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[1]

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Abstract

Commentators claim a shortage of skills, particularly artisanal labour, in South Africa is constraining output and that a rise in skill supply would benefit less skilled occupations. This assumes/implies skilled and unskilled labour are q-complements. This paper estimates Hicks Elasticities of Complementarity and elasticities of factor price. Aggregate estimates suggest more skilled (white collar) labour complements less skilled (blue collar) labour, so a rise in skill supply would lead to a rise in demand for less skilled labour. Disaggregated results show 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, inference on highly non-linear elasticities and a variety of estimation approaches.

1 Introduction

> *"Government's ambition to grow [the] manufacturing base risks being stillborn unless the country addresses a worsening skills crisis." - Paton (2003:18)*

The importance of skills to manufacturing and other industries is a topical issue in developing countries, as evidenced by the above quote from a lead article in the *Financial Mail.* The statement that artisans, for example welders or tool-makers, are "essential to every aspect of manufacturing . . . production" and that their shortage will "severely hinder ... ability to deliver on . . . capital investment projects" (pg 18), articulates the widely held belief 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.

The official unemployment rate is about 25% (Statistics South Africa, 2005). Much of South Africa's unemployment appears to be structural in that an oversupply of unskilled labour exists alongside estimates of 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 imply that skilled and unskilled labour are (Hicks) complements and not substitutes in production. If they are complements, a rise in the supply of skilled workers 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.

Increasing the skills of the workforce is regarded as a key requirement for reducing wage inequality (Bhorat, Leibbrandt, Maziya, van der Berg & Woolard, 2001), which was partly the outcome of South Africa's *apartheid* past. People who acquire such skills or training are likely to earn productivity linked wage increases (Fallon & Lucas, 1998), but this raises the question of 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.

The South African case is an interesting one to study because, due to its political history and labour market characteristics, serious attempts are being made to increase the supply of skills: 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 Sector Education Training Authorities (SETAs). Approximately 46 000 people were enrolled in such programmes at the start of 2004 and the number is rising (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.

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. Similarly, the cross-elasticity of factor price measures the percentage change in a factor price in response to an exogenous change in another factor's quantity. If the effect is positive, the factors are said to be q-complements. If the effect is negative, the factors are q-substitutes.

This paper uses a translog production function to measure Hicks elasticities of complementarity and cross elasticities between capital and five labour occupations. 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) white collar and (less skilled) blue collar workers.

An important early application was performed by Grant & Hamermesh (1981) to examine the interactions between youths, white women and other workers in the United States. Field (1988) investigates the HEC between free and slave labour while Vere (2001) estimates the parameters for skilled and unskilled labour over time in Taiwan. The study closest in spirit to ours is by Mak (2000), who studies whether workers with different education levels are q-complements or q-substitutes in Canada.

All documented empirical work assumes perfectly elastic product demand, which may cause it to find two factors are complements when they are actually substitutes. This paper allows for imperfectly elastic demand. It also adjusts for the possibility of one factor having rigid wages. Furthermore, it presents p values for the elasticities, despite their being non-linear functions of the technological parameters estimated.

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 q-complements while semi-skilled and unskilled labour are q-substitutes.) 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 a rise in the supply of more skilled (white collar) labour would raise demand for less skilled (blue collar) labour.

The results are robust to relatively inelastic demand in the product market while accounting for rigid unskilled wages preserves the relationship, which suggests a rise in the supply of skilled/artisanal workers would raise unskilled employment while a rise in the supply of semi-skilled workers would lower unskilled employment. Similarly, a rise in the supply of more skilled workers would raise less skilled employment. Our results are also robust to the choice of estimation method, whether it be a variety of OLS estimates, a range of instrumental variables methods or the use of an intermediates proxy approach similar to that of Levinsohn & Petrin (2003).

Section 2 compares and contrasts the Hicks concept of substitutability between factors with the more common concept due to Robinson (1933). The Hicks concept is at the core of a model for the macroeconomy presented in section 3, which also shows how we can adjust the model to allow for rigid unskilled wages. Section 4 presents how the elasticities are calculated using translog production function estimates. Section 5 investigates empirical issues, including a description of the firm-level dataset. It also discusses in some detail how we address the potential for endogeneity bias, including the challenges of applying a Levinsohn & Petrin approach and instrumentation methods to a translog function with many inputs. Section 6 presents the main results while section 7 shows they are robust. Section 8 offers concluding comments.

2 Two elasticity concepts: Hicks vs Robinson

> *"What now emerges is that [Joan Robinson] ought to have the sole right to the Elasticity of Substitution. Mine should have been defined by its reciprocal, which should have been given another name – Elasticity of Complementarity? It should then have been proved that in the two-factor case (alone) one was the reciprocal of the other."* – Sir John Hicks (1970:296)

This section introduces two distinct definitions of substitutability between factors, which happen to be equal in the two-factor context. We begin with a general statement on the demand for a factor before making two alternative sets of assumptions, which allow us to describe the elasticity of factor demand on the one hand and the elasticity of factor price on the other. We will present a definition of substitutability applicable to each of these sets of assumptions and argue that the appropriate elasticity concept to incorporate into our model is the Hicks Elasticity of Complementarity.

We refer to the rules developed by Marshall (1920:383) using a linearly homogeneous production function with two factors, say skilled and unskilled labour, $q = f(x_i, x_j)$. With product market price p, wage equals marginal revenue product: $w_i = pf_i$ and $w_j = pf_j$. Hicks (1963:244) writes the own elasticity of demand for x_i, $\frac{d\log x_i}{d\log w_i}$, as:

$$|\lambda_{ii}| = \frac{\sigma_{ij}\left(|\eta| + e_j\right) + s_i e_j\left(|\eta| - \sigma_{ij}\right)}{|\eta| + e_j - s_i\left(|\eta| - \sigma_{ij}\right)} \tag{1}$$

The demand for a factor in an industry is more elastic (high $|\lambda|$) if:

1. It can be easily substituted by the other factor (high σ)
2. Its share of revenue is higher (high s)[1]
3. The supply of the other factor is more elastic (high e)
4. Product demand is more elastic (high $|\eta| \equiv -\frac{d\log q}{d\log p}$)

Point 1 requires a measure of σ, which is a feature of the production technology. One such definition, as given in Robinson (1933), is

$$\sigma_{ij}^{R} = -\frac{d\log\frac{x_i}{x_j}}{d\log\frac{f_i}{f_j}}, \tag{2}$$

where she assumes output and the price of the other factor are constant. σ_{ij}^{R} is high if the factor is easily substituted by the other factor. When the supply of the other factor is perfectly elastic, $e \to \infty$ and we write (1) as:

$$|\lambda_{ii}| \equiv \left|\frac{d\log x_i}{d\log w_i}\right| = \sigma_{ij}^{R}(1 - s_i) + s_i|\eta| \tag{3}$$

Here, σ_{ij}^{R} captures the change in relative demand for the two factors due to the change in relative factor prices at constant output. For a fall in the price of one factor, profit maximizing industry output will rise and so will demand for both factors. However, as industry output rises, the product price falls, which mitigates the increase in demand for both factors. The second term, $s_j|\eta|$, captures the output effect. A measure of the compensated elasticity of labour demand, which does not allow for output effects, is given by:

$$|\bar{\lambda}_{ii}| \equiv \left|\frac{d\log x_i}{d\log w_i}\right|_q = \sigma_{ij}^{R}(1 - s_i) \tag{4}$$

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[1] This rule requires some qualification, specifically that $|\eta| > \sigma$

