.13	1.47	-131.98*	-142.18*
d	-1.64(4)	-1.44	23.46*	23.45*	-29.07	-31.22
Δd	-5.77(3)*	-9.12*	1.25	1.31	-157.33*	-167.92*
TFP	-5.86(3)*	-4.73*	5.26*	4.94*	-104.95*	-104.81*
$credit1$	-2.37(3)	-2.11	12.76*	10.91*	-13.68	-12.72
$\Delta credit1$	-5.48(2)*	-8.47*	1.42	1.37	-144.94*	-139.88*
$credit2$	-2.41(3)	-2.19	13.44*	11.38*	-14.71	-13.46
$\Delta credit2$	-5.33(2)*	-7.68*	1.38	1.46	-141.23*	-146.71*
$infl$	-5.11(3)*	-9.36*	10.54*	11.09*	-152.58*	-150.66*
$deficit$	-2.07(4)	-1.69	10.72*	12.44*	-14.77	-13.56
$\Delta deficit$	-5.21(2)*	-8.73*	1.71	1.56	-144.58*	-146.81*
FDI	-2.37(3)	-2.29	14.67*	10.92*	-13.58	-14.55
ΔTFP	-5.42(2)*	-9.05*	1.17	1.23	-153.52*	-152.38*
TT	-2.28(3)	-2.31	11.35*	11.64*	-14.62	-14.52
ΔTT	-4.81(2)*	-8.81*	1.62	1.52	-148.58*	-145.68*
i	-1.92(3)	-2.04	15.68*	17.81*	-13.28	-12.74
Δi	-5.89(1)*	-9.23*	1.31	1.47	-138.77*	-140.93*

Numbers in parentheses are the augmented lags included in the unit root test.
** denotes statistical significance at 1%*

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4.2 Dynamic Heterogeneity

One issue that is of major concern is the heterogeneity of the firms included in this data set. In particular, through time and across firms, the effects on the depreciation–*TFP* relationship of the different structural operational frameworks established in each firm should be expected to be diverse.

In the statistical framework of this study we first test for heterogeneity through appropriate techniques (Holtz-Eakin, 1986; Holtz *et al*., 1985). The dynamic heterogeneity, i.e. variation of the intercept over firms and time, across a cross-section of the relevant variables can be investigated as follows. The results of this procedure are reported in Table 2. For all four specifications, i.e. growth accounting, the *TFP*-depreciations (bilateral model) relationship, the *TFP*-depreciation (multilateral) model with credit1 relationship and the *TFP*-depreciation (multilateral) model with credit2 relationship, the empirical findings indicate the rejection of the null hypothesis of homogeneity. In other words, the relationships under investigation are characterized by heterogeneity of dynamics and error variance across groups, supporting the employment of panel analysis.

Table 2. **Tests of Dynamic Heterogeneity across Groups**

Specification	ADF(3)	AR(3)	White's Test
Variables			
*y-k-*1	25.68*	36.92*	64.84*
TFP-d	23.44*	32.68*	59.05*
*TFP-d-infl-credit*1*-Deficit-FDI-TT*	26.71*	36.59*	64.51*
*TFP-d-infl-credit*2*-Deficit-FDI-TT*	23.53*	35.44*	60.79*
TFP-d-y-i	29.81*	38.73*	58.92*

ADF(3) reports the parameter equality test (F-test) across all relationships in the panel. AR(3) displays the F-test of parameter equality conducted in a third-order autoregressive model of the relationships. White's test reports the White's test of equality of variances across the investigated relationships in the panel. Model contains only operating earnings, while Model 2 contains both types of earnings.
** denotes statistical significance at 1%.*

4.3 Panel Cointegration Tests-Growth Accounting

Given the presence of heterogeneity in both dynamics and error variances in the panel, the heterogeneous panel cointegration test advanced by Pedroni (1999, 2004), which allows for cross-section interdependence with different individual effects, is employed for the long-run production function dynamics. Table 3 reports both the within and between dimension panel cointegration test statistics for the accounting equation. All seven test statistics reject the null hypothesis of no cointegration at the 1 percent significance level and, thus, validate the presence of cointegration in terms of production function accounting, i.e. there is a long-run relationship between output and capital and labor.

