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Capital and Labor Substitution in Computable General Equilibrium Models

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The ImpactECON working paper series focuses on adapting, testing and transitioning academic work for practical, real world use. The end goal is to improve CGE modeling with emphasis on policy and investment analysis through improvements to data and modeling constructs.

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Introduction

The aim of this report is to provide the OECD with recommendations on how to model substitution possibilities within value added and between labor value added and services in light of recent improvements to the GTAP database that disaggregate labor into five occupational groups. In addition, we explore the substitutability of foreign and domestic labor. Selecting a set of elasticities of substitution is important for CGE modeling since the values selected will determine important micro and macro-economic results. On the micro, or production side, the ability of firms to substitute factors of production will impact a firm's or sector's ability to adjust output in response to changes in demand or prices. At the macro level, the elasticities of substitution, will determine factor shares in national income.

A couple of important challenges arise from the disaggregation of labor into several occupational categories: first, most of the existing literature focuses on education or skill level, in contrast to occupational categories; only recently have studies considered heterogeneous labor categories. Second, the disaggregation of labor, and hence the increase of homogeneity within categories, increases the frequency of complementary relationships between labor categories being found in empirical studies; the same is true for the relationship between labor and capital. This last issue points to the future direction of incorporating more nuanced production structures into CGE models, in order to reflect both substitutes and complements. The more disaggregated factors of production become, the more likely pure substitution effects will no longer dominate. Early research employing disaggregated data on factors of production and resulting elasticity of substitution estimates, point the way; although more research is required.

In the following sections, we first review the theory of factor substitution and factor demand as it relates to CGE modeling. We then follow with a section reviewing the literature we surveyed and the main results found, as well as expounding on any areas of conflicting results. The section on nesting of CGE results includes our best selection of substitution estimates and an associated nesting structure in the current seven factor model (five labor categories and capital). Finally, we conclude the paper.

Elasticities of Substitution and Factor Demand Theory

In the following section we briefly review key concepts as they relate to elasticities of substitution and CGE modeling. We start with the most simple and general definition of the elasticity of substitution, then review key assumptions, functional forms employed for estimation purposes and types of elasticities of substitution encountered in the literature. Finally, we review key concepts on converting elasticities of substitution, the issue of complementarities, and the level of aggregation used when estimating results. Each of these concepts contributes to the information provided in the subsequent sections.

Elasticity of Substitution Defined

The concept of the elasticity of substitution was first published by Hicks (1932)[4]. At its simplest, the elasticity of substitution in production measures the ease or difficulty of substituting one factor for another. More formally, it is measured by the percentage change in the factor quantity ratio relative to the percent change in the rate of technical substitution for a constant level of output (isoquant):

$$\sigma = \frac{Percent\ \Delta\ (K/_L)}{Percent\ \Delta\ RTS} \qquad (1)$$

Importantly for CGE modeling, under conditions of perfect competition and constant returns to scale, the elasticity of substitution can be written as the percentage change in factor quantity ratios resulting from a percentage change in factor price ratio:[5]

$$\sigma = \frac{Percent\ \Delta\ (K/_L)}{Percent\ \Delta\ (w/_r)} \qquad (2)$$

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[4] In fact, Hicks, J. R. (1932). The Theory of Wages, MacMillan: London. credited Joan Robinson for the concept of elasticity of substitution and introduced the concept of elasticity of complementarity, the inverse of the elasticity of substitution.

[5] In the cases of capital and labor, the marginal rate of technical substitution is formally written as $\frac{-dK}{dL}|Q = Q_0$ but can be shown to be equivalent to the ratio of the marginal productivity of labor to capital (MPL/MPK) and in the case of perfect competition and zero profits, where the marginal productivities equivalent to the wage or rental rates, the ratio marginal productivities can be written as the ratio of wage\rental prices (w/r).

From equation (2) it is a relatively small step to derive a factor's share in the firm's total costs and calculate comparative static changes in factor shares resulting from changes in factor prices (Hick's (1932) and then Allen and Hick's (1934)). Allan (1932 and 1938) and Allan and Uzawa (1962) extended Hick's original exposition to multiple factors of production. Multiple factors of production give rise to a number of practical challenges when trying to specify an elasticity of substitution which, by its nature, holds a number of potentially significant variables constant. For example, the introduction of more than two factors of production introduces the distinct possibility of elasticities of substitution which range from negative (complements) to perfect substitutes. As a result, a number of definitions have been adopted to address the complexities of capturing substitution in a multi-factor production function, which we review below.

As subsequently discovered by empirical economists, even if a definition of an elasticity of substitution could be agreed upon, estimating these elasticities of substitution is not straight forward. Empirical evidence from different studies reveals substantial differences in elasticity estimates. Elasticities may differ by orders of magnitude and studies often provide contradictory conclusions on a factor's status as a substitute or complement with other factors. While at first sight these differences are hard to reconcile, they can be attributed to differences in data, functional forms, assumptions and the type of elasticity estimated (Berndt, 1976). As a result, comparisons of elasticities from different sources should be interpreted with care, being aware of the underlying differences in the estimation methodologies. In the following sections, we review some of the major sources of estimate variation including functional forms employed in estimation, economic assumptions, types of elasticities, the problem of complements and substitutes, as well as the conversion of elasticities from one type or functional form into elasticities commonly employed in CGE models, or Allen elasticities.

Assumptions

As mentioned in the prior section, functional forms often imply assumptions that empirical papers may or may not make explicit. The typical range of assumptions a CGE modeler needs to consider include:

- separability;
- homogeneity within the factors defined;
- symmetry;
- homotheticity in functional form; and
- returns to scale.

The assumption of separability is, perhaps, one of the more important assumptions employed by CGE economists, as the nested production functions predominantly used in CGE models assume separability between factors of production. Separability is also used in tandem with a priori information on factor homogeneity. For example, a CGE economist will often nest roughly similar, though not identical, factors in a nest, where a similar substitution elasticity can be employed. This might be the case for different energy inputs or perhaps various types of low skilled labor. The CGE economist is therefore faced with their a priori assumption on homogeneity and separability, and the assumptions underlying the empirical estimates at hand. While it may be impossible to find a compatible set of estimates for a particular nesting structure employed by the CGE economist, empirical estimates may confirm or refute the modeller's assumptions on nesting structures and homogeneity, thereby providing a feedback loop on the structure of the CGE model functions and the elasticities employed. For example, a modeler may decide managers, semi-skilled and low skilled workers are close substitutes, but if empirical estimates suggest that the elasticities of substitution are less than one between managers and low skilled workers – implying that they are not close substitutes – then the economist may opt not to nest these two types of labor with the third type.

Symmetry, which implies the same elasticity of substitution between goods X and Y and between Y and X, is often assumed by CGE modelers. Data on non-symmetrical elasticities are rarely incorporated into CGE models due to difficulties with implementing them. Nevertheless, non-symmetry can give rise to varying estimates for what would appear to be the same factor substitutions.

Finally, assumptions related to homotheticity and returns to scale need to be considered. It would not be appropriate to employ elasticity estimates from an empirical model that assumed strong increasing returns to scale (or rather did not impose constant returns) in a CGE model which assumed constant returns to scale, without careful consideration.

Functional Forms

When estimating elasticities of substitution, economist choose among a variety of functional forms. The most widely used functional forms in the literature we reviewed for estimating factor substitution elasticities were:

- Cobb-Douglas;
- Constant Elasticity of Substitution (CES);
- Translog; and
- Quadratic.

These functional forms vary from the relatively simple functional forms with restrictive assumptions, such as Cobb-Douglas, to the more complex, highly non-linear functional forms with less restrictive assumptions, such as the quadratic[6]. The Cobb-Douglas and the CES, which impose some of the most restrictive assumption, are frequently employed in

[6] We define highly non-linear as a functional form which is not easily linearized in log or log differences.

macroeconomic estimations given their empirical simplicity and tractability (modest data requirements). Importantly, the Cobb-Douglas assumes an elasticity of substitution of one, which means a one percent change in factor prices will result in a one percent change in factor quantities, resulting in constant proportions. While frequently employed in early production function estimations, the Cobb-Douglas function, is less useful as an estimation technique for the elasticity of substitution, but is important as a frame of reference due to its unique properties. From equation 2, it can be shown that a constant elasticity of substitution equal to one, will result in constant factor shares in factor income (costs), a restrictive assumption, but one which finds constructive use in certain CGE applications[7]. In contrast to the Cobb-Douglas, the CES function allows the elasticity of substation to be different from one, but like the Cobb-Douglas, does not allow it to vary over a range of output scenarios. In both cases, estimation often imposes further a priori restriction with respect to returns to scale and homogeneity.

Micro and firm level data, where input and output prices and their associated quantities can be estimated, allows for the specification of flexible functional forms with less restrictive assumptions[8]. The translog (Christensen, Jorgenson, & Lau, 1973) is a generalization of the Cobb-Douglas that has been widely used in estimating elasticities of substitution as it does not impose restrictions about technology or the values of elasticities. Furthermore, separability and homotheticity are not assumed, but can be tested. The quadratic is another flexible functional form that is a more general and non-linearized version of the widely used translog.

The empirical use of flexible functional forms has certain drawbacks: a) collinearity problems may arise due to numerous terms derived from transformations of the same variable[9]; b) functions often fail to satisfy regularity conditions such as convexity, monotonicity and homogeneity over the whole data sample (local versus global solutions) – or must be imposed; c) parameter estimates are often hard to interpret due to non-linearities; and d) there may be convergence problems, also due to the non-linearities (Thompson, 1988).

Needless to say, elasticities estimated using a variety of functional forms and implicitly or explicitly using different assumption are not going to result in the same estimated values. The CGE economist will have to weigh the pros and cons of each measure before settling on an appropriate set of elasticities.

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[7] For example, Kaldor (1961, p 178) makes a widely employed observation on long-term growth that for "the economy as a whole, and over longer periods, income and capital tend to grow at the same rates"; implying that a Cobb-Douglas constant shares form is appropriate for long run income.

[8] A functional form is defined as flexible if at any given set of nonnegative (positive) prices of inputs the parameters of the function can be chosen so that the derived unit-output input demand functions and their own and cross-price elasticities are capable of assuming arbitrary values at the given set of prices of inputs subject to requirements of theoretical consistency Lau, L. J. (1986). "Functional forms in econometric model building." Handbook of econometrics **3**: 1515-1566..

[9] In a regression, an important assumption is that each of the explanatory variables is independent. When variables are transformations of existing variables in the regression, they run the risk of being correlated, violating an important assumption required to unbiased estimators and t-stats.

An additional consideration when selecting an appropriate elasticity measure or functional form is the corresponding functional form in the CGE model—i.e. if a CGE model uses a CES function to specify factor substitution, estimates from a CES function should be considered in that light. However, this does not mean elasticities estimated employing functional forms other than those employed in the CGE model are less informative or are to be depreciated; elasticities estimated with less restrictive assumption may provide useful information on the sensitivity of an analysis to the assumption employed in the CGE model.

In a calibrated CGE model, the elasticity chosen will determine two elements of importance to the CGE economist: first, it will be used to calibrate the parameters and shares in the model; and second, it will determine the responsiveness of variables/factors to a given policy shock (Balistreri et al. 2003). Matching the estimates to the model to calibrate parameters is viewed as affecting shares and productivity indexes, while the second point has consequences on the responsiveness of the model to a policy shock. A variety of point estimates on the elasticity of substitution may suggest a range of elasticities which suit a particular application better than a single point estimate - even if that point estimate was calculated employing the same functional form used in the model. The benefits of each factor must be weighed. We next turn to assumptions and their implications in CGE modeling.

Types of Elasticities Estimated

In the introduction, we presented a general definition of elasticities of substitution, while recognizing that, once more than one factor of production is considered, a single definition is elusive. With this in mind, we review the most commonly estimated "types" of elasticities in the empirical literature:

- Allen-Uzawa partial elasticity of substitution (AES): measures the percentage change in the ratio of factor quantities as a result of the percentage change in the ratio factor prices, holding other factor prices and output constant (i.e. percentage change in relative factor prices → percentage change in relative factor quantities). The AES is often defined as σ and assumes symmetry, $\sigma_{xy} = \sigma_{yx}$[10].
- Hicks partial elasticity of complementarity measures the percentage change in the ratio of factor prices as a result of the percentage change in the ratio of factor quantities, holding other factor quantities and product prices constant (i.e. percentage change in relative factor quantities → percentage change in relative factor prices)[11]. If only two factors of production are considered, the Hicks elasticity of substitution can

[10] Technically, the Uzawa derivation of the Allen partials is from the cost side and requires an assumption of constant returns to scale, though this distinction is infrequently recognized in practice.
[11] Note, output is not held constant, by definition, in contrast to the Allen-Uzawa partial elasticitiy.

be shown to be 1/σ, the reciprocal of the elasticity of substitution[12]. Importantly, the sign definition of complements and substitutes, typically attributed to price elasticities are reversed.

— Own price and cross price elasticity of factor demand: measures the percentage change in factor quantities as a result of the percentage change in its own or another factor's (cross) price.

While these different types of elasticities are not directly comparable, it is possible, for instance, to convert own and cross price elasticities into Allen-Uzawa (AES) elasticities making assumptions about factor shares and, in the simple two factor case, it is possible to calculate the Allen-Uzawa (Robinson) elasticities from the Hicks partial elasticity of complementarity and vice versa.

Elasticity Conversion

Beher (2007) provides a comprehensive overview of converting elasticity estimates from one set of estimates to another, where possible. These conversions fall into two groups: 1) converting translog coefficients into commonly recognized values listed in the previous section; and 2) converting own and cross price elasticities into equivalent Allan-Uzawa (AES) elasticities or vice versa[13]. In all cases, data on factor shares are required to undertake conversions. In the case of papers employing the translog, the conversions are frequently carried out when reporting results. However, *authors, infrequently provide the shares employed in their estimation procedure*. This introduces a problem and a degree of uncertainty. The problem can be solved by employing cost shares found in our CGE model, in this case, the GTAP database. However, since these shares are not likely the same shares employed in the estimation technique, they are rarely exact substitutes, introducing a source of uncertainty in the converted estimates.