An alternative to Robinson's measure of σ is given by Hicks (1932,1963), who introduces,

$$\frac{1}{H_{ij}} = \frac{f_i f_j}{f f_{ij}}, \tag{5}$$

where f_{ij} gives the rate of change of the marginal product of one factor for a change in the quantity of the other factor. As presented in Hicks (1963:245), $\sigma = \frac{1}{H_{ij}}$ is increasing in the "facility of substitution" of the factors. Hicks' measure assumes the quantity of the other factor and the output price are constant. With $e = 0$ we get a measure of the inverse demand for the factor from (1):

$$|\hat{\epsilon}_{ii}| \equiv \left|\frac{1}{\lambda_{ii}}\right| \equiv \left|\frac{d\log w_i}{d\log x_i}\right| = (1 - s_i)H_{ij} + \frac{s_i}{|\eta|} \tag{6}$$

$\hat{\epsilon}$ is the elasticity of factor price (Hamermesh, 1993). It describes the change in factor price necessary for firms to absorb the extra supply of that factor in production. Here, H_{ij} captures the percentage change in relative factor prices that must take place after a change in relative factor quantities, assuming output price is constant. After a rise in factor supply, output expands. However, expanded output lowers price, which lowers the marginal revenue product of the factors and therefore means the price of factor x_i must fall by more. The second term therefore acts to make $|\hat{\epsilon}_{ii}|$ higher. If we assume perfectly elastic product demand, then:

$$|\epsilon_{ii}| \equiv \left|\frac{d\log w_i}{d\log x_i}\right|_p = H_{ij}(1 - s_i) \tag{7}$$

Inspection of (7) and (4) show what appears to be a duality between H_{ij} and σ^R_{ij}. Hicks (1963:373) shows that, in the two factor case, $\sigma^R_{ij} = \frac{1}{H_{ij}}$, but the simple relationship ends when there are more than two factors.[2]

Hicks (1970) labelled H_{ij} the elasticity of complementarity (HEC). Factors i and j are q-complements if $H_{ij} > 0$ ($\hat{\epsilon}_{ij} > 0$ if we allow prices to change). They are q-substitutes if $H_{ij} < 0$. If two factors are q-complements, then a rise in supply of the one factor will lead to a rise in the wage of the other factor. If they are q-substitutes, a rise in the supply of one factor will lead to a fall in the wage of the other factor. In a two factor setting, the factors are necessarily complements, but this does not hold for the multiple factor case modelled in the next section.

3 A macro model of exogenous input quantity changes

This section presents a macroeconomic multiple factor model. The phenomenon we plan to model is the effect of an exogenous increase in the quantity of a factor on demand for other factors, especially unskilled labour, as measured by the effect on wages. This assumes quantities are exogenous and wages are endogenous, not the other way around, and the HEC is therefore the more appropriate concept to measure. Assuming an exogenous increase in inelastic factor supply is appropriate because, like the Department of Labour (1997), we believe it is the supply of training rather than demand that has thus far constrained skill acquisition. The assumption that wages are fully flexible is more difficult to justify. Collective bargaining and other labour

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[2] Allen (1938) extends Robinson's concept to multiple factors. See Sato & Kouizumi (1973) and Syrquin & Hollander (1982) for more detailed relationships between the two elasticity concepts.

market institutions have driven up the costs of labour in some industries, particularly towards the lower end of the skill spectrum (Fallon & Lucas, 1998). Therefore, we augment the standard model with one which allows for unskilled wages to be rigid.

3.1 Fully flexible wages

Our economy uses n exogenously supplied factor inputs, 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.

$$Y = f(X_1, ..., X_n) = hf(x_1, ..., x_n) \tag{8}$$

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

$$P = P(Y), \frac{\partial P}{\partial Y} < 0 \tag{9}$$

Profit maximizing 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.

$$w_i = P(Y) f_i(X_1, ..., X_n), \quad f_i = \frac{\partial f}{\partial X_i} > 0 \tag{10}$$

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 (11):

$$\frac{dw_i}{dX_j} = \frac{dP}{dY} f_i f_j + P f_{ij}, \text{where } f_{ij} = \frac{\partial^2 f}{\partial X_i \partial X_j}, \ f_{ii} < 0 \tag{11}$$

Converting to elasticity form:

$$\begin{aligned} \frac{d \log w_i}{d \log X_j} &= \frac{X_j f_i f_j}{w_i} \frac{dP}{dY} + \frac{P f_{ij} X_j}{w_i} & (12) \\ &= \frac{X_j f_i f_j P}{w_i f} \frac{1}{\eta} + \frac{f_{ij} f}{f_i f_j} \frac{f_i f_j P X_j}{f w_i}, & (13) \end{aligned}$$

$\eta < 0$ is the elasticity of demand in the product market. The Hicks elasticity of complementarity between factors i and j is:[3]

$$H_{ij} = \frac{f_{ij} f}{f_i f_j} \tag{14}$$

Factor j's share of output is given by:

$$s_j = \frac{f_j X_j}{f} \tag{15}$$

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

Together with equation (10), this can be used to rewrite (13) as:

$$\frac{d\log w_i}{d\log X_j} = \hat{\epsilon}_{ij} = s_j\left(H_{ij} - \frac{1}{|\eta|}\right) \tag{16}$$

$\hat{\epsilon}_{ij}$ is the elasticity of factor price. A rise in the supply of a factor, for example, works through 3 channels. (i) Because output is determined by the supply of factors, 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 factors means that, holding output constant, $f_{ij} \lesseqgtr 0$ for $n > 2$ and $i \neq j$.

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

$$\epsilon_{ij} = s_j H_{ij} \tag{17}$$

Equations (16) or (17) can be interpreted as the change in factor returns necessary for the economy to generate 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 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.

3.2 A rigid wage

Given that wages may be rigid and that we do in practice see unskilled unemployment in South Africa and other developing countries, we employ the methods first used by Johnson (1980). In the simple case, where only one factor's wage is completely rigid, we 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. In this model, we do not allow for changes in product price and set $P = 1$ on the assumption of perfectly elastic product demand. The marginal productivity conditions are:

$$w_u = f_u(X_u, X_2, ..., X_n) \tag{18}$$

$$w_i = f_i(X_u, X_2, ..., X_n), \quad i = 2, ..., n \tag{19}$$

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

$$\frac{dx_u}{dx_j} = \frac{-f_{uj}}{f_{uu}} \tag{20}$$

$$\frac{dw_i}{dx_j} = \frac{-f_{iu}f_{uj} + f_{ij}f_{uu}}{f_{uu}}, \quad i = 2, ..., n \tag{21}$$

Using equation (15), $X_i = \frac{fs_i}{f_i}$ and, by equation (14), $f_{ij} = \frac{f_i f_j H_{ij}}{f}$. Hence:

$$\begin{aligned} \frac{d\log x_u}{d\log x_j} &\equiv \rho_{uj} = \frac{-H_{uj}s_j}{H_{uu}s_u} && (22) \\ \frac{d\log w_i}{d\log x_j} &\equiv \epsilon^{\rho}_{ij} = \frac{s_j\left(-H_{iu}H_{uj} + H_{ij}H_{uu}\right)}{H_{uu}}, \quad i = 2, ..., n && (23) \end{aligned}$$

As presented in Grant & Hamermesh (1981), equations (22) and (23) demand a burdensome calculation of coefficients and p values. However, simply using (17) can aid in computation:

$$\begin{aligned} \rho_{uj} &= \frac{\epsilon_{uj}}{-\epsilon_{uu}} && (24) \\ \epsilon^{\rho}_{ij} &= \epsilon_{ij} - \frac{\epsilon_{iu}\epsilon_{uj}}{\epsilon_{uu}} && (25) \end{aligned}$$

ϵ_{uj}, ϵ_{ij}, ϵ_{uu} and ϵ_{iu} represent what the elasticities would have been if all wages were flexible. It is therefore possible to infer the effects of a change in the quantity of a factor on the quantity of unskilled labour (equation (24)) or on the prices of other factors, taking unskilled wage rigidity into account (equation (25)).

