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**DOES TRAINING BENEFIT THOSE WHO DO NOT GET ANY?
ELASTICITIES OF COMPLEMENTARITY AND FACTOR PRICE IN SOUTH
AFRICA**

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Does training benefit those who do not get any? Elasticities of complementarity and factor price in South Africa

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Abstract

Commentators claim that a shortage of skills in South Africa is constraining output and that a rise in skill supply would benefit less skilled occupations. This assumes or implies skilled and unskilled labour are complements. Hicks Elasticities of Complementarity and elasticities of factor price are estimated between capital and five occupations. The results show that skilled/artisanal and unskilled labour are complements while semi-skilled and unskilled labour are substitutes. These results allow for imperfectly elastic product demand, rigid wages and inference on highly non-linear elasticities. Aggregated estimates suggest More skilled labour complements Less skilled labour.

1 Introduction

“Government’s ambition to grow SA’s manufacturing base risks being stillborn unless the country addresses a worsening skills crisis.” - Paton (2003:18)

The importance of skills to manufacturing is a topical issue in South Africa, as evidenced by the above quote from a lead article in the *Financial Mail*. By stating that artisans, for example welders or toolmakers, are “essential to every aspect of manufacturing . . . production” and that their shortage will “severely hinder SA’s ability to deliver on . . . capital investment projects” (pg 18), Paton implies that artisans and other occupations are complements in production; that there are limited opportunities for substitution by other occupations and that the main effect of shortages is to lower output and thereby demand for all factors.

Over one third of the workforce in South Africa is unemployed (Nattrass, 2004). Although rigid wages play a role, much of this unemployment appears to be structural in that an oversupply of unskilled labour exists alongside as many as 500 000 vacancies for skilled workers (The Economist, 2004). These unfilled vacancies are evidence of skills-shortages constraining output: filling them would allow production and employment to rise for all occupations.

Both these observed features of the economy assume or imply that skilled and unskilled labour are complements and not substitutes in production. If they are complements, a rise in the supply of skilled workers (in the face of excess demand for skilled labour) has benefits for all occupations, including the unskilled. If skilled and unskilled labour are substitutes, then unskilled labour will be worse off if there is a rise in the supply of skilled labour. In particular, if vacancies for skilled workers are being partially filled by less skilled workers, then improved availability of the first-choice factor will result in these suboptimal substitutes losing out.

A major determinant of wage inequality in South Africa is explained by skill endowments. Increasing the skills of the workforce is seen as a key requirement for reducing wage inequality (Bhorat, Leibbrandt, Maziya, van der Berg & Woolard, 2001). People who acquire such skills or training are likely to earn productivity linked wage increases (Fallon & Lucas, 1998), but what will happen to those who remain unskilled? If skilled and unskilled labour are substitutes, training aimed at a limited subsection of the labour force may actually worsen wage inequality.

In order to encourage firms to train their workers, the South African Skills Development Act of 1998 introduced a system where firms incur a tax on payroll, which is reduced if they equip workers with skills in cooperation with and recognized by Sector Education Training Authorities (SETAs) (Paton, 2003). 45 898 people were enrolled in such programmes at the start of 2004 and the number is rising fast (Mdladlana, 2004). It is important to gauge whether the types of skills being produced are those most conducive to growth and

most beneficial to the unskilled. Furthermore, the South African government intends relaxing immigration requirements and removing unnecessary obstacles (Ellis, 2004). The question is especially pertinent in this case: will skilled immigration harm or benefit the unskilled?

The Hicks (1970) elasticity of complementarity (HEC) measures the percentage change in the ratio of endogenous factor prices to an exogenous change in their relative quantities. If the effect is positive, the factors are said to be q-complements. If the effect is negative, the factors are q-substitutes (Sato & Koizumi, 1973). Similarly, the cross-elasticities of factor price measure the percentage change in a factor price in response to an exogenous change in another factor's quantity. Grant & Hamermesh (1981) examine the interactions between youths, white women and other workers in the United States. Mak (2000) studies whether workers with different education levels are complements or substitutes in Canada while Vere (2001) estimates the parameters for skilled and unskilled labour over time in Taiwan.

This paper measures Hicks elasticities of complementarity and cross elasticities between capital and five labour occupations. Non-production workers are divided into managers/professionals and sales/clerical workers. Production workers are divided into skilled workers / artisans (like welders or tool-makers), semi-skilled workers (like machine operators) and unskilled workers. It estimates a translog production function on detailed firm-level data to derive the elasticities for South Africa. The relationships of most interest are within the production occupations as this is where the SETAs hope to contribute the most. We also produce estimates using more aggregated groups, dividing the labour force into More skilled and Less skilled groups.

All documented empirical work assumes perfectly elastic product demand, which may cause it to find two factors are complements when they are actually substitutes. Therefore, this paper allows for imperfectly elastic demand. It also allows for the possibility of one factor having rigid wages. Another relatively novel contribution to this literature is the use of the "Delta" method to calculate p values for the elasticities, which are non-linear functions of technological parameters.

The key finding is that a rise in the supply of the skilled/artisan occupation will increase unskilled wages while a rise in the supply of semi-skilled workers will reduce unskilled wages. (Skilled/artisanal and unskilled labour are complements while semi-skilled and unskilled labour are substitutes.) The results are robust to relatively inelastic demand in the product market. Accounting for rigid unskilled wages preserves the relationship, suggesting a rise in the supply of skilled/artisans would raise unskilled employment while a rise in the supply of semi-skilled workers would lower unskilled employment. The findings are consistent with the view that a shortage of artisans is holding back production and that relieving the shortage will raise demand for unskilled labour. Aggregated results suggest capital complements more skilled labour but not less skilled labour and that a rise in the supply of more skilled labour would raise demand for less skilled labour, but these results are somewhat

more susceptible to product demand elasticity and flexible wage assumptions than the disaggregated results are.

