Total factor productivity in the G7 countries: a short note

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The analysis of the composition of economic growth in the G7 countries has been motivated by the desire to identify regularities that contribute to explaining economic success. Such analysis must be carried out with a long term perspective, and the relevant production function should reflect existing world technology and not just domestic conditions. Moreover, in order to assess the relative performance of each country, economic growth should be broken down such that total factor productivity (TFP) is not determined as a mere residual. The seminal papers in modern economic growth literature are those of Solow (1956), Romer (1986, 1990) and Lucas (1988). The empirical research literature in this area consists of two different strands. One strand decomposes economic growth in a given economy on the basis of factor accumulation and total factor productivity. The other uses cross-country regressions, with a multitude of explanatory variables. In the last few years, progress in computation methods has facilitated the use of Bayesian statistical methods in economic research. Nevertheless, the utilisation of Bayesian inference techniques in growth accounting is still very limited. The exceptions are the initial contributions of Koop, Osiewalski and Steel (1999, 2000), on which we rely heavily throughout this paper. In this paper we use Bayesian stochastic production frontiers in a growth accounting exercise for the period 1960/2005, assuming a dynamic translog production function and using data on 21 OECD economies. The results provide information on the contribution of inputs to GDP growth, on capital and labour elasticities and on TFP contribution. Furthermore, TFP is broken down into technological change (TC) and degree of efficiency. Intuitively, these components represent two different aspects. TC corresponds in general to more *efficient* production techniques. Improvements in efficiency correspond to better institutional and organisational arrangements, ie the more *efficient* use of the current level of inputs and technology. However, in practice it is often difficult to establish a clear distinction as TC and efficiency interact. Thus, not surprisingly, although the statistical method used provided contributions for both components, the degree of precision is smaller than the one associated with the computation of total TFP. In addition, it should be noted that, although it uses less conventional methods, this paper is still a growth accounting exercise. Thus, it does not reveal economic causation channels.

The stochastic frontier approach

Before presenting the model, it is important to discuss some methodological issues. Firstly, contrary to most of the traditional empirical growth accounting exercises, GDP growth decomposition is jointly and simultaneously computed for several economies, under the

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assumption that there is an international production function (IPF). Conceptually, this means that all countries have access to the same technology, implying that if two countries have equal labour and capital endowments the one with higher GDP is more efficient, ie closer to the stochastic IPF. The speed of international dissemination of TC and its implications in terms of growth theory are discussed by Basu and Weil (1998). They argue that the dissemination of TC in production systems occurs at a slower pace than the diffusion of knowledge. In the OECD countries, knowledge diffusion should occur at a very fast pace, generating a common set of potentially available production technologies. Therefore, the time that elapses until a country effectively adopts the technological innovations in its production systems becomes reflected in its relative production efficiency. In addition, if a TC is potentially available for all, the IPF expands over time in some way. We simply assumed that TC evolves according to a linear trend during each period considered. The analysis focuses on eight 11-year periods (10 annual growth rates), for which stochastic production frontiers were computed. The length of the periods is enough to encompass the average duration of economic cycles, thus averaging out cyclical effects on the macroeconomic variables considered. All results of the growth accounting exercise are presented in terms of 10-year average growth rates or contributions. The partition of the sample in sub-periods is necessary because of the assumption on the dynamics of TC. In fact, it does not seem reasonable to assume that technology evolves linearly throughout several decades. Regarding the production function specification, a translog formulation was used. This formulation includes as a special case the (log)Cobb-Douglas production function, though it is much more flexible than the latter. Temple (2006) argues that the assumption of a Cobb-Douglas specification may lead to spurious results in economical and statistical terms. Traditional growth accounting exercises treat TFP as unobservable (omitted variable), limiting specification testing. In fact, if the researcher had identified a good proxy for TFP and the data were actually generated by a translog, a suitably specified regression would accurately recover the parameters of that translog production function, and reject the Cobb-Douglas specification. Classical econometrics allows for the estimation of stochastic production functions, namely through maximum likelihood methods, but relies on asymptotic inference, which may not be supported by relatively small samples. We opted to use Bayesian methods as they have the relative advantage of allowing inferences even when samples are small. Moreover, Bayesian methods make it possible to rationally combine observed data with economically meaningful priors. In practical terms, for each parameter in the model, observed data and initial assumptions (priors) generate a posterior distribution function. The posterior distribution functions of all parameters are derived simultaneously, leading to the posterior distribution function of GDP growth components. The prior for the posterior distribution function of the efficiency parameter is an asymmetric positive distribution. The rationale behind this assumption is twofold. Firstly, this parameter measures the distance to the production frontier, so it should not be negative. Secondly, there is a smaller probability of finding observations as we move further towards the production frontier. This assumption is common in the literature. As to the specification of the distributions, given its relative advantages, we chose a normal-gamma model (normal distribution of the residual component and gamma distribution for the efficiency component).