4 Elasticities and translog production functions

To find the elasticities of interest, we need to estimate the parameters of the underlying technology. The estimation of a production function with exogenous input quantities, rather than a cost function with exogenous input prices, is consistent with the assumptions underlying the HEC and elasticity of factor price. The possibility that input quantities are endogenously chosen by the firm is an estimation issue discussed in section 5. Furthermore, production function estimates provide a far more tractable method for calculating the HEC and elasticities of factor price. This study uses translog functions, which were developed by Christensen, Jorgenson & Lau (1973) and employed to estimate H by Mak (2000).

$$\log q = \log \alpha_0 + \sum_i \alpha_i \log x_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \log x_i \log x_j + \omega \tag{26}$$

q is a measure of output (value added or turnover) and x_i, x_j are inputs earning $w_i = \frac{\partial q}{\partial x_i}, w_j = \frac{\partial q}{\partial x_i}$. We assume representative firms make random errors in their use of the inputs available to them, resulting in error term ω, which is normally distributed with a mean of zero and a constant variance. The error term must be orthogonal to the inputs, an issue which is discussed in section 5.4.

Slutsky symmetry conditions $\beta_{ij} = \beta_{ji}$ 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 elasticities. Furthermore, technological features are not assumed but tested for and, if accepted, imposed on the system. Equation (26) is homogeneous of degree k if:

$$\sum_j \beta_{ij} = \sum_i \beta_{ij} = 0 \text{ and } \sum_i \alpha_i = k \tag{27}$$

If $k = 1$, there are constant returns to scale (Chung, 1994). Differentiating (26) with respect to $\log x_i$ yields

$$\frac{d \log q}{d \log x_i} = \alpha_i + \sum_j \beta_{ij} \log x_j, \tag{28}$$

but

$$\frac{d \log q}{d \log x_i} = \frac{\partial q}{\partial x_i} \frac{x_i}{q} = s_i, \tag{29}$$

which is the share of factor i in output. Therefore:

$$s_i = \alpha_i + \sum_j \beta_{ij} \log x_j \tag{30}$$

It is common to estimate the system of equations (30) to improve efficiency characteristics (Berndt, 1991). However, in the data used for this chapter, factor shares are not available, so the parameters estimated in (26) are used to predict s_i and calculate elasticities in a translog context: observe that $w_i = \frac{q}{x_i} s_i$, so

$$\frac{d \log w_i}{d \log x_j} = \frac{x_j}{w_i} \frac{d}{dx_j} \left(\frac{q}{x_i} s_i \right) \tag{31}$$

Differentiating (26), holding the product price component of q constant and recalling $\frac{dq}{dx_j} = w_j$:

$$\frac{d \log w_i}{d \log x_j} = \frac{x_j}{w_i} \left(\frac{q \beta_{ij}}{x_i x_j} + \frac{w_j s_i}{x_i} \right) = \frac{\beta_{ij}}{s_i} + s_i \left(\frac{w_j x_j}{q} \right) \left(\frac{q}{w_i x_i} \right) \tag{32}$$

Therefore:

$$\epsilon_{ij} = \frac{\beta_{ij}}{s_i} + s_j \tag{33}$$

By (17):

$$H_{ij} = \frac{\beta_{ij}}{s_i s_j} + 1 \tag{34}$$

If all $\beta_{ij} = 0$, we have a Cobb Douglas production function in (26), constant factor shares for each factor in system (30) and $H_{ij} = 1$. Furthermore (Binswanger, 1974):

$$\epsilon_{ii} = \frac{\beta_{ii}}{s_i} + s_i - 1 \tag{35}$$

$$H_{ii} = \frac{\beta_{ii}}{s_i^2} + 1 - \frac{1}{s_i} \tag{36}$$

5 Empirical issues

This section introduces the data used for estimation and argues why it is informative for our model of the macroeconomy. We discuss issues of inference on the non-linear elasticity estimates as well as theoretical and empirical aspects of separability. The possibility of endogeneity bias and potential remedies - including various proxies and the use of instrumental variable approaches - is analyzed in the context of the fully flexible and rigid wage models.

5.1 Data from the firm-level manufacturing survey

The dataset is the National Enterprise Manufacturing Survey (NE survey) covering the period of 1998. After adjusting for non-response and outliers and because we choose to use firms that have a value added of more than 1 million Rand only, the number of firms in the sample is abut 250. Descriptive statistics of the key production function variables in our data are in Appendix A, but for a thorough analysis of the data, see Bhorat & Lundall (2002). The variables for the production function are the capital stock (adjusted for shift capacity utilization in most specifications) and employment numbers by occupation group. The five occupations are:

- Managerial/Professional
- Sales/Clerical
- Skilled/Artisan (technicians, welders)
- Semi-skilled (machinery operators)
- Unskilled (labourers, security guards)

Disaggregated estimates use all five occupations while aggregated estimates combine the Managerial/Professional and Sales/Clerical occupations into white collar workers and aggregate the Skilled/Artisan, Semi-skilled and Unskilled occupations into blue collar workers.

There is 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. Then raw materials as a percentage (p) are multiplied by turnover (q) to get a measure of raw materials costs. Value added is constructed as sales minus the constructed raw materials so that

$$v = (1 - p)q \tag{37}$$

Wages and the cost of capital, which are candidate instrumental variables, are not available from the NE survey. However, such data have been constructed for use in other work and can be used here.[4]

5.2 Firm-level data for a macro model

Using firm-level manufacturing information to make inferences about the macroeconomy relies on the assumption of constant returns in the model, which we find in section 6.1. Constant returns allows us to consider many representative firms and one single firm for the economy interchangeably. This means we can use variations across firms in their inputs to estimate the parameters of a macro production function. In other words, if we know the parameters in (26) and if the firms in the economy have identical linearly homogeneous production functions, then we can use equations (33)-(36) to make statements about economy wide effects.

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[4] Details of construction and the application of such data are available in Edwards & Behar (2006). In summary, we use household data to estimate wages for each firm and occupation type using characteristics common to both data sources.

One potential drawback of using manufacturing data is that the firms in the survey may not be sufficiently representative of those 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), contributing about 20% to GDP (Smith, 2003). It also includes a particularly heterogeneous range of economic activity by international standards, ranging from the beneficiation of primary commodities to relatively service intensive industries (Wood, 1995). This means manufacturing is quite representative of broader economic activity. 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.