The paper derives the elasticity of factor price, its relationship to the HEC and how it can be used to allow for rigid unskilled wages in section 2. Section 3 shows how the elasticities are calculated using translog production functions. Section 4 describes the firm level data, specification issues and estimation. Section 5 presents the results and section 6 offers concluding comments.

2 Elasticities of Complementarity and Factor Price

This paper estimates Hicks Elasticities of Complementarity while, for other motives, Behar (2004) estimates Allen Elasticities of Substitution. With two factors and constant returns, the one is merely the inverse of the other. For general cases, the somewhat complex relationships between these two and other elasticities are explored by Sato & Koizumi (1973) and recently by Stern (2004). The Allen (1938) Elasticity can be used to examine the impact of exogenous relative factor price changes on endogenous factor quantities, holding the prices of other factors constant: the elasticity of factor demand. On the other hand, the Hicks Elasticity of Complementarity can be used to measure the effects of exogenous changes in relative factor supply on relative factor prices. A related concept is the elasticity of factor price, which measures the effects of changes in one factor quantity on factor prices. This section provides a derivation of the elasticity of factor price when all factor prices are flexible before showing how this can be adjusted if unskilled wages are rigid.

All n factor inputs are exogenously supplied to the economy, with factor prices adjusting to ensure full employment. Economy-wide output (Y) is determined by factor input quantities (X_i) according to a linearly homogeneous technology utilized by all h representative firms in the economy.

$$Y = f(X_1, \dots, X_n) = hf(x_1, \dots, x_n) \quad (1)$$

If not in a small open economy, the price (P) received is determined by output.

$$P = P(Y), \quad \frac{\partial P}{\partial Y} < 0 \quad (2)$$

Profit-maximising firms pay each input a wage (w_i) equal to its marginal revenue product, which is a function of the supply of all the inputs in the economy.

$$w_i = P(Y)f_i(X_1, \dots, X_n), \quad f_i = \frac{\partial f}{\partial X_i} > 0 \quad (3)$$

A change in factor supply has two effects on wages. First, it changes overall output and hence prices and, second, it changes the marginal rate of technical substitution given by the production technology, as shown respectively by the first and second terms of (4):

$$\frac{dw_i}{dX_j} = \frac{dP}{dY}f_i f_j + P f_{ij}, \text{ where } f_{ij} = \frac{\partial^2 f}{\partial X_i \partial X_j}, \quad f_{ii} < 0 \quad (4)$$

Converting to elasticity form:

$$\frac{d \log w_i}{d \log X_j} = \frac{X_j f_i f_j}{w_i} \frac{dP}{dY} + \frac{P f_{ij} X_j}{w_i} \quad (5)$$

$$= \frac{X_j f_i f_j P}{w_i f} \frac{1}{\eta} + \frac{f_{ij} f}{f_i f_j} \frac{f_i f_j P X_j}{f w_i}, \quad (6)$$

where $\eta < 0$ is the elasticity of demand in the product market. The Hicks elasticity of complementarity between factors i and j is:¹

$$H_{ij} = \frac{f_{ij} f}{f_i f_j} \quad (7)$$

It can be interpreted as the effect of an exogenous change in factor quantities on the ratio of factor prices, holding other factor quantities constant (Hicks 1970; Sato & Koizumi, 1973). Factor j 's share of output is:

$$s_j = \frac{f_j X_j}{f} \quad (8)$$

Together with equation (3), this can be used to rewrite (6) as:

$$\frac{d \log w_i}{d \log X_j} = \hat{\epsilon}_{ij} = s_j \left(H_{ij} - \frac{1}{|\eta|} \right) \quad (9)$$

$\hat{\epsilon}_{ij}$ is the elasticity of factor price. Equation (9) expresses the percentage change in the wage of factor i necessary for firms to alter their input demand after an 1% exogenous change in the supply of factor j . A rise in the supply of a factor, for example, works through 3 channels. (i) Because output is determined by the supply of factor inputs, a rise in supply of a factor necessarily leads to a rise in output and demand for all other factors. (ii) However, this effect is mitigated because a rise in output leads to a fall in product price and hence a fall in factor demand. (iii) Furthermore, the nature of the technological relationship between inputs means that, holding output constant, $f_{ij} \leq 0$ for $n > 2$ and $i \neq j$.

As $\eta \rightarrow \infty$, there are no price effects, yielding the elasticity of factor price ϵ_{ij} in the context of perfectly elastic demand. This captures effects (i) and (iii) only (Sato & Koizumi, 1973) and is most suited to small open economies.

$$\epsilon_{ij} = s_j H_{ij} \quad (10)$$

Equations (9) or (10) can be interpreted as the change in factor returns necessary for firms to maintain factor demand equal to the new factor supply; that is, to accommodate the change in supply of one factor and keep demand for all factors equal to their (unchanged) supply. ϵ_{ij} will tend to produce

¹This is the same value at economy and firm levels, because $f(X_1, \dots, X_n) = hf(x_1, \dots, x_n)$, $f_i(X_1, \dots, X_n) = f_i(x_1, \dots, x_n)$ and $f_{ij}(X_1, \dots, X_n) = h^{-1} f_{ij}(x_1, \dots, x_n)$ for a linear homogeneous technology.

elasticities that are higher than $\hat{\epsilon}_{ij}$ so, unlike other documented work, this study allows for product price effects. Another potential adjustment to ϵ_{ij} accommodates the possibility that the wage of one factor is rigid, as discussed next.