In most cases, we have converted own and cross price elasticities to Allen elasticities of substitution using the GTAP v9 pre-release data, since these are commonly employed in CGE models. It is important to note, it may be useful to convert the Allen elasticities of substitution back to own and cross price elasticities when reviewing the nesting structure, since the nesting structure can change the shares applied to a given set of Allen partials and result in own and cross price elasticities which diverge from the literature.

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[12] Hicks is famously credited with the elaboration of the price elasticity of substitution, however, Hicks' himself noted his exposition was of something different (Hicks 1970), that something different was the reciprocal of the concept which Joan Robinson first elaborated-the elasticity of price substitution.

[13]For example, the basic equation for converting cross price elasticities and AES is $\sigma_{ij} = \frac{\eta_{ij}}{s_j}$ where sigma i,j, is the price elasticity of substitution for good i given a change in the price of good j. η_{ij} is the cross price elasticity between i and j and s_j is the cost share of j in total cost.

Complements and Substitutes

As the name suggests, elasticities of substitution generally follow a pattern where a rise in the price of one product or factor, leads to substitution toward another product or factor of production. In this case, the elasticity of substitution is expected to be positive—when the price of one product or factor rises, the quantity demand of another also rises. In certain cases, two goods or factors of production must be employed together, that is they are complementary. For example, in the case of a ticket agent, the agent and the ticketing machine are complements—removing the ticket agent from the machine causes the output of the machine to fall to zero. Hence, a rise in the wage of ticket agents, will result in a drop in demand for ticket machines. The opposite can also be true, the fall in the price of ticketing machines will increase the demand for ticket agents. While this example is naively simple, it can also be used to highlight some of the difficulties in the estimation of substitution vs. complements. For instance, one could imagine the cost of machines going up, and the ticketing office deciding to run double shifts to employ the same machine more efficiently. In this case, labor is a substitute for another machine. In an extreme case, one might imagine the owner training the ticket agents to fill in manual tickets and hiring extra workers to handle the paper work. In the area of factor substitution, studies have found numerous contradictory results, depending on the dataset employed and the time covered.

Two areas in our CGE model require special attention in this area: capital and labor as complements and the degree of complementarity between occupational groups of labor. In contrast to the other areas covered in this section, it is often difficult to point to a particular assumption or functional form which gives rise to complements or substitutes. Often the results are intimately tied up with the data sets employed and the level of aggregation of the various factors under consideration.

Economy-wide (Macroeconomic) Estimation

Given the data available at the macroeconomic level, studies that employ a macroeconomic framework assume that aggregate output is generated by a two factor[14] production function with physical capital and labor serving as inputs. Numerous studies assume that the functional form of this production function is a Cobb-Douglas. As reviewed earlier, Cobb-Douglas imposes linear homogeneity and a constant elasticity of substitution equal to unity and, consequently, the fact that each factor's share of income is constant over time. This assumption is consistent with one of the "stylized facts" of growth of Kaldor (1961) that finds that the share in income of capital and labor are relatively constant over time. The Cobb-Douglas as an aggregate production function has been replaced with a relatively more flexible functional form, the Constant Elasticity of Substitution (CES). The CES does not impose a

[14] With recent increases in data availability, it is possible to move away from the usual $Y = f(K,L)$ and introduce for instance skilled and unskilled labor, human capital, materials etc.

unitary elasticity of substitution and allows for testable hypotheses regarding the value of the elasticity.

Despite their empirical tractability and appeal, aggregate production functions have several weaknesses. Felipe and Fisher (2003) provide an excellent summary of their uses and misuses and conclude among others that due to the so called aggregation problem[15], "the conditions under which a well-behaved aggregate production function can be derived from micro production functions are so stringent that it is difficult to believe that actual economies satisfy them. Therefore, aggregate production functions do not have a sound theoretical foundation." At the same time, despite the strong assumptions required, these functions have been found to be enormously useful in their general representation of the economy.

Firm Level (Microeconomic) Estimation

Increased availability of firm level data opens up possibilities for researchers to move away from aggregate production functions and make use of information available at the microeconomic level. Detailed data can in turn be used to specify flexible functional forms, releasing the estimates from the stringent assumptions found in aggregate estimates and rigid functional forms, such as the Cobb-Douglas. At the firm level, elasticity estimates can be derived from several data sources related to economic theory. These data sources and function forms include:

- Production functions: describing the maximum output that can be produced from given quantities of factor inputs with the firm's existing technological expertise;
- Cost functions: describing the minimum cost of producing any given output quantity, using the cost minimizing quantity of inputs;
- Profit/revenue functions: describing the maximum level of profit that the firm could attain over all possible net output vectors.

The theory describing the dual relationship between production and cost functions was first introduced by Shephard (1953) with subsequent contributions from Uzawa (1964), Diewert (1974) and many others. In simple terms, the duality theory between production and cost functions originates from the fact that finding the optimum levels of inputs to produce a given output, can be seen on the one hand as a cost minimization problem (finding the lowest isocost tangent to the production isoquant) and on the other, as output maximization problem (choosing the highest isoquant tangent to a given isocost).

Duality theory is an essential component of producer theory as it allows economists to derive systems of demand and supply equations that are consistent with maximizing and

[15] The aggregation problem arises as a result of having to aggregate microeconomic data into an aggregate output.

minimizing behavior of the firm, but can be much easier to derive and implement. Kuosmanen (2003) provides a list of the limitations of duality[16]:

- Duality Theory offers a static view on the firm. The subtle dynamics of production are almost always ignored (a notable exception is Färe, 1978).

- The economic models of Duality Theory focus on the price-taking firm, assuming away any dependence between the volume of transaction and the price.

- Duality Theory usually assumes full certainty both in its economic and production models, thus ignoring the various risks and uncertainties related to the outcomes of the physical production processes as well as the market mechanisms, and the firms' willingness and ability to bear them.

- The production models of Duality Theory always assume convexity in one form or another. To link an extensive collection of economic models and production models together in the powerful "duality diamond" (Färe and Primont, 1994, 1995), Duality Theory requires the entire production possibility set to be convex.

Based on duality, McFadden (1966) extends cost functions to revenue and profit functions. As duality theory allows for full consistency between these three specifications (production, cost or profit/revenue functions), it is expected that ceteris paribus, elasticities derived using any of the three would be fully comparable.

[16] Note that Paris and Caputo (1995) state that the "duality does not seem to suffer from theoretical limitations any more than does the formulation of the primal (the production) problem.

Substitution between Factors of Production

In this section we review estimates of the elasticity of substitution between common factors of production including between labor categories, capital and labor, native and immigrant workers, and labor and outsourcing. We group estimates into two categories:

- Estimates from popular CGE models; and
- Empirical estimates from the literature.

The contrast between these two groups can be understood by realizing that many CGE modelers, employ elasticity estimates which were either assumed or were "informed" by particular analytical studies. This is not to imply that some estimates are better than others, but rather, our goal is to compile as much information as possible, to inform the processes of selecting appropriate elasticities for use in a CGE model.

We start with a review of estimates employed in popular CGE models, then we review the results from the literature in each of the major categories: capital-labor, labor-labor, native-immigrant, and labor-outsourcing. An overview of the papers examined is provided in Appendix I and the elasticities estimated are provided in Appendicies II, III and IV.

Substitution in Popular CGE Models

Appendix V summarizes the elasticities of substitution and nesting structures of value added in some of the well-known CGE models. These results were gathered via a survey of authors (emailed in January 2015) and through an examination of model documentation. The results show that most of the global CGE models employ either one category of labor (G-cubed and FEEM) or are based on the GTAP database and therefore use the original GTAP skilled-unskilled aggregates. The exception is the CGE model for ASEAN (Zhai) that includes labor disaggregated by occupations using an elasticity of substitution of 0.35 between labor categories.

Those using the GTAP skilled and unskilled labor categories include the GTAP model itself, Linkage, GEM-E3, Mirage, GLOBE and Magnet. While the GTAP model places all value-added at the one level, the others have opted for more complicated structures. GLOBE and Magnet have chosen to give the user more flexibility in nesting labor, although they leave the assignment of elasticities to the user. GEM-E3 and Mirage bundle capital and skilled labor (GEM-E3 with an elasticitiy of 0.35 and Mirage with a Cobb-Douglas) and then add unskilled (GEM-E3 using the GTAP elasticities and Mirage using a value of 0.6). The Linkage model (van der Mensbrugghe, 2005), on the other hand, provides even further flexibility by allowing alternative nesting structures for different types of sectors (agriculture, livestock, non-agriculture etc), and allowing labor (skilled and/or unskilled) and capital to be treated as either substitutable or complementary. The recent disaggregation of labor by GTAP is likely to lead to further differences between the value-added nesting structures of models, as they update to the new GTAP database and re-consider their nesting structures.

The GTAP elasticities (ESUBVA) were originally taken from the SALTER model (Hertel, McDougall et al., 2012), although some revisions were made to better match more realistic supply responses in agriculture (Hertel, Tsigas et al., 2012). The short run elasticities used in the SALTER model (Jomini, Zeitsch et al., 1991) were obtained from Caddy (1976). Long run estimates were also provided as part of the SALTER model, by multiplying the short run estimates by two. With the exception of agriculture and food, which have been adjusted, the GTAP elasticities lie part way between these short and long run elasticities. In the agriculture and food sectors, the GTAP elasticities are lower than those used in SALTER, due to the revisions discussed above.

The single country models developed by the Center of Policy Studies—Orani, Monash and USAGE—generally assume an elasticity of 0.35 between labor categories, regardless of the producing sector. This estimate is based on a number of Australian studies that are discussed below. The elasticity between labor and capital was originally set to 0.5, also following evidence provided by Caddy (1976).[17]

None of the models surveyed allow for substitution between labor and services. Finally, it is clear that the source of these elasticities is sometimes based on educated guesses, even if the authors suggest they have referenced the literature—a good deal of judgment is often employed.

Capital-Labor Substitution

The economic literature contains findings of both complementarities between capital and labor on one hand (Griliches 1969), and high substitution between capital and labor on the other (Behar 2007). A large number of papers, that have estimated the aggregate economy-wide level of substitution between capital and labor, find positive values for the elasticity of substitution, but these values are most frequently found to be less than one (poor substitutes).

[17] Unfortunately the elasticitiy used in Monash and USAGE could not be found, so it is not known if these have been updated.

This last group of papers include Balistreri et al. (2003); Arrow, Chenery, Minhas, & Solow, (1961); and Klump et al. (2004). Klump et al. (2004) review eleven sets of aggregate capital-labor substitution estimates for the USA and a similar number of countries internationally, which, with few exceptions, estimate the aggregate elasticity of substitution between capital and labor as between zero and one.

The debate on the substitution between capital and labor is a nuanced and has a storied history, since the debate often hangs on the all-important shares of capital and labor in a growing economy and policy recommendations for long-term economic and wage growth. Foremost in this frame of reference are the observed facts of: a) growing capital stocks (relative to labor); b) growing wages of skilled labor; and c) declining wages of unskilled labor. Growing stocks of capital would suggest that the prices of capital are falling, and in a traditional neo-classical model, wages are growing relative to capital, as labor becomes the relatively scarce resource. Additionally, the shares of capital and labor will change, depending on the price elasticity of demand for capital – if the price of capital falls less than the growth in capital, its share in income will increase. It is against this back drop that capital-labor substitution in a CGE model must be reconciled. It is also the fuel for the ongoing debate of capital-labor complementarity—which, at times, can reconcile often contradictory observations on income shares, resource scarcity, wages and productivity. Given the importance of this debate, we explore further, in the following paragraphs, the rational for capital-labor complementarity, especially as it relates to CGE modeling.[18]

Reconciling the sometimes contradictory conclusions from stable capital-labor shares in the economy and the substitution \ complementarity of capital and labor has often been viewed from the lens of measurement and aggregation bias. Jorgenson and Griliches (1967) first proposed the problem as one of aggregation and measurement bias, since capital stocks and rental rates would appear to be one of the most heterogeneous groups of products, which often change with technological development. Griliches (1969) split capital in to structures and equipment and labor into “educated” and “uneducated” categories. (Griliches 1969). This approach gained some ground and suggested capital equipment (properly measured) was a complement for “educated” labor, but capital equipment was a substitute for unskilled labor. Berndt and Christiansen (1973), employing a translog function, determine that capital equipment and labor are substitutes. Importantly, Berndt and Christiansen test for the consistent aggregation of capital equipment and structures, and find no evidence of aggregation bias when adding the two together with proper indexes. Krusell et al. 2000, employing carefully constructed indexes of capital equipment (hedonic indexes) and structures, which take into account the productivity enhancing effects of technical change, once again find that capital equipment and skilled labor are Hicks complements and capital equipment and unskilled labor are substitutes. Importantly, in Krusell et al. they distinguish

[18] Another issue raised by Caddy (1976) is the idea that substitutability between labor and capital may also differ due to the age or vintage of the capital. The Linkage model includes vintages and allows for the possibility that elasticities of substitution may differ depending on the vintage of the capital with which the labor is substituting.

between shocks to the capital stock (Hicks) and shocks to the price of capital (Allen), and find that capital and skilled labor are q-complements (Hicks), but p-substitues (Allen).[19] Krusell et al. conclude much of the growing wage gap between skilled and unskilled workers can be explained by the complementarity between capital equipment, the growing stock of capital equipment (when measured hedonically), and skilled labor and the high substitution between capital equipment and unskilled labor.

As researchers employ increasingly disaggregated databases and definitions of labor and capital, it would appear theory and evidence will develop further. Behar 2007, employing a data set employing several occupation-based labor categories also find nuanced results, with capital being a p-substitute (AES) for all types of labor and a Hicks q-complement to certain types of skilled labor (semi-skilled and skilled/Artisan). Again, the level of aggregation and measurement become key variables.

In the case of the global CGE modeler, we are presented with several additional problems. First, the quality of capital stock data and rental rates are likely to vary significantly—carefully constructed hedonic indexes of capital are rarely employed internationally. Second, we have one measure of capital, which does not distinguish between equipment and structures (though some researchers do not find this aggregation to be biased). Finally, the GTAP based expanded definition of labor is occupation based in contrast to knowledge or skill based. This means a clerical work in Nigeria is not likely of the same education of a clerical worker in Europe. If there is a complementarity between capital and labor, the literature suggests that education classification is better than occupation-based classifications, since occupations only roughly map education, particularly across countries at different stages of development

It is against this back drop that we review the substitution of labor and capital. In the following sections we briefly outline the results from several classes of studies included in Table AII- 1 and Table AII- 3.

