Trade in Intermediates and Relative Wages in General Equilibrium A GNP Approach

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1. Introduction

During the last two decades many developed countries, in particular the US and the UK, have witnessed a sharp increase in domestic wage inequality, while the preceding decades were characterised by a relative stable wage structure. As relative wages *and* employment both increased in the same direction the key explanations proposed in the literature are demand-based. Three of the main demand-side explanations proposed in the literature that will be addressed in the present paper are skill-biased technological change, globalisation and deindustrialisation. The principal interest goes out the impact of international trade on wage inequality as will be reflected in the methodology.

In order to analyse the impact of globalisation, and in particular, international trade, several methodologies have been advanced. As of yet no consensus exists as to which one is the most appropriate. Each method has its own specific virtues and weaknesses.

The 'labour market approach' consists of estimating *factor demand regressions* at either the industry or firm level. Trade economists have criticised this approach as it is embedded in a partial equilibrium framework, while standard trade theory is based on general equilibrium theory. Although factor demand regressions might be useful to analyse some potential sources of the increase in wage inequality, they are certainly not an appropriate method to evaluate the impact of international trade on relative wages.

Several methodologies have been developed that are, in principle, consistent with general equilibrium trade theory. The two most popular approaches are the *mandated wage approach* and the *factor content approach*. The mandated wage approach departs from the small open economy scenario in which wages are set on the margin. The focus of study is on relative price changes as a result of international trade that shift the relative demand for labour between sectors (sector bias). The factor content approach instead focuses on the domestic factor requirements needed to produce imported goods at home. Consequently, the focus is on the volume of trade rather than the impact of trade, or trade policy, on prices. Loosely speaking factor content studies focus on the factor bias effects of international trade which change the relative demand for labour within industries. Assuming that both the factor and sector bias of trade matter the two approaches only partially address the impact of trade on wages by concentrating on sector and factor bias effects respectively.

The literature suffers also from two general shortcomings. First, the literature on trade and wage inequality focuses almost exclusively on manufacturing. One might justify this on the basis that the lion share of international trade concerns trade in manufacturers. Moreover, data problems make it difficult to extend the analyse to services. Nevertheless, considering that one should analyse the impact of international trade in general equilibrium ignoring up to three quarters of the economy might seriously affect results.[1]

Second, most studies concentrate on trade in final goods while trade in intermediates comprises a substantial and growing part of international trade. Exceptions are amongst others Feenstra and Hanson (1996, 1999).

A relatively new methodology originally due to Burgess (1974) and Kohli (1991) and recently introduced to the wage inequality debate by Harrigan and Balaban (1999), Harrigan (2000) and Tombazos (2003) uses duality to analyse the impact of trade on the economy. Consistent with standard trade theory a GNP function is estimated which treats factor supplies and goods prices as exogenous and factor prices and outputs supplies as endogenous. In order to capture the fact that unlike domestic inputs imports do not have a fixed supply, the GNP approach takes the form of a variable profit function (Samuelson, 1953) where domestic inputs are exogenous and foreign inputs endogenous. As such the methodology allows one to evaluate the role of sector bias effects in the form of relative price changes and productivity growth, factor bias effects and factor supplies on factor prices. Although so far studies have included a trend term to account for skill-biased technological change (factor bias) the

[1] On the basis of trade theory one might justify ignoring the non-tradable sector when the number of traded goods is larger or equal than the number of immobile factors and factor demand is perfectly elastic (as will normally be the case in the small open diversified economy). Under these circumstances tradable goods prices uniquely determine factor prices.

model offers in principle a complete characterisation of the determination of factor prices.

In spite of its virtues this methodology failed to reach the centre stage. Results do not seem to carry sufficient credibility to be truly convincing. The main reasons seem to be related to the level of aggregation and dimensionality, the reliability of the data and the appropriateness of econometric techniques.

The GNP function approach is necessarily conducted at the country level. Consequently structural relationships might be obscured by unobserved heterogeneity. Moreover, due to need to work on the country level it is difficult to obtain a large sample while econometrics techniques employed in the studies mentioned above typically rely on the asymptotic properties of estimators. In most cases the small sample completely excludes the possibility to appropriately address the time-series properties of the data. Nonlinearities brought about by curvature restrictions make instrumenting endogenous variables a daunting task while in some cases the model might even become insolvable. Furthermore, no guidance exists for the choice of the most appropriate dimension in terms of the number of goods and factors. Finally the intangible nature of services gives rise to numerous measurement problems. Reliable data on prices and productivity growth might therefore well beyond the capabilities of statistical offices today.

Clearly, the credibility of the GNP approach would be greatly enhanced if more work with the GNP approach with alternative specifications or for different countries were to be undertaken. How would results be affected if services were to be excluded? How sensitive are the results to different time periods? Is it possible to detect similar relationships for different countries? In addition, greater transparency with respect to the limitations of the econometric techniques would be desirable. Finally, a more precise measure of skill-biased technological change would give greater insight in the importance of factor bias effects.

The present paper aims to address these three issues by estimating the GNP function in relation to the trade and relative wages debate for the United Kingdom using data for the period 1975-1999. As such it will be the first study not to focus on the United

States. Furthermore the GNP function will be estimated for two models in several specifications. The first model serves as a baseline model which concentrates explicitly on the role of nontradables but does not explicitly address the role of international trade. The second model distinguishes only two domestic goods but accounts for imports of different types of goods. Test statistics on the validity of overidentifying restrictions and cointegration will be reported where possible.

