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The Demand for Heterogeneous Capital and Labour Inputs in a Developing Economy

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By using translog cost function this paper examines the structure of production of India's manufacturing sector when heterogeneous labour and capital are employed. It concludes that (a) machinery, equipment and structures are substitutable for different types of labour; (b) non-production workers work more intensively with machines and equipment than production workers in most of the manufacturing industries; (c) non-production workers are substitutable for production workers; and (d) non-production and production workers must be treated as separate labour inputs in production, and machinery and equipment and structures should be treated as separate capital inputs.

I. INTRODUCTION

A major assumption made in studies of production technologies for developing countries is that capital and labour can be aggregated. By representing capital as an aggregate and labour as an aggregate it is implicitly assumed that various types of capital and labour are separable. With the recent development of more generalized functional forms to describe the characteristics of production technologies, it is possible to test the validity of this assumption. Also, by providing a more disaggregated specification of the production technology, we are able to assess the economic impact of policy and other changes more accurately. For example, Diewert [9] has shown that when the assumptions necessary for aggregating inputs are violated, there are gains to be made (through disaggregation) in predicting the behaviour of input prices and estimating the partial elasticities of substitution between different kinds of labour and capital inputs.

Only a small amount of work has been done in this area – mostly in the context of developed economies, especially the United States. Hardly any worthwhile study relating to a developing economy has appeared so far. The main reason for this appears to be the non-availability of disaggregated data on labour and capital

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for the industrial sectors of most of the developing countries. For India, fortunately, disaggregated data are available for both labour and capital. In view of the fact that India is a rapidly industrializing economy and the proportion of non-production to production workers is on the increase, it should be enlightening to know the extent to which various types of labour are substitutable for various types of capital. Currently, in many industries in India, non-production workers comprise about fifteen to twenty-five percent of the total labour force.

The importance of disaggregating labour into production and non-production workers is not difficult to comprehend. To spur growth, the current policy emphasis in India and several other developing countries is on modernizing and upgrading plant and equipment in the manufacturing sector. Fiscal policy measures such as investment tax credits, and accelerated depreciation on capital investment in new plants and equipment are designed to expand employment opportunities for all kinds of labour. The effects that these policies will have on the use of various types of capital assets and the different kinds of labour depend on the extent of substitution between these factors of production. Moreover, economic planners often strive to put into place systematic manpower planning and development targets linking occupational skill requirements to projected growth in the economy. Thus, estimates of the substitution possibilities between various types of labour and capital also permit us to gauge the extent to which government policies can encourage employers to replace one category of worker by another or with different types of capital assets.

The case for disaggregating various types of capital assets is also well established. The arguments by the Cambridge school against aggregating diverse capital asset types are quite compelling and need not be developed here. Estimates of the substitution possibilities between different types of capital take on added importance for the less developed countries because many economists have identified the scarcity of capital as a constraint on economic development. For example, there has been considerable discussion among Indian planners on the role of capital in India's economic development. This debate has been succinctly summarized and given its historical context in a very illuminating paper by Smithies [16].

The relative use of physical capital acquires significance if foreign exchange becomes a serious constraint and the import of capital goods becomes prohibitive. Currie [5] points out that the import content of various types of capital assets such as structures is very low, while the overall labour component is high and the supply of domestic raw materials is quite elastic. Thus it may be found, for example, that additional investment of a few million dollars in cement making, brick or tile works or glass-making equipment can permit a multifold expansion in factory buildings. Thus, the question of the degree of substitutability between different types of capital becomes quite important for planning purposes.

Similarly, the nature of the contribution made by skilled and unskilled labour or workers and the supervisory staff (non-production workers) is also different and hence should be treated differently. The dichotomy in both labour and capital involves the larger question of the choice of techniques, which, in turn, affect not only the rate of growth of output but also the course and direction of adopted policies.

In order to relate these issues to a developing economy, this study develops a production model for the Indian manufacturing sector. We treat production and non-production workers as distinct labour inputs, and structures and machinery and equipment as distinct capital inputs. This study seeks to make two contributions. One, through an analysis of the partial elasticities of substitution among the various factors we can describe the structure of production technology in India's manufacturing sector. Two, it seeks to establish whether disaggregation of factor inputs is desirable for the Indian manufacturing sector, and whether such a disaggregation contradicts the conditions needed for the Leontief fixed coefficient, the Cobb-Douglas, and the CES production functions.