ECONOMY-WIDE ESTIMATES

Several studies that cover a wide range of time periods, countries and reliable empirical methodologies are included in Table AI- 1. Aggregate estimates of the elasticity of substitution between capital and labor range from 0.24 to 2.01 (Bentolila & Saint-Paul, 2003; Berthold, Fehn, & Thode, 2002; Bolt & Van Els, 2000; Ma et al., 2008). The estimates from Bolt & Van Els (2000) for Europe, US and Japan are based on quarterly time-series data from 1975-1996 and all between 0.24 and 1.0. Time-series data are generally thought to provide short run elasticity estimates (Jomini, Zeitsch et al., 1991), although some judgement should be used in

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[19] Behar (2007) and Krusell et al. (2000) also both find capital to be a Hicks complements (quantity) to skilled or skilled/Artisan labor respectively. Behar (2007), like Hick's (1970) also distinguishes the different estimates of elasticity of substitution by applying the useful notation p-substitutes and q-substitutes or p-complements or q-substitutes to differentiate between Hicks quantity substitution and Allen-Uzawa price substitutes.

applying this rule of thumb. The Berthold, Fehn, & Thode (2002), on the other hand, produce long run elasticities for Germany, France and the USA that are greater than one. Given they are long run elasticities it is not surprising that the Berthold, Fehn, & Thode (2002) elasticities are all significantly larger than the Bolt & Van Els (2000) elasticities for the same countries. We might therefore conclude that short run estimates are within the range 0.24 and 1, while long run estimates are between 1 and 2, approximately double.

Unfortunately, there is insufficient data on developing countries to determine if there are any differences between developed and developing countries at this level of aggregation.

SECTOR SPECIFIC ESTIMATES

Selected studies that examine sectoral substitution possibilities between capital and labor are Balistreri, McDaniel, and Wong (2003) for the US economy, Claro (2003) for a cross section of 34 countries, De Wet (2005) for South Africa and Goldar, Pradhan, and Sharma (2013) for India (Table AII- 3).

Balistreri et al. (2003) estimate a comprehensive set of long-run capital-labor substitution elasticities for 28 industries of the US economy. The range of their point estimates is between -34.6 for food and kindred products to 76.3 in petroleum and coal products. After excluding these outliers, estimates are in the range of 0.307 in the case of farms to 3.736 in the case of Electronic and electric equipment[20]. Such elasticities are easy to reconcile with the range of economy-wide estimates quoted above. Importantly, these authors find that they cannot reject the null hypothesis of a Cobb-Douglas structure (elasticity of substitution of one) for over 20 industries – reinforcing the argument for a Cobb-Douglas production structure.

The remaining three studies (Claro, 2003; De Wet, 2005; Goldar et al., 2013) that cover sectoral variation in the estimation of capital-labor substitution produce estimates that are in the range between zero and two. Claro (2003) uses a panel dataset of 34 countries for the year 1990. They find that the substitution possibilities between capital and labor are the highest in the tobacco industry 2.02 and lowest in non-metalic mineral products 0.63. Despite using time series data, De Wet (2005) and Goldar et al. (2013) obtain similar results to Claro (2003).

A comparison of these elasticitities with the GTAP and SALTER elasticities (Jomini et al., 1991) is provided in Table AII- 2. The more recent empirical estimates still seem reasonably close to the original SALTER model estimates, with the exception of a few of the long run estimates by Balistreri, McDaniel et al. (2003) that are higher.[21] While the estimates of Balistreri, McDaniel et al. (2003) are generally larger than the other studies, they are not double.

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[20] The authors do not indicate why the range is the size that it is.

[21] Jomini, Zeitsch et al (1991) also argue that cross section estimates are likely to be long run while time series are more likely to be short run estimates, suggesting that De Wet (2003) and Goldar (2013) are also likely to be longer-run elasticities than Claro (2003).

SUBSTITUTION BY OCCUPATIONAL GROUPS

Behar's (2007) work is of significance here due to the fact that his estimation is based on occupational groups, rather than education, that are similar to those used in the new GTAP database (Table 1). Behar's categories include managerial, skilled/Artisan, Clerks/sales workers and unskilled which correspond roughly, although not perfectly, to managers, technicians, medium skilled (the aggregate of clerks and service workers), and low skilled in the new GTAP database. Behar (2007) finds that that capital is an Allen-Uzawa p-substitute for all occupational groups with the highest capital-labor substitution elasticity found between skilled/artisan occupations (2.91) and the lowest with unskilled workers (1.74). This finding is consistent with the findings of Krusell et al. 2000, who likewise find p-substitutability between capital and skilled (1.67) and unskilled (0.67) labor, albeit Behar's (2007) estimates are higher. The higher elasticities may reflect the fact that Behar (2007) use a cross section panel database of 300 firms, while Krusell et al. (200) use a time series dataset – suggesting that Behar's estimates may represent a longer time horizon (Jomini et al, 1991). Finally, Behar (2007) argues that their finding, that all labor types are substitutes for capital, implies that nothing is lost when aggregating different types of heterogeneous labor to form a labor-capital composite. The Allen elasticities between capital and disaggregated labor are provided in Table AII- 3.

Table 1: List of GTAP labor categories

ISCO-88 Major group	Abbreviated name (used in GTAP)	Short names	ILO Descriptions
1,2	off_mgr_pros	Managers	Managers, senior officials and Legislators (Major Groups 1), and professionals (Major Group 2)
3	tech_aspros	Technicians	Technicians and associate professionals (ICT, health, teachers, engineers, specialized administration, arts, entertainment, design and sport)
4	Clerks	Clerks	Clerical support workers
5	service_shop	Service workers	Service workers and shop and market sales workers
6,7,8,9	ag_othlowsk	Low skilled	Skilled agricultural and fishery workers (Major Group 6), craft and related trade workers (Major Group 7), plant and machine operators and assemblers (Major Group 8), and elementary occupations (Major Group 9)

Source: Walmsley and Carrico (2013) and International Labor Organization (2012).

Falk and Koebel (1997) also estimate results for multiple skill categories in Germany, although the division is education based (graduates, post-secondary vocational training, and no degree). They find a large number of very small complementarities between capital and graduates in manufacturing (-0.17); and vocational training in construction (-0.93), banking (-0.10) and wholesale (-0.10). However, they also find small complementarities between capital and low skilled in energy (-0.26) and banking (-0.08). The remaining pairs show substitution, particularly in construction (graduates and no degree). Based on the ILO's (2012) mapping of the occupational categories to education, the top two education categories in Falk and Koebel (1997), graduate and vocational, would be equivalent to the two highest occupational categories in GTAP – managers and technicians. The remaining GTAP occupations would correspond to 'no degree'. In this case we have mapped graduate to managers, vocational to technicians, and no degree to medium (clerks and service workers) and low skilled, although this is clearly not an adequate mapping. This is common issue with the education based studies, which usually examine only tertiary and non-tertiary education in developed countries.

Substitution among Heterogeneous Labor Categories

Moving away from an aggregated "labor" category poses an important initial question with regards to how exactly one should define disaggregated labor groups. Much of the existing research that analyses substitution possibilities among labor categories differentiates between skilled and unskilled labor by education. More recently however, with increased data availability it has become possible to further disaggregate labor groups by many different criteria such as education levels, occupations, tasks, jobs, gender, race or immigration status. As pointed out by (Griffin, 1996), using classifications such as those based on race, gender or immigration status that cover much heterogeneity within one group could be less empirically valid than using classification based on education or occupations.

The most recent version of the GTAP database contains five new labor categories that were defined based on occupational groupings. More specifically, the five categories are: managers, technicians, clerks, service workers, and low skilled (Walmsley & Carrico, 2013). While the goal of this study was to look for existing literature analyzing substitution possibilities that cover these exact five occupational categories, due to recent data limitations the number of such studies is still very limited. In order to provide a more comprehensive picture, we find it useful to refer back to a classification based on skill levels and research the literature for substitution possibilities among skill groupings[22].

The seminal work of (Griliches, 1969) was among the first ones to suggest that educated labor is more complementary with physical capital than uneducated or "raw" labor. One of the main difficulties faced by researchers in identifying skill differentiated elasticities of substitution is the so called identification (simultaneity) problem. The identification problem (Hamermesh, 1996) arises from the fact that the skill premium and the relative share of skilled to unskilled workers are determined simultaneously by both supply and demand. For instance, in a world characterized by skill biased technological change both the relative demand and supply of skilled (educated) workers increases. As the relative wage of skilled workers increases the interplay between the "expansion" and "substitution" effects are the ones that determine the final slope of the relative demand curve for skilled workers.

[22] One could assume that the first two occupational categories (managers and technicians) correspond to a "skilled" category while the remaining ones (clerks, service workers, low skilled) are "unskilled".

ECONOMY-WIDE ESTIMATES

Overall, the aggregate long-run elasticity of substitution between skilled and unskilled labor is found to be in the range of 1.31 – 2.0 (Angrist, 1995; Caselli & Coleman, 2000; Fallon & Layard, 1975; Johnson, 1970; Katz & Murphy, 1992; Krusell, Ohanian, Ríos-Rull, & Violante, 2000). All of the studies, however proxy unskilled and skilled with education data on secondary and post-secondary schooling. A good summary of such estimates is to be found in (Ciccone & Peri, 2005). The studies considered here include both cross-section and time series data, taking into account a cross section of countries and time periods. All these studies attempt to tackle the above mentioned simultaneity problem of supply and demand and are comparable to a large extent. In addition, most of these estimates are based on a CES production function and implicitly assume that the relative demand for skilled workers with respect to the relative wage of skilled workers is constant along the relative demand curve. Using a more flexible functional form (translog) would keep the elasticity estimates in the same range (Ciccone & Peri, 2005). Studies that include both developed and developing countries in their sample (Caselli & Coleman, 2000; Fallon & Layard, 1975) find no significant differences from the ones that include developed countries only. Unfortunately, we could not find any more recent cross country studies.

SECTOR SPECIFIC ESTIMATES

While aggregate economy-wide estimates provide a good macroeconomic perspective, it is safe to assume that sectoral level estimates of the elasticity of substitution between skilled and unskilled labor would reveal significant variation. Empirical evidence (Blankenau & Cassou, 2011; Katz & Murphy, 1992) show that aggregate data tends to cover significant sectoral variation and industry-level substitution possibilities are considerably higher. On the one extreme, the authors find two sectors (Agriculture and Other services) that exhibit almost perfect substitutability between skilled and unskilled labor. On the other extreme, it is Information, Professional and Financial services that have the lowest substitution possibilities between skilled and unskilled labor.

SUBSTITUTION BY OCCUPATIONAL GROUPS

The economic literature that estimates the substitution possibilities by occupational groups is very limited. A number of Australian economists, interested in CGE modeling, produced elasticities based on occupation groups in the late 1970s for the Australian economy (Higgs, Parham, & Parmenter, 1981; Ryland & Parham, 1978). While these studies are relatively outdated, these estimates are still used today (Roos, 2013) to parameterize CGE models such as ORANI or USAGE. Other studies that explore substitution possibilities between occupational groups are Falk and Koebel (1997) for Germany, Hijzen, Görg, and Hine (2005) for the United Kingdom and Behar (2007) for South Africa. Given that the goal of this study is to determine elasticities of substitution between occupational groups, in this section we focus our attention on each study in detail.

Ryland and Parham (1978) divide labor into five occupational groups including Professional, Skilled White Collar, Unskilled White Collar, Skilled Blue Collar and Unskilled Blue Collar. Their estimates of Allen Elasticities of Substitution range from zero to 1.70. Few of these values are statistically significant. The highest elasticities of substitution are found to be between Skilled White Collar workers and Skilled Blue Collar workers 1.72 and Skilled White Collar workers and Unskilled Blue Collar workers 1.11. The least substitutable are found to be Skilled Blue Collar and Unskilled Blue Collar workers 0.215. Finally, the authors find complementarity between Professional and Skilled White Collar workers -0.18 or Skilled White Collar and Unskilled White Collar workers -0.55.

Higgs et al. (1981) calculate endogenously generated elasticities of substitution for nine categories of occupational groups for the Australian economy. These groups are similar but more narrowly defined than in Ryland and Parham (1978): Professional; Skilled White Collar; Semi and Unskilled White Collar; Skilled Blue Collar, Metal and Electrical; Skilled Blue Collar, Building; Skilled Blue Collar, Other; Semi and Unskilled Blue Collar; Rural Workers and Armed Services. As in Ryland and Parham (1978), these implied elasticities of substitution range from 0.10 to 1.05.

Falk and Koebel (1997) estimate own- and cross-price elasticities for the three education-based categories with a sectoral dimension (Manufacturing; Energy, Water and Mining; Construction; Wholesale and Retail; Banking and Insurance) for Germany (Table 2). The magnitude of calculated AES elasticities (using GTAP shares) vary from -1.09 (Technicians – medium skilled in Energy) to 7.47 (managers – unskilled in Construction). Managers and technicians are generally found to be complements with each other (or very low substitutes), and substitutes with unskilled workers.

Hijzen et al. (2005) define three categories of occupational groups based on the Standard Occupation Classification: skilled (Managers and Professionals), semi-skilled (Associate Professionals, Clerical, Craft, Personal and Sales) and unskilled (Plant and Machine and Other Occupations) and explore own and cross price elasticities for the United Kingdom. The AES elasticities (converted by Hijzen (2005)) show that all types of labor are complements. Elasticities range from -0.45 (technicians / medium skilled and managers labor) to -0.24 (technicians / medium skilled and low skilled labor).