The remainder of this paper will be structured as follows. The paper sets off with a review on the literature using the GNP approach to analyse the impact of trade on the domestic distribution of earnings. Section 3 discusses the methodology. Section 4 provides details on data sources and presents some stylised facts for the UK. Section 5 discusses the econometric results obtained from the baseline model. Section 6 discusses results for a GNP function which account for different types of imports. Finally, Section 7 concludes.

2. Literature review

In this section the reviews the empirical literature employing the systems approach to the analysis of international trade. The emphasis will be primarily on methodological issues such as duality, separability, dimensionality, and functional form.

The application of the systems approach to the analysis of international trade is due to Burgess (1974a, 1974b).[2] The systems approach is characterised by the use of duality, i.e. the simultaneous estimation of the partial derivatives of an appropriately chosen objective function. The development of flexible functional forms and particularly the transcendental logarithmic, or simply translog, by Christensen, Jorgenson and Lau (1973) enabled researchers at last to estimate rather than to impose the production technology, and in particular, the role of international trade therein.

Burgess (1974a, 1974b) applied duality theory to two important areas in the analysis of international trade. Burgess (1974a) employs a cost function to estimate the import

[2] Actually, unpublished research by Denny (1971) employs a similar approach.

demand function for the United States (1974a), while Burgess (1974b) opts for a production function approach to study the distributional effects of trade policy in general equilibrium. His research departs from the literature on import demand, which is mainly concerned with balance of payments issues, by relaxing the assumption of separability between imports and primary factors. Under the assumption of separability trade policy can of course have no effect on the distribution of income. The second main innovation is based on the observation that the bulk of international trade consists of intermediate products that requires further processing in the importing country. For this reason all imports are treated as intermediate imports. In spite of these two interesting innovations the methodology introduced by Burgess has received very little attention in the literature on trade and wages.

Burgess (1974a) estimates a system of cost and revenue equations derived from a translog cost function using data for the United States for the period 1929-1969. The joint cost function is characterised by a three-input, two-output technology. Burgess (1974b) estimates a system of output share equations (derived from a translog production function) using country-level data for the United States for the period 1947-1968. The empirical model could be either interpreted as a one-sector model or as multi-sector model with joint production in which inputs and outputs are separable.

Results in Burgess (1974a, 1974b) indicate that imports and domestic primary factors of production are not separable in production thus invalidating the use of domestic value-added function. Burgess (1974a) finds that imports and labour services are substitutes, while imports and capital are complements. An increase in the rental rate of capital therefore will stimulate the demand for imports. Burgess (1974b) finds that increased protection distributes a larger share to capital at the expense of labour. Trade liberalisation is expected to benefit the country as whole and particularly owners of labour services.

From a methodological point of view it is worth mentioning a study by Berndt and Wood (1975) who use duality to analyse the derived demand for energy. They estimate a system of cost share equations derived from a translog cost function using data for the United States for the period 1947-1971. They also find that the value-added specification of technology (separability between imports and primary factors) is not justified for the United States evaluated on the basis of different concepts of separability.

It is indicative for the lack of attention for the original work by Burgess that it took more than a decade passed before the next study appeared applying the systems approach to study the distributional effects of international trade. Aw and Roberts (1985) are particularly interested in the distributional impact of the growing volume of imports from newly-industrialising countries (NICs) to the United States in the light of the increasing demand for protection at the time. The study also addresses concerns voiced by NICs that the GATT negotiations have eroded preferential access of NIC imports to the US market. They extend the methodology developed by Burgess (1974a) by distinguishing between imports from American NICs, Asian NICs and imports from developed countries. Aw and Roberts find that imports from NICs complement both domestic labour and imports from developed countries. Imports from developed countries substitute for domestic labour services. Consequently, they conclude that imports from developed countries tend to require less domestic processing than imports from developing countries. Note that they use their cost function estimates to shed light on the impact of US commercial policy on the domestic distribution of earnings, while Burgess (1974a) does not do so. The use of duality would have favoured a production function approach where trade policy enters the model exogenously and factor prices endogenously. Indeed, Burgess (1974b) uses a production function approach to analyse the distributional effects of trade policy.

Tombazos (1998) extends the work by Burgess (1974a) and Aw and Roberts (1985) by distinguishing between six groups of imports according to their domestic processing requirements. For this purpose Tombazos estimates a symmetric normalised quadratic (SNQ) cost function originally proposed by Diewert and Wales (1987) using data for the United States for the period 1967-1994. The advantage of using the SNQ compared to other flexible functional forms, amongst which the popular translog function, is twofold. First, one can impose curvature conditions globally without compromising its flexibility. Second, the SNQ is better equipped to deal with a relatively large number of aggregates.[3] Tombazos finds that 'final good'

[3] Its virtues despite Kohli (1991, p. 242) prefers the translog over the SNQ. Comparing the results across functional forms shows that estimates for the SNQ tend to be smaller than those with the

imports are substitutes for both capital and labour, while imports that require substantial 'downstream handling' are substitutes for capital but complements for labour. They note that the latter category increased from 47% of total imports in 1967 to 67% in 1980.