Section II outlines the model and data set. Section III discusses the results and Section IV presents some concluding remarks.

II. MODEL AND DATA

Since we are primarily concerned with determining the extent of substitution possibilities between different types of labour and capital, it is desirable to use the most general functional form which does not impose *a priori* restrictions on the partial elasticities of substitution. Recent applied econometric studies have made extensive use of the translog functional form [12; 6; 4; 2; 8]. In this study we use the translog format to identify all the features of the production technology. We describe the production technology of the Indian manufacturing sector by the four input translog cost function.

$$\ln C = \ln \alpha_0 + \alpha_Q \ln Q + \sum_1^4 \alpha_i \ln P_i + 1/2 \sum_1^4 \sum_1^4 \beta_{ij} \ln P_i \ln P_j + 1/2\, \alpha_{QQ} (\ln Q)^2 \quad \ldots \quad (1)$$

where C is total cost, Q is output, $\beta_{ij} = \beta_{ji}$, and P_i and P_j are the prices of the ith and jth inputs respectively. The four inputs are production workers (P), non-production workers (NP), machinery and equipment (E), and structures (S).

Differentiating Equation (1) with respect to the P_i's and relying on Shephard's lemma [15] the cost-share formulas are obtained:

$$M_i = \alpha_i + \Sigma_j \beta_{ij} \ln P_j \quad \ldots \quad (2)$$

where M_i is the share of the ith input in total cost.

For the cost function to represent a well-behaved technology, it must be positive, linearly homogeneous, monotonically increasing, and concave in input prices. The homogeneity property implies the following parameter restrictions:

$$\sum_i \alpha_i = 1; \Sigma_i \beta_{ij} = \Sigma_j \beta_{ij} = \Sigma_i \Sigma_j \beta_{ij} = 0 \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

Monotonicity requires that the fitted cost-shares, (M_i) in Equation (2), be positive and concavity requires that the Hessian matrix of second-order derivatives of the cost function be negative semi-definite within the range of input prices.

To show relationships among inputs, we derived the Allen [1] partial elasticities of substitution, using information from Equation (2), as follows:

$$\sigma_{ii} = \frac{\beta_{ii} + M_i \ (M_i - 1)}{M_i^2}; \quad \sigma_{ij} = \frac{\beta_{ij} + M_i M_j}{M_i M_j} \quad \ldots \quad \ldots \quad (4)$$

The own and cross-price elasticities of input demand are

$$\eta_{ii} = M_i \, \sigma_{ii}; \ \eta_{ij} = M_j \, \sigma_{ij} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

In order to estimate the model, we follow the usual practice in applications of the model and assume that there are errors in cost-minimization behaviour, in which case the observed shares deviate from the predicted shares in Equation (2) in some random fashion. To account for this, we append an additive error term to Equation (2). Since the factor shares (M_i) sum to unity, their errors must sum to zero. Then only N-1 share equations are independent. This restriction implies that their covariance structure is singular and that one cost-share equation must be deleted in the estimation procedure. The cost-share associated with structures (M_S) was deleted. Equations M_P, M_{NP}, and M_E are estimated using a nonlinear Zellner estimation procedure. Zellner [19] and Kmenta and Gilbert [13] have shown that iteration of the Zellner procedure until convergence yields results that approach sufficiently maximum likelihood estimates.[1]

The data used are the prices and cost shares of the four inputs for a cross-section of two-digit manufacturing industries in India for 1968. Information is taken from all those establishments which employ 50 or more workers with the aid of power, or 100 or more workers without the aid of power. All data relate to the average firm in the industry. These data are taken from the *Annual Survey of*

[1] The iterative Zellner [19] efficient estimation procedure does not depend on which equation is deleted. The (IZEF) estimator is asymptotically equivalent to the maximum likelihood estimator and, consequently, the (IZEF) coefficients are asymptotically efficient.

Manufacturing Industries, 1968, published in ten volumes by the Central Statistical Organization of the Government of India [10]. This is the latest year for which a complete data set is available.