Table 3. **Panel Cointegration Tests**

Growth accounting	
Panel v-stat	37.44691*
Panel rho-stat	-32.57973*
Panel pp-stat	-30.26533*
Panel adf-stat	-7.47246*
Group rho-stat	-30.24439*
Group pp-stat	-31.47709*
Group adf-stat	-7.93356*

** denotes statistical significance at 1%*

Having established that there is a linear combination that keeps the pooled variables in proportion to one another in the long run, we can proceed to generate individual long-run estimates for both model equations. Following Pedroni (2000), the fully modified OLS (FMOLS) methodological technique considers the long-run relationship between income, capital, and labor yielding:

$$Y_{it} = a_{it} + b_{li} K_{it} + b_{2i} L_{it} + \hat{\varepsilon}_{it} \quad (8)$$

where $i = 1,...,N$ for each firm in the panel and $t = 1,...,T$ refers to the time period. Y is aggregate or total real income, K is fixed capital and L measures labor. Given the variables are in natural logarithms, the parameters b_1 and b_2 represent the long-run elasticity estimates of total output with respect to fixed capital and labor, respectively. The FMOLS estimator not only generates consistent estimates of the β parameters, but it also controls for the likely endogeneity of the regressors and serial correlation.

Table 4 displays the FMOLS results. In this model the coefficients are shown to be positive and statistically significant at the 1 percent significance level. In particular, the results display that a 1-percent increase in capital leads to a 0.49 percent increase in total income, while a 1-percent increase in labor leads to 0.48 percent increase in total income. Looking at the model's overall performance, as reported by a battery of diagnostic tests, the estimated equation satisfies certain econometric criteria, namely the absence of serial correlation (LM test), the absence of functional misspecification (RESET test) and the absence of heteroskedasticity (HE test). Once these estimations are available, the residuals representing TFP are saved. Table 4 also presents the estimated TFP measure from the fitted value of the Kalman filter (the state-space model). The likelihood function is maximized by using the Berndt-Hall-Hall-Hausman algorithm. Starting values for the parameters come from the FMOLS estimations from above. The coefficient describing the capital per worker-output

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association turns out to be 0.465. The correlation coefficient (ρ) between the two alternative measures of *TFP* is also reported in Table 4. It is worth noting the high correlation between *TFP* estimated by the growth accounting model and *TFP* estimated by the state-space model.

Table 4. **FMOLS Estimates**

Growth accounting						
y =	0.357 + 0.491 k + 0.484 l					
	(4.82)* (5.39)* (4.58)*					$\bar{R}^2$ = 0.86
LM=1.28[0.40]	RESET=2.13[0.26]	HE=1.17[0.34]				
State-space model						
y =	0.078	+ 0.465 kk	+ 0.376 TFP(-1)	+ 0.205 TFP(-2)	+ 0.173 TFP(-3)	
	(3.77)*	(4.81)*	(4.11)*	(4.55)*	(4.08)*	
Correlation Coefficient for Alternative Estimations of TFP Growth						
ρ =	0.79					

Figures in parentheses denote t-statistics. LM is a serial correlation for the residuals test, RESET is a model specification test and HE is a heteroskedasticity test. Figures in parentheses denote p-values.
** denotes significance at 1%*

4.4. TFP and Fixed Capital Depreciations: Causality Tests-Bilateral Model

The fact that *TFP* is an $I(0)$ variable, while fixed capital depreciations are an $I(1)$ variable excludes the case of cointegration. Thus, the absence of a long-run cointegrating relationship lends itself to the estimation of a panel vector autoregressive (VAR) model in order to infer the short-run causal relationships among the variables. Next, the following benchmark dynamic VAR model is estimated:

$$TFP_{it} = \omega_{1j} + \sum_{k=1}^{q}\gamma_{11ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{12ik}\Delta d_{it-k} + \hat{u}_{1it} \tag{9}$$