Kohli (1991) offers a very useful methodological guide to the analysis of trade using the systems approach building on about twenty years of active research leading to a large collection of papers. His training as a trade economist is reflected by the preference for the production function approach. More in particular, Kohli frequently employs the GNP function (or the joint revenue function) which is a function of output prices and input usage. In accordance to neoclassical trade theory for the small open diversified economy factor endowments and output prices are exogenous, while factor prices and output supplies are endogenous. Moreover, in contrast to the early work by Burgess (1974b) and studies on immigration and labour markets,[4] which are typically based on a single sector, the GNP function explicitly distinguishes between different sectors. The GNP function approach is therefore in principle consistent with general equilibrium trade theory characterised by non-joint production. Any change in the composition of output will directly affect aggregate factor demands at given goods prices (factor prices).[5] As imports unlike domestic inputs are not in fixed supply the GNP approach with imports typically takes the form of a variable profit function where domestic inputs are exogenous and foreign inputs endogenous.

Kohli is particularly interested in the determination of imports and exports, but also discusses some issues related to the distributional impact of international trade. Some of his main findings are that the quantity elasticities of inverse factor demand are quite small, but far from negligible; the aggregate demand for imports is fairly price inelastic; the demand for imports of nondurables is less price elastic than for imports of durables.

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translog. Kohli concludes from this that the greater structure to satisfy global curvature conditions might reduce its ability to precisely estimate the structural parameters locally.

[4] See Gaston and Nelson (2001) for a survey.

[5] Interestingly, the issue of separability resurfaces as in contrast to the one sector model implicitly or explicitly adopted elsewhere in the literature, international trade can have distributional effects while imports are separable from domestic production via its impact on relative output prices and

Amongst the many applications ranging from models with two goods and two factors to fairly extensive models incorporating import demand and export supply estimated with different flexible functional forms, the discussion on the inclusion of disaggregated imports in the translog GNP function is particularly interesting for the present purposes. He mentions three methods.

First, one might directly include different types of imports to the GNP function. In order to keep the number of aggregates under control one might like to aggregate some the outputs or inputs. He provides an example for the case of two outputs (tradable and nontradable), three types of imports (durable, nondurable and services) and two factor of production (capital and labour). Results indicate that an increase in the price of durables harms labour, but benefits capital. Imports of nondurables and services do not have sizable effects on the distribution of earnings.

Second, instead of including disaggregated imports directly one could first estimate the quantity of aggregate imports, domestic inputs and outputs and in a second stage given the profit-maximising quantity of aggregate imports estimate the appropriate mix of disaggregated imports. This method is known as the two-stage budgeting procedure and is well known in consumer theory. The procedure is based on the assumption that imports are weakly separable from domestic inputs in the second stage. While this procedure is preferable in the presence of many types of imports, it is ill-suited for the study of trade and wages.

Third, one might use a semiflexible form in order to limit the number of parameters while increasing the number of import categories.

Harrigan and Balaban (1999) and Harrigan (2000) are the first to apply the systems approach to the debate on the rise in wage inequality. More in particular they employ the GNP function methodology developed by Kohli (1991) in order to analyse the causes in the rise of wage inequality in general equilibrium. The main contribution of their work is to analyse the issue of wage inequality in an elegant and more general

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productivity. In other words the violation of the separability assumption in the early work by Burgess (1974b) and Berndt and Wood (1975) might be due to aggregation of different sectors.

theoretical framework compared to the existing literature on wage inequality. The results however might be considered tentative or provoking rather than definite.

Harrigan and Balaban (1999) investigate the role of relative prices, sector-biased productivity growth and factor supplies on relative wages using data for the US for the period 1963-1991. They distinguish four domestic outputs according to skill-intensity and tradability. Note that even though they do not explicitly consider trade, in a small open-economy prices of tradables outputs are determined on world markets. In theory, factor prices will be uniquely determined by tradable goods prices as long as the number of tradable outputs is at least as large as the number of immobile factors of production. However, Harrigan and Balaban account for four factors of production so that the number of factors exceeds the number of tradables reflecting their scepticism towards the validity of the factor price insensitivity theorem. With the number factors exceeding the number of tradables the relative demand for labour curve will be downward-sloping, and consequently, changes in relative factor supplies can have an impact on relative prices.

The descriptive statistics show that both tradable and non-tradable relative output prices could potentially have an important effect on relative wages during the 1980s while such a pattern does not prevail for productivity growth. Although the estimated price elasticities of inverse factor demand are sizable (particularly for nontradables) the pattern is only weakly consistent with Stolper-Samuelson reasoning. The relative price of nontradables is estimated to have significantly contributed to the increase in the wage gap between high school graduates and college graduates. The remainder of elasticities raises more questions than it answers.

The main finding emerging from their analysis, however, is undoubtedly that factor-price insensitivity does not hold as illustrated by the estimated non-zero quantity elasticities of inverse factor demand. In particular, capital accumulation contributed importantly to wage inequality. During the period 1970-1990 capital accumulation increased the relative wage of college graduates to high school dropouts by 64% and that of college graduates to high school graduates by 21%.[6]

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[6] Real wage effects are ambiguous if Stolper-Samuelson elasticities are between 0 and 1.

In a similar paper Harrigan (2000) re-estimates the U.S. GNP function using data for the period 1967-1995, but this time focuses explicitly on the role of international trade. In addition to a domestic skill-intensive and unskilled-intensive sector Harrigan includes the three types of imports being 1) durables, 2) nondurables and services and 3) oil. He extends the work by Kohli by distinguishing between three types of labour.