All the industries are classified into subclasses by the industry number. For example, Food and Beverages Manufacturing is comprised of the following subclasses – Flour, Rice, Dal (Legumes), Sugar Manufacturing, etc. Following others, such as Humphrey and Moroney [12], we assume that the production functions are the same among sub-industries within a specific two-digit product group but they may differ across two-digit categories. Again, in studying the characteristics of India's manufacturing sector, we follow the examples of Griliches [11], Zarembka [18], and Dennis and Smith [7] by examining the performance of the average firm in the industry and by assuming that this correctly depicts the behaviour of the industry as a whole. The set of cost shares to be estimated requires share prices and information for each input. Wages for production and non-production workers were obtained by dividing the total earnings of each labour type by the number of man-hours worked by that type. The cost shares for each labour type were obtained by dividing total payroll for each type by total cost. The service price of each type of capital is calculated as $P_j = q_j\ (r + \sigma)$ where P_j is service price of the jth type of capital, q_j is current expenditure on the jth type of capital, r is a discount rate and σ is the rate of depreciation. We used a rate of depreciation of 0.03 for structures and of 0.06 for equipment and machinery.[2] The total cost is the sum of the expenditures on each factor input.

III. EMPIRICAL RESULTS

Table 1 presents the estimated coefficients for the cost-share equations for each industry group. The parameters were estimated with *a priori* imposition of the symmetry and homogeneity restrictions. The numbers in parentheses below the estimates are asymptotic standard errors. All of the estimated cost-share equations satisfy the monotonicity condition. The concavity test of the cost function is satisfied to a large extent for seven of the nine industries. Industry 35 (metal products except machinery and transportation) and industry 39 (miscellaneous manufacturing) failed to satisfy the test of concavity and were excluded from the analysis.[3]

[2]Caves, *et al.,* [3] uses a rate of .03 for structures and .06 for equipment, whereas Clark and Freeman (1980) use a depreciation rate of 0.0337 for equipment and .018 for structures. To the best of our knowledge, no such estimates are available for India or any other developing economy. However, since we are dealing with the advanced industrial sector of India, we felt that the rates of depreciation used by Caves, *et al.,* were not inappropriate.

[3]Concavity is checked by observing the signs of the principal minors of the Hessian matrix. Over 75 percent of the observations for these two sectors had sign reversals.

Table 1

Parameter Estimates for Input Share Functions by Manufacturing Industry

Parameter	(20, 21)	(23)	(31)	(33)	(34, 36)	(37)	(38)
β_E	0.0523 (0.1453)	0.0054 (0.1140)	–0.2238 (0.1025)	–0.2213 (0.1229)	–0.3361 (0.1005)	0.8278 (0.1970)	–0.1905 (0.1934)
β_S	0.0005 (0.1642)	0.2204 (0.0853)	–0.0144 (0.0931)	0.1486 (0.0451)	–0.0211 (0.0476)	–0.3662 (0.0736)	0.0517 (0.1240)
β_{NP}	0.1820 (0.0837)	0.4698 (0.0576)	0.5184 (0.0773)	0.2296 (0.0499)	0.4517 (0.0485)	0.0749 (0.1099)	0.4110 (0.0667)
β_P	0.7652 (0.2221)	0.3044 (0.1241)	0.7198 (0.1216)	0.4005 (0.0881)	0.9055 (0.0970)	0.4635 (0.1472)	0.7278 (0.2282)
α_{PP}	0.0564 (0.0332)	0.0062 (0.0161)	0.0616 (0.0126)	0.0058 (0.0109)	0.0587 (0.0141)	–0.0131 (0.0374)	0.0419 (0.0283)
α_{SP}	–0.0155 (0.0224)	0.0019 (0.0139)	–0.0203 (0.0122)	–0.0075 (0.0044)	–0.0315 (0.0079)	–0.0855 (0.0181)	0.0117 (0.0174)
α_{PNP}	0.0156 (0.0190)	–0.0046 (0.0151)	0.0001 (0.0129)	0.0162 (0.0040)	0.0213 (0.0085)	0.0437 (0.0320)	0.0080 (0.0104)

Continued –

Table 1 – (*Continued*)