We started with the assumption that all factor prices adjust to ensure full employment. Given that wages may be rigid in South Africa and that we do in practice see unskilled unemployment, one can adjust for this using the methods first used by Johnson (1980). In the simple case, where only one factor's wage is completely rigid, one can calculate the effect of an exogenous change in the quantity of another factor on the quantity of that factor. This means the HEC can be used to infer effects on employment rather than wages for a particular factor. Following Grant & Hamermesh (1981), assume all factors' prices are flexible except for unskilled labour, which has wage w_u . All factor quantities are fixed except unskilled labour, which has quantity X_u . We do not allow for changes in produce price and set $P = 1$. The marginal productivity conditions are:

$$w_u = f_u(X_u, X_2, \dots, X_n) \quad (11)$$

$$w_i = f_i(X_u, X_2, \dots, X_n), \quad i = 2, \dots, n \quad (12)$$

Differentiating the equations with respect to X_j and solving the resulting system:

$$\frac{dx_u}{dx_j} = \frac{-f_{uj}}{f_{uu}} \quad (13)$$

$$\frac{dw_i}{dx_j} = \frac{-f_{iu}f_{uj} + f_{ij}f_{uu}}{f_{uu}}, \quad i = 2, \dots, n \quad (14)$$

Using equation (8), $X_i = \frac{f_{si}}{f_i}$ and, by equation (7), $f_{ij} = \frac{f_i f_j H_{ij}}{f}$. Hence:

$$\frac{d \log x_u}{d \log x_j} = \rho_{uj} = \frac{-H_{uj} s_j}{H_{uu} s_u} \quad (15)$$

$$\frac{d \log w_i}{d \log x_j} = \epsilon_{ij}^\rho = \frac{s_j (-H_{iu} H_{uj} + H_{ij} H_{uu})}{H_{uu}}, \quad i = 2, \dots, n \quad (16)$$

As presented in Grant & Hamermesh (1981), equations (15) and (16) demand a burdensom calculation of coefficients and p values. However, simply using (10) can make the computer's task somewhat easier:

$$\rho_{uj} = \frac{-\epsilon_{uj}}{\epsilon_{uu}} \quad (17)$$

$$\epsilon_{ij}^\rho = \epsilon_{ij} - \frac{\epsilon_{iu} \epsilon_{uj}}{\epsilon_{uu}} \quad (18)$$

It is therefore possible to infer the effects a change in the quantity of a factor on the quantity of unskilled labour (equation 17) or on the prices

of other factors, taking unskilled wage rigidity into account (equation 18). However, before performing any calculations, it is necessary to estimate the relevant technological coefficients.

3 Elasticities and Translog Production Functions

To find the elasticities of interest, we need to estimate the parameters of the underlying technology. The translog production function, due to Christensen, Jorgenson & Lau (1973), can be viewed as a second order Taylor approximation to an unknown technology - with the coefficients being the first (α_i) and second (β_{ij}) derivatives of the function in the approximation - or as an exact production function in its own right (Denny & Fuss, 1977). q is output and is a function of six disaggregated inputs. We assume representative firms make random errors in input selection and usage resulting in orthogonal error term u .

$$\log q = \log \alpha_0 + \sum_i \alpha_i \log x_i + \frac{1}{2} \sum_i \sum_j \beta_{ij} \log x_i \log x_j + u, \quad (i, j = 1, \dots, 6) \quad (19)$$

A twice continuously differentiable production function implies the underlying marginal productivity conditions satisfy the symmetry conditions $\beta_{ij} = \beta_{ji}$, which are imposed in the construction of the variables. The main advantage of the translog function for this study is that there are no assumptions imposed on the underlying elasticities. Furthermore, separability and homotheticity are not assumed but tested for and, if accepted, imposed on the system. Equation (19) is homogeneous of degree k if:

$$\sum_j \beta_{ij} = \sum_i \beta_{ij} = 0 \text{ and } \sum_i \alpha_i = k \quad (20)$$

$k = 1$ implies there are constant returns to scale (Chung, 1994). Tests of the restrictions (20) and of $k = 1$ fail to reject the hypothesis of constant returns in the data, so they are imposed to enhance efficiency. Differentiating (19) with respect to $\log x_i$ yields $\alpha_i + \sum_j \beta_{ij} \log x_j$, but $\frac{d \log q}{d \log x_i} = \frac{\partial q}{\partial x_i} \frac{x_i}{q} = s_i$. Therefore:

$$s_i = \alpha_i + \sum_j \beta_{ij} \log x_j \quad (21)$$

It is common to estimate the system of equations (21) to improve efficiency characteristics (Berndt, 1991). However, in this paper's data, factor shares are not available, so the parameters estimated in (19) are used to predict s_i and calculate elasticities in a translog context: By (3) and (8):

$$\begin{aligned} \epsilon_{ij} &= \frac{x_j}{w_i} \cdot \frac{d}{dx_j} \left(\frac{qs_i}{x_i} \right) \\ &= \frac{\beta_{ij}}{s_i} + s_j \end{aligned} \quad (22)$$

By (10):

$$H_{ij} = \frac{\beta_{ij}}{s_i s_j} + 1 \quad (23)$$

If all $\beta_{ij} = 0$, we have a Cobb-Douglas Production Function and $H_{ij} = 1$. Furthermore (Binswanger, 1974a):

$$\epsilon_{ii} = \frac{\beta_{ii}}{s_i} + s_i - 1 \quad (24)$$

$$H_{ii} = \frac{\beta_{ii}}{s_i^2} + 1 - \frac{1}{s_i} \quad (25)$$

The next section discusses the data and method used to estimate equation (19) and calculate the elasticities.

4 Data, specification and estimation

The National Enterprise Manufacturing Survey (NE survey) is a single cross section covering the period of 1998. For a thorough analysis of the data, see Borhat & Lundall (2002).

One potential drawback of using manufacturing data is that the firms in the survey may not be sufficiently representative of firms in the broader economy. Using evidence from manufacturing for the whole economy would be invalid if the production technology is fundamentally different in manufacturing compared to other sectors. However, manufacturing is the largest sector in the South African economy (Bhorat & Hodge, 1999) and includes a particularly heterogeneous range of economic activity by international standards (Wood, 1995), so estimates should be informative regarding the broader economy. Using the data to make inferences about manufacturing alone would require relaxing the assumption of perfectly exogenous labour supply at the cost of far greater complexity. Being fully aware of these issues, Grant & Hamermesh (1981) also employ cross-sectional manufacturing data. Borjas (1986) yields the same results from estimates for the whole economy and for manufacturing alone in the United States.