Again results invalidate the factor-price insensitivity theorem. In addition to the argument of more factors than goods implicit in Harrigan and Balaban (1999) Harrigan also mentions the presence of joint production and changes in the product mix as plausible explanations for the failure of the factor-price insensitivity theorem. The three types of labour are each others substitutes, while capital complements all types of labour.

Harrigan concludes that price effects offer a partial explanation for the increase in wage inequality. While this is true for the relative wage between college and high school graduates the largest estimated elasticities apply to high school dropouts and are opposed to Stolper-Samuelson logic. The impact of trade is likely to have been very small given the small estimated elasticities and small changes in import prices. However, in principle part of the impact of trade could be captured by changes in domestic relative prices as Harrigan acknowledges in the conclusion.

Finally, Tombazos (2003) adopts a similar approach as Harrigan (2000) by focussing on the role of different types of imports on relative wages in the United States. For this purpose he estimates a SNQ variable profit function introduced by Kohli (1993) using data for the US for the period 1961-1991. More in particular, he estimates a system of six equations consisting of domestic output supply, imports from developing and developed countries, and the inverse demand for capital, unskilled and skilled labour. Results indicates that imports from developing countries have only marginal effects if anything on the wage of unskilled workers, while imports from developed countries tend to stimulate the demand for unskilled labour from 1980 onwards. Given that imports from developed countries due to their relatively high skill-intensity are unlikely to have large displacement effects for unskilled workers, fairly small processing requirements might already render the sign positive. The impact of imports from developing countries on the wage of skilled workers is insignificant, while the impact of imports from developed countries seems to positive. Comparing the relative size of the 'Stolper-Samuelson elasticities' in conjunction with the actual reduction in the price of LDC imports does not reveal a substantial role for LDC imports in explaining the trend in wage inequality. Instead capital accumulation and skill-biased technological change seem to have played an important role.

3. Methodology

In the present paper the Kohli-Harrigan approach is adopted. The approach consists of estimates a GNP function which in accordance to neoclassical trade theory for the small open diversified economy factor endowments and output prices are exogenous, while factor prices and output supplies are endogenous. Moreover, in contrast to the early work by Burgess (1974b) and studies on immigration and labour markets, which are typically based on a single sector, the GNP function explicitly distinguishes between different sectors. The GNP function approach is therefore in principle consistent with general equilibrium trade theory characterised by non-joint production. Any change in the composition of output will directly affect aggregate factor demands at given goods prices (factor prices). As imports unlike domestic inputs are not in fixed supply the GNP approach with imports typically takes the form of a variable profit function (Samuelson, 1953) where domestic inputs are exogenous and foreign inputs endogenous.

This section will shortly set out the empirical framework. Throughout this paper it is assumed that markets are perfectly competitive and that firms produce under constant returns to scale. For more on the underlying theory the reader is referred to Dixit and Norman (1980).

As in Burgess (1974a, 1974b) and Kolhi (1991), it is assumed that the economy's GNP function can be approximated by a translog function. The main reason for using a flexible functional form is that elasticities can vary over the sample and need not be parametric. Flexible functional forms put much less restrictions prior to estimation than more traditional functional forms. The limitation of flexible functional forms to approximate true but unknown structures and ensure global curvature properties should be considered secondary (Chambers, 1988).

(3.1)

$$G(p,v,t) = \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln p_i + \sum_{k=1}^{M} \beta_k \ln v_k + \frac{1}{2}\sum_{j=1}^{M}\sum_{i=1}^{N} \alpha_{ij} \ln p_i \ln p_j$$
$$+ \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln v_k \ln v_l + \frac{1}{2}\sum_{i=1}^{N}\sum_{k=1}^{K} \gamma_{ik} \ln p_i \ln v_k + t\sum_{i=1}^{N} \delta_i \ln p_i$$
$$+ t\sum_{l=1}^{K} \delta_k \ln v_k + \delta_1 t + \delta_2{}^2 t$$

where p refers to the sum of value-added prices and total factor productivity (effective prices) and v to factor utilisation and t to non-neutral technological change (in addition to Hicks neutral technological change included in p) which is assumed to be a function of the time index. Note that simply adding up prices and TFP gives their joint impact on factor prices net of productivity pass-through (Feenstra and Hanson, 1999). It is assumed that the GNP function is twice differentiable in prices and factor endowments, increasing and convex in prices, increasing and concave in factor endowments.

The assumption of profit maximisation implies linear homogeneity in prices[7] and the assumption of constant returns to scale in line with perfect competition implies linear homogeneity in factor endowments:

(3.2) $$\sum_{i=1}^{N} \alpha_i = \sum_{k=1}^{M} \beta_k = 1 \text{ and } \sum_{i=1}^{N} \alpha_{ik} = \sum_{k=1}^{M} \alpha_{ik} = \sum_{i=1}^{N} \beta_{ik} = \sum_{k=1}^{M} \beta_{ik} = \sum_{i}^{N} \delta_i = \sum_{k=1}^{M} \delta_k = 0$$

Without loss of generality impose symmetry restrictions following Young's Theorem:

(3.3) $\alpha_{ij} = \alpha_{ji}$ and $\beta_{kl} = \beta_{lk}$ and also $\gamma_{ik} = \gamma_{ki}$

[7] Since a proportional change in all prices does not change the optimal vector of output supply.