$$\Delta d_{it} = \omega_{2j} + \sum_{k=1}^{q}\gamma_{21ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{22ik}\Delta d_{it-k} + \hat{u}_{2it} \tag{10}$$

where Δ is the first-difference operator, q is the lag length set at three, based on likelihood ratio tests, and $u1$ and $u2$ are the error terms from equations (9) and (10), respectively. In equations (9) and (10), Δd represents the rate at which depreciation expenses change over time. Panel I in Table 5 reports the results of the causality tests as previously outlined in the bilateral model. The short-run dynamics suggest a (positive) unidirectional causality from fixed capital depreciations to *TFP*. In the same panel of Table 5, the causality tests between the *TFP* measurement from the state-

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space model and fixed capital depreciations are also reported. These findings reach the same results as in the growth accounting specification.

Table 5. Panel Causality Tests

Dependent Variable	Independent Variables	Diagnostics	
PANEL I. Bilateral Model			
Growth accounting			
(9) *TFP*	*TFP*	Δd	
	----	20.23(+)*	
		[0.00] LM=1.05[0.47] RESET=1.93[0.32]	
(10) Δd	0.02(-)	----	
	[0.86]	LM=1.22[0.41] RESET=1.77[0.38]	
State-space model			
TFP	*TFP*	Δd	
	----	18.05(+)*	
		[0.00]	
Δd	0.11(-)	---	
	[0.54]		
PANEL II. Multilateral model (with credit1)			
Growth accounting			
(9) *TFP*	*TFP*	Δd	
	----	27.81(+)*	
		[0.00] LM=1.05[0.47] RESET=1.93[0.32]	
(10) Δd	0.03(-)	---- LM=1.54[0.28] RESET=1.70[0.38]	
	[0.61]		
State-space model			
TFP	*TFP*	Δd	
	----	24.37(+)*	
		[0.00]	
Δd	0.13(-)	----	
	[0.42]		
Multilateral model (with credit2)			
Growth accounting			
(9) TFP	TFP	Δd	
	----	26.59(+)*	
		[0.00] LM=1.10[0.44] RESET=1.78[0.42]	
(10) Δd	0.03(-)	---- LM=1.21[0.40] RESET=1.21[0.51]	
	[0.60]		
State-space model			
TFP	*TFP*	Δd	
	----	24.12(+)*	
	[0.00]		
Δd	0.12(-)	---	
	[0.47]		
PANEL III. Bilateral model with income			
Growth accounting			
(11) *TFP*	*TFP*	Δd	ΔI
		----	34.52(+)* 37.86(+)*

	[0.00]	[0.00]	
	LM=1.14[0.43] RESET=1.60[0.47]		
(12) Δd	52.17(+)*	----	45.61(+)*
	[0.00]		[0.00]
	LM=1.05[0.47] RESET=1.93[0.32]		
(13) ΔI	49.89(+)*	51.37(+)*	----
	[0.00]	[0.00]	
	LM=1.20[0.41] RESET=1.84[0.36]		
State-space model			
TFP	*TFP*	Δd	ΔI
	----	31.22(+)*	40.82(+)*
	[0.00]	[0.00]	
Δd	48.28(+)	----	39.80(+)*
	[0.00]		[0.00]
ΔI	45.62(+)*	56.71(+)*	----
	[0.00]	[0.00]	

PANEL IV. Bilateral model with investment expenses
Growth accounting

(14) *TFP*	*TFP*	Δd	Δy
	----	42.33(+)*	58.71(+)*
	[0.00]	[0.00]	
	LM=1.18[0.42] RESET=1.51[0.47]		
(15) Δd	47.75(+)*	----	47.06(+)*
	[0.00]		[0.00]
	LM=1.11[0.48] RESET=1.60[0.43]		
(16) Δy	39.84(+)*	44.08(+)*	----
	[0.00]	[0.00]	
	LM=1.07[0.60] RESET=1.36[0.51]		
State-space model			
TFP	*TFP*	Δd	Δy
		----	36.72(+)*
51.90(+)*			
	[0.00]	[0.00]	
Δd	54.18(+)*	----	42.85(+)*
	[0.00]		[0.00]
Δy	38.71(+)*	38.90(+)*	----
	[0.00]	[0.00]	