The model

The model considered for the growth accounting exercise follows Koop, Osiewalski and Steel (1999). The GDP is defined by:

$$Y_{ti} = f_t\,(K_{ti}, L_{ti})\,\tau_{ti} w_{ti} \qquad (1)$$

where Y_{ti}, K_{ti} and L_{ti} denote the real output, the capital stock and labour in period t ($t = 1, \ldots, T$) in country i ($i = 1, \ldots, N$), respectively. Furthermore, τ_{ti} ($0 < \tau_{ti} \leqslant 1$) is the efficiency parameter and w_{ti} represents the measurement error in the identification of the frontier or the stochastic nature of the frontier itself.

As mentioned above, the basic model assumes a flexible translog production function:

$$y_{ti} = x_{ti}^{\prime}\beta_t + v_{ti} - u_{ti} \tag{2}$$

where:

$$x_{ti}^{\prime} = \left(1, k_{ti}, l_{ti}, k_{ti}l_{ti}, k_{ti}^2, l_{ti}^2\right) \tag{3}$$

$$\beta_t = (\beta_{t1}, \ldots, \beta_{t6})^{\prime} \tag{4}$$

and lower case letters indicate natural logs of upper case letters. The logarithm of the measurement error v_{ti} is *iid* $N(0, \sigma_t^2)$ and the logarithm of the efficiency parameter is one sided to ensure that $\tau_{ti} = \exp(-u_{ti})$ lies between zero and one. The prior for u_{ti} is taken to be a gamma function with a time specific mean λ_t. The contribution of input endowment, technology change and efficiency change to GDP growth is defined in a fairly simple way. The GDP growth rate in country i in period $t + 1$ can be written as:

$$y_{t+1,i} - y_{t,i} = \left(x_{t+1,i}^{\prime}\beta_{t+1} - x_{t,i}^{\prime}\beta_t\right) + \left(u_{t,i} - u_{t+1,i}\right) \tag{5}$$

where the first term includes TC and factor accumulation and the second term represents efficiency change. The first term can be further decomposed as:

$$\frac{1}{2}\left(x_{t+1,i} + x_{ti}\right)^{\prime}\left(\beta_{t+1} - \beta_t\right) + \frac{1}{2}\left(\beta_{t+1} + \beta_t\right)^{\prime}\left(x_{t+1,i} - x_{ti}\right) \tag{6}$$

The technical change for a given level of inputs results from the first term of the previous eqnarray and is defined as:

$$TC_{t+1,i} = \exp\left[\frac{1}{2}\left(x_{t+1,i} + x_{ti}\right)^{\prime}\left(\beta_{t+1} - \beta_t\right)\right] \tag{7}$$

and the input change defined as the geometric average of two pure input change effects, relatively to the frontiers successive periods:

$$IC_{t+1,i} = \exp\left[\frac{1}{2}\left(\beta_{t+1} + \beta_t\right)^{\prime}\left(x_{t+1,i} - x_{ti}\right)\right] \tag{8}$$

The efficiency change is defined as:

$$EC_{t+1,i} = \exp(u_{ti} - u_{t+1,i}) = \frac{\tau_{t+1,i}}{\tau_{t,i}} \tag{9}$$

Ten-year geometric averages are computed for each of these growth components. As mentioned above, we assumed that TC evolves linearly in each decade. Therefore we adopted the following formulation:

$$\beta_t = \beta^{*} + t\beta^{**} \tag{10}$$

and

$$\sigma_t^2 = \ldots = \sigma_T^2 = \sigma^2 \tag{11}$$

Thus the model can be written as:

$$y = X^*\beta - u + v \tag{12}$$

with

$$y = \left(y_1' \ldots y_T'\right), u = \left(u_1' \ldots u_T'\right), v = (v_1 \ldots v_T)', \beta = \left(\beta^{*\prime}\beta^{**\prime}\right)' \tag{13}$$

where β is a 12 × 1 vector and:

$$X^* = \begin{bmatrix} X_1 & X_1 \\ . & . \\ X_t & tX_t \\ . & . \\ X_T & TX_T \end{bmatrix} \tag{14}$$

where X_t is a 21 × 6 vector.
At this stage, the full likelihood function of the model can be written as:

$$f_N^{TN}\left(y\left|X^*\beta - u, \sigma^2 I_{TN}\right.\right) p\left(\sigma^{-2}\right) p\left(\lambda^{-1}\right) \prod_{t=1}^{T}\prod_{i=1}^{N} f_G\left(u_{ti}\left|1, \lambda^{-1}\right.\right) \tag{15}$$

where f_N^{TN} stands for a multivariate $T \times N$ normal probability distribution function, f_G stands for a gamma probability distribution function and:

$$p\left(\lambda^{-1}\right) = f_G\left(\lambda^{-1}\left|1, -\ln(\theta)\right.\right)$$

$$p\left(\sigma^{-2}\right) = \sigma^2 \exp - \frac{10^{-6}}{2\sigma^2}$$

Note that the prior for λ^{-1} assumes a gamma distribution with the first parameter equal to 1, meaning a very flat prior and second parameter such that $(-ln(\theta))^{-1}$ is the prior median efficiency. We assume $\theta = 0.03$ so that the median of the efficiency distribution is 0.75. The robustness of results to this prior was confirmed taking different initial values for θ. As for σ^{-2} we assume the usual flat prior. Given this prior structure the posterior marginal distributions that compose the Gibbs sampler are easily derived. The conditional for β is:

$$p\left(\beta\left|Data, u, \sigma^{-2}, \lambda^{-1}\right.\right) \propto f_N^{2J}\left(\beta\left|\widehat{\beta},\ \sigma^2\left(X^{*\prime}X^*\right)^{-1}\right.\right) \tag{16}$$

where

$$\widehat{\beta} = \left(X^{*\prime}X^*\right)^{-1} X^{*\prime}(y + u) \tag{17}$$

The conditional for σ^{-2} to be used in the Gibbs sampler is:

$$p\left(\sigma^{-2}\left|Data, \beta, u, \lambda^{-1}\right.\right) \propto f_G\left(\sigma^{-2}\left|\frac{n_0+TN}{2}, \frac{1}{2}\left[a_0+(y-X^*\beta+u)'(y-X^*\beta+u)\right]\right.\right) \quad (18)$$

Next, the conditional for u is:

$$p\left(u\left|Data, \beta, \sigma^{-2}, \lambda^{-1}\right.\right) \propto f_N^{TN}\left(u\left|X^*\beta-y-\frac{\sigma^2}{\lambda}i, \sigma^2 I_{NT}\right.\right) \quad (19)$$

Finally, the marginal posterior distribution for the λ^{-1} is:

$$p\left(\lambda^{-1}\left|Data, \beta, u, \sigma^{-2}\right.\right) = f_G\left(\lambda^{-1}\left|1+TN, -\ln(\theta)+\sum_{t=1}^{T}\sum_{i=1}^{N}u_{it}\right.\right) \quad (20)$$

The sequential Gibbs sampling algorithm defined by eqnarrays 16 to 20 was run with 420,000 iterations for each separate decade, with a burn-in of the first 20,000 iterations to eliminate possible start-up effects. The traditional algorithm convergence criteria were computed and the posterior distributions were analysed.