α_{PE}	–0.0565	–0.0035	–0.0414	–0.0145	–0.0485	0.0549	–0.0616
	(0.0189)	(0.0139)	(0.0102)	(0.0068)	(0.0110)	(0.0187)	(0.0186)
α_{SS}	0.1562	–0.0019	0.1722	0.1162	0.1854	0.0953	0.0836
	(0.0265)	(0.0852)	(0.0089)	(0.0084)	(0.0200)	(0.0122)	(0.0184)
α_{SNP}	–0.0243	–0.0052	–0.0193	–0.0102	–0.0010	0.0174	–0.0353
	(0.0132)	(0.0109)	(0.0100)	(0.0059)	(0.0081)	(0.0162)	(0.0080)
α_{SE}	–0.1164	–0.0819	–0.1326	–0.0985	–0.1469	–0.0272	–0.0599
	(0.0194)	(0.0147)	(0.0102)	(0.0148)	(0.0130)	(0.0099)	(0.0123)
α_{NPNP}	–0.0063	0.0493	0.0477	–0.0007	0.0158	–0.0598	0.0251
	(0.0173)	(0.0205)	(0.0118)	(0.0087)	(0.0089)	(0.0300)	(0.0079)
α_{NPE}	0.0150	–0.0395	–0.0285	–0.0053	–0.0301	–0.0023	0.0022
	(0.0122)	(0.0101)	(0.0079)	(0.0062)	(0.0083)	(0.0151)	(0.0074)
α_{EE}	0.1579	0.1249	0.2025	0.1183	0.2255	–0.0254	0.1193
	(0.0224)	(0.0195)	(0.0089)	(0.0130)	(0.0167)	(0.0251)	(0.0105)
No. of observations	24	22	21	19	41	15	11

Note: Numbers in parentheses are asymptotic standard errors.

The Allen partial elasticities of substitution are of great interest and presented in Table 2. They are computed at the mean of the data. Positive values of the elasticities of substitution imply that the input pairs are substitutes, whereas negative values imply that they are complements. The results in Table 2 show the extent of substitution of one type of capital for another (σ_{SE}), of one type of labour for the other (σ_{PNP}), and one type of capital for one type of labour (σ_{SP}, σ_{EP}, σ_{ENP}, σ_{SNP}). In all industries, there is a fairly high substitution possibility between production workers and non-production workers. There are two distinct substitution possibilities. One, the elasticities of substitution between equipment and the two types of labour σ_{EP} and σ_{ENP} across product groups indicate that $\sigma_{ENP} < \sigma_{EP}$ for textiles (industry 23), chemical and chemical products (industry 31), and non-metallic mineral products (industry 33), and electrical machinery (industry 37) and machinery except electrical and basic metal products (industries 34, 36). These industries constitute 72.09 percent of the sample output. This finding suggests that, if the price of machinery and equipment decreases relative to wages for labour, firms would tend to substitute machinery for both kinds of labour. However, because $\sigma_{ENP} < \sigma_{EP}$, the proportionate increase in equipment and machinery to non-production workers will be less than that of equipment and machinery to production workers, so that the ratio of non-production to production workers would tend to increase. Therefore, an increase in demand for equipment and machinery would create a tendency for non-production workers to be retained more than production workers. Two, $\sigma_{EP} < \sigma_{ENP}$ for food and beverages (industries 20 and 21) and transport equipment (industry 38). Therefore, if there is an increase in the demand for machinery and equipment because of a decrease in its price relative to wages, the employment of production workers will tend to increase somewhat more than the employment of non-production workers even though the employment of both types of labour will tend to decrease. Thus, we infer that the former group of industries in which $\sigma_{ENP} < \sigma_{EP}$ will tend to be skill-oriented and the latter group more non-skill-oriented. Notice, however, that in both cases the elasticity of substitution between the production and non-production workers is very high. However, the own price elasticity of non-production workers is greater than the own price elasticity of the production workers in industries constituting nearly two-thirds of the total sample output. Therefore, as the price of equipment increases, which is relatively price-inelastic (see Table 3), chances are that it will not make a significant difference in the relative employment of the two types of labour. But the availability of additional equipment will tend to favour the additional employment of the production workers relative to the non-production workers. These results seem to confirm the common-sense view of the process of economic development where the earlier phases of industrialization are marked by both increased employment and output.