PANEL V. Bilateral model with Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, UK and US.
Growth accounting

(9) *TFP*	*TFP*	Δd	
	----	48.09(+)*	
	[0.00]		LM=0.76[0.72] RESET=1.19[0.55]
(10) Δd	58.73(+)	----	
	[0.00]		LM=1.13[0.57] RESET=1.64[0.43]
State-space model			
TFP	*TFP*	Δd	
	----	51.36(+)*	
	[0.00]		
Δd	57.69(+)	----	
	[0.00]		

Bilateral model with Korea, Mexico, Poland, Portugal, Brazil, China, South Africa			
Growth accounting			
(9) *TFP*	*TFP*	Δd	
	----	27.15(+)*	
	[0.00]		LM=0.91[0.64] RESET=1.28[0.59]
(10) Δd	26.81(+)	----	
	[0.00]		LM=1.02[0.60] RESET=1.53[0.50]
State-space model			
TFP	*TFP*	Δd	
	----	21.44(+)*	
	[0.00]		
Δd	23.07(+)	----	
	[0.00]		

Partial F-statistics are reported with respect to short-run changes in TFP and Δd (δ). +/- denotes whether the sum of the lagged coefficients on the independent variables are positive or negative. Probability values are in parentheses. LM is a serial correlation for the residuals test and RESET is a model specification tests.
** denotes significance for summation at 1%.*

4.5 Robustness Tests

In order to test the validity of our results, we employ the *TFP*-capital depreciation relationship to extend the analysis by examining the role of (control) variables that seem to exert an impact on *TFP*. In particular, such determinants, based on data availability, are inflation, financial sector development, openness of trade, budget deficits and *FDI* inflows. At this point it is worth mentioning that while the primary series under investigation are on a firm-level basis, the control variables are on a country-level basis. The use of country-level data along with firm-level data does not negate the empirical analysis. In econometric terms, Hsiao (1979) and Palm and Nijman (1982) argue that a regression that contains both forms of aggregation still generates efficient estimations. Moreover, the use of country-level variables, such as inflation, imposes an homogeneous pattern for the future course of goods prices on the economy and, therefore, on manufacturing firms.

In terms now of the variables used as controls, inflation captures the stability of the economy, which is considered to be a prerequisite for *TFP*. Moreover, inflation adds to *TFP* by generating employment. Openness is considered to have a favorable impact on *TFP*. More specifically, more open economies are capable of growing more rapidly through greater access to cheap imported intermediate goods as well as to advanced technologies (Grossman and Helpman, 1994). According to Kohli (1991) and Senhadji (1999), changes in the terms of trade, proxying the openness of the economy, can increase output without producing more inputs, simply by increasing the amount of imported inputs. *FDI* brings technology and creates employment. It helps to adopt new methods of production, while it raises the level of competition in the economy. It also introduces novel management and organizational skills, reduces the barriers to adopting technology and improves the quality of labor and capital inputs in the host economy.

In terms of the concept of financial development, financial markets tend to enhance *TFP* through efficient capital reallocation, i.e. shifting capital from declining industries to those with better growth potential (Restruccia and Rogerson, 2007). Moreover, the deepening of financial markets tends to reduce financial frictions that are responsible for information and transaction costs associated with capital reallocation (Levin, 1997). The majority of the literature finds financial development boosts *TFP* (Levin and Zervos, 1998; Beck *et al*., 2000; Fisman and Love, 2004). In other words, financial development promotes growth by allocating funds towards the most profitable investments. Moreover, easier access to credit stimulates greater *TFP*.

Panel II in Table 5 reports the multilateral model (both versions) results of the causality tests. Once again, the short-run dynamics, through their probability values reported in brackets, suggest not only a (positive) association between the two variables under study, but also unidirectional causality running from fixed capital depreciations to *TFP*, since the p-value of Δd to *TFP* is zero, while that of *TFP* to Δd is above 0.10, implying statistical nonsignificance.