Table 2: Summary elasticities for sectoral labor and capital

		Second category of substitution			
		Skilled (tertiary)		Unskilled (no tertiary)	
Source	First category of substitution*	Managers (tertiary)	Technicians (vocational)	Medium skilled (Clerks and Service)	Low skilled
ENERGY, WATER, MINING					
Falk & Koebel (1997)	Capital**	0.01, 0.02	0.13, 0.01	-0.26, -0.01	
Falk & Koebel (1997)	Managers	0.17	-1.09	2.78	
Falk & Koebel (1997)	Technicians	-0.07	0.17	0.39	
Falk & Koebel (1997)	Unskilled	0.42	0.87	0.26	
MANUFACTURING					
Behar (2007)	Capital	2.20	2.90	2.73	1.74
Behar (2007)	Managerial	-5.96	-	-	-
Behar (2007)	Technicians	-5.77	-7.28	-	-
Behar (2007)	Medium skilled	-1.46	-7.28	-5.48	
Behar (2007)	Low skilled	-2.04	1.79	-2.44	-5.94
Falk & Koebel (1997)	Capital**	-0.04, -0.17	0.03, 0.04	0.18, 0.21	
Falk & Koebel (1997)	Managers	0.42	1.83	5.21	
Falk & Koebel (1997)	Technicians	0.11	0.48	2.53	
Falk & Koebel (1997)	Unskilled	0.29	1.41	2.42	
Hijzen et al (2004)	Managers	-0.90	-0.43		-0.17
Hijzen et al (2004)	Technicians / Medium skilled	-0.45	-0.46		-0.24
Hijzen et al (2004)	Low skilled	-0.18	-0.24		0.05
CONSTRUCTION					
Falk & Koebel (1997)	Capital**	0.07, 1.10	-0.59, -0.42	0.37, 1.02	
Falk & Koebel (1997)	Managers	0.70	-0.93	7.47	
Falk & Koebel (1997)	Technicians	-0.04	0.12	1.78	
Falk & Koebel (1997)	Unskilled	0.08	0.47	1.05	
BANKING					
Falk & Koebel (1997)	Capital**	0.05, 0.17	-0.03, -0.03	-0.04, -0.01	
Falk & Koebel (1997)	Managers	1.23	-0.11	1.58	
Falk & Koebel (1997)	Technicians	-0.01	0.21	0.35	
Falk & Koebel (1997)	Unskilled	1.51	2.47	1.24	
WHOLESALE AND RETAIL TRADE					
Falk & Koebel (1997)	Capital**	0.02, 0.31	-0.07, -0.05	0.03, 0.03	
Falk & Koebel (1997)	Managers	0.13	0.13	0.69	
Falk & Koebel (1997)	Technicians	0.05	0.02	0.07	
Falk & Koebel (1997)	Unskilled	0.02	0.05	0.05	

* *GTAP notation used where possible to assist in mapping categories used by different papers.*

***Falk* & Koebel (1997) do not impose symmetry, hence the two numbers for capital.

Source: Various. The first category is the factor i and the second category is the j in $\sigma_{i,j}$.

Finally, in Behar (2007) the occupational classification follows very closely that of GTAP using five categories of labor: Managers/Professional, Sales/Clerical, Skilled/Artisan, Semiskilled and Unskilled. Estimates of Allen Elasticities of Substitution among occupational groups are found to be significantly lower than in other comparable studies. Estimates of AES elasticities (converted by Behar (2007)) range from -7.28 (medium skilled – technicians) to 1.79 (low skilled – technicians). Overall, all occupational categories are found to be complements with the exception of low skilled – technicians which are substitutes. Following the rule of thumb noted by Jomini et al. (1991), the estimates of Behar (2007) are likely to be more long run than those of Falk and Keobel (1997) suggesting that the complementarities might get stronger in the long run.

Substitution between Natives and Immigrants

The extensive empirical literature that examines the substitutability or complementarity between native and immigrant labor has so far yielded two interesting conclusions: first, overall immigrant workers seem to be substitutes for natives in production and second, while there is a general consensus that the effect of immigration on the wages of natives is statistically significant, this effect is found to be much smaller than expected.

The seminal work of Grossman (1982) first provided evidence that is consistent with substitutability between natives and immigrants. The author uses 1970 US Population Census data to specify a translog production function where natives, second generation workers and immigrants are separate inputs into production. Results show that both second generation and foreign born workers are substitutes for natives but second generation workers are much more highly substitutable for natives than are foreign-born workers. Capital is found to be Hicks complementary (quantity based, or q-complements in contrast to p-complements in Hicks notation) with all types of labor but the degree of complementarity is strongest with foreign-born workers and weakest with native workers.

Later studies are well summarized by Borjas (1994). Point estimates of the elasticity of native wages with respect to the number of immigrants range between -0.01 and -0.02 indicating that native's wages are only marginally impacted by immigration. Evidence in these reviewed studies also indicates that the same results hold not only on average but also across all types of natives, i.e. white or black, skilled or unskilled, male or female.

Few studies focus on substitution possibilities between immigrants and natives within occupations or skill groups (Fromentin, 2011; Jaeger, 1996; Manacorda, Manning, & Wadsworth, 2012; Ottaviano & Peri, 2012). More recently, Ottaviano and Peri (2012) find an elasticity of substitution of around 20 between natives and immigrants for the US. Allowing this elasticity to vary across education groups, results in significantly lower estimates. As results show, substitution possibilities between natives and immigrants are lowest for workers with high school degree (around 11.2), followed by workers with no degree (13.7) and with some degree (14). On the other extreme, however, the substitution between natives and immigrants with a college degree is close to perfect (58.8). In the long run, these estimates imply an overall positive effect of immigration on native wages of about 0.6 percent.

Substitution between Labor and Outsourcing

The economic literature that examines a firm's decision to contract out or outsource versus the use of internal resources has been growing as the organization of production of firms is undergoing important changes. More and more, activities that used to be performed in-house (e.g. audit, accounting, engineering, design, IT, maintenance, repair, transportation, janitorial or legal services) are now outsourced. This has in turn contributed to the growth of business services sectors. As a result, economic researchers have been showing growing interest in arrangements external to firms such as contracting out, subcontracting, outsourcing and the use of temporary employees.

As pointed out by Abraham and Taylor (1993), the reasons for contracting out rather than having the work performed in house could be multifold. First, firms might want to take advantage of low external wage rates for certain types of low skill work. Second, contracting out would allow firms to accommodate uneven and volatile demand for its products or services without having to carry the costs associated with having more workers on the payroll. Finally, the organization might lack specialized equipment or skills that an external contactor could provide making use of potential economies of scale.

The better part of the empirical literature on this topic focuses on the one hand, on characteristics of firms that determine their propensity to outsource (Abraham & Taylor, 1993; Gray, Roth, & Tomlin, 2009) and on the other hand, on the influence of contracting out on the profitability of a firm (Gilley & Rasheed, 2000; Görzig & Stephan, 2002). At this point, we are not aware of any empirical studies that analyze substitution possibilities between internal labor and external labor/services.

In terms of outsourcing of production, Hijzen et al. (2005) take a unique approach by gauging outsourcing in intermediate inputs and find that some types of low skill labor are substitutes for particular imported intermediate inputs which are intensive in low skill labor. This analysis finds that, especially when intermediate inputs in the same sector classification are employed (the principal diagonal of the IO matrix) substitution can be high with low skilled labor. The relationship between high skilled labor and intermediate inputs is less pronounced.

Value Added Nest

Having reviewed the existing literature on the substitutability of capital and labor, we turn the CGE value added nesting structure and how to incorporate the new GTAP occupational categories (Table 1).

Ideally, assumptions, functional form and the data used in the econometric estimation of the elasticities of substitution would be fully consistent[23] with the functional form employed in the CGE model. For example, if the econometric estimation uses a translog to estimate Allen partial elasticities based on cross-section data assuming symmetry and increasing returns to scale, the CGE model where these elasticities are implemented should also use a translog with the same assumptions and data. Due to constraints, however, most CGE models use a nested CES approach, which considerably reduces the number of parameters required. As suggested by Perroni and Rutherford (1995), nested functional forms can replicate conditions in the same way more flexible functional forms do. The authors also argue that a nested CES structure has a better behavior and less convergence problems than flexible functional forms.

The convention used to establish a nesting structure for a CGE model, is "that factors of production that are close complements are grouped together at low levels of the nesting, whereas factors that are good substitutes are combined at a higher level" (p,1682, Boeters and Savard, 2012). This results in elasticities of substitution that are higher at high levels of the nest, than those at the lower levels. There is no empirical evidence for this convention, however, the convention may have developed as a way of ensuring plausible demand elasticities.

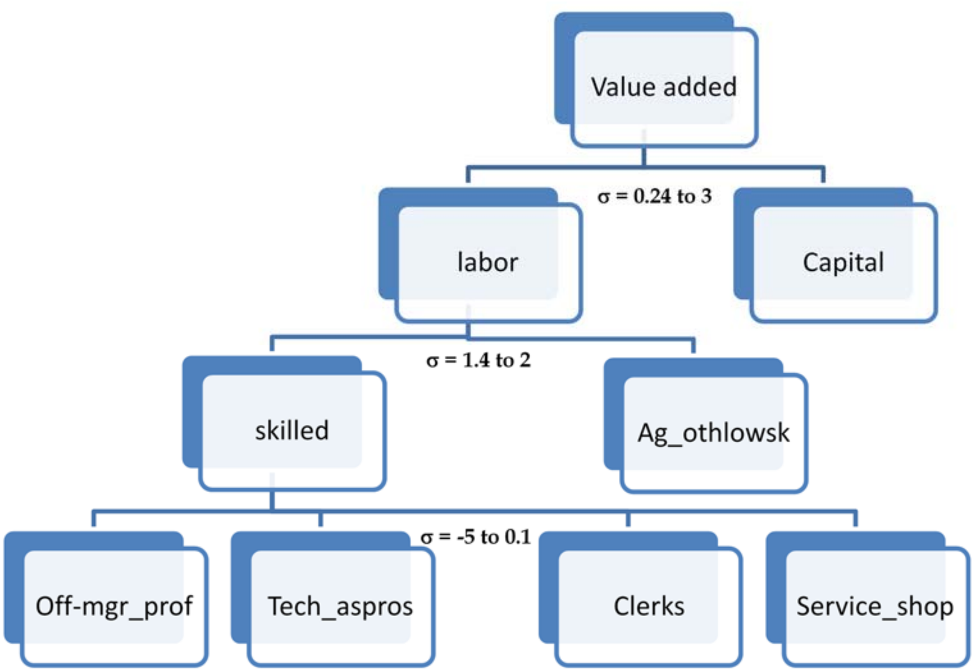
Why is this a concern? As the number of "nests" in the production function increases, it becomes increasingly important to ensure that the resulting implied elasticities make sense. Boeters and Savard (2012), for instance, state that the emphasis on elasticities of substitution may be misplaced, since nesting structures alter the implied demand elasticities. Ultimately CGE modellers should be concerned about the resulting demand elasticities from the combined choice of their nesting structures and elasticities of substitution, and adjust them

[23] Note for instance that a latent assumption of all nested CES structures is the so called separability that should also be present in the econometric estimation of the elasticities.

accordingly to match empirical estimates.[24] For instance, it is possible to get complementarities in a nesting structure even if the elasticitiy of substitution is greater than zero. Appendix VI contains the formulas used to calculate these implied Allen partial elasticities of substitution associated with a nested production function.[25]

Keeping these caveats in mind and using the summary data in Table 2, we suggest the following nesting structure for capital and the five new occupational labor types, which is represented in Figure 1. In this nesting structure capital and aggregate labor are combined at the top level to reflect the (Allen) substitution between capital and labor that was seen in the empirical studies examined here (Behar, 2007 and Krusell, 2000). The empirical evidence suggests that the implied elastcitiy of substitution between aggregate capital and labor at this upper level should be between 0.24 and 3.0 depending on the sector and the time-frame (less than 1 for short run and greater than 1 for the long run). At the second level, we group labor into two clusters reflecting the complementarities found between skilled categories (Managers, Technicians, Clerks and Service), and the high substitution between skilled and low skilled. This lower level structure is consistent with the results of both Behar (2007) for South Africa and Falk & Koebel (1997) for Germany (Table 2). This structures is also consistent with Hijzen et al. (2004), since the complementarity between skilled and unskilled labor is somewhat weaker than that amongst the other skilled categories, suggesting the same two clusters as Figure 1.

Figure 1: Value added nesting structure with capital-labor aggregate



Source: Author's construction

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[24] Hence the adjustment made to the GTAP agricultural elasticities in order to obtain expected supply responses (Hertel, Tsigas et al, 2012).

[25] The geelast.tab file accompanying the GTAP model calculates these elasticities in RunGTAP automatically.

Estimated elasticities between skilled and unskilled (for all sectors) seem to be more closely grouped together, between 1.4 and 2, although there are some larger differences between sectors, see estimates from Blankenau & Cassou (2011) and Falk & Koebel (1997). A comparison of Balistreri, McDaniela et al. (2003) with Claro (2003), De Wet (2005) and Goldar (2013) would suggest higher elasticities should be used for the longer run, than for the short run. Also we'd expect elasticities to fall as we proceed down the nest. Elasticities within the new skill categories are low or negative, indicating complements. Assuming Behar's (2007) estimates are closer to the long run, this would suggest that there might be more complementarity between skilled labor types in the long run.

Despite evidence that some forms of capital and skilled labor are complementary, we have not proposed a composite aggregating skilled labor and capital. The main reason for this is that the GTAP capital stock is an aggregation of capital equipment, structures and infrastructure, and in general skilled labor and 'aggregate' capital are found to be (Allen) substitutes (Behar, 2007 and Krusell, 2007). In addition, the complementarities found between skilled labor and capital appear to be weak (Falk and Koebel, 1997) and have also been related to new capital equipment and/or tertiary educated (managers and technicians) labor. Incorporation of capital-skilled complementarities should therefore be done in conjunction with additional changes to the model and GTAP data to disaggregate capital and capture capital vintages.

Conclusions

In this paper we first explored empirical evidence of the substitutability between and within capital and disaggregated labor; as well as between foreign and domestic labor in order to obtain some recommendations for nesting the five new occupation-based labor categories in the GTAP database.

With regard to the capital-disaggregated labor substitutability, the findings are inconclusive. Two papers (Behar, 2007 and Krusell et al., 2000) obtain that capital is a p-substitute against all disaggregated labor types, albeit they are slightly smaller for unskilled workers, and a q-complement with some labor types. Falk and Keobel (1997) on the other hand find some p-complementarities between capital and skilled and/or unskilled labor depending on the sector. The two papers are very different. Behar (2007) uses South African firm level data for 300 firms and four occupations; while the Falk and Keobel (1997) paper uses time series data on education levels (tertiary, vocational and no degree) for Germany. Krussel et al. (2000) also uses education data, but disaggregates capital equipment from other forms of capital and uses hedonic indexes to obtain the measure of capital.

