TFP GROWTH IN SPANISH REGIONS: EFFECTS OF QUASI-FIXED AND EXTERNAL FACTORS AND VARYING CAPACITY UTILIZATION

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Abstract

The aim of this paper is to evaluate empirically the relevance of the presence of quasi-fixed and external inputs, non constant returns to scale, and degree of capacity utilization in the calculation of TFP growth for the private productive sector of Spanish regions over the 1980-1993 period. Using a parametric framework based on the estimation of cost functions, we find that for the whole of the Spanish private sector, the traditional "Solow" estimate of TFP growth overestimates true technological progress due to the omission of infrastructures. Nevertheless, we find clear cyclical behavior, given that in economic expansions the "Solow" estimate underestimates true technological progress, while in times of recession the opposite is true. This result is also common to the majority of the Spanish regions, as is the fact that on average almost all of them have over-utilized installed capacity.

Keywords: infrastructures, private capital, costs and productivity.
JEL Classification: H54, O47.

1. Introduction.

Total factor productivity growth (TFP) measured as the difference between output growth and a weighted average of the growth of inputs, constitutes the most widely used general index of productive efficiency. Growth accounting exercises have been the usual way to calculate technical change, looking for explanations for the evolution of productivity in countries, regions or sectors. The utilization of Solow's (1957) growth accounting formula has been usual practice in many empirical applications, given that the simplifying assumptions it involves makes it easy to compute and to interpret. Nevertheless, it is well known that this formula generates important biases if inputs services are erroneously measured (as Solow pointed out himself in his 1957 work) or if the underlying assumptions are violated. In this sense, pioneering work by Denison (1962 and 1967), Jorgenson and Griliches (1967) or Kendrick (1973) aimed to reduce the growth accounting residual introducing qualitative measures for the inputs.

The productivity slowdown in many industrialized countries from the beginning of the seventies onwards, further stimulated the concern to properly measure TFP growth. Different explanations appeared in the literature in an attempt to account for the productivity slowdown. Among others, the reduction in public investment growth, specifically infrastructures (Aschauer, 1989a,b); the economic rigidities that hindered from adjusting to the energy crisis generating exceptional capital scrapping (Baily, 1981 or Maddison, 1987); distortions to the efficient allocation of resources due to governmental regulations (Kendrick, 1981); or the acceleration of economic obsolescence of acquired knowledge (Englander, Evenson and Hanazaki, 1988).

In any case, attempts to properly measure the services of productive factors where not the only source of improvements in the literature of the growth residual. In fact, many works shared the view that TFP growth was systematically mismeasured, because of the inappropriate use of theoretical assumptions imposed on growth accounting exercises. Concretely, the theoretical assumptions that were questioned are that all inputs adjust instantaneously to their optimal endowment levels, that returns to scale are constant, that there are no external factors or that the economy behaves under the perfect competition hypothesis. If certain productive factors, specifically private capital, are quasi-fixed inputs that do not adjust instantaneously to their long run equilibrium levels, then observed output does not necessarily coincide with potential output. This means that the degree of capacity utilization (CU) affects the measurement of TFP growth. In other words, input shares have to be amended using the shadow price of capital instead of the user cost (Berndt and Fuss, 1986). If returns to scale are different than constant, firms increase (or decrease) their efficiency when output grows, independently of technical change (Denny, Fuss and Waverman, 1981 or Morrison, 1985a,b, 1986, 1989). Also if perfect competition fails, traditional TFP growth accounting needs to be reconsidered to take into account the existence of market power and mark-up rules (Hall, 1988; Morrison, 1989 or Nadiri and Kim, 1992). Finally, other authors study the incidence of external effects (Caballero and Lyons, 1990 or Morrison and Siegel, 1997) or of agglomeration economies (Morrison Paul and Siegel, 1999) in the calculation of TFP growth.

The aim of this paper is to evaluate empirically the relevance of the presence of quasi-fixed and external inputs, non-constant returns to scale, and the degree of capacity utilization in the calculation of TFP growth for the private productive sector of Spanish regions. First, using a dual approach based on cost functions, we bring together into a compact expression different corrections to Solow's traditional growth accounting formula that so far were disperse in the literature. The theoretical development we present in the second section of this paper derives essentially from three contributions in the literature. In Morrison and Schwartz (1996), these authors present also a corrected formula to properly calculate TFP growth taking into account the effects of quasi-fixed and external inputs and the degree of returns to scale. Nevertheless, as demonstrated in de la Fuente (1999), this formula suffers from two kinds of inconsistencies[1]. On the one hand, it is a formula to calculate the rate of cost reduction induced by technical change, instead of actually the rate of TFP growth. On the other hand, the decomposition of the short-run cost elasticity with respect to output performed by these authors is not carried out in a consistent theoretical and mathematical way. Thus, we follow closely de la Fuente (1999) in amending these inconsistencies. Finally, in none of these two papers is the treatment of capacity utilization made explicit. So, from theoretical developments in Morrison (1986) we incorporate explicitly into the corrected growth accounting formula the effect of capacity utilization, isolated from the effects of returns to scale and the quasi-fixed and external direct effects

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[1] In this paper, the author amends and clarifies a number of important aspects regarding the relation of cost performance measures and total factor productivity measures in the empirical literature based on cost functions.

of some inputs.

Second, using a parametric framework based on the estimation of a generalized Leontief cost function, we apply the corrected growth accounting formula to compute TFP growth for the private productive sector of Spanish regions over the 1980-1993 period. For the whole of the Spanish private sector, we find that the traditional measure of TFP growth overestimates true technological progress due to the effect of infrastructures. Nevertheless, we find a clear cyclical behavior, given that in economic expansions the "Solow" estimate of TFP growth underestimates true technological progress, while in times of recession the opposite is true. This result is also common to the majority of the Spanish regions, as is the fact that on average almost all of them have over-utilized installed capacity.

The remainder of this paper is organized as follows. In section 2, we provide the derivation of the corrected formula to compute TFP growth. Section 3 presents a brief description of the data and the empirical model we estimate. Section 4 presents our main results evaluating the impact of quasi-fixed and external factors, returns to scale and capacity utilization in the calculation of TFP growth. The final section deals with the most important conclusions.

2. The dual approach to TFP growth.

Clearly, the measurement of productivity growth aims to capture the increase in production efficiency over time. Efficiency gains can be computed in two different ways. First, as the increase in output growth due to technical change for given inputs (primal approach) and second, as the rate of reduction of production costs due to technical change for given output and factor prices (dual approach). As demonstrated by Otha (1974), under the restrictive assumptions implicit in Solow's growth accounting formula both approaches deliver exactly the same measure of total factor productivity growth. However, if these restrictive assumptions are not met, input shares in total output (if we use the primal approach), or input shares in total cost (if we use the dual approach) need to be amended in order for the new underlying assumptions to be taken into account.