5.3 Separability

Separability of the production technology implies we can aggregate certain inputs or exclude inputs to estimate elasticities of complementarity. It also is needed to justify the value added specification (Chung, 1994). Drawing on Berndt & Christensen (1973ab), a translog production function is weakly separable with respect to input x_r if:

$$s_i \beta_{jr} - s_j \beta_{ir} = 0 \tag{38}$$

Each factor share is positive so strong separability holds if:

$$\beta_{ir} = 0 \ \forall i : i \neq r \tag{39}$$

If (39) does not hold for some β_{ir}, we can draw on Berndt & Christensen (1973b) to establish the condition for weak separability:

$$\frac{\alpha_i}{\alpha_j} = \frac{\beta_{ii}}{\beta_{ij}} = \frac{\beta_{ij}}{\beta_{jj}} = \frac{\beta_{ir}}{\beta_{jr}} \tag{40}$$

This must hold for each factor pair x_i, x_j whose elasticity we wish to obtain. If the production function is weakly separable with respect to x_r, then we can legitimately drop it for estimation purposes. Furthermore, Sato (1975) shows how weak separability with respect to raw materials can be used to justify the value added specification, where raw materials are omitted and value added (rather than turnover) is used as the measure of output. We test restrictions of the form (39) or (40) using Wald tests on full output regressions. Tests of (39) are rejected but tests of weak separability for each combination of factors do not reject separability, even if we do not adjust for the probability of a type I error.[5] Most p values are well above 0.90. The tests therefore justify the use of the value added specification in the production function.[6]

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[5] When performing multiple tests, it is arguably appropriate to make an adjustment to the statistics used in each test to prevent the false rejection of the null hypothesis. We perform Wald tests which do and don't adjust the probability values required for each restriction. We use the Sidak adjustment(see Statacorp, 2003). The choice of method does not appear to matter. Even were we not to make such an adjustment, we still fail to reject weak separability.

[6] Full details are available on request.

For us to aggregate factors x_i and x_j, they must be weakly separable from all others in the production function such that, analogous to (38),

$$s_i\beta_{jk} - s_j\beta_{ik} = 0 \ \forall k : k \neq i, k \neq j \tag{41}$$

If we wish to combine occupations types j in set J into an aggregate - for example managers/professionals and sales/clerical workers into a white collar aggregate - a sufficient condition is that:

$$\beta_{jk} = 0 \ \forall j : j \in J, k \notin J \tag{42}$$

The discussion of results will confirm that this holds.

5.4 Endogeneity bias

The default stochastic specification (26) assumes firms face exogenous variation in the inputs available to them. In addition, they make errors in the use of the inputs available, which we assume to be normally distributed with a mean of 0 and a constant variance ω. A necessary condition for valid estimation by ordinary least squares (OLS) is that the errors are orthogonal to the inputs and other controls for technology. While exogeneity of the factors is arguably valid for the economy as a whole, it is not justified at the firm level.

Each firm chooses its inputs using information (I) possibly not in our dataset. For example, I may contain information on a positive productivity shock or an improved market outlook, which would lead to increased use of inputs and output. In equation (26) ω would include I and hence would be correlated with x_i, causing biased estimates. Although it is difficult to judge the direction of potential endogeneity bias with many inputs (Greene, 2003), it is likely the bias would be upwards, producing high estimates of returns to scale. Furthermore, inputs that are more flexible would tend to be biased the most. This problem is common to many studies but is likely to be less acute with cross sectional data like ours.[7]

Griliches & Mairesse (1995) observe a number of responses to this endogeneity problem. One is outright denial or implicit assumptions on the orthogonality of ω. Grant & Hamermesh (1981), Johnson (1980), Field (1988), Appelbaum & Kohli (1997) and Mak (2000) make no mention of the issue.

One can try to control for the unobserved information in the error term through proxies, which are variables that are correlated with I because they give an indication of the firm's expectations of conditions for the relevant time period. Amongst our set of firm-specific controls, we have information on the firm's expected price change for the year and on the firm's expected impact of changes in labour legislation.

Levinsohn & Petrin (2003) establish conditions under which including variables for observed use of intermediate goods (like raw materials) adequately proxies for the unobserved shocks and hence generates consistent estimates of the other inputs. The procedure involves two steps. The first step controls for the unobservables by expressing value added in terms of the inputs and a non-parametric function of capital[8] and raw materials $\phi(x_k, x_r)$. Alternatively, the non-parametric function can be approximated by a higher order polynomial, as done by Blalock

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[7] Panel data allows the use of fixed effects estimates, but they only address this source of endogeneity if the unobserved shock is constant in each firm over time (Ackerberg, Caves & Frazer, 2005).

[8] Capital differs from the other inputs on the assumption that the capital stock at time t was actually decided at $t-1$, while the other inputs are chosen at t conditional on the full information set.

& Gertler (2004). It only requires terms at time t and can therefore be employed in a single cross-section. The second step, however, does require information over multiple periods, which we do not have. This would be needed to identify the capital coefficient and the higher order terms in capital, which is necessary for the calculation of all elasticities (cf equations (33) and (34)).

A further complication is our use of a translog rather than Cobb Douglas function. Although Blalock & Gertler (2004) apply the method to a translog function, they do not need to identify their terms in capital. In addition, the credentials of the procedure have not to our knowledge been verified formally in a translog context. Furthermore, recent doubts on its validity and reliability have been expressed even under standard settings (see Ackerberg, Caves & Frazer, 2005).

With these caveats in mind, and recalling our raw materials measure is constructed, we implement a variant of the Levinsohn-Petrin procedure as a robustness check. We assume the production technology is a Cobb Douglas aggregation of capital and labour, where labour is a translog function of labour inputs. In terms of equation (39), we assume all $\beta_{ik} = 0$, where k is capital, such that capital is separable from the other inputs. Thus, all higher order terms in capital are exclusively capturing the unobservables I, not an underlying feature of the technology. In other words, we write (26) as:

$$\log q = \log \alpha_0 + (\alpha_k \log x_k) + \left(\sum_i \alpha_i \log x_i + \frac{1}{2} \sum_i \sum_j \beta_{ij} \log x_i \log x_j \right) + \phi\left(x_k, x_r\right) + \omega \quad (43)$$

If the procedure is valid, $\phi\left(x_k, x_r\right)$ controls for I such that ω is orthogonal to the inputs. Furthermore, we use the assumption of constant returns to scale ($\sum_i \alpha_i = k$) to identify capital's contribution to output and for use in elasticity calculations. The assumption that all $\beta_{ik} = 0$, which entails assuming $H_{ik} = 1$, is a worthwhile restriction to make in order to test the robustness of our findings of interest, namely those between labour inputs.

Another possible robustness check is the use of instrumental variables approaches: instead of controlling for the endogenous component of the error term, one generates predicted values of the inputs using instruments. Good instruments are uncorrelated with I while good proxies must be correlated with I. Our application requires an extraordinarily large number of instruments, which effectively denies us the option of performing standard two stage least squares (2SLS) in most cases. For a translog function, we would need one instrument to identify each of the six inputs and their interactions. However, using a simpler Cobb Douglas specification, results suggest the use of OLS with proxies is superior to the use of 2SLS.[9]

Our core model has wages as fully flexible and endogenous while all inputs are exogenous. Estimation by OLS corresponds to these assumptions. However, in the rigid wage model, one factor quantity is endogenous by assumption and must be instrumented accordingly. In

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[9] We estimate a Cobb Douglas function with proxies and compare the results to 2SLS, which now requires a manageable number of instruments. The Hausman specification test for endogeneity finds a p value of 0.90 for the null hypothesis that the coefficients do not differ systematically, so there is no endogeneity bias. The difficulty with this test is the underlying conjecture that the IV regression coefficients are consistent. A Hausman type 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 variable. Although these results do not in themselves validate OLS, they motivate its being preferable to 2SLS. Full details of these results are available on request.

other words, the rigid wage model says we must instrument for the input whose wage is rigid. Instrumenting for only one input reduces the number of instruments required. This makes a case for applying 2SLS and instrumenting for the unskilled wages.