Key variables are the capital stock and employment numbers by occupation. The five occupations are non-production workers, divided into Managerial/Professional and Sales/Clerical, and production workers, divided into Skilled/Artisan (technicians, welders), Semi-skilled (machinery operators) and Unskilled (labourers, security guards). Capital stock is available in currency (Rand) values. It is not possible to adjust this for capacity utilization directly but, using data on the actual and maximum average shift length and the number of shifts per week, it is possible to construct a shift capacity utilization variable as a reasonable proxy.

The NE dataset has information on what percentage of total costs is comprised of raw materials costs, but there is no data on total costs or on raw materials costs. To derive a measure of raw materials costs, it is necessary to assume that turnover equals total costs. Instead of multiplying raw materials

as a percentage of costs by costs to get raw materials costs, raw materials are multiplied by turnover to get a measure of raw materials costs. Value added is constructed as sales minus the constructed raw materials. The issue is whether to regress turnover on the factor inputs and raw materials or value added on the factor inputs only. Grant & Hamermesh (1981) express output in terms of capital and four forms of labour, while Mak (2000) does not have raw materials inputs in her system of share equations. Neither tests the validity of omitting raw materials. Of the 12 studies listed by Chung (1994), only three test for value-added separability while Hamermesh (1993) does not discuss value-added separability in his comprehensive survey. It is likely that data constraints make this the only option.

The validity of the value added specification, as exposed by Sato (1975), depends on whether raw materials are separable from the other inputs. Capturing the essential characteristic that changes in raw materials (x_r) do not affect the marginal rate of technical substitution between factors,

$$\beta_{ir} = 0, \quad (i = 1, \dots, 6), \quad (26)$$

is a sufficient condition for separability of inputs (Berndt & Christensen (1973a,b)). Wald tests for the six restrictions in (26) reject (additive) separability. However, non-additive separability of raw materials with respect to factor pairs i and j holds if (ibid.):

$$\frac{\alpha_i}{\alpha_j} = \frac{\beta_{ii}}{\beta_{ij}} = \frac{\beta_{ji}}{\beta_{jj}} = \frac{\beta_{ir}}{\beta_{jr}} \quad (27)$$

Wald tests of (27) are not significant for each of our fifteen factor combinations, so raw materials is separable from the other inputs and we adopt the value added specification in this paper.² With a view to adopting a parsimonious more aggregated production function in addition to the disaggregated estimates, we also test (26) for the Sales/Clerical group and consequently drop it. We do this because the skill content of this occupation is not clear and can vary enormously. Furthermore, we test:

$$\beta_{ik} = \beta_{jk} \text{ for all } k \quad (28)$$

i and j are the Managerial/Professional and Skilled/Artisan occupations and k is each of the other occupations. Failure to reject this test means we can validly aggregate these occupations into the More skilled group (Fuss, 1977). Similarly, we can validly aggregate Semi-skilled and Unskilled labour into the Less skilled group.

Estimating production functions presents the danger of endogeneity bias because the error term may contain factors observed by the firms in time to affect their choice of inputs (Griliches and Mairesse, 1995). The choice

²These tests may be too stringent as they also implicitly test for the exactness of the functional form of the translog function. See Denny & Fuss (1977) and Blackorby et al (1977) for details and alternative tests.

between Two Stage Least Squares estimation and OLS with proxies clearly depends on the data. To be a good proxy/control, the variable must be highly correlated with the missing variable and uncorrelated with the error term. In contrast, instruments must be uncorrelated with the error term (Wooldridge, 2002). Therefore, the variables in one's data set can each be either good instruments or good proxies, but not both.

Among the candidate variables, one can suggest that a variable for market conditions, which would be correlated to both output and input choice, would make a good proxy but would not remove the endogenous component from the input if included in the input's instrumenting equation. Industry dummies and variables on export quantities, while controlling for an aspect of the technology, would also be good proxies. Valid instruments for the inputs are harder to find; recruitment difficulty or wages are themselves endogenous to market conditions and would at best only partially purge the factor input of its endogeneity. They are also likely to be extremely weak instruments. Furthermore, wages are not part of the dataset but were constructed using alternative sources³, making them less effective as instruments.

We first estimate equation (19) by OLS with the appropriate proxies used to control for firm specific technology and other unobservables that influence the choice of factor inputs. The Hausman specification test for endogeneity compares these estimates with 2SLS regressions, finding a p value of 0.90 for the null hypothesis that the coefficients do not differ systematically. In other words, there is no endogeneity bias and there is no need to consider IV in the first place. The difficulty with this test is the underlying conjecture that the IV regression coefficients are consistent. The possibility for this not being the case is tested using a Hausman type test on the 2SLS regression. The test does not reject the exogeneity assumption at the 20% level. Besides, standard errors on each of the factor inputs are six or seven times greater in the second stage of the 2SLS estimates than for OLS, and the confidence bands of the OLS estimates are within those of the 2SLS estimates for every single variable⁴. Although these results are most likely driven by the weakness of the instruments and do not powerfully validate OLS, they certainly motivate its being preferable to 2SLS.

Estimation by OLS is consistent with a theory that assumes all factor supplies are exogenous, but it could be argued that, in the rigid wage example, the factor is endogenous and must be instrumented accordingly. Like Johnson (1980) and Grant & Hamermesh (1981), we initially use the same OLS regression for the rigid wage case as for the flexible wage case. Nonetheless, we do try to endogenise for the factor with a rigid wage. The difficulty in this application is the (still) large number of endogenous variables that need valid instruments: the 6-factor example requires 7 instruments (for itself, its square and its interaction with the other 5 factors). In addition to the instrument difficulties discussed above, it would be theoretically appropriate to use only

³See Behar (2004) for details of the methodology.

⁴Full details of the estimations are available on request.

that factor's wage as a valid instrument. This is because the model implies that wages, except the rigid wage, are endogenous to output and therefore by definition invalid instruments.