Differentiation of the revenue function (3.1) with respect to lnv_k gives the share of factor k in GDP:[8]

$$(3.4) \quad s_k = \beta_{0k} + \sum_{j=1}^{N} \gamma_{kj} \ln p_j + \sum_{l=1}^{K} \beta_{kl} \ln v_l + \delta_k t,$$

where $s_k = \frac{w_k v_k}{Y}$. Differentiation of the revenue function (3.1) with respect to lnp_i yields the share of final output i in GDP:

$$(3.5) \quad s_{i,-j} = \alpha_{0i} + \sum_{j=1}^{N} \alpha_{ij} \ln p_i + \sum_{l=1}^{K} \gamma_{il} \ln v_k + \delta_i t,$$

where $s_{i,-j} = \frac{p_i x_i}{Y}$ is the combined vector of final output share in GDP and the negative vector of positive import shares in GDP.

The GNP function is well behaved if its convex in prices and concave in factor endowments. If curvature conditions are not satisfied the results are inconsistent with economic theory and therefore meaningless. More often than not the use of flexible functional forms is generally compromised by violations of the curvature conditions. The translog GNP function does not satisfy these properties globally. One should therefore check whether the curvature conditions are satisfied at each observation. Fortunately, in the translog case curvature conditions can be imposed locally without destroying its flexibility. However imposing curvature at one point implies that curvature conditions can still be violated elsewhere. Estimating the model and testing for curvature violations yields that both convexity in prices and concavity in factor endowments are violated in a number of years. Thus curvature is imposed locally following the methodology originally due to Wiley, Schmidt and Bramble (1973), but a clear representation can also be found in Kohli (1991) and Ryan and Wales (2000).

[8] Since linear homogeneity is imposed on the aggregate production function one can rewrite the regressors of the factor share equations in relative terms. See Kohli (1991, p. 124-125).

Convexity (concavity) implies that the matrix of second-order derivatives with respect to prices (factor endowments) is positive (negative) semi-definite which implies that all the principal minors should be positive (negative).[9] It can be shown that the Hessian of the translog GNP function will be negative semidefinite, provided that $G > 0$, if and only if the matrix of the partial elasticities of complementarity substitution, Σ, is also negative semidefinite. The partial elasticities of complementarity are given by:

$$(3.6) \quad \sigma_{ij} = \alpha_{ij} - S_i \phi_{ij} + S_i S_j$$

where $\phi_{ij} = 1$ if *i=j* and *0* otherwise. Normalising prices and factor supplies at *t=t*,* the point where curvature violations are most pronounced , yields $S_i = \alpha_i$ so that one can rewrite (3.6) as follows:

$$(3.6') \quad \sigma_{ij} = \alpha_{ij} - \alpha_i \phi_{ij} + \alpha_i \alpha_j$$

Imposing convexity (concavity) in prices (factor endowments) at the point of normalisation can be attained by equating $\Sigma = (-)DD'$, where D is an upper triangular matrix whose positive (negative) product equals the substitution matrix. Rewriting with respect to α_{ij} gives:

$$(3.7) \quad \alpha_{ij} = -(DD')_{ij} + \alpha_i \phi_{ij} - \alpha_i \alpha_j$$

where $(DD')_{ij}$ refers to the *ij*th element of DD'. The resulting model will be necessarily nonliner in its parameters.

The complete system of share equations (3.4 and 3.5) will be estimated using either Zellner's method for seemingly unrelated regression equations (SUR) or three-stage least squares (3SLS). Although our prime interest goes out to the cost share equations

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[9] Harrigan and Balaban (1999) and Harrigan (2000) simply impose the necessary but not sufficient that condition that all own price-output elasticities are positive and all own supply-factor price elasticities negative.

including the output share equations should lead to greater efficiency due to the correlation of the disturbances and the cross equation restrictions, $\gamma_{ik} = \gamma_{ki}$. Since the output and cost share equations add up to unity so that the disturbance covariance matrix will be singular, one should drop one equation from each system. SUR or 3SLS estimates will normally not be invariant to the equation deleted. Fortunately, invariance can be obtained by iterating Zellner's method (ISUR) or three-stage least squares (I3SLS) so that the parameter estimates and residual covariance matrix converge (Berndt and Wood, 1975).[10]

Imposing curvature conditions as described above renders the optimisation process nonlinear in the parameters. The SUR and 3SLS procedure in TSP 4.4 can both deal with linear and nonlinear models.

The results will be discussed on the basis of the estimated elasticities rather than the direct regression estimates as their interpretation is not straightforward due to the fact that the explanatory variables are in natural logarithms while the dependent variables are not. Instead of using the Hicksian elasticities of complementarity (Allen-Uzawa elasticities of substitution in a cost function context) the direct price and quantity elasticities are reported. There are two reasons for doing so. First, Berndt and Wood (1981) recommend this as the partial elasticities of complementarity can become quite volatile in the presence of small cost or output shares. Second, Blackorby and Russell (1989) argue that the Allen-Uzawa generalisation to more than two inputs has no meaning as a quantitative measure.

The elasticity of supply *i* with respect to a change in the sum of price *j* and total factor productivity *j* is given by:

$$(3.8a) \quad \varepsilon_{ij} = \frac{\partial \ln y_i}{\partial \ln p_j} = \frac{\alpha_{ij}}{s_i} + s_j - \phi_{ij}$$

where $\phi = 1$ if $i = j$. The elasticity of nominal return to factor *k* with respect to a change in the utilisation of factor *l* is given by:

[10] However, convergence might not always be possible.