Thus, although we initially use OLS for the rigid wage case, like Johnson (1980) and Grant & Hamermesh (1981), we perform additional estimations which endogenize 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, it would be theoretically appropriate to use only that factor's wage (rather than all factor prices) as an instrument. This is because the model assumes that wages, except the rigid wage, are endogenous to output and therefore by definition invalid instruments.

Instead of instrumenting for every term involving the unskilled wage, which would be done in the first stage of 2SLS, we only predict the first order term for unskilled labour (using the unskilled wage as the identifying instrument) and use that predicted value to construct predicted values for all the terms involving unskilled labour.[10] We also perform this procedure for aggregated inputs, instrumenting for blue collar workers rather than unskilled labour. For the aggregated inputs, it is also feasible in terms of the number of instruments required to perform standard 2SLS, treating blue collar labour and its interactions with the other two factors as endogenous.

In summary, we will present our main flexible-wage results based on OLS estimates with proxies. As a robustness check, we will present the results based on a variant of the Levinsohn Petrin (2003) approach. Our model allowing for rigid wages will also draw on OLS, but robustness will be verified using instrumental variable approaches.

5.5 Inference

The elasticity estimates are highly non-linear combinations of the coefficients and data. 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 (eg Chung, 1994; Hamermesh, 1993). With respect to translog estimates of H and ϵ, Vere (2001) is the only person who presents confidence intervals for elasticity estimates. For our main results, we apply the "Delta" method, which calculates Taylor approximations to underlying distributions of functions of parameters (Greene, 2003), to the elasticity estimates. The resulting p values can be sensitive to the distributions of the underlying parameters in finite samples, and should be treated as indications only.

6 Main results

This section presents our main results. We start with the disaggregated results, where the discussion briefly reviews the underlying regression before discussing the elasticities under the flexible- and rigid-wage cases. We then discuss the aggregate results.

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[10] Such manual procedures dictate 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 might be inconsistent.

Table 1: 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

6.1 Disaggregated results

Unrestricted regressions[11] yielded returns to scale estimates of 1.06, which were insignificantly different from unity, suggesting upward bias is limited. Imposing the restriction of constant returns, besides enhancing efficiency, further limits the potential endogeneity bias. The regression results for our main disaggregated OLS regression are in Appendix B (OLS1 in column I). The overall fit is good and coefficients on all the higher order terms are jointly significant, rejecting the null hypothesis that the production technology is Cobb Douglas. The control variables used are not of direct interest but they are significant, contribute explanatory power and suggest many of the firm-specific effects are controlled for. Our variable for the expected maket effects of labour legislation (g) is significant, which suggests it captures some of the source of potential engoeneity bias. The results of separability tests permit us to proceed to more aggregated estimates, but first we present our disaggregated elasticities.

6.1.1 Fully flexible wages

Table 1 presents the HEC estimates calculated using equations (30), (34) and (36).

The results show 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 complements while semi-skilled and unskilled labour are substitutes. There appears to be no pattern of complementarity between capital and the occupations.

Table 2 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) and p values calculated using the Delta method.[12] 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 the technology does not exhibit a strong pattern of complementarity.

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[11] Results are available on request.

[12] The Hicks elasticity involves far more parameters than the elasticity of factor price. This is especially challenging because two predicted factor shares, each of which contains many paramteres, are *multiplied* by each other. The reliability of such p values would be greatly compromised. We found very high p values for the majority of estimates, despite finding low p values for the elasticity of factor price.

Table 2: 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	.

There are many parameters so we focus on unskilled wages. 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 a key result. 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 can be considered a small open economy. Nonetheless, if product demand elasticities are not perfect, the estimates will tend to be too positive, so some factor pairs thought to be complements may be substitutes. No documented studies attempt to allow for this, but we calculate values of η that would make $\hat{\epsilon}_{ij}$ equal to zero. By (16), $\eta = -H_{ij}^{-1}$ for strictly positive factor shares. If the elasticity is η or less elastic, then a positive elasticity would become negative. Obviously, for $\epsilon_{ij} < 0$, $\eta > 0$, so the calculation is not presented. In other words, we ask how inelastic demand must be to overturn a result that two inputs are complements. The more inelastic demand must be, the less likely it is that we are incorrectly predicting two factors are q-complements.

The calculations in the table yield many relatively high threshold values of $|\eta|$ that could easily exceed the true value. In contrast, the low value of $|\eta| = 0.13$ suggests skilled/artisanal and unskilled labour are complements even after accounting for imperfectly elastic product market demand.

6.1.2 Rigid wages

The bottom right corner of table 3 presents the employment response of unskilled workers to changes in the quantities of other factors (equation (24)) based on the same regression. 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 the table presents the price responses of the other five factors (equation (25)). There are a few sign switches relative to table 2, but these are 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. Note that a rise in supply of semi-skilled workers could lead to a rise in its own wage. Equation (25) 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.

6.2 Aggregate results

Aggregation may be desirable for various reasons. It is less demanding of the data and the vast majority of models employ a single elasticity between skilled and unskilled labour, often proxied by white and blue collar workers. Appendix D has the results of the OLS regression in column I, which again provides a good fit and jointly significant higher order terms.

Turning to the elasticities[13] in table 4, the numbers suggest capital and white collar workers tend to complement each other in production while capital and blue collar workers appear to sub-

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[13] Out 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 maxium of three.

Table 3: 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

Table 4: Hicks Elasticities of Complementarity (blue and white collar workers)

$H_{ij} = H_{ji}$		j		
		Capital	White	Blue
	Capital	-0.35	0.33	-0.65
i	White	0.33	-0.71	1.70
	Blue	-0.65	1.70	-4.35

stitute each other in production. This is similar to the concept of capital-skill-complementarity employed by Krussell et al. (2000), but the findings are not robust. In the disaggregate results, capital was not necessarily a bigger complement with the more skilled occupation types. A finding that is consistent with the disaggregate findings is the complementarity between the more skilled and less skilled occupation types: a general rise in the proportion of skilled workers would lead to a fall in the wage premium.

Table 6.2 presents elasticities of factor price. A rise in the quantity of capital would raise white collar wages but lower blue collar wages. However, the findings are not significant, and the value of η suggests allowing for imperectly elastic product demand would overturn the positive effect on white collar workers. In contrast, the second last row suggests a 1% rise in the quantity of white collar workers would lead to a 1.05% rise in blue collar wages. This estimate is significant and it would require moderately inelastic product demand to be overturned. Therefore, a general rise in the skill supply would benefit the less skilled.

Table 5: Elasticities of Factor Price (blue and white collar workers)

Table 6: Elasticities after allowing for rigid wages (blue and white collar)

ϵ_{ij}				
i	j	coef	p	η
Capital	Capital	-0.05	0.86	.
	White	0.20	0.47	-3.06
	Blue	-0.15	0.55	.
White	Capital	0.05	0.50	-3.06
	White	-0.44	0.00	.
	Blue	0.39	0.00	-0.59
Blue	Capital	-0.10	0.55	.
	White	1.05	0.01	-0.59
	Blue	-0.96	0.01	.

These conclusions are re-inforced when blue collar wages are assumed rigid. The interaction between capital and the occupation types is practically zero and imprecisely estimated. The last row suggests a 1% rise in white collar workers would lead to a 1.05% rise in blue collar employment, an estimate which is significant.

i	j	coef	p
ϵ^{ρ}_{ij}			
Capital	Capital	-0.04	0.91
	White	0.04	0.91
White	Capital	0.01	0.91
	White	-0.01	0.91
ρ			
Blue	Capital	-0.10	0.58
	White	1.05	0.00

In summary, our main findings are that a rise in skill supply would benefit less skilled workers. Within blue collar occupations, a rise in skilled/artisanal workers would lead to a rise in unskilled wages/employment while a rise in semi-skilled workers would lead to a fall in unskilled wages/employment. Capital exhibits no clear pattern of complementarity with the disaggregated occupation types, although there is tentative evidence capital complements white collar workers and substitutes for blue collar workers.