Instead, we perform a manual two stage procedure, where unskilled labour is predicted using the unskilled wage. The predicted unskilled wage is then interacted with the other factors to yield predicted higher order terms before use in the second stage regression⁵. A similar procedure is followed in the more aggregated specification for Less skilled labour. It is also feasible to perform standard 2SLS for the aggregated specification, treating less skilled labour and its interactions with the other two factors as endogenous. The results will be discussed under the results section and in the appendix.

Inference presents particular difficulties because the elasticity estimates are highly non-linear combinations of the coefficients and data (Greene, 2003). Significant regression coefficients neither imply nor are necessary for significant elasticities (Anderson & Thursby, 1986). Reviews of empirical work using translog cost or production functions make no mention of significance with respect to elasticities (Chung, 1994; Hamermesh, 1993). Some studies do not report confidence intervals for the estimates at all (Bergström & Panas, 1992; Chung, 1987; Teal, 2000). Others (Binswanger, 1974b, Mak, 2000) regard the factor shares as fixed and treat the β_{ij} coefficient as the only one with a confidence interval, incorrectly inferring significance from a standard t-statistic.

Analysing famous pioneering translog cost studies, Anderson & Thursby (1986) find that confidence intervals for many of the elasticity measures span both the negative and positive orthants, bringing their forceful conclusions into doubt. They do so after presenting conditions under which Allen Elasticities of Substitution asymptotically follow the normal or ratio-of-normals distribution, finding they do so only if the means of the actual factor shares are used.

This paper does not have the option to adapt the Anderson & Thursby result as no actual shares are available. It therefore applies the "Delta" method to the elasticity estimates and uses it to present p values. Before proceeding to the results, it is important to realise that the p values can be sensitive to the distributions of the underlying parameters in finite samples, and must be treated as indications only. Estimating equation (19) with six inputs is already asking much of the data, even before using the parameters in further complex elasticity calculations. Despite this, the data do yield some meaningful results, as discussed next.

⁵Such manual procedures require regressing the endogenous variable on all exogenous variables including the identifying instrument(s) (Wooldridge, 2002). This is done but the higher order terms involving unskilled labour are excluded. Omitting the interaction terms involving unskilled labour in the first stage and not performing first stage regressions to identify them means the coefficients in the second stage regression will be inconsistent.

5 Results

This section presents the regressions and the resulting elasticities. We concentrate on the disaggregated estimates in full before motivating and discussing the more aggregated specification. The full regression results for the six disaggregated inputs are in table 1. The fit is good overall. Furthermore, the coefficients on all the higher order terms are jointly significant, which rejects the null hypothesis that the production function is a Cobb Douglas technology. The coefficients generate (statistically significant) positive factor shares for the representative firms so the monotonicity conditions ($f_i > 0$) are confirmed. The results of the separability tests are also presented.

Table 2 presents the HEC estimates calculated using equations (21), (23) and (25). The results show, for example, that a 1% rise in the ratio of managers or professionals to unskilled workers would raise the ratio of unskilled to managerial/professional wages by 4.47%. Relative rises of this occupation would in fact help all other forms of labour, making them q complements. Pairs which are q substitutes are more rare: capital and skilled/artisanal labour are an example. The results suggest skilled/artisanal and unskilled labour are big complements while semi-skilled and unskilled labour are substitutes. While these numbers are best used as inputs in computable general equilibrium models, the elasticities of factor price, which have the same sign as the elasticities of complementarity, are of more direct interest.

Table 3 presents ϵ_{ij} - the percentage change in the price of factor i after a 1% rise in the quantity of factor j , assuming perfectly elastic demand in the product market, as well as p values (η will be explained shortly). It is encouraging to report that all own-elasticities are negative and, with the exceptions of capital and semi-skilled labour, significantly so. Some coefficient values are virtually zero, suggesting some factors are neither complements nor substitutes. Other coefficients are imprecisely estimated, partially because of the estimation and inference procedure, but also because the technology does not exhibit a strong pattern of complementarity.

However, we do find many low p values for the effects on unskilled wages, which are in any case of most concern for this study. Taken literally, the results suggest that a 10% rise in the supply of skilled/artisanal labour would lead to a 7.1% rise in unskilled wages while a similar rise in the supply of semi-skilled labour would lead to a 10.1% fall in unskilled wages. These effects are significant and are the key result of this study. In fact, skilled/artisanal labour complements all other factors, which strongly supports the claim that the shortage of this labour type is hampering output growth.

The assumption of perfectly elastic demand could be justified given that South Africa is a small open economy. South Africa is still highly commodity based and there are strong indications that even manufactured export elasticities are near perfect (Behar & Edwards, 2004). Nonetheless, if product demand elasticities are not perfect, the estimates will tend to be too positive. In particular, some factor pairs thought to be complements may indeed be