Panel III in Table 5 provides additional evidence by adding a control variable regarding investment cash flow expenses (I, which is also a stationary variable in first differences, Table 1), on the grounds that causality could run the other way: firms invest in new capital due to higher *TFP* levels and, therefore, depreciation expenses are expected to increase. The new model yields:

$$TFP_{it} = \omega_{3j} + \sum_{k=1}^{q}\gamma_{11ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{12ik}\Delta d_{it-k} + \sum_{k=1}^{q}\gamma_{13ik}\Delta I_{it-k} + \hat{u}_{3it} \quad (11)$$

$$TFP_{it} = \omega_{4j} + \sum_{k=1}^{q}\gamma_{21ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{22ik}\Delta d_{it-k} + \sum_{k=1}^{q}\gamma_{23ik}\Delta I_{it-k} + \hat{u}_{4it} \quad (12)$$

$$TFP_{it} = \omega_{5j} + \sum_{k=1}^{q}\gamma_{31ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{32ik}\Delta d_{it-k} + \sum_{k=1}^{q}\gamma_{33ik}\Delta I_{it-k} + \hat{u}_{5it} \quad (13)$$

The empirical findings validate that in both econometric versions of the model there is bi-directional causality between the two variables under investigation.

Panel IV presents the results, according to which, it has been argued that firms usually tend to smoothen their reported results, which can be achieved by writing higher depreciations in years when turnover is high. In order to control for this strategy, the operating income variable was introduced expressly. The econometric model turns out to be:

$$TFP_{it} = \omega_{6j} + \sum_{k=1}^{q}\gamma_{11ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{12ik}\Delta d_{it-k} + \sum_{k=1}^{q}\gamma_{13ik}\Delta y_{it-k} + \hat{u}_{3it} \quad (14)$$

$$TFP_{it} = \omega_{7j} + \sum_{k=1}^{q}\gamma_{21ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{22ik}\Delta d_{it-k} + \sum_{k=1}^{q}\gamma_{23ik}\Delta y_{it-k} + \hat{u}_{4it} \quad (15)$$

$$TFP_{it} = \omega_{8j} + \sum_{k=1}^{q}\gamma_{31ik}TFP_{it-k} + \sum_{k=1}^{q}\gamma_{32ik}\Delta d_{it-k} + \sum_{k=1}^{q}\gamma_{33ik}\Delta y_{it-k} + \hat{u}_{5it} \quad (16)$$

Once again, the empirical findings validate the presence of a bi-directional causality effect. Both of these new findings indicate the strong (positive) association between TFP and depreciation expenses, validating our argument that firm reports on higher fixed capital depreciations just indicate the capability of firms to assimilate higher capital stocks, which embodies new technological achievements and, thus, higher overall productivity.

Finally, Panel V displays the results for two different groups of countries. Chenery (1986) finds that low-income countries have lower *TFP* contributions to growth processes, while high-income countries display larger figures for such contributions. Thus, the countries in our sample are grouped according to more specific economic behavior based on their level of development. In particular, one group contains Korea, Mexico, Poland, Portugal, Brazil, China and South Africa and the second group the remaining economies.

In both cases (and in all econometric specifications) the bi-directional causality between *TFP* and fixed capital depreciations still remains valid. However, the intensity of the *F*-test is drastically reduced for the case of the group that includes the less developed countries, indicating that the signaling of higher fixed capital depreciations for *TFP* weakens. These empirical findings indicate that a lower level of development is very likely to weaken institutional efficiency, i.e. greater leniency in regard to corruption leniency as well as the presence of state financing interventions as extra incentive for firms to accumulate higher capital stocks. Both of these issues can potentially weaken the impact of such depreciations on *TFP*.

5. Concluding Remarks and Policy Implications

Using firm-level data on fixed capital stock depreciations and *TFP* from a group of 25 countries and from 4,030 industrial firms over the period 1990-2008, this study provides empirical insight into the impact of fixed capital depreciations on *TFP*.