7 Robustness

We have presented our claims based on our preferred OLS estimate. We now present some alternative results based on a variety of estimations. To keep the number of combinations manageable, we restrict ourselves to presenting alternative estimates of H_{ij} and ϵ_{ij} based on OLS regressions and the Levinsohn-Petrin (2003) variants. We show the robustness of estimates of ϵ^{ρ}_{ij} and ρ to instrumental variables approaches.

7.1 Disaggregated estimates

7.1.1 Disaggregated regression results

Appendix B presents a table of the regression results from five representative regressions. We postpone the bulk of comparisons to the actual elasticity estimates, because it is very hard to compare such a large number of coefficients in a translog function. The first column is the OLS used for the main results in the previous section. The second column is an alternative OLS regression with an additional control variable. This variable is a measure of the firm's expected change in the product's price for the current period. On the assumption this expectation was formed at the start of the relevant period, it would provide a remedy to potential endogeneity bias. Overall it makes little difference to the results but comes at the cost of some 21 observations, which is why the regression in column 1 is preferred.

In columns II and IV, LP1 and LP2 refer to Levinsohn Petrin (2003) regressions.[14] The difference is that, while LP1 uses the capacity-adjusted capital stock like the other regressions, LP2 uses the unadjusted stock. While adjusting for capacity arguably produces a better measure of the capital input, it undermines its claim to being a state variable determined in the previous period, which is a necessary condition for consistent estimates under this procedure.

There are no interactions between capital and the occupations because of the identifying assumptions described in section 5.4, while the coefficient on capital is to be interpreted as part of the quadratic approximation to $\phi\left(x_k, x_r\right)$. The higher order terms are not jointly significant. In contrast, a joint test of the terms involving raw materials is significant in both LP specifications[15] This would be consistent with the interpretation that these proxy variables are capturing some of the potential endogeneity bias.[16]

MAN in column V is the manual instrumental variables procedure described in section 5.4. The p values have not been adjusted for the two stage procedure, but indicate the instrumented terms involving unskilled labour are estimated with some precision and the overall fit remains good.

7.1.2 Disaggregated elasticities

The first four columns of the table in Appendix C present measures of elasticities of complementarity (H_{ij}), which are useful for summarising differences in signs. Comparing OLS1 and OLS2, we see that only two pairs have different signs: managerial/professional - skilled/artisanal and sales/clerical - unskilled. Comparing the LP regressions to OLS1, our identification assumptions necessarily make $H_{ij} = 1$ for terms involving capital, which leads to differences in three of

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[14] In addition to the translog regressions presented, we ran Cobb Douglas specifications comparing the results with no controls, the controls in columns 1 and 2, and LP proxies. The choice of control variable made little difference to the specification, suggesting there is either little endogeneity bias or they are inadequately capturing it. The use of LP proxies tended to affect the variables in the manner predicted, with the coefficient on capital rising and that on the most flexible labour type(s) falling. If the production technology is Cobb Douglas, this suggests the LP proxies are capturing some of the unobserved sources of endogeneity. However, it could just be that the higher order terms, especially involving capital, are merely reflecting the fact that the technology is not adequately represented by Cobb Douglas first-order terms only.

[15] Higher order polynomial approximations were also investigated, but the highest order terms were insignificant and the choice of polynominal made no difference to the results.

[16] However, this could just be capturing some firm-specfic aspects of the production technology. All other specifications have a control variable for the share of raw materials in costs to capture this aspect.

the five signs involving capital in LP1 and LP2. Of the remaining ten pairs, only the sign between the sales/clerical and skilled/artisanal occupations differs in LP1 while LP2 also reports a difference for sales/clerical and managerial/professional workers. Purely looking at the sign switches and ignoring any magnitudes, it appears the estimation approaches yield consistent results. Even if we constrain the technology as we do in the LP estimates, the relationships within the production relationships are intact. In other words, semi-skilled and unskilled workers are q-substitutes while skilled/artisanal and unskilled workers are q-complements.

Some of the sign switches involve estimates which were very close to zero, while others may yield materially different numbers despite having the same sign. For a better gauge of magnitudes, we use columns IV-VIII, which present elasticities of factor price (ϵ_{ij}). Dramatic variation in estimates is limited; one example is the elasticity of semiskilled workers with respect to sales/clerical workers. The biggest range involving a sign switch is the effect of sales/clerical workers on unskilled workers, where the range is from -0.15 to 0.74. Overall, it seems most of the uncertainty involves the sales/clerical occupation, which may be because this occupation involves a wide range of tasks and activities. Focussing on the effects on unskilled labour, we see there is some variety in the size of the estimates, but in no case is the estimate in column 1 the largest, so our estimates presented in the main results are conservative.

Columns IX-XI refer to the rigid unskilled wage model, comparing two OLS estimates and the manual instrumentation approach (MAN). ϵ^{ρ}_{ij} - the elasticity of factor price between the other factors when unskilled wages are fixed - can vary somewhat, especially between OLS1 and OL2. Many of these estimates are merely being consistent in predicting values of about zero. We are more interested in the effects on unskilled employment (ρ). Here, we notice some variation involving the effects of capital and sales/clerical workers. Most importantly, however, we see complete consistency within the production occupations. In both cases, our original OLS estimates were the most conservative estimate. The manual IV process generates the median values among the three: a 1% rise in skilled/artisanal labour would raise unskilled employment by 0.89% while a rise in semi-skilled labour would reduce unskilled employment by 1.91%.

7.2 Aggregate estimates

Appendix D presents four sets of regression results. The first coumn is the OLS regression used for the main results. The second column is a LP regression with the unadjusted capital stock. The third column presents the second stage of estimates performed using standard 2SLS.[17] The fourth is based on the manual instrumentation procedure. In all cases, we find the higher order terms are jointly significant, which rejects the null hypothesis that the technology is Cobb Douglas. The 2SLS estimates are generally less precise while p values from the manual procedure are likely to be too low. Column 2 reports jointly significant terms in raw materials, suggesting a role for the LP proxy in eliminating potential sources of endogeneity bias.

With three inputs, it is manageable to compare some of the coefficient estimates, although it is still not straightforward for a translog function. We note the sign patterns on the higher order terms are consistent across estimates, with those from the main OLS regressions being the lowest in absolute value. The first order coefficient for white collar workers is highest in the OLS estimates. Looking at the first order terms in isolation, this is consistent with the view that, because white collar workers are arguably the most flexible input, the other methods employed are acting to reduce endogeneity bias.

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[17] The lower number of inputs makes this procedure feasible, unlike for the disaggregated production function.

Appendix E compares elasticity estimates. For the fully flexible wage model, we restrict our comparison to that between OLS and LP. The elasticity between blue and white collar workers is positive, suggesting the skill types are complements. Using ϵ_{ij} to compare magnitudes, all elasticities tend to be larger under the LP procedure. In particular, a 1% rise in the supply of white collar workers is estimated to lead to a 1.64% rise in blue collar wages, while the elasticity is only 1.05 under OLS.