Table 1: Production Function Parameter Estimates

Dependent variable: Value Added					
Variable	Coefficient	p value	Variable	Coefficient	p value
Constant	-0.90	0.01	ind2	0.31	0.04
Capital	0.19	0.00	ind3	0.16	0.33
Man/Prof	0.09	0.34	ind4	0.58	0.00
Sale/Cler	0.43	0.00	ind5	0.15	0.33
Skil/Art	-0.02	0.71	ind6	0.24	0.15
Semi	0.11	0.08	ind7	0.26	0.07
Un	0.20	0.00	ind8	0.03	0.85
0.5*Capital ²	0.09	0.01	ind9	0.23	0.12
Capital*Man/Prof	-0.07	0.10	loc2	0.24	0.35
Capital*Sale/Cler	0.04	0.26	loc3	0.09	0.42
Capital*Skil/Art	-0.02	0.56	loc4	0.16	0.18
Capital*Semi	-0.05	0.12	loc5	0.34	0.19
Capital*Un	0.00	0.97	loc6	-0.38	0.32
0.5*Man/Prof ²	-0.04	0.69	loc7	-0.82	0.04
Man/Prof*Sale/Cler	-0.01	0.88	loc8	-0.17	0.62
Man/Prof*Skil/Art	0.02	0.71	loc9	0.12	0.31
Man/Prof*Semi	0.04	0.41	exports %	0.27	0.16
Man/Prof*Un	0.06	0.21	raw materials %	-0.02	0.00
0.5*Sale/Cle ²	0.05	0.56	recruitment ease Man/Prof	0.04	0.59
Sale/Cler*Skil/Art	-0.04	0.45	recruitment ease Sale/Cler	0.08	0.18
Sale/Cler*Semi	-0.03	0.57	recruitment ease Skil/Art	-0.02	0.79
Sale/Cler*Un	-0.02	0.60	recruitment ease Semi	0.00	0.99
0.5*Skil/Art ²	-0.09	0.08	recruitment ease Un	0.17	0.09
Skil/Art*Semi	0.07	0.05	training %	0.38	0.00
Skil/Art*Un	0.05	0.09	market conditions	0.02	0.10
0.5*Semi ²	0.05	0.28	firm size > 50 employees	0.47	0.00
Semi*Un	-0.09	0.00	computer investment %	2.60	0.01
0.5*Un ²	0.00	0.96	ownermanaged	0.37	0.02
obs		239	Separability (equations (27) and (28):		
"R squared"		0.96	Exclude Sales/Clerical 0.53		
Joint test on all $\beta_{ij} = 0$		0.02	Aggregate Man/Prof & Skil/Art 0.77		
			Aggregate Semi & Unskilled 0.69		

Table 2: Hicks Elasticities of Complementarity

$H_{ij} = H_{ji}$		j					
		Capital	Man/Prof	Sale/Cler	Skil/Art	Semi	Un
Capital		-1.81	-1.13	1.68	-0.23	-3.01	1.07
Man/Prof		-1.13	-5.14	0.85	2.10	3.89	4.47
i	Sale/Cler	1.68	0.85	-1.22	0.03	0.11	0.14
	Skil/Art	-0.23	2.10	0.03	-20.82	11.87	7.83
	Semi	-3.01	3.89	0.11	11.87	-3.28	-13.87
	Un	1.07	4.47	0.41	7.83	-13.87	-10.93

Table 3: Elasticities of Factor Price

ϵ_{ij}									
i	j	coef	p	η	i	j	coef	p	η
Capital	Capital	-0.30	0.19	.	Skil/Art	Capital	-0.04	0.92	.
	Man/Prof	-0.22	0.41	.		Man/Prof	0.41	0.48	-0.48
	Sale/Cler	0.67	0.01	-0.59		Sale/Cler	0.01	0.99	-39.5
	Skil/Art	-0.02	0.92	.		Skil/Art	-1.89	0.01	.
	Semi	-0.22	0.26	.		Semi	0.87	0.12	-0.08
	Un	0.09	0.54	-0.94		Un	0.64	0.11	-0.13
Man/Prof	Capital	-0.19	0.42	.	Semi	Capital	-0.49	0.35	.
	Man/Prof	-0.99	0.06	.		Man/Prof	0.75	0.34	-0.26
	Sale/Cler	0.34	0.38	-1.17		Sale/Cler	0.04	0.95	-9.49
	Skil/Art	0.19	0.49	-0.48		Skil/Art	1.08	0.11	-0.08
	Semi	0.28	0.28	-0.26		Semi	-0.24	0.71	.
	Un	0.37	0.12	-0.22		Un	-1.14	0.14	.
Sale/Cler	Capital	0.28	0.01	-0.59	Un	Capital	0.17	0.56	-0.94
	Man/Prof	0.16	0.36	-1.17		Man/Prof	0.86	0.16	-0.22
	Sale/Cler	-0.48	0.02	.		Sale/Cler	0.16	0.72	-2.46
	Skil/Art	0.00	0.99	-39.5		Skil/Art	0.71	0.09	-0.13
	Semi	0.01	0.95	-9.49		Semi	-1.01	0.05	.
	Un	0.03	0.73	-2.46		Un	-0.90	0.03	.

substitutes. No documented studies attempt to allow for this. One reason may be that, at a macro level, the elasticity is a difficult concept to pin down, let alone estimate. Rather than impose a value for η , we calculate values of η that would make $\hat{\epsilon}_{ij}$ equal to zero. By (9), $\eta = -H_{ij}^{-1}$ for strictly positive factor shares. If the elasticity is η or less elastic, then $\hat{\epsilon}_{ij} < 0$ even if $\epsilon_{ij} > 0$. Obviously, for $\epsilon_{ij} < 0$, $\eta > 0$, so the calculation is not presented.

The calculations in table 3 yield many relatively high threshold values of $|\eta|$ that could easily exceed the true value. If similar thresholds were to be found with other data, this suggests that many studies finding two factors are complements may be doing so misleadingly. This may be so even for relatively large positive values, as the case of capital and sales/clerical workers demonstrates. In contrast, demand would have to be highly inelastic for the managerial/professional and unskilled labour coefficient to change sign. Furthermore, the calculations strongly suggest skilled/artisanal and unskilled labour are complements even after accounting for imperfectly elastic product market demand.

We now investigate the effects of allowing for the effects of rigid wages on the results. The bottom right corner of table 4 presents the employment response of unskilled workers to changes in the quantities of other factors (equation 17) based on the OLS regression in table 1. A 10% rise in the quantity of skilled/artisanal workers would lead to a 7.9% rise in unskilled employment while a rise in semi-skilled workers would reduce unskilled employment. The low p values are telling given the large number of parameters involved in the calculation.

The rest of table 4 presents the factor price responses of the other five factors (equation 18). There are a few sign switches relative to table 3, but these were for small coefficients that were not significant. Many of the changes occur for semi-skilled workers, largely because they are large substitutes for unskilled labour, showing that elasticities of factor price could be misleading if there is even one rigid wage. In particular, note that a rise in supply of semi-skilled workers could even lead to a rise in its own wage. Equation(18) shows this is more likely for factor $i = j$ if the technology is such that, with completely flexible wages, the own elasticities of factors i and u are low, and the two factors are large complements or large substitutes.