Through the methodology of panel data, the empirical findings display that fixed capital depreciations have a positive and statistically significant impact on *TFP*.

Our results contrast what was expected bearing in mind theoretical arguments. In particular, higher depreciation levels associated with government-provided investment incentives could lead to a higher marginal cost of capital maintenance, while higher depreciation levels including corruption in capital goods procurement, lead to a lower effectiveness of converting new investment into capital stock. However, our empirical findings provide evidence of a puzzle related to the association of the two variables under discussion. In particular, our findings provide empirical support for the presence of a positive association between the variables under study, implying the absence of potential adverse effects. Those findings could be explained by the fact that developed countries, vis-à-vis the developing economies, have stronger institutions that reduce levels of corruption as well as more intense production embodying high technological achievement that reduces the cost of capital maintenance.

In addition, higher fixed capital depreciations could indicate that the stock of fixed capital is more sensitive to the volatility of fixed investment and, thus, to the volatility of the macroeconomic environment of the firm. However, our empirical results imply that the effectiveness of policy making potentially minimizes the impact of such volatility on investments and, therefore, on *TFP*. Finally, our results also contrast the argument that higher fixed capital depreciations should adversely affect the growth patterns of the economy due to the presence of distortions stemming from government financing policies, such as special tax credits for corporate investments and/or subsidies for investment loans. Such distortions are not prevalent in the majority of OECD economies.

The policy implications of our empirical results are closely related to the growth effect, i.e. increasing the depreciation rates of fixed capital stock can significantly stimulate a more intense process of capital accumulation and, thus, indirectly promote capital and output growth.

The puzzle raised by these results and, according to the neoclassical growth theory, is that higher depreciation rates were expected to be associated with low *TFP*, while our results reached the opposite conclusion, indicating that the period under study can be characterized by a lower-degree of government intervention as well as import-substitution industrialization. The minimization of such interventions is associated with fewer restrictions to international trade, a lower degree of licensing and cartelization and the absence of targeted investment subsidies.

In order to understand the underlying causes for high depreciation rates, further research may fully develop a conceptual framework to explore the economic implications of various political-economy factors for capital accumulation. Relevant inquiries may include whether government and international financing policies can reduce the incentive to maintain existing assets and, thus, result in faster depreciation. It should be noted that the applicability of our empirical framework is bounded by existing technical restraints. More specifically, this paper does not include sectorial differences. Human capital is measured without any adjustment for changes in educational levels. When calculating the capital stock, we only adopt one method from the literature, thus excluding tests of the robustness of the results. These limitations provide scope for further work on the subject. Finally, further extensions of this study could be to explore the related association across different business cycle phases, since low (high) TFP firms entail higher (lower) risk, implying higher (lower) risk premia, which could have a contractive (expansive) effect on growth.

Acknowledgements

The authors wish to thank two referees as well as the Editor of this Journal for their valuable and constructive comments on an earlier draft of the manuscript that tremendously improved the quality of the paper. Needless to say, the usual disclaimer applies.

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Appendix A

Countries and the number (in parenthesis) of manufacturing firms in each country: Australia (215), Austria (156), Belgium (150), Brazil (70), Canada (250), China (15), Denmark (124), Finland (64), France (230), Germany (418), Italy (234), Japan (345), Korea (155), Mexico (88), Netherlands (70), New Zealand (35), Norway (49), Poland (15), Portugal (63), S. Africa (10), Spain (127), Sweden (80), Switzerland (42), UK (480), US (545).

Appendix B

Countries and the percentage of the manufacturing sector in terms of GDP (in parenthesis) in 2009:

Australia (10.93), Austria (19.61), Belgium (19.01), Brazil (16.49), Canada (14.29), China (42.11), Denmark (14.96), Finland (22.37), France (12.47), Germany (22.67), Italy (19.49), Japan (20.19), Korea (29.74), Mexico (18.94), Netherlands (12.47), New Zealand (15.90), Norway (10.63), Poland (19.58), Portugal (14.95), S. Africa (16.09), Spain (14.67), Sweden (18.10), Switzerland (19.96), UK (12.13), US (13.89).