For the rigid blue-collar wage model, we compare estimates from OLS, 2SLS and MAN. Estimates of ϵ^{ρ}_{ij} generated by OLS and MAN are consistently close to zero. 2SLS estimates are also close to zero for the effect on white collar wages but differ moderately for the effect on the return to capital. The effect of a rise in the capital stock on blue collar employment varies. In general, we have found the relationship between capital and blue collar workers - between capital and all occupation types for that matter - is not robust. However, we find the effects of white collar workers on blue collar employment are robust. The elasticity ranges from 0.90 for 2SLS estimates to 1.27 for MAN estimates.

8 Conclusion

> *"Yet both unemployment and poverty are still at unacceptably high levels, which mean our growth is not fairly shared. The most fatal constraint to shared growth is skills, and it should be noted that skills are not just one of the constraints facing AsgiSA but a potentially fatal constraint. That fact should be admitted with emphasis. We have to overcome the shortage of suitable skilled labour if our dreams for this economy are to be realised; the task is huge."* - South African Deputy President, Phumzile Mlambo-Ngcuka (2006), at the launch of JIPSA, which is part of the new Accelerated and Shared Growth Initiative for South Africa (AsgiSA):[18]

As is clear from the quote, and as the name of the program suggests, a cornerstone of AsgiSA is that improvements in living standards are to be shared by all segments of society, in particular the poor. Implicit in the argument for the role of skills in AsgiSA is the claim that expanded and improved educational access, which would equip a portion of the population with skills, will generate enough growth in a way that benefits those who do not get access to those skills.

Our main estimates of aggregated inputs find more skilled and less skilled labour are q-complements, although this depends on how elastic product demand is. The key disaggregated 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. We have presented a number of alternative estimations to gauge robustness and address potential endogeneity bias. We feel we have shaken our main claims quite vigorously without dislodging them.

The findings suggest there is a general skills shortage. In particular, addressing the shortage of artisans would expand output and the unskilled would benefit from a rise in their availability. However, trade union officials claim it is only so-called soft skills which are being provided by firms so that they can reclaim their skills levy, the government is frustrated at the inability of its skills strategy to produce the intended skills (Ntuli, 2006) and prospective artisans make up

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[18] AsgiSA is the new flagship of government economic policy, taking over from the 1996 GEAR policy.

a low proportion of those being trained (Paton, 2003). By producing the wrong types of skills, these training programs may raise unskilled unemployment.

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A Descriptive statistics

	Sales (Rm)	Value Added (Rm)	Capital (Rm)	Man/Prof	Sale/Cle	Skil/Art	Semi	Un
mean	110	48	51	22	40	27	120	87
median	13	7	5	5	6	5	19	14
p25	5	3	1.5	2	2	1	5	4
p75	50	24	21	11	20	15	68	50

B Disaggregated regressions

Dependent variable:	OLS1		OLS2		LP1		LP2		MAN	
value added	I		II		III		IV		V	
Variable	coeff	p	coeff	p	coeff	p	coeff	p	coeff	p
Constant	-0.90	0.01	-1.13	0.00	-1.64	0.05	-1.87	0.02	-0.65	0.05
Capital	0.19	0.00	0.18	0.00	0.03	0.89	-0.00	0.99	0.26	0.00
Man/Prof	0.09	0.34	0.11	0.27	0.26	0.02	0.23	0.03	0.01	0.91
Sale/Cler	0.43	0.00	0.41	0.00	0.19	0.04	0.16	0.06	0.34	0.00
Skil/Art	-0.02	0.71	-0.04	0.55	0.06	0.42	0.08	0.25	-0.05	0.53
Semi	0.11	0.08	0.13	0.04	0.12	0.09	0.11	0.07	0.16	0.04
Un	0.20	0.00	0.21	0.00	0.15	0.01	0.17	0.00	0.28	0.01
0.5*Capital^2	0.09	0.01	0.08	0.02					0.12	0.00
Capital*Man/Prof	-0.07	0.10	-0.05	0.24					-0.04	0.43
Capital*Sale/Cler	0.04	0.26	0.05	0.29					-0.01	0.85
Capital*Skil/Art	-0.02	0.56	-0.03	0.30					0.01	0.86
Capital*Semi	-0.05	0.12	-0.03	0.34					-0.05	0.13
Capital*Un	0.00	0.97	-0.01	0.63					-0.04	0.37
0.5*Man/Prof^2	-0.04	0.69	0.03	0.76	0.03	0.80	0.03	0.80	-0.04	0.62
Man/Prof*Sale/Cler	-0.01	0.88	-0.05	0.49	-0.07	0.39	-0.07	0.34	-0.04	0.66
Man/Prof*Skil/Art	0.02	0.71	-0.02	0.69	0.01	0.82	0.03	0.80	-0.04	0.49
Man/Prof*Semi	0.04	0.41	0.03	0.57	0.02	0.75	-0.00	0.97	0.04	0.77
Man/Prof*Un	0.06	0.21	0.06	0.16	0.01	0.77	0.03	0.52	0.11	0.14
0.5*Sale/Cle^2	0.05	0.56	0.09	0.28	0.03	0.56	0.01	0.91	0.11	0.21
Sale/Cler*Skil/Art	-0.04	0.45	-0.03	0.62	-0.04	0.47	-0.05	0.29	-0.04	0.48
Sale/Cler*Semi	-0.03	0.57	-0.05	0.28	0.03	0.53	0.05	0.24	-0.06	0.59
Sale/Cler*Un	-0.02	0.60	-0.01	0.80	0.05	0.18	0.06	0.08	0.00	0.98
0.5*Skil/Art^2	-0.09	0.08	-0.06	0.31	-0.05	0.44	-0.01	0.84	-0.57	0.44
Skil/Art*Semi	0.07	0.05	0.06	0.10	0.03	0.53	0.02	0.63	0.07	0.08
Skil/Art*Un	0.05	0.09	0.08	0.03	0.05	0.16	0.02	0.45	0.05	0.29
0.5*Semi^2	0.05	0.28	0.07	0.16	-0.01	0.88	0.01	0.90	0.11	0.03
Semi*Un	-0.09	0.00	-0.12	0.00	-0.06	0.06	-0.08	0.01	-0.15	0.01
0.5*Un^2	0.00	0.96	0.03	0.47	-0.05	0.22	-0.03	0.30	0.02	0.16
raw					0.32	0.27	0.41	0.13		
Capital*raw					0.01	0.77	0.02	0.60		
raw^2					-0.02	0.53	-0.02	0.32		
Capital^2					0.01	0.75	0.00	0.77		
controls	a-g,ijk		a-k		a-e,jk		a-e,jk		bcdfijk	
instruments									l	
Number of observations		239		218		236		262		258
"R squared"		0.96		0.96		0.95		0.96		0.95
Joint test on all $\beta_{ij} = 0$		0.02		0.02		0.43		0.15		0.02
Test on terms in raw materials						0.09		0.06		
Aggregate white collar		0.69		0.83		0.65		0.13		0.40
Aggregate blue collar		0.44		0.51		0.65		0.13		0.50

Controls: a=exports/sales, b=training/sales, c=firm size dummy, d=computer investment, e=ownermanaged dummy,f=rawmaterials/costs, g=labourconditions, h=expectedpricechange i=easeofrecruitment,j=industrydummies,k-locationdummies,l=blue collar wage variables