Alternative calculations based on endogenised unskilled labour are presented in table 9 in the appendix. Of the 30 calculations, only 5 signs differ. Most notably, the effects of semi-skilled and skilled/artisanal labour on the the unskilled is preserved.

The separability tests have shown it is valid to estimate a production function in terms of three inputs - Capital, More skilled and Less skilled labour - instead of six. This may be desirable for various reasons. First, simpler estimates are somewhat less demanding of the data. Second, the vast majority of models employ "the" elasticity between skilled and unskilled labour, so such an estimate would be needed to make predictions using those models. This pertains to applied computable general equilibrium (CGE) models in partic-

Table 4: Elasticities after adjusting for rigid unskilled wages

i	j	coef	p	i	j	coef	p
ϵ_{ij}^ρ							
Capital	Capital	-0.28	0.21	Skil/Art	Capital	0.09	0.81
	Man/Prof	-0.14	0.61		Man/Prof	1.03	0.16
	Sale/Cler	0.68	0.01		Sale/Cler	0.13	0.82
	Skil/Art	0.05	0.82		Skil/Art	-1.38	0.05
	Semi	-0.32	0.24		Semi	0.14	0.84
Man/Prof	Capital	-0.11	0.61	Semi	Capital	-0.71	0.32
	Man/Prof	-0.64	0.35		Man/Prof	-0.34	0.79
	Sale/Cler	0.40	0.36		Sale/Cler	-0.16	0.86
	Skil/Art	0.48	0.16		Skil/Art	0.18	0.83
	Semi	-0.13	0.79		Semi	1.05	0.54
ρ							
Sale/Cler	Capital	0.28	0.01	Un	Capital	0.19	0.54
	Man/Prof	0.20	0.33		Man/Prof	0.96	0.19
	Sale/Cler	-0.48	0.01		Sale/Cler	0.18	0.72
	Skil/Art	0.03	0.83		Skil/Art	0.79	0.08
	Semi	-0.03	0.85		Semi	-1.13	0.12

ular. Third, while many training programmes are aimed at the lower end of the skill spectrum, it is still important to understand what general rises in the broad skills of the population would yield for the relatively less skilled. Table 5 presents the estimates of the translog function with Capital, More skilled labour (Managerial/Professional & Skilled/Artisanal) and Less skilled labour (Semi-skilled and Unskilled). Control variables are not presented. Despite the simpler specification, the fit is still good. Tests reject the null hypothesis that all $\beta_{ij} = 0$ and monotonicity is satisfied.

Table 6 presents Hicks Elasticities of Complementarity⁶, which intuitively show Capital and More skilled labour tend to complement each other in production while Capital and Less skilled labour appear to substitute each other in production. This is analagous to the Griliches (1969) concept of capital-skill-complementarity, where a fall in the price of capital benefits higher skilled labour more than lower skilled labour (or harms higher skilled labour less). We also find a that, even at more aggregated levels, occupations of a higher skill type tend to complement lower-skilled occupations. This finding masks the distinction between Skilled/Artisanal and Managerial/Professional labour on the one hand and Semi-skilled labour on the other (table 2), but suggests that a general rise in the economy's education/skill levels will benefit those who remain relatively less skilled.

⁶Out of the three pairs of H_{ij} ($i \neq j$), at least two pairs must be positive (Sato & Koizumi, 1973). These results meet that minimum as opposed to the maximum of three.

Table 5: Production Function Parameter Estimates (aggregated inputs)

Dependent variable: Value Added		
Variable	Coefficient	p value
Constant	-1.25	0.00
Capital	0.46	0.00
More	0.43	0.00
Less	0.10	0.20
0.5*Capital ²	0.12	0.00
Capital*More	-0.00	0.90
Capital*Less	-0.12	0.00
0.5*More ²	-0.01	0.84
More*Less	0.01	0.68
0.5*Less ²	0.10	0.03
obs		329
"R squared"		0.89
Joint test on all $\beta_{ij} = 0$		0.00

Table 6: Hicks Elasticities of Complementarity (aggregated inputs)

$H_{ij} = H_{ji}$		j		
		Capital	More	Less
i	Capital	-1.07	0.96	-0.60
	More	0.96	-1.25	1.10
	Less	-0.60	1.10	-1.17

Table 7: Elasticities of Factor Price (aggregated inputs)

ϵ_{ij}				
i	j	coef	p	η
Capital	Capital	-0.25	0.10	.
	More	0.44	0.01	-1.04
	Less	-0.19	0.29	.
More	Capital	0.23	0.01	-1.04
	More	-0.57	0.00	.
	Less	0.34	0.00	-0.90
Less	Capital	-0.14	0.27	.
	More	0.50	0.00	-0.90
	Less	-0.36	0.02	.

Table 7 presents the elasticities of factor price and the value of η that would make a positive coefficient negative. It is encouraging to report that the own elasticities for capital in tables 3 and 7 are similar and relatively precisely estimated. The own elasticities for the aggregated labour types are also significantly negative. The results suggest a highly significant positive effect on less skilled wages after a rise in more skilled labour. However, despite the generally lower p-values, the positive coefficients would become negative at quite plausible product demand elasticities of approximately unity. Therefore, while the precision of ϵ_{ij} will be of use to CGE modellers, the values of η mean policy inferences regarding the effects of More skilled on Less skilled labour must be made with some caution.

After adjusting for the possibility that the Less skilled labour market has rigid wages, we find in table 8 that many of the coefficients are close to zero and are not significant⁷. Estimates which endogenise Less skilled labour and its higher order terms are presented in the appendix. Both conventional 2SLS and the manual procedure analagous to the six-input case yielded implausible results, including own elasticities of factor price as high as 17.83. In the 2SLS case, where they are valid, p values were all 0.85 or higher. Returning to the OLS-based results, capital and labour could be neither complements nor substitutes in the presence of rigid wages, in contrast to the flexible wages case. However, the results still suggest a rise in the supply of skilled labour would lead to a large and statistically significant rise in the quantity of unskilled employment.