In the remainder of this section, we will provide a derivation of a total factor productivity growth formula which explicitly corrects the traditional Solow accounting expression (in terms of input shares in total cost) for the effects of quasi-fixed and external factors as well as the effects of returns to scale and the degree of economic capacity utilization. As stated in the introduction we will pick up from different contributions in the literature the necessary amendments to the Solow formula. To do so, we start our analysis assuming a firm that produces with two variable inputs, labor (*L*) and intermediate inputs (*M*), one quasi-fixed input, private capital (*Kp*), and one external factor, public capital (*Kg*). Thus, we can write the production function used by the firm as:

$$Y = F(L, M, Kp, Kg, t) \qquad [1]$$

where *Y* is gross output and *t* time, included to capture exogenous technical progress. As stated before, *Kp* is fixed in the short run and *Kg* is an unpaid input for the firm, provided free of charge by the government. Under these assumptions, we can obtain the total cost function (*C*) dual to the production function in [1] by minimizing variable costs for given output and given stocks of public and private capital. Being *G* the variable cost function, *w* the price of labor, v the price of intermediate inputs and P_{Kp} the user cost of private capital, the dual total cost function can be written as[2]:

$$C(w,v,Kp,Kg,Y,t) = G(w,v,Kp,Kg,Y,t) + P_{Kp}Kp \qquad [2]$$

Next, let us write the primal measure of technical progress (the rate of TFP growth), which by definition is:

$$\varepsilon_{Y,t} \equiv \frac{\partial Y}{\partial t}\frac{1}{Y} = \hat{Y} - \varepsilon_{Y,Kp}\hat{Kp} - \varepsilon_{Y,Kg}\hat{Kg} - \varepsilon_{Y,L}\hat{L} - \varepsilon_{Y,M}\hat{M} \qquad [3]$$

where the circumflex accent denotes the rate of growth of the corresponding variable.

As is readily apparent, this expression is written in terms of output elasticities. However, the standard practice is to calculate technical progress by non-parametric techniques assuming the traditional Solow assumptions, i.e. that there are no fixed or external factors, that inputs are paid according to their marginal productivities, that markets are competitive, and that technology displays constant returns to scale. With these assumptions TFP growth is usually computed such as:

$$\tilde{\varepsilon}_{Y,t} = \hat{Y} - S_{Kp}\hat{Kp} - S_L\hat{L} - S_M\hat{M} \qquad [4]$$

where $S_{Kp} = \dfrac{P_{Kp}Kp}{C}$, $S_L = \dfrac{wL}{C}$ and $S_M = \dfrac{vM}{C}$ are the shares of private capital, labor and intermediate inputs in total cost, respectively. Notice that for convenience, we use shares in total cost rather than in output, given that both coincide under the "Solow assumptions". Additionally, no effect appears of public capital, given its nature as an external input. As is obvious, [4] is a good measure to calculate TFP growth only if the restrictive Solow assumptions are met, otherwise shares in total cost (or output) are not a good approximation of the relevant output elasticities.

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[2] The short-run variable cost minimization problem can be written as:

$$G(w,v,Kp,Kg,Y,t) = \min_{L,M}\{wL + vM \quad \text{s.t.} \quad F(L,M,Kp,Kg,t), \text{and } Kp, Kg \text{ given}\}$$

In what follows, we will show all the corrections to the cost shares that are necessary to take into account the effects of quasi-fixed and external inputs, so that we can transform these cost shares into the relevant output elasticities. To do so, first of all from the first order conditions of the cost minimization problem faced by the firm we get that the prices of the variable factors equal their respective marginal productivities multiplied by the marginal cost (*MgC*):

$$w = \frac{\partial F}{\partial L} MgC \qquad [5]$$

$$v = \frac{\partial F}{\partial M} MgC \qquad [6]$$

Second, using the envelope theorem we get that the shadow prices of the fixed and the external factors, Z_{Kp} and Z_{Kg}, equal also their marginal productivities times the marginal cost. These shadow prices are defined as the marginal contribution to the reduction of variable costs of these inputs:

$$Z_{Kp} \equiv -\frac{\partial G}{\partial Kp} = \frac{\partial F}{\partial Kp} MgC \qquad [7]$$

$$Z_{Kg} \equiv -\frac{\partial G}{\partial Kg} = \frac{\partial F}{\partial Kg} MgC \qquad [8]$$

Notice, that we can translate these shadow prices into shadow shares in total cost as:

$$S^*_{Kp} \equiv \frac{Z_{Kp} Kp}{C} \quad \text{and} \quad S^*_{Kg} \equiv \frac{Z_{Kg} Kg}{C} \qquad [9]$$

Finally, using expressions [5] to [9], we can compute the output elasticities with respect to the fixed and the variable inputs as[3]:

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[3] Notice that we are making use of the definition of the elasticity of total cost with respect to output, that is given by the ratio of marginal to average cost: $\varepsilon_{C,Y} \equiv \frac{\partial C}{\partial Y}\frac{Y}{C} = \frac{MgC}{C/Y}$.

$$\varepsilon_{Y,Kp} \equiv \frac{\partial F}{\partial Kp}\frac{Kp}{Y} = \frac{Z_{Kp}Kp}{C}\frac{C/Y}{MgC} \equiv \frac{S_{Kp}^{*}}{\varepsilon_{C,Y}} \qquad [10]$$

$$\varepsilon_{Y,Kg} \equiv \frac{\partial F}{\partial Kg}\frac{Kg}{Y} = \frac{Z_{Kg}Kg}{C}\frac{C/Y}{MgC} \equiv \frac{S_{Kg}^{*}}{\varepsilon_{C,Y}} \qquad [11]$$

$$\varepsilon_{Y,L} \equiv \frac{\partial F}{\partial L}\frac{L}{Y} = \frac{wL}{C}\frac{C/Y}{MgC} \equiv \frac{S_{L}}{\varepsilon_{C,Y}} \qquad [12]$$

$$\varepsilon_{Y,M} \equiv \frac{\partial F}{\partial M}\frac{M}{Y} = \frac{vM}{C}\frac{C/Y}{MgC} \equiv \frac{S_{M}}{\varepsilon_{C,Y}} \qquad [13]$$

If we now introduce the results in equations [10] to [13] into the definition of technical progress in equation [3], we get the first version of a corrected formula to compute TFP growth:

$$\varepsilon_{Y,t} = \hat{Y} - \frac{S_{Kp}^{*}}{\varepsilon_{C,Y}}\hat{Kp} - \frac{S_{Kg}^{*}}{\varepsilon_{C,Y}}\hat{Kg} - \frac{S_{L}}{\varepsilon_{C,Y}}\hat{L} - \frac{S_{M}}{\varepsilon_{C,Y}}\hat{M} \qquad [14]$$

As commented previously, Morrison and Schwartz (1996) derive also a corrected formula[4] to properly calculate technical change, which should be analogous to previous expression [14]. Nevertheless, their formula suffers from a conceptual error, as demonstrated by de la Fuente (1999), given that Morrison and Schwartz are deriving a formula to compute the rate of cost reduction induced by technical progress, instead of actually the corrected rate of TFP growth[5]. For this reason, our equation [14] follows de la Fuente (1999) in amending this inconsistency. The intuition behind this equation is straightforward, the shares in total cost of fixed or external factors have to be replaced by

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[4] Equation (2) in Morrison and Schwartz (1996), page 1099.