Table 2

Allen Partial Elasticities of Substitution

Product Group	σ_{SE}	σ_{SP}	σ_{SNP}	σ_{EP}	σ_{ENP}	σ_{PNP}	No. of Observations
Food and Beverages (20, 21)	0.0878 (0.0521)	0.7135 (0.2144)	0.2085 (0.1307)	0.2334 (0.0564)	1.3589 (0.2918)	1.8814 (0.6731)	24
Textiles (23)	–0.0289 (0.1847)	1.0291 (0.2132)	0.8274 (0.3609)	0.9655 (0.1369)	0.1596 (0.2149)	0.8805 (0.3922)	22
Chemical and Chemical Products (31)	–0.0647 (0.0019)	0.4690 (0.1385)	0.3580 (0.3333)	0.4880 (0.1457)	0.4013 (0.1439)	1.0048 (0.7633)	21
Non-metallic Mineral Products (33)	0.0681 (0.1400)	0.8661 (0.0786)	0.6062 (0.2278)	0.8467 (0.0719)	0.6087 (0.1419)	1.7013 (0.1733)	19
Machinery except Electrical and Basic Metal Products (34, 36)	–0.3990 (0.1238)	0.3298 (0.1681)	0.7603 (0.2774)	0.4451 (0.1259)	0.4426 (0.1537)	1.8765 (0.3498)	41
Electrical Machinery (37)	0.2866 (0.1491)	–0.7962 (0.0413)	1.5151 (0.4813)	1.7070 (0.2406)	0.9581 (0.2746)	2.0980 (0.8039)	15
Transport Equipment (38)	0.3010 (0.1435)	1.1853 (0.0276)	–0.1897 (0.2694)	0.3841 (0.1860)	1.0468 (0.1571)	1.2318 (0.3006)	11

Note: The numbers in parentheses are asymptotic standard errors.

Table 3

Own Price Elasticities of Demand

Product Group	η_S	η_E	η_{NP}	η_P
Food and Beverages (20, 21)	–0.1835 (0.0537)	–0.2043 (0.0866)	–0.9627 (0.9627)	–0.5048 (0.1879)
Textiles (23)	–0.3971 (0.0554)	–0.2932 (0.0765)	–0.4970 (0.1537)	–0.6902 (0.0558)
Chemical and Chemical Products (31)	–0.0792 (0.0187)	–0.1034 (0.0341)	–0.4705 (0.1075)	–0.4332 (0.0859)
Non-metallic Mineral Products (33)	–0.3838 (0.0307)	–0.0357 (0.0336)	–0.7939 (0.0841)	–0.7504 (0.0489)
Machinery except Electrical and Basic Metal Products (34, 36)	–0.0165 (0.0379)	–0.0476 (0.0840)	–0.7485 (0.0726)	–0.5057 (0.0711)
Electrical Machinery (37)	–0.3243 (0.0765)	–0.7498 (0.0608)	–1.1826 (0.1788)	–0.8180 (0.1577)
Transport Equipment (38)	–0.4078 (0.0285)	–0.3077 (0.0792)	–0.6757 (0.0619)	–0.8183 (0.1044)

Note: The numbers in parentheses are asymptotic standard errors.

With respect to the relationship between structures and the two types of labour, notice from Table 2 that structures are highly substitutable for all types of workers in all industries except electrical machinery (industry 37), where structures and production workers are complements, and the transport equipment industry (industry 38), where structure and non-production workers are complements. Results in Table 3 indicate that the own price elasticity of structures is much less than the own price elasticity of both the production and the non-production workers in all industries. Thus, factory buildings are going to be demanded if equipment is available, irrespective of the price of structures. This is also clearly indicated by the fact that either equipment and structures are complementary inputs or the value of the elasticity of substitution is so low (close to zero) as to make them virtually complementary.