(3.8b) $\varepsilon_{kl} = \dfrac{\partial \ln w_k}{\partial \ln v_l} = \dfrac{\beta_{kl}}{s_k} + s_l - \phi_{kl}$

where $\phi = 1$ if $l = k$. The Rybczynski elasticities are given by:

(3.8c) $\varepsilon_{ik} = \dfrac{\partial \ln y_i}{\partial \ln v_k} = \dfrac{\gamma_{ik}}{s_i} + s_k$

The Stolper-Samuelson elasticities of nominal factor prices to the sum of goods prices and total factor productivity is given by:

(3.8d) $\varepsilon_{ki} = \dfrac{\partial \ln w_k}{\partial \ln p_i} = \dfrac{\gamma_{ki}}{s_k} + s_i$

Due to fact that the elasticities are derived from highly nonlinear relationships, the standard errors of the estimated coefficients are asymptotic, and the binding curvature-related inequality constrained standard errors of the elasticities should be interpreted with caution or not be reported at all. The command ANALYZ in TSP can used to obtain approximate standard errors (Kohli, 1991).

4. Data

Labour market data are obtained from the New Earnings Survey Panel Data Set (NESPD). Data on capital stocks and TFP are obtained from the National Institute Sectoral Productivity Database (NISPD). For more information on the sources and the construction of these variables the reader is referred to O'Mahony (1999).The following analysis will be using data for the period 1975-1999 only due to the availability of the NESPD for earlier years.

Disaggregated producer price indices for the UK are only available for the 1990s for the UK and only for manufacturing industries. However, Indices of Production are available at the sectoral level for both services and manufacturing. Such indices should reflect the growth in output by sector in real terms. This index has been compiled on a more or less consistent basis since the 1940s. The construction of these indices is based on turnover data deflated using weighted combinations of producer price indices and export price indices. Without having data on price indices one could retrieve the 'producer price indices' by combining data on value added at current prices with the index of production, that is, to convert nominal value-added into an index (1995=100) and subsequently divide the index of value added (current prices) by the index of production (constant prices). Obviously constructing producer price indices for services is subject to many problems. In particular the output indices might not be limited to the real growth of output of services as it is maybe even impossible to disentangle cost-price effects from volume effects. Data on output indices and nominal value added are obtained from the ONS.

GNP is represented as a function of a four-input, four-output technology. The four inputs are skilled and unskilled-intensive tradables and nontradables. The measure of skill-intensity used to classify sectors is based on the cost share of skilled labour in value-added the year 1987. The composition of each sector aggregate is represented in Table 4.1 together with their respective levels of skill-intensity. It can be seen that the skill-intensity ranking of sectors is fairly constant across time. In the remainder the possibility of factor intensity reversals will therefore be ignored.

Table 4.1: Model I - Skill-intensity by sector and year

		1975	1980	1985	1990	1995	1999
	Unskilled, tradable (Y_2)						
1000	Agriculture and Forestry	0.029	0.026	0.024	0.045	0.100	0.112
3000	Mining and extraction	0.227	0.057	0.100	0.295	0.271	0.208
4010	Food, drink and tobacco	0.167	0.156	0.196	0.186	0.269	0.319
4020	Textiles, clothing and leather	0.095	0.124	0.148	0.185	0.247	0.259
4040	Wood products	0.077	0.106	0.151	0.225	0.286	0.291
4080	Rubber & Plastics	0.245	0.234	0.223	0.255	0.276	0.373
4090	Non-metallic mineral products	0.187	0.187	0.261	0.261	0.321	0.639
4100	Basic metals & fabricated metal products	0.315	0.353	0.230	0.205	0.253	0.289
4140	Furniture and miscellaneous	0.233	0.343	0.262	0.316	0.353	0.276
	Skilled, tradable (Y_1)						
4050	Paper and printing	0.294	0.325	0.340	0.353	0.413	0.418
4070	Chemicals	0.399	0.431	0.400	0.426	0.481	0.667
4005	Total machinery and equipment	0.318	0.453	0.590	0.627	0.588	0.712
5000	Electricity, gas and water	0.217	0.284	0.338	0.373	0.335	0.425
	Unskilled, nontradable (Y_4)						
6000	Construction	0.158	0.217	0.193	0.233	0.342	0.354
7300	Hotels and catering	0.050	0.055	0.071	0.072	0.115	0.193
9100	Transport	0.182	0.225	0.208	0.209	0.269	0.260
	Skilled, tradable (Y_3)						
7200	Retail	0.374	0.431	0.460	0.492	0.578	0.623
8000	Financial and business services	0.218	0.259	0.336	0.448	0.483	0.511
9200	Communications	0.191	0.351	0.458	0.384	0.358	0.413
15000	Personal services	0.149	0.278	0.533	0.490	0.570	0.385

Table 4.2 represents the trends in the aggregate sector output share and the factor cost shares. These aggregates serve as the dependent variables in the econometric estimation.