[5] As this author shows the rate of cost reduction induced by technical progress ($-\varepsilon_{C,t}$) is the product of the elasticity of total cost with respect to output and the true rate of technical progress (or TFP growth), i.e. $-\varepsilon_{C,t} = \varepsilon_{C,Y}\varepsilon_{Y,t}$. For this reason, when Morrison and Schwartz (1996) calculate in their equation (2) the "corrected rate of technological change" ($-\varepsilon_{C,t}^{T}$ in their notation) they are actually calculating the rate of cost reduction induced by technical progress ($-\varepsilon_{C,t}$ in our notation). So, their equation (2) to allegedly calculate the "corrected rate of technological change" looks like $-\varepsilon_{C,t}^{T} = \varepsilon_{C,Y}\hat{Y} - S_{Kp}^{*}\hat{Kp} - S_{Kg}^{*}\hat{Kg} - S_{L}\hat{L} - S_{M}\hat{M}$, which is clearly our equation [14] multiplied by $\varepsilon_{C,Y}$.

the shadow shares (see Berndt and Fuss, 1986), while the shares of variable inputs remain unchanged. In addition, all the relevant shares need to be further corrected using the elasticity of total cost with respect to output. Indeed, as we will show next, this elasticity may be capturing a mixture of the effects of returns to scale in production and the degree of capacity utilization. To see why this is the case, our first step consists in decomposing the short-run cost elasticity with respect to output into two parts, a returns to scale component and a subequilibrium component that captures the effects of fixed and external factors. Thus, from the definition of overall returns to scale in production ($\lambda \equiv \varepsilon_{Y,Kp} + \varepsilon_{Y,Kg} + \varepsilon_{Y,L} + \varepsilon_{Y,M}$), and using equations [10] to [13] it follows that:

$$\varepsilon_{C,Y} = \frac{S^*_{Kp} + S^*_{Kg} + S_L + S_M}{\lambda} \qquad [15]$$

Thus, effectively, the short-run cost elasticity with respect to output combines the effects of overall returns to scale in production and the existence of fixed and external factors[6]. Our next step consists in using results in Morrison (1986) to show that the numerator of equation [15] is the ratio between total shadow cost (C^*) and effective total cost (C), and that this ratio is one of the most widely used measures of economic capacity utilization in the literature[7]:

6 Our approach in previous equation [15] to decompose the short-run cost elasticity with respect to output follows again de la Fuente (1999), instead of Morrison and Schwartz (1996). Morrison and Schwartz use the following decomposition: $\varepsilon_{C,Y} = \varepsilon^L_{C,Y} - \varepsilon_{C,Kp}\varepsilon^L_{Kp,Y} - \varepsilon_{C,Kg}\varepsilon^L_{Kg,Y}$, where $\varepsilon^L_{C,Y}$ is the long-run cost elasticity with respect to output (the inverse of a measure of long-run returns to scale), $\varepsilon_{C,Kp}$ and $\varepsilon_{C,Kg}$ are the short-run cost elasticities with respect to *Kp* and *Kg*, and $\varepsilon^L_{Kp,Y}$ and $\varepsilon^L_{Kg,Y}$ are the long-run elasticities of the optimal demand for *Kp* and *Kg* with respect to output. Nevertheless, it is easy to show that both equations coincide under the assumption that $\varepsilon^L_{C,Y} = \varepsilon^L_{Kp,Y} = \varepsilon^L_{Kg,Y} = 1/\lambda$. In any case, to make this decomposition operative from an empirical point of view, one need to compute elasticities evaluated on the short-run cost curve (the one whose parameters will be estimated) and elasticities evaluated on the long-run cost curve (that which will not be estimated). So, we prefer to use the decomposition in equation [15], whose terms are directly computable from the parameter estimates of the short-run cost curve.

7 In Lee (1995), there is a review of the performance of different measures of economic capacity utilization. Other measures such as the ratio of optimal to observed private capital (Kp^*/Kp) have the disadvantage of considering only the effect of the fixed character of *Kp*, discarding the effects of, for example, external factors.

$$CU = \frac{C^*}{C} = \frac{Z_{Kp}Kp + Z_{Kg}Kg + wL + vM}{P_{Kp}Kp + wL + vM} = S^*_{Kp} + S^*_{Kg} + S_L + S_M \qquad [16]$$

Finally, to arrive to the final formula to compute TFP growth, we simply introduce [15] and [16] in [14] to get:

$$\varepsilon_{Y,t} = \hat{Y} - \lambda \frac{S^*_{Kp}}{CU}\hat{K}p - \lambda \frac{S^*_{Kg}}{CU}\hat{K}g - \lambda \frac{S_L}{CU}\hat{L} - \lambda \frac{S_M}{CU}\hat{M} \qquad [17]$$

The growth accounting formula in [17] departs from the formula in Morrison and Schwartz (1996), because it overcomes its conceptual shortcomings in the way proposed by de la Fuente (1999), and it departs from the final formula derived by this author in incorporating explicitly the effect of capacity utilization, isolated from the direct effects of the fixed and external factors in production. As can be seen, variable inputs shares need not be corrected, while the fixed and external factors relevant shares in total cost are the shadow shares. In addition, all the relevant shadow or real cost shares need to be further multiplied by total returns to scale and divided by a measure of economic capacity utilization, namely the ratio of shadow to effective total cost.

To adequately evaluate the biases in traditional growth accounting exercises our last step is to subtract the traditional Solow measure of TFP growth (equation [4]) from the corrected rate of technical change (equation [17]):

$$\varepsilon_{Y,t} - \tilde{\varepsilon}_{Y,t} = \left(S_{Kp} - \lambda \frac{S^*_{Kp}}{CU} \right)\hat{K}p - \lambda \frac{S^*_{Kg}}{CU}\hat{K}g + \left(S_L - \lambda \frac{S_L}{CU} \right)\hat{L} + \left(S_M - \lambda \frac{S_M}{CU} \right)\hat{M} \qquad [18]$$

The previous expression indicates that the omission of public capital in traditional growth accounting produces an overestimation of true technical progress (provided that public capital is productive, S^*_{Kg}>0, and infrastructures grow, $\hat{K}g$>0). The quasi-fixed input effect depends on whether it is insufficiently provided by private firms or not, $S_{Kp} \gtrless S^*_{Kp}$, and also on the compound effect of capacity utilization and overall returns to scale. Finally, variable inputs will tend to generate an underestimation of true technical progress if the ratio between overall returns and capacity utilization is less than one (provided that variable inputs grow, $\hat{L},\hat{M}>0$).

3. Data and empirical implementation.

The basic data for the seventeen Spanish regions are taken from the BD.MORES database (see Dabán et al., 1998). The level of regional disaggregation corresponds to NUTS2 in Eurostat nomenclature of statistical territorial units. This database allows us to assemble series of gross value added[8], gross earnings of private employees, numbers of employees, public and private capital stocks[9], user costs of private and public capital[10] and the necessary price indices for the period 1980-1993. The series of intermediate inputs and their price indices are taken from Díaz (1998), and are fully compatible with BD.MORES data. The output measure used in this paper is gross output, which results from adding intermediate inputs to gross value added.

Table 1 presents the growth rates of the main economic magnitudes for the private sector in the whole of the Spanish economy. The first column corresponds to gross output, which shows the cyclical pattern of the Spanish economy. Labor and intermediate inputs are clearly pro-cyclical, presenting average negative rates of growth from 1980 to 1985 and positive rates of growth from 1985 to 1991, the beginning of a new economic recession. Differences in growth rates among the productive factors are important. For the period as a whole, public capital displays the highest annual average growth rate (4.8%), followed by private capital (2.3%) and intermediate inputs (1.9%), whereas on average employment

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8 Gross value added includes production of goods and services at factor costs produced in the regions by the private productive sectors: agriculture (forestry and fishing), industry (mining, manufacturing, construction and utilities) and private services (commerce, transport, and communications, banking and other private services). Housing rents are excluded.

9 Private capital data refer to the net stock of capital held by the productive private sector. Thus, it neither includes the stock of residential buildings, nor the stock of productive infrastructures. Public capital data refer to the net stock of productive infrastructures. It comprises transportation networks, energy supply networks, water supply and sewage systems. These may be offered by government or government agencies, by regulated private or public enterprises, or by public or private organizations.

10 The user cost of private capital for a given region is computed as $P_{K_P}=\frac{q}{p}(r-\hat{q}+\delta)$, where q is the private capital investment deflator, p is the output deflator, r is a long run interest rate, δ is the private capital depreciation rate and $\hat{q}$ is the rate of growth of the investment deflator. The user cost of public capital is computed analogously, the interest rate being the average return to public debt.

remained almost constant. Nevertheless, it is clear that during the 1980-85 crisis, the growth rates of output and productive factors (with the exception of infrastructures) were very low, being even negative for employment and intermediate inputs. The economic expansion experienced in Spain from 1986 to 1991 is also apparent in the figures, the rates of growth of infrastructures in these years being quite noticeable.