The empirical evidence on substitutability within occupational categories is more consistent. Behar (2007), Falk and Keobel (1997) and Hijzen et al. (2005) all show that as more skill categories are considered, and homogeneity within categories increase, the elasticities of substitution fall and the frequency of complementary relationships between labor categories increases, particularly between skilled labor types.

There was insufficient evidence that elasticities differ between developed and developing countries, as only a few studies look at cross country estimates (Claro, 2003) of elasticities or developing countries (India: Goldar, 2011) and they show no differences. On the other hand there are significant differences between sectors, as illustrated by Balistreri et al. (2003), Claro (2003), De Wet (2003), Goldar (2013), Blankenau & Cassou (2011) and Falk and Keobel (1997).

In the case of immigration, it is generally found that native and immigrant workers are strong substitutes and hence elasticities are high. Unfortunately, no research was available on the substitutability between labor and services.

Since the aim of this report was to provide recommendations on how to model substitution possibilities within value added and between labor value added and services in a CGE model, particularly in light of recent improvements to the GTAP database that disaggregate labor in to five occupational groups (Table 1), we provide those here.

First, given the high substitutability between labor and capital, and the complementarities amongst skilled labor categories and high substitutability with low skills we suggested a nesting structure that aggregated capital and labor, and then disaggregated labor according to skill (Figure 1). While we chose not to combine capital and skilled labor, this could be done, however we would recommend some additional changes to the model and data to disaggregate capital and include capital vintages.

In the case of immigrants, it is generally accepted that the elasticities between native and immigrant workers can be set at relatively high levels.

Given the interaction between the chosen model elasticities of substitution and the nesting structure, and hence the likelihood of unintended demand elasticities, we strongly recommend that the implied demand elasticities are calculated before the final structure and set of elasticities are chosen.

For labor and services we would recommend not including this, except perhaps as part of sensitivity analysis when examining services related issues. More research is required.

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Appendix I Sources of Elasticities of Substitution

Table AI- 1: Overview of sources of elasticity estimates

Source	Estimates	Sector	Country	Type	Data	Function	Time frame*
LABOR - CAPITAL							
Bolt and van Els (2000)	Labor - capital	Overall	Austria	AES (CES)	Quarterly time-series data	CES	
Ma et al. (2008)	Labor - capital	Overall	China	AES	31 provinces in China and annual 1995–2004	two-stage translog cost function	Long run
Berthold et al. (2002)	Labor - capital	Overall	US	AES (CES)	Semi-annual 1970-1995	CES	Long run
Balistreri et al (2003)	Labor - capital	Various	USA	AES (CES)	long panel (1947-1999)	CES	long run
Claro (2003)	Labor - capital	Various	34 countries	AES (CES)	cross-section of 28 industries and 34 countries 1990	CES	
De Wet (2003)	Labor - capital	Various	South Africa	AES	Time series data for 45 industries	CES	
Goldar (2013)	Labor - capital	Various	India	AES (CES)	annual time series 1980-2008	CES	
SKILLED AND UNSKILLED - CAPITAL EQUIPMENT							
Krusel et al (2000)	Skilled and unskilled - capital equipment. Education based (>16 years of schooling, <16 years of schooling)	Overall	USA	AES (CES)	time series, US data 1963-1992	CES (labor) and Cobb Douglas (between capital types)	
SKILLED - UNSKILLED (EDUCATION)							
Ciccone & Perri (2005)	Years of schooling, less than and greater than 12 years	Overall	USA	AES (CES)	1950-1990, decennial data	CES	long run
Caselli & Coleman (2000)	No education or primary, secondary and higher	Overall	52 countries	AES (CES)	cross section of 52 countries	Nested CES	
Krusel et al (2000)	>16 years or Tertiary, <16 or secondary	Overall	United States	AES (CES)	time series, US data 1963-1992	CES (labor) and Cobb Douglas (between capital types)	
Katz & Murphy (1992)	College - high school labor	Overall	United States	AES (CES)	times series, 1964-1988	CES	
Johnson (1997)	College - high school labor	Overall	United States	AES (CES)	times series	CES	
Angrist (1995)	no education, schooling	Overall	Palestine	AES (CES)	times series, 1981-1991	CES	
Fallon & Layard (1975)	less educated - more educated	Overall	Multiple countries	AES (CES)	Industry cross section 1968-73	CRESH	

Bowles (1969)	0-7 years schooling - 8-11 years schooling - greater than 12 years	Overall	12 countries	AES (CES)	Data for 12 countries	CES	
Blankenau & Cassou (2011)	years of schooling, less than and greater than 12 years	Various	United States	AES (CES)	time series, 1968-2006	CES	
DISAGGREGATED LABOR							
Falk & Koebel (1997)	capital and disaggregated labor (Education based - graduates, vocational and no-degree)	Various	Germany	cross price elasticity	time series, 1977-1994	Normalized quadratic cost function	
Behar (2007)	capital and disaggregated labor (Managers, Skilled Artisans, semi-skilled and unskilled)	Manufacturing	South Africa	AES	cross section, 300 firms	Translog	
Hijzen et al (2004)	Occupation based (skilled, semi-skilled and unskilled)	Manufacturing	UK	AES	time series, 1982-1996	Translog	
Higgs et al (1981)	Occupation based (9 occupations: professionals, white collar, blue collar-skilled and unskilled)	Overall	Australia	AES	Industry cross section 1968-73	CES/CRESH	
Ryland & Parham (1978)	Occupation based (5 occupations: white collar, blue collar, skilled and unskilled)	Overall	Australia	AES	Industry cross section 1968-73	CRESH	
IMMIGRATION							
Fromentin (2011)	High, medium and unskilled natives and immigrants	Manufacturing	France	Own price elasticity	2008 data on migrants for 36 sectors and based on occupations	translog	
Borjas et al. (2011)	Male and female native and immigrant	Overall	USA	AES (CES)	1960-2000 decennial censuses and 2006 American Community Survey	CES	
Jaeger (2007)	Education level and sex, native and immigrants, education and male/female	Overall	USA	AES (CES)	1990 panel	CES	
Bauer (1998)	White/blue collar, skilled and unskilled, native and immigrants	Overall	Germany	Hicks elasticity	1990 cross section data	translog	
Greenwood and Hunt (1995)	native and foreign born	Overall	USA	price elasticity	1980 cross sectional data		
Grossman (1982)	Native, foreign born and second generation	Overall	USA	Hicks elasticity	1970 cross section	translog	

* *Time frame is outlined in paper. If missing then authors did not mention.*

Appendix II Elasticities of Substitution between Labor and Capital

Table AII- 1: Estimates of elasticities between labor and capital (overall and by sector)

Source	Original description	Value of elasticity	Sector	Country	Type
		OVERALL			
Bolt and van Els (2000)	Labor - capital	0.24	Overall	Austria	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.78	Overall	Belgium	AES (CES)
Ma et al. (2008)	Labor - capital	0.338	Overall	China	AES
Bolt and van Els (2000)	Labor - capital	0.61	Overall	Denmark	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.34	Overall	Finland	AES (CES)
Berthold et al. (2002)	Labor - capital	2.01	Overall	France	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.73	Overall	France	AES (CES)
Berthold et al. (2002)	Labor - capital	1.45	Overall	Germany	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.53	Overall	Germany	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.52	Overall	Italy	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.3	Overall	Japan	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.27	Overall	Netherlands	AES (CES)
Bertolila and Saint-Paul (2003)	Labor - capital	1.06	Overall	OECD	AES
Bolt and van Els (2000)	Labor - capital	1	Overall	Spain	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.68	Overall	Sweden	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.6	Overall	UK	AES (CES)
Bolt and van Els (2000)	Labor - capital	0.82	Overall	US	AES (CES)
Berthold et al. (2002)	Labor - capital	1.15	Overall	US	AES (CES)
		BY SECTOR			
Balistreri et al (2003)	Labor - capital	0.364	Agricultural services, forestry and fishing	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	2.051	Apparel and other textile products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.448	Chemicals and allied products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.271	Coal mining	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.893	Construction	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	3.736	Electronic and other electric equipment	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.393	Fabricated metal products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.307	Farms	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	-34.6	Food and kindred products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.007	Furniture and fixtures	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.815	Industrial machinery and equipment	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.599	Instruments and related products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	-1.532	Leather and leather products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.12	Lumber and wood products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.67	Metal mining	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.684	Misc. mfg. industries	USA	AES (CES)

Source	Original description	Value of elasticity	Sector	Country	Type
Balistreri et al (2003)	Labor - capital	0.4	Motor vehicles and equipment	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.893	Nonmetallic minerals,	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.735	Oil and gas extraction	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.322	Other transportation equipment	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.907	Paper and allied products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	76.3	Petroleum and coal products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.533	Primary metal industries	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.51	Printing and publishing	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.806	Rubber and misc. plastics products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	0.501	Stone, clay, and glass products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.138	Textile mill products	USA	AES (CES)
Balistreri et al (2003)	Labor - capital	1.226	Tobacco products	USA	AES (CES)
Berndt and Christensen (1973)	Labor - capital	1.42	Manufacturing	USA	AES
Claro (2003)	Labor - capital	0.7	Apparel	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.86	Bever age	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.8	Chemicals	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.69	Electrical Machinery	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.91	Fabricated Metal Products	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.76	Food Products	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.58	Footwear	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.81	Furniture	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.96	Glass	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.94	Iron & Steel	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.86	Leather	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.96	Machinery except Electrical	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.92	Misc. Products of Petroleum & Coal	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.66	Non-Ferrous Metals	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.74	Other Chemicals	34 countries	AES (CES)
Claro (2003)	Labor - capital	1.38	Other Manufacturing Industries	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.63	Other Non-Metallic Mineral Products	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.8	Paper Products	34 countries	AES (CES)
Claro (2003)	Labor - capital	1.08	Petroleum Refineries	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.59	Plastic	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.83	Pottery	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.68	Printing and Publishing	34 countries	AES (CES)
Claro (2003)	Labor - capital	1.02	Professional & Scientific Equipment	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.66	Rubber	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.93	Textile	34 countries	AES (CES)
Claro (2003)	Labor - capital	2.12	Tobacco	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.88	Transport Equipment	34 countries	AES (CES)
Claro (2003)	Labor - capital	0.71	Wood	34 countries	AES (CES)
De Wet (2003)	Labor - capital	0.74	Agriculture, forestry and fishing	South Africa	AES
De Wet (2003)	Labor - capital	0.83	Basic chemicals	South Africa	AES
De Wet (2003)	Labor - capital	1.01	Basic iron and steel	South Africa	AES
De Wet (2003)	Labor - capital	0.81	Basic non-ferrous metals	South Africa	AES

Source	Original description	Value of elasticity	Sector	Country	Type
De Wet (2003)	Labor - capital	0.28	Beverages	South Africa	AES
De Wet (2003)	Labor - capital	1.05	Building construction	South Africa	AES
De Wet (2003)	Labor - capital	0.29	Business services	South Africa	AES
De Wet (2003)	Labor - capital	0.5	Catering and accommodation services	South Africa	AES
De Wet (2003)	Labor - capital	0.91	Civil engineering and other construction	South Africa	AES
De Wet (2003)	Labor - capital	0.38	Coal mining	South Africa	AES
De Wet (2003)	Labor - capital	0.28	Coke and refined petroleum products	South Africa	AES
De Wet (2003)	Labor - capital	1.45	Communication	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Electrical machinery	South Africa	AES
De Wet (2003)	Labor - capital	0.26	Electricity, gas and steam	South Africa	AES
De Wet (2003)	Labor - capital	0.34	Finance and insurance	South Africa	AES
De Wet (2003)	Labor - capital	0.34	Food	South Africa	AES
De Wet (2003)	Labor - capital	0.81	Footwear	South Africa	AES
De Wet (2003)	Labor - capital	0.58	Furniture	South Africa	AES
De Wet (2003)	Labor - capital	0.72	Glass and glass products	South Africa	AES
De Wet (2003)	Labor - capital	0.42	Gold and uranium ore mining	South Africa	AES
De Wet (2003)	Labor - capital	1.02	Leather and leather products	South Africa	AES
De Wet (2003)	Labor - capital	0.77	Machinery and equipment	South Africa	AES
De Wet (2003)	Labor - capital	0.35	Medical, dental and other health and veterinary services	South Africa	AES
De Wet (2003)	Labor - capital	0.91	Metal products excluding machinery	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Motor vehicles, parts and accessories	South Africa	AES
De Wet (2003)	Labor - capital	0.69	Non-metallic minerals	South Africa	AES
De Wet (2003)	Labor - capital	0.27	Other chemicals and man-made fibres	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Other community, social and personal services	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Other industries	South Africa	AES
De Wet (2003)	Labor - capital	0.29	Other mining	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Other producers	South Africa	AES
De Wet (2003)	Labor - capital	0.91	Other transport equipment	South Africa	AES
De Wet (2003)	Labor - capital	0.36	Paper and paper products	South Africa	AES
De Wet (2003)	Labor - capital	0.73	Plastic products	South Africa	AES
De Wet (2003)	Labor - capital	0.61	Printing, publishing and recording media	South Africa	AES
De Wet (2003)	Labor - capital	0.77	Professional and scientific equipment	South Africa	AES
De Wet (2003)	Labor - capital	0.85	Rubber products	South Africa	AES
De Wet (2003)	Labor - capital	0.83	Television, radio and communication equipment	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Textiles	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Tobacco	South Africa	AES
De Wet (2003)	Labor - capital	0.66	Transport and storage	South Africa	AES
De Wet (2003)	Labor - capital	0.173	Water supply	South Africa	AES
De Wet (2003)	Labor - capital	0.78	Wearing apparel	South Africa	AES
De Wet (2003)	Labor - capital	0.74	Wholesale and retail trade	South Africa	AES
De Wet (2003)	Labor - capital	0.38	Wood and wood products	South Africa	AES
Goldar (2013)	Labor - capital	0.74	Manufacture of medical, precision and optical instruments, watches and clocks	India	AES (CES)