Database

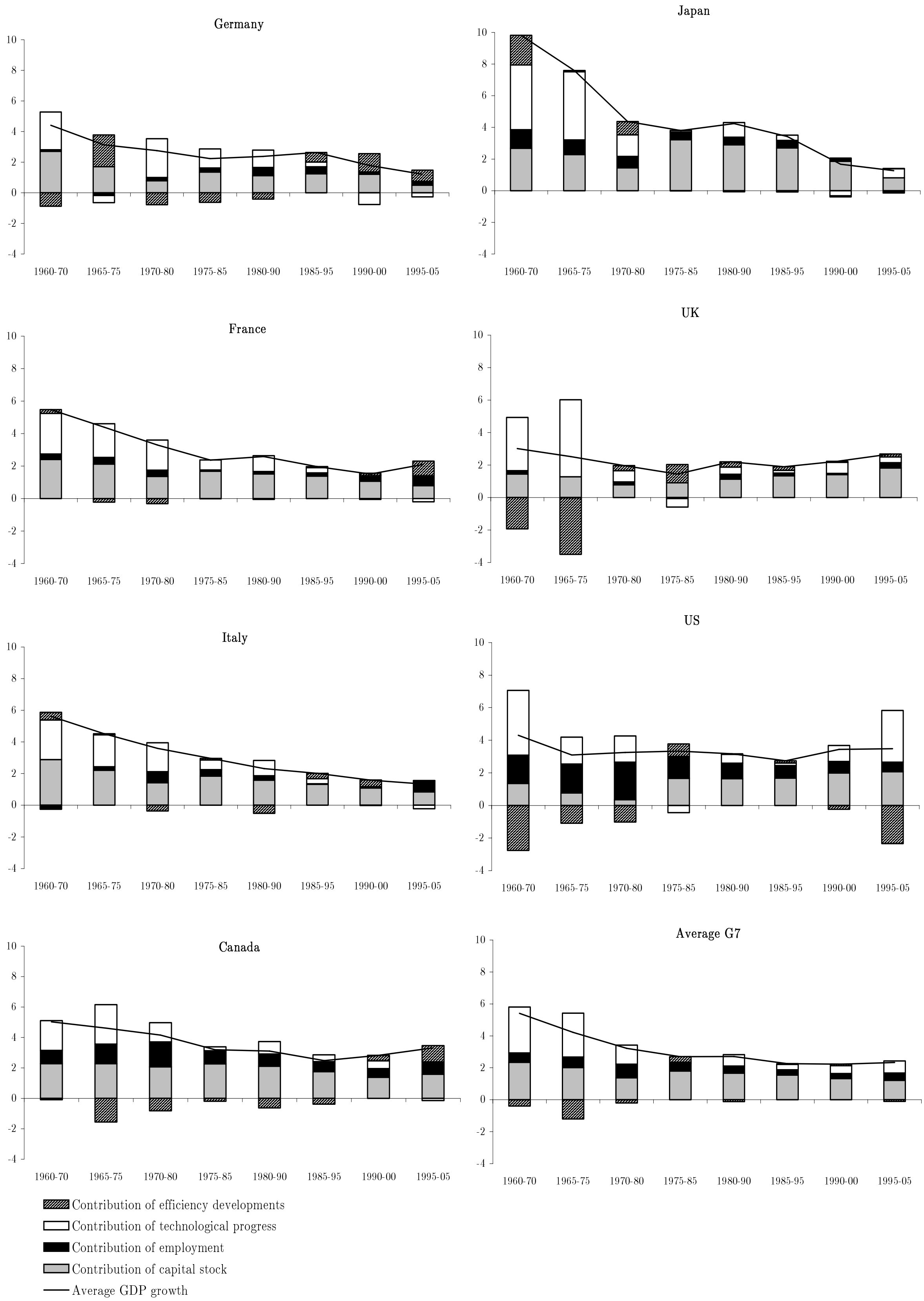
The data used for employment and GDP from 1960 until 2005 was obtained from the European Commission AMECO database (December 2005 version). As for the capital stock, for the first period in the sample, the stock of capital in each country was obtained from King and Levine (1994). These levels were updated using the capital real growth rates in the AMECO database. The reasons for this procedure are twofold. On the one hand, we did not adopt the initial capital stock of AMECO because, as an assumption, it simply corresponds to 3 times the GDP for 1960, which is an obvious limitation. On the other hand, it is not possible to use only data from King and Levine as they end in 1994. Other series of capital stock were tested, but the results do not change qualitatively. It should be noted that, in spite of the international conventions on national accounts compilation, there are important country-specific practices that tend to blur international comparisons. The compilation of value added for some services, namely those associated with general government activities, also poses difficulties in international comparisons. These problems may affect the results obtained, though, we hope, not dramatically.

Growth accounting for the G7 countries – country-specific results

Graph 1 plots the contributions of factor endowments and TFP to the average real GDP growth rates of the G7 countries. The contribution of inputs is separated into labour and capital, using the respective computed elasticities, and the contribution of TFP is broken down into TC and efficiency developments (the numeric results behind this graph as well as other details of the growth accounting exercise can be found in an extended version of this paper, available as working paper on the Banco de Portugal website: http://www.bportugal.pt/root/publish/wp/2007-9.pdf). Next we briefly analyse the results for each country. The US economy presents a relatively stable growth pattern. Firstly, it presents average growth rates around 3 and 4 percent in the decades considered. Secondly, it shows a relatively high contribution of labor to GDP