Table 1. Rates of growth in the Spanish private sector.

Year	$\hat{Y}$	$\hat{Kp}$	$\hat{Kg}$	$\hat{L}$	$\hat{M}$
	[1]	[2]	[3]	[4]	[5]
1981	-2.988	2.050	1.611	-3.569	-5.498
1982	0.578	1.544	3.525	-1.615	0.270
1983	1.501	1.466	3.568	-1.029	1.199
1984	1.266	0.869	2.639	-3.133	0.664
1985	0.870	0.551	3.979	1.093	-0.871
1986	3.859	1.405	4.492	1.092	4.969
1987	5.686	2.482	4.471	4.096	5.978
1988	5.746	3.352	5.479	3.059	6.718
1989	5.449	4.287	7.430	2.719	6.685
1990	3.756	4.016	8.759	3.085	4.060
1991	2.052	3.709	7.598	0.337	2.334
1992	0.154	3.216	5.505	-2.358	0.261
1993	-1.555	1.412	2.838	-4.008	-2.103
Average	2.029	2.335	4.761	-0.018	1.897

Table 2 presents information about regional disparities using the same economic variables as analyzed before. Asturias is the region with the lowest rate of growth in output, employment and intermediate inputs. Madrid, on the other hand, displays high growth rates of output and all productive factors. Infrastructures have grown in all regions at a higher rate than private capital (with the exceptions of La Rioja and Navarre), showing the important investment effort carried out by Spanish central and local governments. Columns 6 and 7 show the relative position of each region in terms of the ratio of public to private capital and of public capital to output. It is obvious that there are again considerable disparities among the Spanish regions. La Rioja and Navarre are the regions with the highest ratio of public to private capital and, together with Castile-La Mancha, Castile and Leon, the Canary Islands, Asturias, Aragon, the Basque Country and Andalusia, are over the national average. On the other hand, it is worthwhile pointing out the low endowment of public capital in relation to both output and private capital in Madrid, Baleares, Catalonia, Murcia and Valencia. Finally, the last column of Table 2 shows the weight of the private sector of each region in Spanish total gross output. As we can see, only five regions produce 63% of the gross output of the private sector in Spain (Catalonia (20%), Madrid (13%), Andalusia (13%), Valencia (9%) and the Basque Country (8%)).

Table 2. Regional disparities in growth rates and other indicators.

Regions	$\hat{Y}$	$\hat{Kp}$	$\hat{Kg}$	$\hat{L}$	$\hat{M}$	Kg/Kp	Kg/Y	Y_i/Y
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**
Andalusia	2.004	2.277	7.583	0.053	1.770	0.172	0.181	0.129
Aragon	2.751	1.738	2.521	-0.154	2.995	0.193	0.224	0.036
Asturias	0.416	1.836	4.627	-1.424	0.257	0.202	0.181	0.034
Baleares	2.930	2.152	4.602	0.586	2.910	0.116	0.115	0.022
Canary Islands	2.638	2.757	3.667	0.558	2.507	0.210	0.211	0.031
Cantabria	1.926	1.231	6.037	-1.326	2.009	0.164	0.173	0.015
Castile and Leon	1.875	1.629	3.101	-1.058	1.955	0.229	0.260	0.067
Castile-La Mancha	1.673	2.298	4.507	-0.320	1.401	0.198	0.315	0.035
Catalonia	2.269	2.638	4.271	0.221	2.067	0.144	0.124	0.196
Valencia	1.771	2.937	5.643	0.411	1.889	0.167	0.158	0.093
Extremadura	2.889	1.647	4.938	-0.766	2.922	0.139	0.281	0.017
Galicia	1.602	2.160	3.952	-1.244	1.621	0.167	0.173	0.063
Madrid	2.566	3.602	5.914	1.303	2.235	0.119	0.083	0.134
Murcia	2.003	2.309	8.463	0.683	1.631	0.125	0.132	0.023
Navarre	2.394	2.820	2.452	0.308	2.620	0.269	0.220	0.019
The Basque Country	1.050	0.969	4.124	-0.390	0.985	0.184	0.168	0.075
La Rioja	2.256	2.656	0.127	-0.208	2.215	0.373	0.284	0.010
Average	2.060	2.215	4.502	-0.163	1.999	0.187	0.193	----

Note: 1980-1993 averages.

With respect to the empirical implementation, we have chosen a Generalized Leontief variable cost function to estimate the parameters needed to calculate the different elasticities, shadow shares and other measures necessary to compute the growth accounting formula developed in the preceding section. The specification of the Leontief function is the same as in Morrison (1988) which incorporates fixed inputs and does not impose the degree of returns to scale. It can be expressed as

$$G = Y\left[\sum_i\sum_j \alpha_{ij} P_i^{1/2} P_j^{1/2} + \sum_i\sum_m \delta_{im} P_i s_m^{1/2} + \sum_i P_i \sum_m\sum_n \gamma_{mn} s_m^{1/2} s_n^{1/2}\right] + \\ + Y^{1/2}\left[\sum_i\sum_k \delta_{ik} P_i x_k^{1/2} + \sum_i P_i \sum_m\sum_k \gamma_{mk} s_m^{1/2} x_k^{1/2}\right] + \sum_i P_i \sum_k\sum_l \gamma_{lk} x_k^{1/2} x_l^{1/2} \qquad [19]$$

where P_i and P_j denote the prices of variable inputs V_i (L and M), x_k and x_l are the quasi-fixed inputs (K_p and K_g); and s_m and s_n denote the remaining arguments (Y and t). Using Shephard's lemma, we get the two input demand equations for the variable inputs, $V_i = \frac{\partial G}{\partial P_i}$, which we will estimate jointly with the variable cost function [19]. Additionally, following Morrison and Schwartz[11] (1996), we add to the above system of three equations a fourth one that captures firms profit maximization behavior. This equation is a short-run pricing equation that equates the price of output to the marginal cost ($P_Y = \frac{\partial G}{\partial Y}$).

Estimation of the above system of four equations was carried out using annual data from 1980 to 1993 for the 17 Spanish regions. Seemingly unrelated regression (SUR) techniques were used for estimation, since the four equations share common parameters. As is standard practice in the literature, we imposed the cross-equation restrictions among the common parameters in the four equations. It has to be noticed that imposing the parameter restrictions between the variable cost equation and the short-run pricing equation is only valid in the case of inexistence of market power. Thus, imposing these parameter restrictions may not be justified. However, attempts to estimate the system without imposing these restrictions produced always economically unreasonable results. Some examples of why these estimates were meaningless are the following. First, these estimates imply a mark-up of around 25 per cent (which in terms of value added would imply a mark-up of around 45-50 per cent). Second, the shadow price of private capital estimated in this way would mean that there is an excess of around 25 per cent of existing private capital in the Spanish private sector. Third, we get a negative value of the shadow price of public infrastructure in all regions, implying that there is no scarcity of public infrastructure in Spain. Finally, estimating without imposing the cross equation restrictions we obtain a persistent pattern of under-utilization of capacity for the whole Spanish private sector. All these results seem clearly at odds with our understanding and beliefs about the behavior of the private sector in Spanish regions, so that we decided to include the pricing equation with the cross equation restrictions, as is standard practice in the literature, although econometrically this may not be justified.

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[11] In fact, we are using exactly the same estimating equations as these authors.