Source	Original description	Value of elasticity	Sector	Country	Type
Goldar (2013)	Labor - capital	0.66	Manufacture of wearing apparel ; dressing and dyeing	India	AES (CES)
Goldar (2013)	Labor - capital	0.54	Manufacture of basic metals	India	AES (CES)
Goldar (2013)	Labor - capital	0.88	Manufacture of chemicals and chemical products	India	AES (CES)
Goldar (2013)	Labor - capital	0.84	Manufacture of coke, refined petroleum products and nuclear fuel	India	AES (CES)
Goldar (2013)	Labor - capital	0.73	Manufacture of electrical machinery and apparatus n.e.c.	India	AES (CES)
Goldar (2013)	Labor - capital	0.81	Manufacture of fabricated metal products, except machinery and equipment	India	AES (CES)
Goldar (2013)	Labor - capital	0.94	Manufacture of food products and beverages	India	AES (CES)
Goldar (2013)	Labor - capital	0.87	Manufacture of furniture; manufacturing	India	AES (CES)
Goldar (2013)	Labor - capital	0.87	Manufacture of machinery and equipment n.e.c.	India	AES (CES)
Goldar (2013)	Labor - capital	0.86	Manufacture of motor vehicles, trailers and semi-trailers	India	AES (CES)
Goldar (2013)	Labor - capital	0.73	Manufacture of office, accounting and computing machinery	India	AES (CES)
Goldar (2013)	Labor - capital	0.81	Manufacture of other non-metallic mineral products	India	AES (CES)
Goldar (2013)	Labor - capital	0.71	Manufacture of other transport equipment	India	AES (CES)
Goldar (2013)	Labor - capital	0.73	Manufacture of paper and paper products	India	AES (CES)
Goldar (2013)	Labor - capital	0.82	Manufacture of radio, television and communication equipment and apparatus	India	AES (CES)
Goldar (2013)	Labor - capital	0.8	Manufacture of rubber and plastics products	India	AES (CES)
Goldar (2013)	Labor - capital	0.64	Manufacture of textiles	India	AES (CES)
Goldar (2013)	Labor - capital	0.64	Manufacture of tobacco products	India	AES (CES)
Goldar (2013)	Labor - capital	0.97	Manufacture of wood and of products of wood and cork, except furniture;	India	AES (CES)
Goldar (2013)	Labor - capital	0.93	Publishing, printing and reproduction of recorded media	India	AES (CES)
Goldar (2013)	Labor - capital	0.56	Tanning and dressing of leather; manufacture of luggage, handbags, harness and footwear	India	AES (CES)

Source: Various.

a. If indicated in paper

** 34 countries refers to Austria, Barbados, Belgium, Bulgaria, Canada, Colombia, Cyprus, Czechoslovakia, Denmark, Ecuador, Fiji, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Korea, Kuwait, Luxembourg, Mexico, Mongolia, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Singapore. Zimbabwe, Egypt, United Kingdom, United States*

Table AII- 2: Comparison of labor-capital elasticity of substitution across sectors

<table>
<tr><th>GTAP code</th><th colspan="2">GTAP description</th><th>GTAP[a]</th><th>SALTER Model[b] short run</th><th>USA[c]</th><th>South Africa[d]</th><th>India[e]</th><th>34 countries[f]</th></tr>
<tr><td>pdr</td><td colspan="2">Paddy rice</td><td>0.24</td><td>0.4</td><td rowspan="12">0.307</td><td rowspan="14">0.74</td><td></td><td></td></tr>
<tr><td>wht</td><td colspan="2">Wheat</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>gro</td><td colspan="2">Cereal grains n.e.c.</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>v_f</td><td colspan="2">Vegetables, fruit, nuts</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>osd</td><td colspan="2">Oil seeds</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>c_b</td><td colspan="2">Sugar cane, sugar beet</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>pfb</td><td colspan="2">Plant-based fibers</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>ocr</td><td colspan="2">Crops n.e.c.</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>ctl</td><td colspan="2">Bovine cattle, sheep and goats, horses</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>oap</td><td colspan="2">Animal products n.e.c.</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>rmk</td><td colspan="2">Raw milk</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>wol</td><td colspan="2">Wool, silk-worm cocoons</td><td>0.24</td><td>0.4</td><td></td><td></td></tr>
<tr><td>frs</td><td colspan="2">Forestry</td><td>0.2</td><td>0.4</td><td rowspan="2">0.364</td><td></td><td></td></tr>
<tr><td>fsh</td><td colspan="2">Fishing</td><td>0.2</td><td>0.4</td><td></td><td></td></tr>
<tr><td>coa</td><td colspan="2">Coal</td><td>0.2</td><td>0.8</td><td>1.271</td><td>0.38</td><td></td><td></td></tr>
<tr><td>oil</td><td colspan="2">Oil</td><td>0.2</td><td>0.8</td><td rowspan="2">0.735</td><td></td><td></td><td></td></tr>
<tr><td>gas</td><td colspan="2">Gas</td><td>0.2</td><td>0.8</td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">omn</td><td rowspan="4">Minerals n.e.c.</td><td>metal mining</td><td rowspan="4">0.2</td><td rowspan="4">0.2</td><td>0.67</td><td></td><td></td><td></td></tr>
<tr><td>gold/uranium</td><td></td><td>0.42</td><td></td><td></td></tr>
<tr><td>other mining</td><td></td><td>0.29</td><td></td><td></td></tr>
<tr><td>non-metalic minerals</td><td>0.893</td><td>0.69</td><td></td><td></td></tr>
<tr><td>cmt</td><td colspan="2">Bovine meat prods</td><td>1.12</td><td>0.8</td><td rowspan="8">-34.6</td><td rowspan="7">0.34</td><td rowspan="8">0.94</td><td rowspan="7">0.76</td></tr>
<tr><td>omt</td><td colspan="2">Meat products n.e.c.</td><td>1.12</td><td>0.8</td></tr>
<tr><td>vol</td><td colspan="2">Vegetable oils and fats</td><td>1.12</td><td>0.8</td></tr>
<tr><td>mil</td><td colspan="2">Dairy products</td><td>1.12</td><td>0.8</td></tr>
<tr><td>pcr</td><td colspan="2">Processed rice</td><td>1.12</td><td>0.8</td></tr>
<tr><td>sgr</td><td colspan="2">Sugar</td><td>1.12</td><td>0.8</td></tr>
<tr><td>ofd</td><td colspan="2">Food products n.e.c.</td><td>1.12</td><td>0.8</td></tr>
<tr><td>b_t</td><td rowspan="2">Beverages and tobacco products</td><td>Beverages</td><td rowspan="2">1.12</td><td rowspan="2">0.8</td><td>0.28</td><td>0.86</td></tr>
<tr><td></td><td>tobacco only</td><td>1.226</td><td>0.66</td><td>0.64</td><td>2.12</td></tr>
<tr><td>tex</td><td colspan="2">Textiles</td><td>1.26</td><td>0.9</td><td>1.138</td><td>0.66</td><td>0.64</td><td>0.7</td></tr>
<tr><td>wap</td><td colspan="2">Wearing apparel</td><td>1.26</td><td>0.9</td><td>2.051</td><td>0.78</td><td>0.66</td><td>0.7</td></tr>
<tr><td>lea</td><td rowspan="2">Leather products</td><td>footwear</td><td rowspan="2">1.26</td><td rowspan="2">0.8</td><td rowspan="2">-1.532</td><td>0.81</td><td rowspan="2">0.56</td><td>0.58</td></tr>
<tr><td></td><td>leather and leather products</td><td>1.02</td><td>0.58</td></tr>
<tr><td>lum</td><td colspan="2">Wood products</td><td>1.26</td><td>0.9</td><td>1.12</td><td>0.38</td><td>0.97</td><td>0.71</td></tr>
<tr><td>ppp</td><td rowspan="2">Paper products, publishing</td><td>paper and paper products</td><td rowspan="2">1.26</td><td rowspan="2">0.8</td><td>0.907</td><td>0.36</td><td>0.73</td><td>0.8</td></tr>
<tr><td></td><td>Printing and</td><td>1.51</td><td>0.61</td><td>0.93</td><td>0.68</td></tr>
</table>

GTAP code	GTAP description		GTAP[a]	SALTER Model[b] short run	USA[c]	South Africa[d]	India[e]	34 countries[f]
		publishing						
p_c	Petroleum, coal products	Coke products	1.26	0.9	76.3	0.28	0.84	0.92
		Refineries						1.08
crp	Chemical, rubber, plastic products	Chemicals	1.26	0.9	1.448	0.83	0.88	0.8
		other chemicals				0.27		0.74
		Plastic			0.806	0.73	0.8	0.59
		Rubber				0.85		0.66
nmm	Mineral products n.e.c.	Glass	1.26	0.9	0.501	0.72	0.81	0.96
		Non-metalic mineral products						0.63
i_s	Ferrous metals		1.26	0.9	0.533	1.01	0.54	0.94
nfm	metals n.e.c.		1.26	0.8		0.81		0.66
fmp	Metal products		1.26	0.8	1.393	0.91	0.81	0.91
mvh	Motor vehicles and parts		1.26	0.9	0.4	0.66	0.86	
otn	Transport equipment n.e.c.		1.26		0.322	0.91	0.71	0.88
ele	Electronic equipment	Electronic equip	1.26	0.9	3.736		0.73	
		Radio, TV etc				0.83	0.82	
ome	Machinery and equipment n.e.c.	Electrical machinery	1.26		0.815	0.66	0.73	0.69
		machinery and equipment				0.77	0.87	0.96
		Instruments or scientific equip.			0.599	0.77	0.74	1.02
omf	Manufactures n.e.c.	Furniture	1.26	0.9	1.007	0.58	0.87	0.81
		Pottery						0.83
		Other Manufacturing			1.684		0.66	1.38
ely	Electricity		1.26	0.9		0.26		
gdt	Gas manufacture, distribution		1.26	0.9				
wtr	Water		1.26	0.9		0.173		
cns	Construction	Building	1.68	1	0.893	1.05		
		Civil engineering				0.91		
trd	Trade		1.68	1.2		0.74		
otp	Transport n.e.c.		1.68			0.66		
wtp	Water transport		1.68					
atp	Air transport		1.68					
cmn	Communication		1.26	0.9		1.45		
ofi	Financial services n.e.c.		1.26			0.34		
isr	Insurance		1.26					
obs	Business services n.e.c.		1.26			0.29		
ros	Recreational and other services		1.26			0.5		
osg	Public Admin, Defense, Education, Health		1.26	0.9		0.35		

GTAP code	GTAP description	GTAP[a]	SALTER Model[b] short run	USA[c]	South Africa[d]	India[e]	34 countries[f]
dwe	Dwellings	1.26	0.9				

a. *Hertel, McDougall at al. (2012)*
b. *Jomini, Zeitsch et al (1991), SALTER model elasticities based on Caddy (1976)*
c. *Balistreri et al (2003)*
d. *De Wet (2003)*
e. *Goldar (2013)*
f. *Claro (2003)*

Table AII- 3: Estimates of elasticities between disaggregated labor and capital by sector

Source	Original description	AES	Original Elasticity	Sector	Country	Type
Krusel et al (2000)	skilled - capital equipment	1.67	1.67	Overall	USA	AES (CES)
Krusel et al (2000)	Unskilled - capital equipment	0.67	0.67	Overall	USA	AES (CES)
SUBSTITUTION BETWEEN CAPITAL AND HIGH SKILLED OCCUPATIONS (OFF_MGR_PROS/TECH_ASPROS)						
Falk & Koebel (1997)	capital - high skilled	0.06	0.02	banking and insurance	Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - capital	0.27	0.10	banking and insurance	Germany	cross price elasticity
Falk & Koebel (1997)	capital - high skilled	0.13	0.05	construction	Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - capital	0.55	0.22	construction	Germany	cross price elasticity
Falk & Koebel (1997)	capital - high skilled	0.01	0.01	energy, water, mining	Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - capital	0.02	0.01	energy, water, mining	Germany	cross price elasticity
Behar (2007)	Managerial/Professional - Capital	2.19	2.19	Manufacturing	South Africa	AES
Behar (2007)	Skilled/Artisan - Capital	2.91	2.91	Manufacturing	South Africa	AES
Falk & Koebel (1997)	capital - high skilled	-0.04	-0.01	manufacturing	Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - capital	-0.17	-0.06	manufacturing	Germany	cross price elasticity
Falk & Koebel (1997)	capital - high skilled	0.03	0.01	wholesale and retail	Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - capital	0.30	0.11	wholesale and retail	Germany	cross price elasticity
SUBSITUTION BETWEEN CAPITAL AND MEDIUM SKILLED OCCUPATIONS (CLERKS AND SERVICE/SALES)						
Falk & Koebel (1997)	medium skilled - capital	-0.10	-0.01	banking and insurance	Germany	cross price elasticity
Falk & Koebel (1997)	capital - medium skilled	-0.06	-0.02	banking and insurance	Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - capital	-0.62	-0.07	construction	Germany	cross price elasticity
Falk & Koebel (1997)	capital - medium skilled	-0.93	-0.38	construction	Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - capital	0.13	0.02	energy, water, mining	Germany	cross price elasticity
Falk & Koebel (1997)	capital - medium skilled	0.01	0.01	energy, water, mining	Germany	cross price elasticity
Behar (2007)	Semi-skilled - Capital	2.73	2.73	Manufacturing	South Africa	AES
Falk & Koebel (1997)	medium skilled - capital	0.03	0.01	manufacturing	Germany	cross price elasticity
Falk & Koebel (1997)	capital - medium skilled	0.04	0.01	manufacturing	Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - capital	-0.06	-0.02	wholesale and retail	Germany	cross price elasticity
Falk & Koebel (1997)	capital - medium skilled	-0.10	-0.04	wholesale and retail	Germany	cross price elasticity

Source	Original description	AES	Original Elasticity	Sector	Country	Type
SUBSITUTION BETWEEN CAPITAL AND LOW SKILLED OCCUPATIONS (AG_OTHLOWSK)						
Falk & Koebel (1997)	unskilled - capital	-0.08	-0.01	banking and insurance	Germany	cross price elasticity
Falk & Koebel (1997)	capital - unskilled	-0.01	-0.01	banking and insurance	Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - capital	0.42	0.21	construction	Germany	cross price elasticity
Falk & Koebel (1997)	capital - unskilled	1.13	0.46	construction	Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - capital	-0.26	-0.07	energy, water, mining	Germany	cross price elasticity
Falk & Koebel (1997)	capital - unskilled	-0.01	-0.01	energy, water, mining	Germany	cross price elasticity
Behar (2007)	Unskilled - Capital	1.74	1.74	Manufacturing	South Africa	AES
Falk & Koebel (1997)	unskilled - capital	0.18	0.08	manufacturing	Germany	cross price elasticity
Falk & Koebel (1997)	capital - unskilled	0.21	0.07	manufacturing	Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - capital	0.03	0.01	wholesale and retail	Germany	cross price elasticity
Falk & Koebel (1997)	capital - unskilled	0.03	0.01	wholesale and retail	Germany	cross price elasticity

Source: Various.