C Disaggregated elasticities

		H_{ij}				ϵ_{ij}				ϵ^{ρ}_{ij}		
i	j	I OLS1	II OLS2	III LP1	IV LP2	V OLS1	VI OLS2	VII LP1	VIII LP2	IX OLS1	X OLS2	XI MAN
Capital	Capital	-1.81	-1.97	-5.67	-2.98	-0.30	-0.29	-0.90	-0.75	-0.28	-0.29	-0.13
	Man/Prof	-1.13	-0.72	1	1	-0.22	-0.14	0.27	0.24	-0.14	-0.13	-0.21
	Sale/Cler	1.68	1.82	1	1	0.67	0.67	0.32	0.25	0.68	0.67	0.24
	Skil/Art	-0.23	-1.14	1	1	-0.02	-0.12	0.15	0.09	0.05	-0.12	0.03
	Semi	-3.01	-1.28	1	1	-0.22	-0.12	0.08	0.05	-0.32	-0.13	0.07
	Un	1.07	0.04	1	1	0.09	0.00	0.08	0.12			
Man/Prof	Capital	-1.13	-0.72	1	1	-0.19	-0.11	0.10	0.25	-0.11	-0.10	-0.23
	Man/Prof	-5.14	-3.32	-2.23	-2.78	-0.99	-0.65	-0.63	-0.66	-0.64	0.04	0.27
	Sale/Cler	0.85	0.28	0.15	-0.26	0.34	0.10	0.04	-0.06	0.40	-0.01	0.49
	Skil/Art	2.10	-0.09	1.37	2.11	0.19	-0.01	0.16	0.18	0.48	0.73	0.54
	Semi	3.89	2.61	2.31	0.86	0.28	0.24	0.11	0.05	-0.13	-0.66	-1.07
	Un	4.47	4.78	2.18	1.95	0.37	0.42	0.09	0.24			
Sale/Cler	Capital	1.68	1.82	1	1	0.28	0.27	0.10	0.25	0.28	0.27	0.13
	Man/Prof	0.85	0.28	0.15	-0.26	0.16	0.05	0.04	-0.06	0.20	-0.00	0.24
	Sale/Cler	-1.22	-1.05	-2.08	-2.86	-0.48	-0.39	-0.61	-0.71	-0.48	-0.38	-0.29
	Skil/Art	0.03	0.34	-0.06	-1.34	0.00	0.04	-0.01	-0.12	0.03	-0.03	0.06
	Semi	0.11	0.63	3.03	5.11	0.01	0.06	0.15	0.27	-0.03	0.13	-0.14
	Un	0.41	-0.40	5.09	2.96	0.03	-0.03	0.21	0.37			
Skil/Art	Capital	-0.23	-1.14	1	1	-0.04	-0.17	0.10	0.25	0.09	-0.16	0.06
	Man/Prof	2.10	-0.09	1.37	2.11	0.41	-0.02	0.39	0.50	1.03	1.33	1.04
	Sale/Cler	0.03	0.34	-0.06	-1.34	0.01	0.13	-0.02	-0.33	0.13	-0.09	0.22
	Skil/Art	-20.82	-13.50	-10.45	-11.86	-1.89	-1.44	-1.27	-1.04	-1.38	0.18	-0.88
	Semi	11.87	7.49	5.43	4.81	0.87	0.69	0.26	0.25	0.14	-1.08	-0.44
	Un	7.83	9.34	10.00	2.95	0.64	0.82	0.42	0.37			
Semi	Capital	-3.01	-1.28	1	1	-0.49	-0.19	0.10	0.25	-0.71	-0.20	0.09
	Man/Prof	3.89	2.61	2.31	0.86	0.75	0.51	0.65	0.20	-0.34	-1.39	-1.30
	Sale/Cler	0.11	0.63	3.03	5.11	0.04	0.23	0.89	1.27	-0.16	0.53	-0.35
	Skil/Art	11.87	7.49	5.43	4.81	1.08	0.80	0.65	0.42	0.18	-1.25	-0.28
	Semi	-3.28	-2.13	-23.05	-15.73	-0.24	-0.20	-1.12	-0.83	1.05	2.34	1.83
	Un	-13.87	-13.23	-30.69	-10.57	-1.14	-1.15	-1.29	-1.31		ρ_{ij}	
Un	Capital	1.07	0.04	1	1	0.17	0.01	0.10	0.25	0.19	0.01	-0.27
	Man/Prof	4.47	4.78	2.18	1.95	0.86	0.93	0.61	0.46	0.96	0.65	1.80
	Sale/Cler	0.41	-0.40	5.09	2.96	0.16	-0.15	1.50	0.74	0.18	-0.26	0.48
	Skil/Art	7.83	9.34	10.00	2.95	0.71	1.00	1.21	0.26	0.79	1.77	0.89
	Semi	-13.87	-13.23	-30.69	-10.57	-1.01	-1.22	-1.49	-0.56	-1.13	-2.17	-1.91
	Un	-10.93	-6.47	-48.50	-9.25	-0.90	-0.57	-2.05	-1.14			

D Aggregated regressions

Dependent variable: value added

	OLS		LP		2SLS		MAN	
	I		II		III		IV	
Variable	coeff	p	coeff	p	coeff	p	coeff	p not valid
Constant	-1.83	0.00	-2.34	0.00	-0.98	0.00	-1.45	0.00
Capital	0.31	0.00	0.05	0.77	0.25	0.11	0.40	0.00
White	0.43	0.00	0.32	0.00	0.40	0.09	0.40	0.08
Blue	0.25	0.02	0.38	0.00	0.35	0.24	0.20	0.51
0.5*Capital^2	0.12	0.00			0.10	0.07	0.13	0.00
Capital*White	-0.06	0.11			-0.09	0.15	-0.04	0.49
Capital*Blue	-0.06	0.12			-0.01	0.93	-0.09	0.18
0.5*White^2	-0.04	0.57	-0.16	0.01	-0.08	0.62	-0.16	0.24
White*Blue	0.10	0.10	0.16	0.01	0.17	0.32	0.20	0.18
0.5*Blue^2	-0.04	0.54	-0.16	0.01	-0.16	0.41	-0.10	0.57
raw			0.35	0.18				
Capital*raw			0.01	0.82				
raw^2			-0.01	0.48				
Capital^2			0.01	0.45				
controls	b-g,ijk		a-e,jk		b-g,jk		b-g,ijk	
instruments					il		l	
obs		223		262		243		243
"R squared"		0.90		0.92		0.91		0.90
Joint test on all $\beta_{ij} = 0$		0.01		0.01		0.09		0.01
Test on terms in raw materials				0.02				

Controls: a=exports/sales, b=training/sales, c=firm size dummy, d=computer investment, e=ownermanaged dummy,f=rawmaterials/costs, g=labourconditions, h=expectedpricechange i=easeofrecruitment,j=industrydummies,k-locationdummies,l=blue collar wage variables

E Aggregated elasticities

		H_{ij}		ϵ_{ij}			ϵ^{ρ}_{ij}	
		I	II	III	IV	V	VI	VII
i	j	OLS	LP2	OLS	LP2	OLS	2SLS	MAN
Capital	Capital	-0.35	-2.33	-0.05	-0.70	-0.04	-0.26	0.02
	White	0.33	1	0.20	0.55	0.04	0.26	-0.02
	Blue	-0.65	1	-0.15	0.15	-	-	-
White	Capital	0.33	1	0.05	0.30	0.01	0.06	-0.00
	White	-0.71	-1.34	-0.44	-0.74	-0.01	-0.06	0.00
	Blue	1.70	2.97	0.39	0.44		ρ_{ij}	
Blue	Capital	-0.65	1	-0.10	0.30	-0.10	0.05	-0.33
	White	1.70	2.97	1.05	1.64	1.05	0.90	1.27
	Blue	-4.15	-6.32	-0.96	-1.94			