Following with specification issues, we also included two statistically significant regional dummies in the intercept of both variable input demand equations (and consequently in the corresponding coefficients of the variable cost and pricing equations) to pick up regional heterogeneity[12]. Additionally, as is common practice in the literature, we imposed the cross-equation restrictions that are derived from Shephard's lemma. The null hypothesis that labor and intermediate inputs are at their optimal demand levels, and consequently behave as variable inputs, was safely accepted at conventional statistical levels[13]. Additionally, we also performed another specification test, namely the Shankerman and Nadiri test[14]. This is a specific econometric test to investigate the divergence of quasi-fixed factors from their static equilibrium levels. The null hypothesis that private capital is close to its static equilibrium level (and consequently behaves as a variable input) was strongly rejected[15]. The conclusion is that the stock of private capital is not found at the optimal level, and therefore it must be considered when specifying the model as a quasi-fixed factor.

Overall, the fit of the four equations is high and the estimated coefficients are statistically significant, although the sign and magnitude of them has little intuitive value from an economic viewpoint given the complexity of the cost function used. For this reason, and to save space, we do not present parameter estimates. However, further technical details about the estimation can be found in Boscá, Escribá and Murgui (2002)[16].

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12 The first dummy takes the value one in Catalonia, Madrid, Valencia and Murcia and zero in the rest, and the second takes the value one in Castile-La Mancha, Extremadura, Castile and Leon, Navarre, Rioja and Cantabria and zero in the rest. These two groups have been chosen according to a mixture of two criteria. First, because regions in the first group display very low *Kg/Y* and *Kg/Kp* ratios compared to the national average. Second, because those regions in the first group hold considerable weight in the output of the Spanish private sector. The second set of regions follows the opposite pattern.

13 Concretely, the result of Shephard's lemma test is: $\chi^2(36) = 22.96$ (P-Value = 0.955). It should be noticed that the dummy variables included in the equations are very important in getting this result. In fact, if the model is estimated with none of these variables, the test rejects the null hypothesis (($\chi^2(32)=48.42$, P-Value = 0.031).

14 See Shankerman and Nadiri (1986).

15 The Schankerman and Nadiri test: χ^2 (10) = 8186.44 (P-Value = 0.00). This result is similar to the one which Moreno, López Bazo and Artís (1998 and 2002) obtained for the manufacturing branches in Spanish regions.

16 In this companion paper, we use the same specification to compute short-run output and cost measures of the effects of public infrastructure on private regional production. We also calculate long-run shadow prices of public capital and the long-run optimal private capital stock across Spanish regions.

4. The results.

To start our analysis, we present in Table 3 the standard growth accounting exercise (equation [4]) performed under the traditional Solow assumptions. The decomposition of the sources of gross private output growth at the regional level is shown in the top panel. The average annual growth rate of output across regions over the 1980-93 period was 2.06 percentage points. From these, labor explains -0.055 points (-2.7%), while intermediate inputs account for 0.973 points (47.2%) and private capital for 0.294 (14.3%). Thus, the Solow residual amounts to 0.858 percentage points, indicating that the measure of our ignorance represents approximately 41-42% of average annual output growth. The pattern across regions is not very different to the average, although there are some noticeable regional disparities. The regions with higher TFP growth are Extremadura, Cantabria, Castile and Leon, Aragon, Galicia and Baleares, which are regions with little weight in Spanish private production, while other regions with more weight, such as Valencia, Madrid or the Basque Country, display rates of TFP growth below the average[17]. The contribution of labor to the explanation of output growth is negative in the nine regions where labor actually decreased over the sample period. Thus, in general, the regions with positive labor growth rates have a lower residual or, in other words, TFP growth explains a smaller portion of output growth. With respect to the contribution of intermediate inputs and private capital, the differences across regions are mainly motivated by the differences in growth rates across regions shown in Table 2.

[17] Notice that many of the regions where TFP growth rates are higher than the national averages are also poor regions. A tentative explanation of this result may be that there is an ongoing process of technological catching-up and, thus, of convergence among the Spanish regions.

Table 3. Growth accounting exercise: Solow assumptions.

	$\hat{Y}$	$S_L \hat{L}$	$S_M \hat{M}$	$S_{Kp} \hat{K}p$	$\tilde{\varepsilon}_{Y,t}$
Region	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**
Andalusia	2.004	0.020	0.864	0.299	0.834
Aragon	2.751	-0.056	1.463	0.253	1.091
Asturias	0.416	-0.526	0.132	0.215	0.613
Baleares	2.930	0.237	1.318	0.308	1.071
Canary Islands	2.638	0.221	1.176	0.372	0.841
Cantabria	1.926	-0.486	1.001	0.166	1.238
Castile and Leon	1.875	-0.393	0.954	0.230	1.108
Castile-La Mancha	1.673	-0.115	0.637	0.425	0.828
Catalonia	2.269	0.085	1.021	0.321	0.879
Valencia	1.771	0.156	0.927	0.381	0.346
Extremadura	2.889	-0.290	1.198	0.349	1.604
Galicia	1.602	-0.492	0.775	0.272	1.076
Madrid	2.566	0.551	1.053	0.381	0.586
Murcia	2.003	0.249	0.827	0.298	0.639
Navarre	2.394	0.109	1.400	0.321	0.537
The Basque Country	1.050	-0.143	0.499	0.122	0.587
La Rioja	2.256	-0.065	1.295	0.278	0.712
Regional average	**2.060**	**-0.055**	**0.973**	**0.294**	**0.858**
Year	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**
1981	-2.988	-1.391	-2.837	0.193	1.047
1982	0.578	-0.606	0.137	0.180	0.867
1983	1.501	-0.386	0.623	0.154	1.110
1984	1.266	-1.086	0.340	0.123	1.889
1985	0.870	0.388	-0.450	0.071	0.860
1986	3.859	0.409	2.405	0.198	0.847
1987	5.686	1.517	2.793	0.404	0.973
1988	5.746	1.167	3.217	0.468	0.894
1989	5.449	1.017	3.181	0.644	0.607
1990	3.756	1.168	1.876	0.640	0.072
1991	2.052	0.132	1.071	0.555	0.294
1992	0.154	-0.923	0.117	0.517	0.443
1993	-1.555	-1.638	-0.970	0.184	0.871
Spain average	**2.029**	**-0.018**	**0.885**	**0.333**	**0.829**

Turning now to the lower panel in Table 3, we can appreciate that for the whole of the Spanish private sector[18], average annual TFP growth amounts to 0.829 points, roughly 41% of output growth, which averages 2.029% per annum. The relative contribution of the different inputs is also very similar to the pattern found for the simple non-weighted averages in the upper panel (labor and intermediate inputs explain somewhat less and

[18] When we refer to Spain the implied variables correspond to the aggregate of the private sector and not to the average value across regions.

private capital somewhat more of output growth). The time evolution of TFP growth does not show cyclical behavior[19], although the contribution of the three productive factors clearly reflects the business cycle of the economy.

As extensively discussed in the theoretical section, the previous growth accounting exercise may be biased due to the existence of quasi-fixed and external factors in production, which may lead firms to produce away from the minimum of the average cost curve. In other words, if traditional Solow assumptions are not satisfied, factor shares in total cost need to be corrected to recognize the quasi-fixed or external character of some inputs and to take into account the degree of returns in production and the degree of economic capacity utilization. To get a general picture of the magnitude of these effects, in Table 4 we present the growth accounting exercise according to the corrected TFP growth formula in equation [17].