The upshot of the above discussion is that the speed at which labour, especially the production workers (who constitute the bulk of the labour force), is going to be absorbed is dependent on the price and the availability of equipment and the raw material such as steel, cement, etc., to build the structures. Based on this analysis, since labour is relatively cheap and abundant, the speed of modern industrialization in India will be determined by the rate of capital formation in machinery and equipment. These results confirm our previous findings that in order to foster the speed of capital formation in India it is essential that the monetary authorities should strive for stable prices and relatively low rates of interest. Stable prices will tend to stabilize the price of wage goods and thereby the wage rates of labour. Lower interest rates will help to increase the demand for equipment relative to structures and thereby bring about the demand for more capital-intensive means of production.[4]

As noted before, the previous studies on the characteristics of the production structure for developing economies have two major shortcomings. One, capital and labour are considered to be homogeneous inputs in production. Two, the more restrictive Leontief, Cobb-Douglas, and CES functional forms, which assume separability among the inputs, are fitted to the data. To test the validity of the linear separability assumption, we must test the parametric restrictions in the translog model that production workers and machinery are separable from non-production workers and structures, by imposing the restrictions $\alpha_{PNP} = \alpha_{ENP} = \alpha_{ES} = \alpha_{PS} = 0$.[5] A wide array of different combinations of separability is investigated in Table 4. In terms of the parameters of the cost-share functions and factor shares, production workers (P) and machinery (E) are separable from non-production workers (NP) and structures (S) if and only if $M_P\ \alpha_{ENP} - M_E\ \alpha_{PNP} = 0$, and $M_P\ \alpha_{ES} - M_e\ \alpha_{PS} = 0$. Since the shares are positive, the linear separability conditions are satisfied if $\alpha_{PNP} = \alpha_{ENP} = \alpha_{ES} = \alpha_{PS} = 0$ [2].

Table 4 summarizes the results of the formal tests for separability with homotheticity, homogeneity in factor prices, and symmetry in cross-price terms maintained. First we perform test for global separability. The restriction requires that all α_{ij} terms be equal to zero. This separability restriction imposes a Cobb-Douglas function specification on our general model. The results indicate that the hypothesis implied by this form of separability is rejected at the five-percent level of significance. Also, the null hypothesis implied by all other combinations of separability is rejected for each industry. These findings suggest that it is necessary to treat the two types of labour and the two types of capital as distinct inputs in production. Firms can vary the use of inputs in response to prices, but, in doing so, they must

[4] See Laumas and Williams [14].

[5] The weak separability condition of the production function holds if the marginal rate of substitution between any pair of inputs x_i and x_j forming a subset of the set of inputs N_i is independent of the inputs outside the subset.

Table 4

Results of Linear Separability Tests by Industry[a]

Restrictions	Industry						
	(20, 21)	(23)	(31)	(33)	(34, 36)	(37)	(38)
Global Separability	42.90	48.80	96.28		107.72	57.32	56.32
[(pE), (Nps)]	30.10	26.22	65.66		59.80	48.52	37.52
[(pNp), (s, E)]	10.46	27.22	25.88		49.46	52.88	31.12
[(ps), (ENp)]	37.72	26.48	77.12		76.08	42.32	55.70

[a]The table presents X^2 statistics to test the linear separability conditions with homogeneity of degree one in factor prices and symmetry in cross-price terms and homotheticity imposed. The critical value $X^2 = 0.05$ $(df = 2) = 5.99$. $ln\ L_R$ is the log of the calculated maximum of the restricted likelihood function and L_U the log for the calculated maximum of the unrestricted likelihood function.

consider changes in the quantities of all the remaining inputs. Furthermore, our results suggest that any attempt to fit the more restrictive functional forms to this data set is inappropriate.

IV. CONCLUSIONS

The principal conclusions of this paper are as follows: (a) machinery, equipment and structures are substitutable for different types of labour; (b) non-production workers work more intensively with machines and equipment than production workers in most of the manufacturing industries; (c) non-production workers are substitutable for production workers in each industry; (d) non-production and production workers must be treated as separate labour inputs in production, and machinery and equipment and structures should be treated as separate capital inputs; and (e) the demand for the different types of labour is more elastic than the demand for different types of capital.

Our finding that equipment and machinery are substitutable for production and non-production workers has interesting implications. For example, in industries that are more skill-oriented, an increase in the demand for equipment and machinery would result in a larger decrease in the employment of unskilled workers than in that of skilled workers. Furthermore, any policy of accelerated depreciation and investment tax credits would tend to increase the demand for machinery and equipment and structures and to substitute machinery and structures for both types of labour.

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