Appendix III Elasticities between Labor Types

Table AIII- 1: Estimates of elasticities between labor types across all sectors

Source	Original description	Value of Elasticity	Country	Type
Blankenau & Cassou (2011)	Skilled - Unskilled	1.39	United States	AES (CES)
Ciccone & Perri (2005)	less educated - more educated	1.5	USA	AES (CES)
Caselli & Coleman (2000)	less educated - more educated	1.31	52 countries	AES (CES)
Krusel et al (2000)	Skilled - Unskilled	1.67	United States	AES (CES)
Katz & Murphy (1992)	Colledge - high school labor	1.41	United States	AES (CES)
Johnson (1997)	Skilled - Unskilled	1.5	United States	AES (CES)
Angrist (1995)	less educated - more educated	2	Palestine	AES (CES)
Higgs et al (1981)	Professional - Skilled blue collar, Building	0.42	Australia	AES
Higgs et al (1981)	Professional - skilled blue collar, Metal&Electrical	0.17	Australia	AES
Higgs et al (1981)	Professional - Skilled blue collar, Other	0.3	Australia	AES
Higgs et al (1981)	Professional - Skilled white collar	0.42	Australia	AES
Higgs et al (1981)	Professional - Unskilled blue collar	0.1	Australia	AES
Higgs et al (1981)	Professional - Unskilled white collar	0.25	Australia	AES
Higgs et al (1981)	Professional -Rural	0.4	Australia	AES
Higgs et al (1981)	Skilled blue collar, Building - Skilled blue collar, Other	0.75	Australia	AES
Higgs et al (1981)	Skilled blue collar, Metal&Electrical - Skilled blue collar, Building	0.43	Australia	AES
Higgs et al (1981)	Skilled blue collar, Metal&Electrical - Skilled blue collar, Other	0.31	Australia	AES
Higgs et al (1981)	Skilled white collar - Skilled blue collar, Building	1.05	Australia	AES
Higgs et al (1981)	Skilled white collar - skilled blue collar, Metal&Electrical	0.43	Australia	AES
Higgs et al (1981)	Skilled white collar - Skilled blue collar, Other	0.75	Australia	AES
Higgs et al (1981)	Skilled blue collar, Building - Unskilled blue collar	0.24	Australia	AES
Higgs et al (1981)	Skilled blue collar, Building -Rural	0.98	Australia	AES
Higgs et al (1981)	Skilled blue collar, Metal&Electrical - Unskilled blue collar	0.1	Australia	AES
Higgs et al (1981)	Skilled blue collar, Metal&Electrical -Rural	0.4	Australia	AES
Higgs et al (1981)	Skilled blue collar, Other - Unskilled blue collar	0.17	Australia	AES

Source	Original description	Value of Elasticity	Country	Type
Higgs et al (1981)	Skilled blue collar, Other -Rural	0.7	Australia	AES
Higgs et al (1981)	Skilled white collar - Unskilled blue collar	0.24	Australia	AES
Higgs et al (1981)	Skilled white collar - Unskilled white collar	0.63	Australia	AES
Higgs et al (1981)	Skilled white collar -Rural	0.99	Australia	AES
Higgs et al (1981)	Unskilled white collar - Skilled blue collar, Building	0.63	Australia	AES
Higgs et al (1981)	Unskilled white collar - skilled blue collar, Metal&Electrical	0.26	Australia	AES
Higgs et al (1981)	Unskilled white collar - Skilled blue collar, Other	0.45	Australia	AES
Higgs et al (1981)	Unskilled blue collar - Rural	0.23	Australia	AES
Higgs et al (1981)	Unskilled white collar - Unskilled blue collar	0.14	Australia	AES
Higgs et al (1981)	Unskilled white collar -Rural	0.59	Australia	AES
Ryland & Parham (1978)	Unskilled white collar - unskilled blue collar	0.517	Australia	AES
Ryland & Parham (1978)	Skilled white collar - skilled blue collar	1.72	Australia	AES
Ryland & Parham (1978)	Professional - Skilled blue collar	0.388	Australia	AES
Ryland & Parham (1978)	Professional - Skilled white collar	-0.175	Australia	AES
Ryland & Parham (1978)	Professional - unskilled blue collar	-0.144	Australia	AES
Ryland & Parham (1978)	Professional - unskilled white collar	0.52	Australia	AES
Ryland & Parham (1978)	Unskilled white collar - skilled blue collar	-0.116	Australia	AES
Ryland & Parham (1978)	Skilled blue collar - unskilled blue collar	0.215	Australia	AES
Ryland & Parham (1978)	Skilled white collar - unskilled blue collar	1.112	Australia	AES
Ryland & Parham (1978)	Skilled white collar - unskilled white collar	-0.551	Australia	AES
Fallon & Layard (1975)	less educated - more educated	1.49	Multiple countries	AES (CES)
Bowles (1969)	0-7 years schooling - 8-11 years schooling	12	12 countries	AES (CES)
Bowles (1969)	0-7 years schooling - >12 years schooling	6.4	12 countries	AES (CES)
Bowles (1969)	8-11 years schooling - >12 years schooling	202	12 countries	AES (CES)

Source: Various as compiled by ImpactECON.
a. If indicated in paper
** 12 countries refers to USA, Belgium, Canada, Chile, UK, France, Greece, India, Mexico, Netherlands, Colombia, Israel; ** 22 countries covers USA, Sweden, Canada, New Zealand, France, Norway, UK, Japan, Greece, Puerto Rico, Mexico, Chile, Colombia, Brazil, Turkey, Philippines, Ghana, South Korea, Thailand, Kenya, India, Uganda*

Table AIII- 2: Estimates of elasticities between labor types by sectors

Source	Original description	Mapping to GTAP occupations	AES	Original Elasticity	Sector	Country	Type
				AGRICULTURE			
Blankenau & Cassou (2011)	Skilled – Unskilled	Mangers and Technicians to Clerks, Service and low skilled	35.48	35.48		United States	AES (CES)
				BANKING AND INSURANCE			
Falk & Koebel (1997)	high skilled - high skilled	Managers to managers	1.23	-1.23		Germany	Own price elasticity
Falk & Koebel (1997)	high skilled - medium skilled	Managers to Technicians	-0.20	-0.06		Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - unskilled	Mangers to Clerks, Service and low skilled	3.84	1.20		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - high skilled	Technicians to managers	-0.06	-0.01		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - medium skilled	Technicians to technicians	0.21	-0.21		Germany	Own price elasticity
Falk & Koebel (1997)	medium skilled - unskilled	Technicians to Clerks, Service and low skilled	2.43	0.24		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - high skilled	Clerks, Service and low skilled to managers	3.67	0.37		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled -medium skilled	Clerks, Service and low skilled to technicians	7.92	0.79		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - unskilled	Clerks, Service and low skilled to Clerks, Service and low skilled	1.24	-1.24		Germany	Own price elasticity
				CONSTRUCTION			
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	9.05	9.05		United States	AES (CES)
Falk & Koebel (1997)	high skilled - high skilled	Managers to managers	0.70	-0.70		Germany	Own price elasticity
Falk & Koebel (1997)	high skilled - medium skilled	Managers to Technicians	-9.26	-0.46		Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - unskilled	Mangers to Clerks, Service and low skilled	13.68	0.68		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - high skilled	Technicians to managers	-0.20	-0.02		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - medium skilled	Technicians to technicians	0.12	-0.12		Germany	Own price elasticity
Falk & Koebel (1997)	medium skilled - unskilled	Technicians to Clerks, Service and low skilled	1.55	0.17		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - high skilled	Clerks, Service and low skilled to managers	0.15	0.08		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled -medium skilled	Clerks, Service and low skilled to technicians	0.85	0.42		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - unskilled	Clerks, Service and low skilled to Clerks, Service and low skilled	1.05	-1.05		Germany	Own price elasticity
				ENERGY, WATER AND MINING			
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	5.38	5.38		United States	AES (CES)

Source	Original description	Mapping to GTAP occupations	AES	Original Elasticity	Sector	Country	Type
Falk & Koebel (1997)	high skilled - high skilled	Managers to managers	0.17	-0.17		Germany	Own price elasticity
Falk & Koebel (1997)	high skilled - medium skilled	Managers to Technicians	-1.09	-0.07		Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - unskilled	Mangers to Clerks, Service and low skilled	2.78	0.19		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - high skilled	Technicians to managers	-0.07	-0.01		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - medium skilled	Technicians to technicians	0.17	-0.17		Germany	Own price elasticity
Falk & Koebel (1997)	medium skilled - unskilled	Technicians to Clerks, Service and low skilled	0.39	0.05		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - high skilled	Clerks, Service and low skilled to managers	0.42	0.11		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled -medium skilled	Clerks, Service and low skilled to technicians	0.87	0.22		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - unskilled	Clerks, Service and low skilled to Clerks, Service and low skilled	0.26	-0.26		Germany	Own price elasticity
		MANUFACTURING					
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	1.41	1.41		United States	AES (CES)
Behar (2007)	Managerial/Professional - Managerial/Professional	Managers to managers	-5.96	-5.96		South Africa	AES
Behar (2007)	Skilled/Artisan - Managerial/Professional	Technicians to managers	-5.77	-5.77		South Africa	AES
Behar (2007)	Skilled/Artisan - Skilled/Artisan	Technicians to Technicians	-7.53	-7.53		South Africa	AES
Behar (2007)	Semi-skilled - Managerial/Professional	Clerks and service to managers	-1.46	-1.46		South Africa	AES
Behar (2007)	Semi-skilled - Skilled/Artisan	Clerks and service to Technicians	-7.28	-7.28		South Africa	AES
Behar (2007)	Semi-skilled - Semi-skilled	Clerks and service to clerks and service	-5.48	-5.48		South Africa	AES
Behar (2007)	Unskilled - Managerial/Professional	Low skilled to managers	-2.04	-2.04		South Africa	AES
Behar (2007)	Unskilled - Skilled/Artisan	Low skilled to technicans	1.79	1.79		South Africa	AES
Behar (2007)	Semi-skilled - Unskilled	Low skilled to Clerks and Service	-2.44	-2.44		South Africa	AES
Behar (2007)	Unskilled - Unskilled	Low skilled to low skilled	-5.94	-5.94		South Africa	AES
Falk & Koebel (1997)	high skilled - high skilled	Managers to managers	0.42	-0.42		Germany	Own price elasticity
Falk & Koebel (1997)	high skilled - medium skilled	Managers to Technicians	1.83	0.17		Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - unskilled	Mangers to Clerks, Service and low skilled	5.21	0.47		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - high skilled	Technicians to managers	0.11	0.02		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - medium skilled	Technicians to technicians	0.48	-0.48		Germany	Own price elasticity
Falk & Koebel (1997)	medium skilled - unskilled	Technicians to Clerks, Service and low	2.53	0.44		Germany	cross price elasticity

Source	Original description	Mapping to GTAP occupations	AES	Original Elasticity	Sector	Country	Type
		skilled					
Falk & Koebel (1997)	unskilled - high skilled	Clerks, Service and low skilled to managers	0.29	0.13		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled -medium skilled	Clerks, Service and low skilled to technicians	2.42	1.06		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - unskilled	Clerks, Service and low skilled to Clerks, Service and low skilled	1.41	-1.41		Germany	Own price elasticity
Hijzen et al (2004)	Managers/Professionals - Managers/Professionals	Managers to managers	-0.90	-0.90		UK	AES
Hijzen et al (2004)	Managers/Professionals - Technical/Clerical/Craft/Protective/Sales	Managers to technicans, clerks and service workers	-0.43	-0.43		UK	AES
Hijzen et al (2004)	Managers/Professionals - Plant/Machine/Agriculture	Managers to low skilled	-0.17	-0.17		UK	AES
Hijzen et al (2004)	Technical/Clerical/Craft/Protective/Sales - Managers/Professionals	Technicians, clerks and service workers to managers	-0.45	-0.45		UK	AES
Hijzen et al (2004)	Technical/Clerical/Craft/Protective/Sales - Technical/Clerical/Craft/Protective/Sales	Technicians, clerks and service workers to technicians, clerks and service workers	-0.46	-0.46		UK	AES
Hijzen et al (2004)	Technical/Clerical/Craft/Protective/Sales - Plant/Machine/Agriculture	Technicians, clerks and service workers to low skilled	-0.24	-0.24		UK	AES
Hijzen et al (2004)	Plant/Machine/Agriculture - Managers/Professionals	Low skilled to managers	-0.18	-0.18		UK	AES
Hijzen et al (2004)	Plant/Machine/Agriculture - Technical/Clerical/Craft/Protective/Sales	Low skilled to technicians, clerks and service workers	-0.24	-0.24		UK	AES
Hijzen et al (2004)	Plant/Machine/Agriculture - Plant/Machine/Agriculture	Low skilled to low skilled	0.05	0.05		UK	AES
Falk & Koebel (2001)	Technical high skilled – low skilled	0	0.42	0.26		Germany	Own price elasticity
Falk & Koebel (2001)	Technical medium skilled – high skilled	0	-0.04	-0.02		Germany	Own price elasticity
Falk & Koebel (2001)	unskilled - management	low skilled to managers	0.14	0.08		Germany	Own Price elasticity
Falk & Koebel (2001)	Skilled and unskilled	Mangers/Technical/Clerks/Sales to low skilled	1.02	0.70		Germany	Cross price elasticity
			WHOLESALE AND RETAIL				
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers/Technical/Clerks/Sales to low skilled	1.92	1.92		United States	AES (CES)
Falk & Koebel (1997)	high skilled - high skilled	Managers to managers	0.13	-0.13		Germany	Own price elasticity
Falk & Koebel (1997)	high skilled - medium skilled	Managers to Technicians	0.68	0.06		Germany	cross price elasticity
Falk & Koebel (1997)	high skilled - unskilled	Mangers to Clerks, Service and low skilled	1.26	0.12		Germany	cross price elasticity