The first interesting result is that independently of looking at the regional averages (top panel) or at the aggregate of the Spanish private sector (lower panel), the Solow average annual estimate of TFP growth overestimates (around 10-15%) the corrected rate[20]. This result is also common to the majority of the Spanish regions, the only exceptions being Andalusia, Canary Islands, Castile and Leon and Navarre. What are at first sight the reasons for this overestimation of technical progress? Of course, the first candidate to explain this result is the omission of public capital in the Solow formula. This suspicion is guaranteed given that previous empirical contributions for the Spanish case based on the dual approach (see Moreno et al., 2002, or Boscá et al., 2002) have always obtained significant positive shadow values of public infrastructure.

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[19] Apparently TFP growth presents lower values at the end of the sample period (mainly from 1989 to 1992). Nevertheless, it would be desirable to have a longer time span to confirm a productivity slowdown.

[20] The Solow estimates are 0.858 and 0.829 (regional average and Spain, respectively), while the corrected average annual rates of TFP growth are 0.744 and 0.748.

Table 4. Corrected growth accounting exercise.

	$\hat{Y}$	$\lambda \frac{S_L}{CU} \hat{L}$	$\lambda \frac{S_M}{CU} \hat{M}$	$\lambda \frac{S^*_{Kp}}{CU} \hat{Kp}$	$\lambda \frac{S^*_{Kg}}{CU} \hat{Kg}$	$\varepsilon_{Y,t}$
Region	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Andalusia	2.004	0.019	0.810	0.376	-0.009	0.869
Aragon	2.751	-0.055	1.433	0.190	0.134	1.070
Asturias	0.416	-0.520	0.129	0.174	0.181	0.463
Baleares	2.930	0.206	1.143	0.028	0.493	1.038
Canary Islands	2.638	0.207	1.099	0.335	0.146	0.882
Cantabria	1.926	-0.452	0.929	0.056	0.499	0.971
Castile and Leon	1.875	-0.370	0.897	0.265	-0.029	1.124
Castile-La Mancha	1.673	-0.119	0.657	0.329	0.223	0.705
Catalonia	2.269	0.082	0.982	0.437	0.020	0.760
Valencia	1.771	0.148	0.878	0.412	0.132	0.201
Extremadura	2.889	-0.333	1.377	0.031	0.766	1.235
Galicia	1.602	-0.481	0.759	0.237	0.194	0.909
Madrid	2.566	0.489	0.933	0.384	0.192	0.550
Murcia	2.003	0.237	0.788	0.098	0.854	0.067
Navarre	2.394	0.099	1.272	0.387	0.031	0.607
The Basque Country	1.050	-0.133	0.463	0.128	0.088	0.508
La Rioja	2.256	-0.058	1.160	0.433	-0.006	0.695
Regional average	**2.060**	**-0.061**	**0.924**	**0.253**	**0.230**	**0.744**
Year	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
1981	-2.988	-1.304	-2.660	0.148	0.090	0.738
1982	0.578	-0.578	0.131	0.126	0.202	0.697
1983	1.501	-0.360	0.581	0.133	0.204	0.942
1984	1.266	-1.030	0.323	0.089	0.150	1.735
1985	0.870	0.359	-0.415	0.062	0.213	0.652
1986	3.859	0.385	2.261	0.153	0.212	0.848
1987	5.686	1.452	2.674	0.279	0.189	1.092
1988	5.746	1.081	2.980	0.383	0.220	1.082
1989	5.449	0.951	2.975	0.516	0.267	0.739
1990	3.756	1.109	1.781	0.502	0.278	0.086
1991	2.052	0.124	1.009	0.482	0.211	0.226
1992	0.154	-0.877	0.111	0.431	0.149	0.340
1993	-1.555	-1.488	-0.882	0.195	0.077	0.544
Spain average	**2.029**	**-0.014**	**0.836**	**0.269**	**0.189**	**0.748**

Thus, given that our empirical estimations confirm that public capital is a productive factor, i. e., in terms of cost performance it displays a significant positive shadow price (Z_{Kg}>0), the accumulation of infrastructures explains 0.230 percentage points[21] of output growth that are not considered under the Solow assumptions. This means

[21] 0.189 points in the case of Spanish aggregate private production.

that infrastructures explain approximately 10-11% of observed output growth in the average region, although there are some noticeable regional disparities. For example, in the four regions where the corrected rate of technical change is higher than the Solow estimate, infrastructures explain less than 5% of output growth[22]. On the other hand, there are other regions where this percentage reaches values between 25 and 40%, as is the case in Asturias, Murcia, Extremadura or Cantabria. Thus, it is not surprising that precisely in these regions the Solow average annual estimate of TFP growth overestimates more severely the corrected rate than in other regions. Nevertheless, for the whole of the Spanish private sector the overestimation of technical progress due to the effect of infrastructures is partially outweighed by the effects of private capital and intermediate inputs, as we will show further below.

If we turn our attention now to the time profile of TFP growth, comparison of the last columns in the bottom panels of Tables 3 and 4 shows that in economic expansions the "Solow" estimate of TFP growth underestimates true technological progress, while in recession times the opposite is true[23]. This is confirmed looking at Figure 1, where we have depicted the corrected rate of technical change, $\varepsilon_{Y,t}$, the Solow estimate of TFP growth, $\widetilde{\varepsilon}_{Y,t}$, and the difference between both, $\varepsilon_{Y,t} - \widetilde{\varepsilon}_{Y,t}$. In the rest of this section, we are going to investigate in depth the reasons behind this result. To do so, our starting point consists of looking at equation [18], which shows all the potential biases to traditional productivity measurement we derived in the theoretical section.

Given that along the sample period the rates of growth of all productive factors have been generally positive[24], the sign of the total bias depends on the differences between the observed cost shares and the corrected shares. To have an idea of the extent of these differences, in Figure 2 we have represented observed and corrected cost shares of the four inputs.

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22 In general, we get positive shadow values of public capital (Z_{Kg}>0) for the Spanish regions. Nevertheless, there are three cases, Andalusia, Castile and Leon and La Rioja, where we obtain a theoretically implausible, although quite low, negative value. Thus, in these regions the contribution of infrastructures to the explanation of output growth is negative, although quite low (ranging between -0.2 and –1.5 per cent of output growth).

23 This pattern is also common to the majority of the Spanish regions, although we do not present these results to save space.

24 Except intermediate inputs that decreased in 1981, 1985 and 1993 and labor that decreased from 1981 to 1984 and from 1992 to 1993.