Table 4.1: Model I - Output and Cost Shares in GDP, 1975-1999

Year	Y_1	Y_2	Y_3	Y_4	L_H	L_S	L_U	K_K
1975	0.359	0.094	0.285	0.261	0.153	0.282	0.216	0.349
1976	0.357	0.099	0.282	0.262	0.152	0.267	0.206	0.375
1977	0.350	0.102	0.286	0.262	0.151	0.250	0.195	0.404
1978	0.343	0.105	0.295	0.256	0.156	0.244	0.190	0.410
1979	0.339	0.111	0.300	0.250	0.171	0.243	0.175	0.412
1980	0.342	0.118	0.303	0.237	0.177	0.242	0.179	0.402
1981	0.334	0.124	0.308	0.234	0.197	0.240	0.156	0.408
1982	0.331	0.126	0.315	0.228	0.193	0.229	0.151	0.426
1983	0.320	0.125	0.337	0.218	0.198	0.219	0.145	0.437
1984	0.314	0.123	0.349	0.214	0.200	0.215	0.145	0.439
1985	0.275	0.134	0.332	0.260	0.201	0.213	0.143	0.444
1986	0.267	0.108	0.357	0.268	0.208	0.210	0.140	0.442
1987	0.250	0.101	0.385	0.264	0.217	0.200	0.133	0.451
1988	0.249	0.093	0.394	0.265	0.220	0.198	0.132	0.451
1989	0.250	0.092	0.394	0.264	0.230	0.194	0.132	0.443

1990	0.242	0.089	0.414	0.255	0.238	0.196	0.132	0.433
1991	0.226	0.087	0.447	0.239	0.255	0.188	0.129	0.427
1992	0.218	0.087	0.465	0.229	0.257	0.185	0.127	0.431
1993	0.217	0.083	0.487	0.213	0.262	0.176	0.119	0.443
1994	0.225	0.081	0.480	0.214	0.258	0.169	0.115	0.457
1995	0.223	0.081	0.485	0.211	0.265	0.160	0.113	0.462
1996	0.221	0.077	0.502	0.200	0.264	0.157	0.111	0.468
1997	0.218	0.071	0.513	0.198	0.266	0.154	0.113	0.466
1998	0.205	0.065	0.538	0.193	0.276	0.155	0.111	0.459
1999	0.197	0.061	0.545	0.196	0.285	0.154	0.107	0.454

Where Y_1 refers to the output share of the skilled-intensive, tradable sector, Y_1 to the unskilled-intensive, tradable sector, Y_3 to the skilled-intensive, nontradable sector, and Y_4 to the unskilled-intensive nontradable sector. See the appendix for details on the composition of the tradable and nontradable sector. Source: ONS, NIESR, NES, own calculations.

In the Table 4.3 the pairwise correlations between the raw and detrended explanatory variables on the one hand and the dependent variables on the other are reported. It can be easily seen that the own output-price effects and the own factor supply-factor price effects do not always yield the expected sign. The diagonal cells for which the pairwise correlation is inconsistent with economic theory are marked in bold. It is interesting that when one detrends the right-hand side variables all the pairwise correlations have the expected sign suggesting that the presence of trends is likely to produce spurious results. Including a time trend would effectively deal with this issue as long the regressors are stationary or trend stationary

Table 4.3: Pairwise correlations

		Y_1	Y_2	Y_3	Y_4	L_H	L_S	L_U	K_K
Raw	$ln(p_1/p_4)$	*0.116*	0.231	0.065	-0.659	0.111	-0.079	-0.138	0.087
	$ln(p_2/p_4)$	0.191	*0.589*	-0.141	-0.394	-0.014	0.008	-0.145	0.170
	$ln(p_3/p_4)$	0.915	0.482	***-0.769***	0.263	-0.850	0.863	0.910	-0.850
	$ln(V_H/V_K)$	0.233	0.651	-0.372	0.263	*-0.278*	0.169	0.019	0.175
	$ln(V_S/V_K)$	0.886	0.824	-0.949	0.679	-0.931	***0.882***	0.803	-0.636
	$ln(V_U/V_K)$	0.889	0.783	-0.943	0.684	-0.943	0.886	***0.831***	-0.653
Detrended	$ln(p_1/p_4)$	*0.173*	0.275	0.007	-0.621	0.054	-0.021	-0.083	0.005
	$ln(p_2/p_4)$	0.132	*0.546*	-0.082	-0.436	0.045	-0.051	-0.203	0.199
	$ln(p_3/p_4)$	0.169	-0.287	*0.133*	-0.606	-0.013	0.037	0.197	-0.256
	$ln(V_H/V_K)$	-0.023	0.472	-0.117	0.087	*-0.018*	-0.095	-0.239	0.413
	$ln(V_S/V_K)$	-0.028	0.367	-0.105	0.137	-0.045	*-0.085*	-0.190	0.387
	$ln(V_U/V_K)$	-0.029	0.260	-0.083	0.146	-0.068	-0.088	*-0.129*	0.358

Where p is defined as $lnp+lnTFP$.

The time series properties are more thoroughly investigated with the help of augmented Dickey-Fuller tests. The results are reported in Table 4.4. It follows that four of the six regressors might be stationary or trend stationary. The remaining two variables are probably I(1) and might make it impossible to make statistical inferences. Unfortunately, the sample is too short to use cointegration techniques. In spite of the presence of I(1) variables the estimation will proceed using a static specification. One should therefore check whether the residuals of the regressions are cointegrated in order to be able to comfortably rely on the estimated results.