Source	Original description	Mapping to GTAP occupations	AES	Original Elasticity	Sector	Country	Type
Falk & Koebel (1997)	medium skilled - high skilled	Technicians to managers	0.12	0.03		Germany	cross price elasticity
Falk & Koebel (1997)	medium skilled - medium skilled	Technicians to technicians	0.02	-0.02		Germany	Own price elasticity
Falk & Koebel (1997)	medium skilled - unskilled	Technicians to Clerks, Service and low skilled	0.05	0.01		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - high skilled	Clerks, Service and low skilled to managers	0.04	0.02		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled -medium skilled	Clerks, Service and low skilled to technicians	0.09	0.04		Germany	cross price elasticity
Falk & Koebel (1997)	unskilled - unskilled	Clerks, Service and low skilled to Clerks, Service and low skilled	0.05	-0.05		Germany	Own price elasticity
			OTHER				
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	1.16	1.16	Financial services	United States	AES (CES)
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	2.50	2.50	Health services	United States	AES (CES)
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	0.68	0.68	Information	United States	AES (CES)
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	2.06	2.06	Leisure servvices	United States	AES (CES)
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	46.97	46.97	Other services	United States	AES (CES)
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	1.07	1.07	Professional services	United States	AES (CES)
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	2.23	2.23	Public administration	United States	AES (CES)
Blankenau & Cassou (2011)	Skilled - Unskilled	Mangers and Technicians to Clerks, Service and low skilled	3.75	3.75	Transportation	United States	AES (CES)

Appendix IV Elasticities between Natives and Immigrants

Table AIV- 1: Estimates of elasticities between natives and immigrants

Source	Original description	Value	Sector	Country	Type
Fromentin (2011)	high skilled natives - high skilled immigrants	0.03	Manufacturing	France	Own price elasticity
Fromentin (2011)	high skilled natives - medim skilled immigrants	0.078	Manufacturing	France	price elasticity
Fromentin (2011)	high skilled natives - unskilled immigrants	0.036	Manufacturing	France	price elasticity
Fromentin (2011)	medium skilled natives - high skilled immigrants	-0.22	Manufacturing	France	price elasticity
Fromentin (2011)	medium skilled natives - medim skilled immigrants	0.034	Manufacturing	France	Own price elasticity
Fromentin (2011)	medium skilled natives - unskilled immigrants	0.051	Manufacturing	France	price elasticity
Fromentin (2011)	unskilled natives - high skilled immigrants	0.24	Manufacturing	France	price elasticity
Fromentin (2011)	unskilled natives - medim skilled immigrants	-0.695	Manufacturing	France	price elasticity
Fromentin (2011)	unskilled natives - unskilled immigrants	0.056	Manufacturing	France	Own price elasticity
Bauer (1998)	unskilled blue collar natives - unskilled blue collar natives	-0.58	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar natives - unskilled blue collar immigrants	0.63	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar natives - skilled blue collar natives	-0.02	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar natives - skilled blue collar immigrants	0.57	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar natives - white collar natives	0.18	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar natives - white collar immigrants	-1.02	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar immigrants - unskilled blue collar immigrants	-4.68	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar immigrants - skilled blue collar natives	-0.15	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar immigrants - skilled blue collar immigrants	-1.84	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar immigrants - white collar natives	0.36	Overall	Germany	Hicks elasticity
Bauer (1998)	unskilled blue collar immigrants - white collar immigrants	-0.64	Overall	Germany	Hicks elasticity
Bauer (1998)	skilled blue collar natives - skilled blue collar natives	-0.22	Overall	Germany	Hicks elasticity
Bauer (1998)	skilled blue collar natives - skilled blue collar immigrants	0.03	Overall	Germany	Hicks elasticity
Bauer (1998)	skilled blue collar natives - white collar natives	0.28	Overall	Germany	Hicks elasticity

Source	Original description	Value	Sector	Country	Type
Bauer (1998)	skilled blue collar natives - white collar immigrants	0.13	Overall	Germany	Hicks elasticity
Bauer (1998)	skilled blue collar immigrants - skilled blue collar immigrants	-2.75	Overall	Germany	Hicks elasticity
Bauer (1998)	skilled blue collar immigrants - white collar natives	0.01	Overall	Germany	Hicks elasticity
Bauer (1998)	skilled blue collar immigrants - white collar immigrants	6.95	Overall	Germany	Hicks elasticity
Bauer (1998)	white collar natives - white collar natives	-0.39	Overall	Germany	Hicks elasticity
Bauer (1998)	white collar natives - white collar immigrants	-1.02	Overall	Germany	Hicks elasticity
Bauer (1998)	white collar immigrants - white collar immigrants	-8.74	Overall	Germany	Hicks elasticity
Borjas et al. (2011)	native male - immigrant male	21.7	Overall	USA	AES (CES)
Borjas et al. (2011)	native (female and male) - immigrant (female and male)	34.4	Overall	USA	AES (CES)
Greenwood and Hunt (1995)	native - foreign born	0.28	Overall	USA	price elasticity
Greenwood and Hunt (1995)	native - native	-0.8	Overall	USA	Own price elasticity
Greenwood and Hunt (1995)	native - capital	0.52	Overall	USA	price elasticity
Greenwood and Hunt (1995)	foreign born - native	4.71	Overall	USA	price elasticity
Greenwood and Hunt (1995)	foreign born - foreign born	-5.23	Overall	USA	Own price elasticity
Greenwood and Hunt (1995)	foreign born - capital	0.52	Overall	USA	price elasticity
Greenwood and Hunt (1995)	capital - native	0.45	Overall	USA	price elasticity
Greenwood and Hunt (1995)	capital -foreign born	0.03	Overall	USA	price elasticity
Grossman (1982)	natives - natives	-0.61	Overall	USA	Hicks elasticity
Grossman (1982)	natives - second generation	-0.92	Overall	USA	Hicks elasticity
Grossman (1982)	natives - foreign born	-0.32	Overall	USA	Hicks elasticity
Grossman (1982)	natives - capital	0.69	Overall	USA	Hicks elasticity
Grossman (1982)	second generation - second generation	-0.26	Overall	USA	Hicks elasticity
Grossman (1982)	second generation - foreign born	-0.61	Overall	USA	Hicks elasticity
Grossman (1982)	second generation - capital	0.73	Overall	USA	Hicks elasticity
Grossman (1982)	foreign born - foreign born	-4.65	Overall	USA	Hicks elasticity
Grossman (1982)	foreign born - capital	0.85	Overall	USA	Hicks elasticity
Grossman (1982)	capital - capital	-0.75	Overall	USA	Hicks elasticity
Jaeger (2007)	native dropout men - immigrant dropout men	9.4	Overall	USA	AES (CES)

Source	Original description	Value	Sector	Country	Type
Jaeger (2007)	native high school grad men - immigrant high school grad men	7.8	Overall	USA	AES (CES)
Jaeger (2007)	native some college men - immigrant some college men	33.3	Overall	USA	AES (CES)
Jaeger (2007)	native college grad men - immigrant college grad men	11	Overall	USA	AES (CES)
Jaeger (2007)	native dropout women - immigrant dropout women	50.1	Overall	USA	AES (CES)
Jaeger (2007)	native high school grad women - immigrant high school grad women	5.9	Overall	USA	AES (CES)
Jaeger (2007)	native some college women - immigrant some college women	-123.9	Overall	USA	AES (CES)
Jaeger (2007)	native college grad women - immigrant college grad women	5.7	Overall	USA	AES (CES)
Manacorda et al (2012)	natives - immigrants	7.8	Overall	UK	AES (CES)
Manacorda et al (2012)	natives - recent immigrants	4.6	Overall	UK	AES (CES)
Manacorda et al (2012)	natives - long term immigrants	10.1	Overall	UK	AES (CES)
Manacorda et al (2012)	natives - immigrants (secondary education)	14.5	Overall	UK	AES (CES)
Manacorda et al (2012)	natives - immigrants (university degree)	5.7	Overall	UK	AES (CES)
Manacorda et al (2012)	natives - immigrants (26-35 years)	7.5	Overall	UK	AES (CES)
Manacorda et al (2012)	natives - immigrants (36-50 years)	12.7	Overall	UK	AES (CES)
Manacorda et al (2012)	natives - immigrants (51-60 years)	90.9	Overall	UK	AES (CES)
Ottaviano and Perri (2012)	native male - immigrant male	18.8	Overall	USA	AES (CES)
Ottaviano and Perri (2012)	native female - immigrant female	27	Overall	USA	AES (CES)
Ottaviano and Perri (2012)	native (female and male) - immigrant (female and male)	31.2	Overall	USA	AES (CES)
Ottaviano and Perri (2012)	native no degree men - immigrant no degree men	13.7	Overall	USA	AES (CES)
Ottaviano and Perri (2012)	native high school grad men - immigrant high school grad men	11.2	Overall	USA	AES (CES)
Ottaviano and Perri (2012)	native some college men - immigrant some college men	14	Overall	USA	AES (CES)
Ottaviano and Perri (2012)	native college grad men - immigrant college grad men	58.8	Overall	USA	AES (CES)
Ozden and Wagner (2013)	natives - immigrants	2.4	Overall	Malaysia	AES (CES)

Source: Various as compiled by ImpactECON.

Appendix V Elasticities of Factor Substitution Employed in Common CGE Models

Table AV- 1: Elasticities employed in common CGE models

Model	Elasticity of substitution between labor	Elasticity of substitution capital-labor	Elasticity of substitution labor-services	Documentation/Other Comments
ASEAN labor market model	mangers, professionals, para-professionals, craft workers, unskilled labor, all other and by gender 0.35 between male and female; 0.65 across occupations	0.85	None, intermediate nest	Literature survey of related models. Plummer, Petri, and Zhai (2014)
G-CUBED	One labor category infinite	12 sectors KLEM Max 1.702 Min 0.2 Avg 0.6858	None, intermediate nest	Estimated with US data from 1958-1982. McKibbin and Wilcoxen (1999)
GEM-E3	Capital/Skilled and unskilled. Elasticity between capital/skilled labor and unskilled varies by sector 0.2 to 1.68 avg 1.125. 21 sectors.	Between capital and skilled labor 0.35	None, intermediate nest	Capros, Van Regemorter, et al (2013)
GLOBE	User can specify their own nesting structure for aggregating the labor types from GTAP, but must specify their own elasticities.	User specified or GTAP (capital, land, natural resources and labor, where labor is defined by the user)	None, intermediate nest	McDonald, Thierfelder et al (2014)
GTAP	None – all labor is at the top level	Between all value added (capital, land, natural resources, managers, technicians, clerks, service/sales, low skilled) - varies by sector 0.2 to 1.68.	None, intermediate nest	Hertel and Tsigas (1997). Originally based on SALTER model and Caddy (197) but revisions made to agriculture.
ICES\FEEM	One labor category infinite	GTAP elasticities	None, intermediate nest	http://www.feem.it/getpage.aspx?id=2455&sez=Research&padre=18&sub=75&idsub=102
Linkage	Nesting differs between agricultural, livestock and non-agricultural goods. The model allows for skilled or unskilled labor to be a complement or substitute with Capital, if user specifies. New Capital is also more substitutable than old capital and energy and feed are also included in the VA bundle for agriculture/livestock.		None, intermediate nest	Van der Mensbrugghe (2005)
Magnet	Usual GTAP skilled and unskilled categories; substitution is flexibile and is up to the modeler	Substitution is flexible and elasticities are up to the user	None, intermediate nest	Woltjer and Kuiper, 2014
Mirage	A CES bundle of capital and skilled labour with an elasticitiy of 0.6.	Cobb Douglas: Land, natural resources, unskilled labour and a capital and skilled labour bundle.	None, intermediate nest	http://www.mirage-model.eu/miragewiki/index.php/Main_Page
Monash	0.35 for all industries		None, intermediate nest	Dixon and Rimmer (2002)
Orani	0.35 for all industries	0.5 based on Caddy (1976)	None, intermediate nest	Dixon, Parmenter et al. (1997)
USITC	753 occupations, elasticity set to 0.35 for all industries		None, intermediate nest	http://www.copsmodels.com/usage.htm

Source: Compiled from by ImpactECON from a survey sent out January 2015 and model documentation.

Appendix VI Equations for Determining the Implied Allen Partial Elasticity of Substitution within a Nested CES

Using Figure 1 as any example, and assuming n and m are factors, then the implied elasticities are given by:

$$
\begin{aligned}
&\forall n \neq m \\
&\sigma_{n,m} = \sigma_{nm,H}\theta_{nm,H}^{-1} - \sum_{l=K+1}^{L} \sigma_{n,l}\left(\theta_{n,l-1}^{-1} - \theta_{n,l}^{-1}\right) \\
&\sigma_{n,n} = -\sum_{l=1}^{L} \sigma_{n,l}\left(\theta_{n,l-1}^{-1} - \theta_{n,l}^{-1}\right)
\end{aligned}
$$

Where:

l is the level of the CES nest 1….L,

L is the highest level (in Figure 1 this coincides with value-added)

H is the lowest common level that include, or are associated with, inputs n and m.

Two examples from Figure 1, follow to help illustrate this,

a) The lowest common level at which both managers and capital exit is the highest level, *L*.
b) The lowest level at which both managers and clerks exist is the skilled labor composite, *L* – 2.

$\sigma_{n,l}$ is the elasticity of substitution associated with the *l*th level nest in which input n is involved.

$\theta_{n,l}$ is the cost share at the *l*th level defined by,

$$\theta_{n,l} = \sum_{m \in n,l} \theta_m$$

Following on with our two examples from Figure 1,

a) $\theta_{n,l} = \theta_{VA}$ at the lowest common level at which both managers and capital exit. Hence the share is 1 (ignoring intermediates)
b) $\theta_{n,l} = \theta_{SKILLED}$, the sum of the shares of all skilled factors (managers, technicians, clerks, and sales and service workers) in total costs.

For a full exposition, see Keller (1980).