Figure 1: Estimates of TFP growth.
Spain 1980-1993

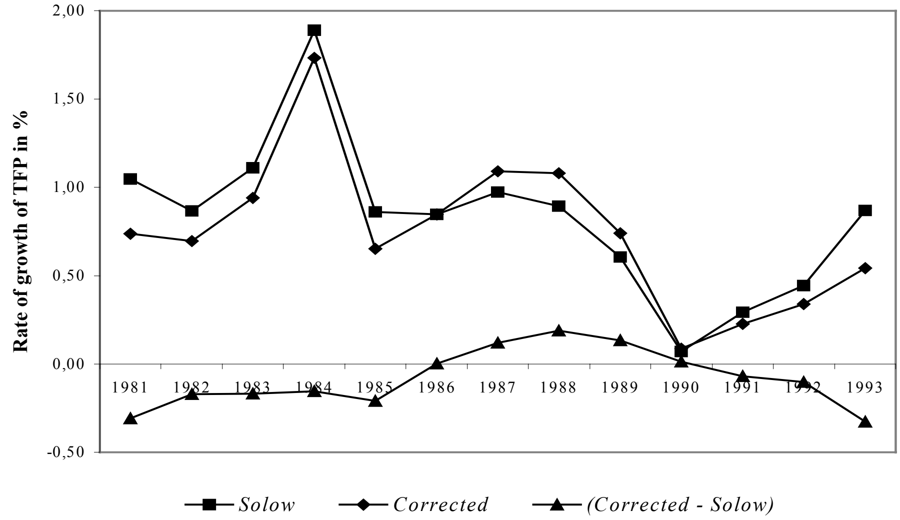
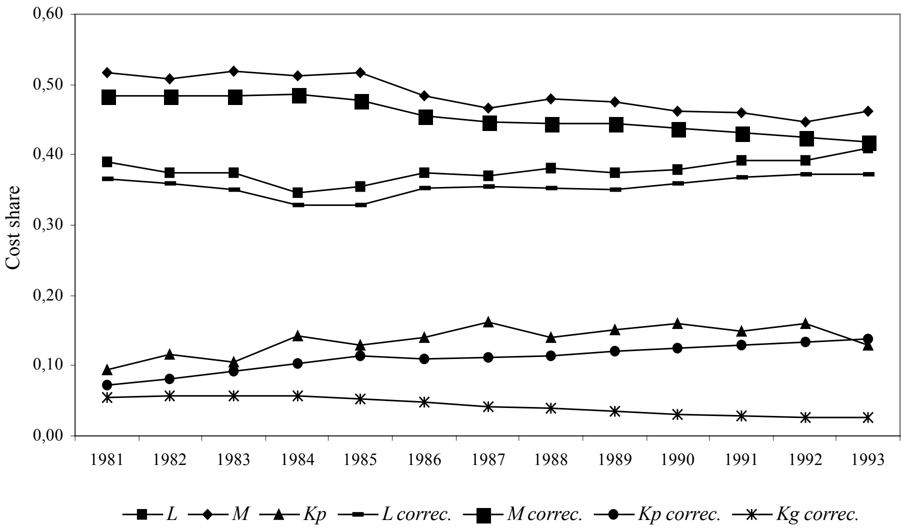


Figure 2: Observed and corrected factor shares in total cost.
Spain 1980-1993



Two interesting results emerge. First, the omission of public capital in traditional growth accounting produces an overestimation of true technical progress ($\tilde{\varepsilon}_{Y,t} > \varepsilon_{Y,t}$), given that, as already commented in previous paragraphs, our results imply that infrastructures are productive, S^*_{Kg}>0. In addition, the corrected share, $\lambda \dfrac{S^*_{Kg}}{CU}$, shows a clear decreasing trend from 1985 onwards that clearly reflects the important investment efforts carried out by the Spanish government to alleviate the endemic scarcity of productive infrastructures of the Spanish economy. This is so, because, as extensively discussed in Boscá et al. (2002), the important amounts of public infrastructure provided by the Spanish government in the eighties, have produced a steady reduction in the shadow price of public capital (Z_{Kg}) and, thus, in its shadow share (S^*_{Kg}).

Second, as Figure 2 clearly shows, observed cost shares are persistently higher than the corrected shares in the case of the three privately owned factors, so that the sign of the three terms in parenthesis in expression [18] is positive. However, this pattern for the aggregated private sector in Spain presents differences at the regional level that are worth mentioning. In the cases of labor and intermediate inputs, the sign of the difference between observed and corrected cost shares is also positive in all regions except Castile-La Mancha and Extremadura, which are the only regions that display elasticities of total cost to output lower than one[25]. In the case of private capital the sign depends both on the value of the elasticity of total cost to output and the difference between observed and shadow cost shares of private capital, $\left(S_{Kp} - \frac{S^*_{Kp}}{\varepsilon_{C,Y}} \right)$. At the regional level, our results indicate that the sign of the parenthesis is negative in the eight regions where $S_{Kp} < S^*_{Kp}$, i.e., in those regions where there exists a shortage of private capital, and is positive in the remaining nine regions. It should be pointed out that the eight regions where observed capital has been on average below the optimal one represent more than 70 per cent of total private production in Spain[26]. This implies that the sign of the difference between observed and shadow shares of private capital in total cost, $\left(S_{Kp} - S^*_{Kp}\right)$, is negative for the whole of the

[25] Recall from the theoretical section that $\varepsilon_{C,Y} = \frac{CU}{\lambda}$, so that the differences between observed and corrected shares of labor, $\left(S_L - \frac{S_L}{\varepsilon_{C,Y}} \right)$, and intermediate inputs, $\left(S_M - \frac{S_M}{\varepsilon_{C,Y}} \right)$, depend only on the value of the elasticity of total cost to output, $\varepsilon_{C,Y}$.

[26] Among these Andalusia, Catalonia, Valencia, Madrid, and the Basque Country represent approximately 63 per cent of total Spanish private production.

private sector[27]. However, given that $\varepsilon_{C,Y}$ is bigger than one in 15 out of the 17 Spanish regions, the sign of $\left(S_{Kp} - \frac{S^*_{Kp}}{\varepsilon_{C,Y}} \right)$ for Spain as a whole is positive.

Turning again to the aggregate results for Spain, the evidence in Figure 2 implies that the compound effect of the three private provided inputs tends to underestimate true technological progress ($\tilde{\varepsilon}_{Y,t} < \varepsilon_{Y,t}$), offsetting, although only partially, the effect of publicly provided infrastructures. The explanation for this result is straightforward if we take into account that, for the whole of the Spanish private sector, firms are producing over the minimum of the short-run cost curve, i.e., with an average elasticity of total cost to output greater than one ($\varepsilon_{C,Y} = 1.065$). To shed further light onto the economic reasons behind these findings, in Table 5 we present the evolution of the short-run elasticity of total cost to output ($\varepsilon_{C,Y}$) and its decomposition into capacity utilization (*CU*) and overall returns to scale (λ).

Table 5. $\varepsilon_{C,Y}$, *CU* and λ in the Spanish private sector.

Year	$\varepsilon_{C,Y}$	*CU*	λ
	[1]	[2]	[3]
1981	1.067	1.041	0.976
1982	1.048	1.029	0.982
1983	1.072	1.053	0.983
1984	1.054	1.024	0.972
1985	1.082	1.051	0.971
1986	1.063	1.033	0.971
1987	1.045	1.011	0.968
1988	1.080	1.041	0.964
1989	1.069	1.031	0.965
1990	1.054	1.023	0.971
1991	1.062	1.036	0.976
1992	1.052	1.030	0.979
1993	1.101	1.077	0.978
Average	**1.065**	**1.037**	**0.974**

[27] In fact, looking at Spain as a whole, there are no remarkable discrepancies between optimal and observed capital stock from 1980 to 1988, although from 1988 to the end of the sample period there is persistent over-utilization of private capital.

The estimates of our economic capacity utilization measure show a persistent pattern along the sample period towards over-utilization of quasi-fixed and external inputs (*CU*=1.037), that is also common to all regions, with the only exception of Extremadura (*CU*=0.94) and Baleares (*CU*=1.00). In other words, firms would have benefited (would have reduced production costs) from additional investment efforts in both public and private capital. In terms of the growth accounting exercise, this means that over-utilization of economic capacity generates a downward bias in the computed rate of technical progress if it is not taken into account. Additionally, our results show that slightly decreasing overall returns to scale (λ=0.974) are prevalent in the Spanish private productive sector[28]. Any tendency towards decreasing returns implies that in a standard growth accounting exercise TFP growth would be biased downwards, because we would have (incorrectly) attributed part of the residual to factor accumulation.

Summing up, the general picture that emerges from our analysis in the previous paragraphs is that firms in the Spanish private sector have operated in the majority of the regions under slightly decreasing overall returns to scale. In addition, our results indicate that both public and private capital display positive shadow values, that jointly imply that shadow costs (C^*) are higher than observed costs (C) and, thus, that there has been over-utilization of economic capacity (*CU*>1). The results also indicate that the public sector has contributed significantly to enhancing productivity and reducing costs in the private productive sector of almost every Spanish region. Nevertheless, there is still scope for the government to continue its investment efforts, given that there remains an appreciable gap between observed and optimal public capital[29]. To our knowledge of the Spanish economy this picture seems quite reasonable, confirming our prior beliefs about the Spanish private productive sector.