⁷The symmetry in results is no coincidence. According to Sato & Koizumi (1973), $\sum_j \epsilon_{ij} = 0$. This can be verified in all the calculations presented. The result implies:

$$\sum_j \epsilon_{ij}^\rho = 0. \text{ In the 3 factor case, it is easy to show. Using equation (18),}$$

$$\epsilon_{ij}^\rho = -\epsilon_{ii}^\rho \text{ implies:}$$

$$\epsilon_{ii} + \epsilon_{ij} = \frac{\epsilon_{iu}(\epsilon_{ui} + \epsilon_{uj})}{\epsilon_{uu}}$$

Therefore, using Sato & Koizumi's result, it implies:

$$\epsilon_{iu} - \frac{\epsilon_{iu}\epsilon_{uu}}{\epsilon_{uu}} = 0.$$

Q.E.D

Table 8: Elasticities after allowing for rigid wages (aggregated inputs)

i	j	coef	p
ϵ_{ij}^{ρ}			
Capital	Capital	-0.18	0.49
	More	0.18	0.49
More	Capital	0.09	0.52
	More	-0.09	0.52
ρ			
Less	Capital	-0.39	0.39
	More	1.39	0.00

6 Conclusion

The key finding is that a rise in the supply of skilled workers / artisans will lead to a rise in demand for unskilled labour while a rise in the supply of semi-skilled workers will lead to a fall in demand for unskilled labour. These results are statistically significant, account for imperfectly elastic product market demand and allow for rigid unskilled wages. For other factor combinations, assuming perfectly elastic demand can predict factors are complements when they are in fact substitutes, while not accounting for rigid wages can also lead to the incorrect sign. Estimates of aggregated inputs also find More skilled and Less skilled labour are q complements.

However, a few cautions are in order. This cross section of firms is being used to simulate supply effects that necessarily will only take place over time. Moreover, much restructuring took place since the early 1990s and has continued beyond the sample period, meaning the nature of technological relationships may have changed since then. In addition, the predicted static effects assume no change in technology choice, which can be endogenous to the supply of skilled labour. There is theoretical and empirical evidence that increased skill supply produces more technologies that encourage firms to demand more skilled labour, with negative consequences for those remaining unskilled (Acemoglu, 1998, 2003). Finally, the parameters estimated only tell us about the macro effects of exogenous supply changes to the extent that the manufacturing technology is similar to that of other sectors.

Nonetheless, the estimated values have some clear policy implications. The findings suggest that there is indeed a shortage of artisans and that addressing this shortage would expand output and benefit those who remain unskilled. There is therefore cause for serious concern because prospective artisans make up a low proportion of those being trained (Paton, 2003). By producing semi-skilled workers, these training programs may raise unskilled unemployment. The highly disaggregated South African data has demonstrated a feature that may apply to other middle-income countries as well. Policy-makers in those countries could well need to think very carefully about which types of skills they wish to produce if they want to create positive

spillovers for their unskilled labour.

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Appendix: Instrumenting for Endogenous factors

Table 9 shows the elasticities endogenising unskilled labour and after adjusting for rigid unskilled wages in the six factor case. In the first stage regression, unskilled labour was predicted using other factor types and their higher order interactions (not those involving unskilled labour), unskilled wages and various controls. The second stage regression uses predicted unskilled labour and its interactions with the other factors. p values are not valid given this procedure. The results are consistent with those based on OLS estimates.

Table 10 presents the calculations in the three factor case based on conventional 2SLS, where unskilled wages, semi-skilled wages and five measures of recruitment difficulty are used as instruments for Less skilled labour and its three higher order terms. The first stage regression for Less skilled labour shows plausible signs including significantly negative unskilled wages (but insignificantly positive semi-skilled wages). The results find evidence for complementarity between skilled and unskilled labour, but the evidence is very weak given the high p values. Furthermore, the elasticities, especially the own-elasticities, are implausibly high.

Table 11 presents the calculations based on a manual two stage procedure. Less skilled labour is predicted using other factor types and their higher order interactions (not those involving Less skilled labour), unskilled and semi-skilled wages as well as various controls. Predicted values are interacted with other factor inputs to generate predicted higher order terms. p values are not valid given this procedure. While lower than for 2SLS, the values are still implausibly high. More skilled and Less skilled labour are found to be substitutes.

Table 9: Elasticities after adjusting for rigid unskilled wages (manual two stage procedure)

i	j	coef	i	j	coef
ϵ_{ij}^ρ					
Capital	Capital	-0.13	Skil/Art	Capital	0.06
	Man/Prof	-0.21		Man/Prof	1.04
	Sale/Cler	0.24		Sale/Cler	0.22
	Skil/Art	0.03		Skil/Art	-0.88
	Semi	0.07		Semi	-0.44
Man/Prof	Capital	-0.23	Semi	Capital	0.09
	Man/Prof	0.27		Man/Prof	-1.30
	Sale/Cler	0.49		Sale/Cler	-0.35
	Skil/Art	0.54		Skil/Art	-0.28
	Semi	-1.07		Semi	1.83
ρ					
Sale/Cler	Capital	0.13	Un	Capital	-0.27
	Man/Prof	0.24		Man/Prof	1.80
	Sale/Cler	-0.29		Sale/Cler	0.48
	Skil/Art	0.06		Skil/Art	0.89
	Semi	-0.14		Semi	-1.91

Table 10: Aggregated elasticities after allowing for rigid wages (2SLS)

i	j	coef	p
ϵ_{ij}^ρ			
Capital	Capital	17.83	0.87
	More	-17.83	0.87
More	Capital	-6.50	0.85
	More	6.50	0.85
ρ			
Less	Capital	-5.51	0.87
	More	6.50	0.85

Table 11: Aggregated elasticities after allowing for rigid wages (manual two stage procedure)

i	j	coef
ϵ_{ij}^{ρ}		
Capital	Capital	9.80
	More	-9.80
More	Capital	-3.17
	More	3.17
ρ		
Less	Capital	-1.35
	More	-2.35