Graph 1

Growth accounting in the G7 countries



growth during all the periods considered. This partly reflects the entrance of baby boomers to the US labor market during the 1960s and the 1970s and significant immigration flows. Thirdly, the contribution of capital is close to the G7 average, showing some increase in the last decades. As for TC, in the beginning of the sample there were positive but decreasing contributions to GDP growth which reached a negative value in the decade 1975-85, the period when the effect of oil shocks was felt most strongly. After that period the contributions increased, reaching more than 3 percent in the decade 1995-2005. The contribution of TC to GDP growth is strong in the first and last decades. Nevertheless, in both periods the contribution of efficiency was negative, partly offsetting the contribution of technology. We discuss the interpretation of this result in the next subsection. The growth pattern of Canada resembles that of the US in some points. The contribution of employment to GDP growth is significant. The contribution of capital is also important and stable. Nevertheless, the contribution of TC in the last two decades considered is smaller than in the US and there is a considerable contribution from efficiency in the period 1995-2005. As regards the G7 countries that are euro area members – Germany, France and Italy – some differences in the growth patterns are identified. Germany recorded a trend decrease in the average GDP growth rates mostly attributable to a lower TFP contribution. The labor contribution has been low, with the exception of the 1980-1995 period, and the contribution of capital accumulation was lower than in the US and Canada, with the exception of 1960-70. As for TFP performance, the TC contribution decreased after the 1970s, and was negative in the period 1990-2000. This result probably captures the consequences of the German reunification. Conversely, in the period 1990-2005, efficiency contributed positively to GDP growth: although the existing input combination penalised growth, the economy moved closer to the computed production frontier. The French economy shows qualitative behavior similar to the Italian, and, to a lesser extent, to the German. In fact, in the comparison with Germany, two major exceptions are worth mentioning. Firstly, the contribution of technology to GDP growth in the decade 1990-2000 is not negative. Nevertheless, it is close to zero and has shown a significant decrease since the 1960s. Secondly, there is a large contribution of labor input to growth in the period 1990-2005. The Italian economy has recorded a continuing decrease in the 10-year average real GDP growth rate since the 1960s. This decline is mainly associated with the decreasing contribution of TC. This is similar to what was identified for France and Germany, but Italy has not benefited from increased efficiency in the last decade considered. However, like France, it recorded a positive contribution from employment in the 1995-2005 period. The UK shows a poor growth pattern in the period considered, though with some revival in the last decade. Is did not record high real GDP growth rates during the 1960s and 1970s, and recent performance is only slightly better than that of the G7 countries that are euro area members. All factors contribute to GDP growth, with a predominant role for capital. In the period 1960-1975, the contribution of TC was very high, partly offset by efficiency losses. This TFP pattern has been attributed to underinvestment and restructuring in some industries, driving a shift of resources to services. The improved performance recorded in the last decade may reflect some payback from these structural changes. The Japanese economy recorded a golden economic growth period in 1960-1975. The contributions of inputs and, most importantly, of technology gains, were strong. From the 1970s until the 1990s the growth pattern changed, with real GDP growth benefiting mostly from capital accumulation, labor input and some technological gains. In the 1990s the asset bubble crisis translated into a negative contribution of TFP (both technology and efficiency) to GDP growth. In the 1995-2005 period, average GDP growth was low, relying as it did on the contribution of capital and technology.

Growth accounting for the G7 countries – general results

One of our general results confirms that a large part of economic growth tends to be attributable to TFP. This is not news. However,when looking at the contribution of technology and efficiency to overall TFP performance, some results are worth mentioning. Firstly, the contribution of TC is stronger than efficiency improvements. Secondly, periods of high technology gain are frequently associated with negative contributions of efficiency. A possible explanation could be made along the following lines. When new technologies appear, countries may have an input mix that is suitable to take advantage of these gains. However, until these new techniques are effectively adopted, GDP growth will not reflect these potential gains and the contribution of efficiency will be reduced. In addition, it is also true that periods of strong TC imply high adjustment costs that, in our model, would be captured in the efficiency component. Another important result is the changes we have observed in the shape and dynamics of the computed world translog production function. The changes seem to indicate that that new technologies favor higher capital-labor ratios, meaning that the TC and potential TFP gains are centered in sectors with higher capital content. This finding is consistent with the idea that productivity gains are essentially associated with technology and capital intensive economic activities. The changes in the shape of the stochastic IPF have consequences in the elasticities computed for capital and labor in each country. The path of the computed elasticities for capital in the G7 countries was quite similar until 1995-2005. A sharp decrease in capital elasticity can be seen in the 1970-1980 period, when severe supply shocks occurred. In the recent periods, the surface of the stochastic production function seems to have became more convex, setting higher computed elasticities of capital for large economies with lower capital-labor ratios. Finally, a related debate concerns the type of returns to scale. The neoclassical view is based on the principle that capital presents diminishing returns at some point, leaving productivity gains to be explained by TC. However, the new growth theory, based on endogenous growth models, deviates from this result, due to either the existence of spillovers or issues of measurement and quality of the production factors. Departing from a simple growth accounting perspective, our analysis provides some results in this area: the sum of the capital and labor elasticities seems to point to the existence of increasing returns to scale in the G7 countries.

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