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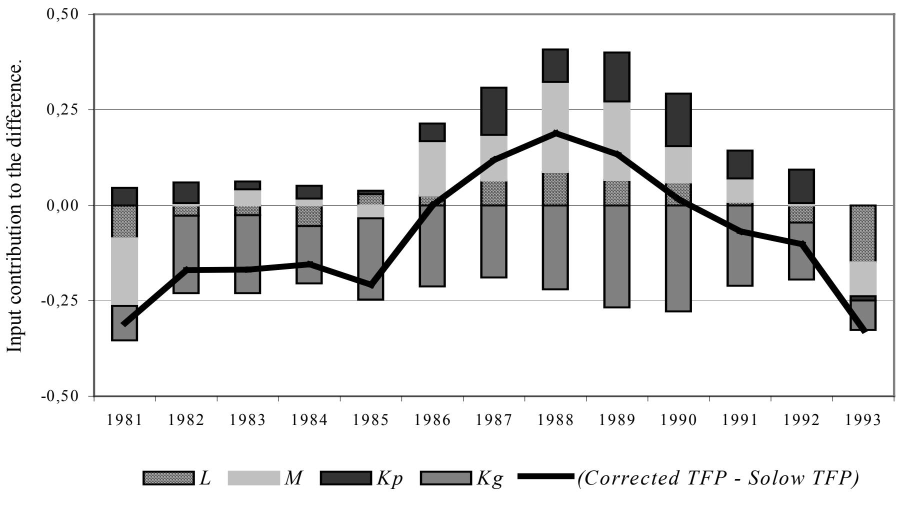
[28] Again there are some regional departures from this average pattern. Concretely, Extremadura and Castile-La Mancha present slightly increasing overall returns (1.08 and 1.03, respectively) and Aragon, Asturias, Catalonia, Valencia and Galicia present almost constant returns to scale. In any case, although we are talking about slightly decreasing overall returns to scale for the whole of the Spanish private sector, these may not differ statistically from constant returns. This is coherent with previous findings in some papers applied to the Spanish economy (see, for example, Goerlich and Orts, 1996) that can not reject the hypothesis of overall constant returns.

[29] In other words, although S^*_{Kg} displays a decreasing trend, indicating that the gap between observed and optimal public capital has narrowed, it is still far from a zero value that would indicate an optimal provision of public infrastructures.

The translation of these findings to the measurement of TFP growth indicates that on average the Solow estimate of technical progress overestimates the true rate of TFP growth, due to the fact that infrastructures are not taken into account. The upward bias generated by the omission of public capital is partially outweighed by the effects of privately owned inputs that tend to explain a bigger portion of output growth in the traditional computation of TFP growth, than they actually explain when correctly measured. This has to do with the existence of slightly decreasing overall returns to scale and with over-utilization of economic capacity. Additionally, as already commented previously, along the business cycle the contribution of the inputs to explaining the biases in traditional growth accounting varies in a systematic way[30]. In Figure 3, we have depicted the difference between the corrected rate of technical change and the Solow estimate, $\varepsilon_{Y,t} - \tilde{\varepsilon}_{Y,t}$, and the contribution of each of the four inputs to explaining this difference (i. e., we are depicting the different terms on both sides of equation [18]).

Figure 3: Explaining the differences between corrected and Solow TFP growth measures.



In economic recessions (1981-85 and 1992-93), the "Solow" estimate of TFP growth overestimates true technological progress, while in expansion times (1986-91) the

30 Although there is clear evidence of cyclical behavior along our sample period, these results need to be taken with caution. As rightly argued by an anonymous referee, the length of the time series may be too short to say much that is meaningful about these effects. Thus, it would be desirable to have more data points to confirm our findings.

opposite is true. The reason for this behavior is straightforward. For example, in the economic recession experienced from 1981 to 1985 the privately owned inputs either grew quite slowly (*Kp* and *M*) or decreased (*L*) with output, so that the Solow estimate of TFP growth is greater than the corrected rate, because the omission of infrastructures in the computation of the Solow residual is not compensated by the higher weight given to these inputs in traditional accounting (i.e., by the fact that the observed cost shares are bigger than the corrected shares).

In economic expansions (1986-90), the opposite is true. The Solow residual is smaller than the corrected one, because private inputs grew at high rates, so that the compound effect of these three inputs more than compensates the omission of public capital in traditional growth accounting. One important result of this exercise is that the average upward bias in the traditional growth accounting exercise survives in the business cycle. Although economic expansions in the Spanish private productive sector generate a Solow residual that underestimates true technical progress, in times of recession the Solow residual overestimates technical change, so that along an entire business cycle the average bias is positive. The magnitude of the bias is important if we take into account that the average annual growth rate of output across regions over the 1980-93 period was 2.029 percentage points (see the last row in Table 4). Of these, public capital explains 0.189 points (9.3%) which are not considered in a traditional growth accounting exercise. On the other hand, the three private inputs explain jointly 1.091 points (55.1%) when correctly measured, while under the Solow assumptions they explain 1.20 points (59.1%). Thus, the rate of TFP growth is reduced from 0.829 to 0.748 percentage points, after performing all the necessary corrections due to the presence of quasi-fixed and external inputs into production.

5. Conclusions.

The aim of this paper has been to evaluate empirically the relevance of the presence of quasi-fixed and external inputs, non-constant returns to scale, and the degree of capacity utilization in the calculation of TFP growth for the private productive sector of Spanish regions over the 1980-1993 period. Using a parametric framework based on the estimation of a generalized Leontief cost function, we have applied the corrected growth accounting formula derived in the second section to evaluate the error biases in traditional growth accounting exercises.

The first interesting result is that independently of whether we look at the regional averages or at the aggregate of the Spanish private sector, the Solow average annual estimate of TFP growth overestimates (around 10-15%) the corrected rate. The omission of public capital in traditional growth accounting produces an overestimation of true technical progress, given that our results imply that infrastructures have a cost reducing effect on private production and, thus, are productive. For the whole of the Spanish private sector, the effect of the three privately provided inputs tends to underestimate true technological progress offsetting, although only partially, the effect of publicly provided infrastructures. The explanation of this result is straightforward if we take into account that our results imply that firms are producing over the minimum of the short-run cost curve, i.e., with an average elasticity of total cost to output greater than one. In fact, we have shown that the short-run elasticity of total cost to output can be decomposed into a capacity utilization measure and an overall returns to scale measure.

Our estimates of the economic capacity utilization measure show a persistent pattern over the sample period towards over-utilization of quasi-fixed and external inputs. In terms of the growth accounting exercise, this means that over-utilization of economic capacity generates a downward bias in the computed rate of technical progress if it is not taken into account. Additionally, our results show that slightly decreasing overall returns to scale are prevalent in the Spanish private productive sector. Any tendency towards decreasing returns implies that in a standard growth accounting exercise TFP growth would be biased downwards, because we would have (incorrectly) attributed part of the residual to factor accumulation.

Finally, we have shown that the positive bias generated by the traditional Solow growth accounting exercise survives in the business cycle. Although economic expansions in the Spanish private productive sector generate a Solow residual that underestimates true technical progress, in times of recession the Solow residual overestimates technical change, so that along an entire business cycle the average bias is positive. This result is also common to the majority of the Spanish regions, as is the fact that on average almost all of them have over-utilized installed capacity.

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