Table 4.4 Unit roots tests

Regressands	ADF	p-value		Regressors	ADF	p-value	
Y_1	-32.815	0.000	***	$ln(p_1/p_4)$	-10.400	0.000	***
Y_2	-2.300	0.434		$ln(p_2/p_4)$	-3.823	0.015	**
Y_3	-3.601	0.030	*	$ln(p_3/p_4)$	-1.568	0.805	
Y_4	-2.147	0.520					
L_H	-2.147	0.520		$ln(V_H/V_K)$	-2.862	0.175	
L_S	-1.858	0.676		$ln(V_S/V_K)$	-3.379	0.054	*
L_U	-1.790	0.709		$ln(V_U/V_K)$	-5.960	0.000	***
K_K	-3.926	0.011	**				

Where *p* is defined as *lnp+lnTFP*.

5. Model I - A baseline model without international trade

Table 5.1a and 5.1b report the results obtained for Model I by estimating a system of 8 share equations (two of which are dropped due to singularity of covariance matrix of the disturbances). Model I is estimated using two alternative econometric techniques. Specification 1 uses the iterative Zellner or seeming unrelated regression estimator (ISUR). Specification 2 accounts for the endogeneity of output prices by using iterated three-stage least squares (I3SLS). The instruments that are used are population, the total population of the United States, Japan and France, the real effective exchange rate, the savings ratio, the discount rate, the government's budget deficit as a share of GDP, and the lagged capital stock.

The results in Table 5.1a are subject to numerous curvature violations. While convexity in prices is satisfied for all observations, concavity in factor endowments fails for most of them. Murphy and Welch (1992) suggest that concavity in factor supplies might fail due to unstable factor demand. The GNP approach however concentrates on the impact of changes in factor supplies at constant goods prices along the demand curve. It is generally accepted, however, that the majority of the increase results form outward *shifts* of the factor demand curve. In the present model shifts in factor demand are simply accounted for by a linear time trend. Given the emphasis in the literature on *shifts* in factor demand it is not unlikely that the system is misspecified. The more appropriate measurement of shifts in factor demand however will be left for a later stage.

As violations seem to be most serious towards the end of the sample, curvature is imposed locally around 1999. As it turns out imposing curvature conditions locally solves also the curvature violations elsewhere in the sample. It is important to note that convergence could not be attained for all parameters after the reparameterization was imposed. However, convergence could be attained for a subset of the parameters by holding β parameters constant to their initial estimates. One should therefore interpret the β parameters with particular caution. However, the failure to achieve convergence is also likely to affect the result for the remaining parameters as reflected by the low R-squares in the inverse factor demand equations. The regression results are reported in Table 5.1b.

The results in Table 5.1b are adjusted for first-order autocorrelation by subtracting the autocorrelation from the data while imposing the restriction that autocorrelation is constant across the set of output share equations as well as across cost share equations. The restriction is necessary to achieve invariance with respect to the deleted equations (Berndt and Savin, 1975). Instead of allowing for first-order autocorrelation in the disturbances one might instead include lagged dependent variable in order to get the long-run elasticities. However, accounting for the long-run might not be that important as it is not implausible to assume that factor markets adjust within one year to changes in prices, productivity or factor supplies. Instead adjustment dynamics are likely to be much more important for the determination of prices and productivity. The explicit empirical modelling of prices and productivity is well beyond the scope of this paper.

Table 5.1a: Model I: Regression results without curvature restrictions

	ISUR			I3SLS		
Parameter	Estimate	Error	t-statistic	Estimate	Error	t-statistic
α_1	0.342	0.045	7.66	0.201	0.061	3.30
α_2	1.322	0.362	3.65	-0.379	0.623	-0.61
α_3	-0.698	0.127	-5.50	0.327	0.410	0.80
β_1	-0.002	0.274	-0.01	1.145	0.318	3.60
β_2	-0.038	0.068	-0.55	-0.047	0.073	-0.64
β_3	0.040	0.044	0.91	0.243	0.070	3.44
α_{11}	0.008	0.044	0.17	-0.177	0.050	-3.56
α_{12}	-0.006	0.002	-3.09	-0.001	0.002	-0.35
α_{13}	0.159	0.020	8.06	0.084	0.059	1.42
α_{22}	1.005	0.100	10.05	1.091	0.356	3.07
α_{23}	-0.048	0.085	-0.57	-0.695	0.206	-3.37
α_{33}	0.061	0.024	2.49	-0.109	0.065	-1.69
β_{11}	0.025	0.024	1.06	0.036	0.064	0.56
β_{12}	-0.073	0.018	-4.00	0.078	0.036	2.15
β_{13}	-0.004	0.001	-4.74	0.000	0.002	0.02
β_{22}	0.204	0.038	5.41	0.272	0.047	5.75
β_{23}	0.839	0.263	3.19	0.006	0.255	0.02
β_{33}	-0.013	0.060	-0.22	-0.035	0.057	-0.62
γ_{11}	-0.095	0.034	-2.77	-0.192	0.049	-3.90
γ_{12}	0.092	0.036	2.55	0.202	0.034	5.87
γ_{13}	0.014	0.002	8.76	0.011	0.002	5.77
γ_{21}	0.226	0.013	17.92	0.269	0.018	14.65
γ_{22}	0.104	0.018	5.67	0.149	0.022	6.90
γ_{23}	-0.062	0.011	-5.42	-0.099	0.019	-5.33
γ_{31}	-0.075	0.011	-7.11	-0.082	0.010	-8.61
γ_{32}	0.001	0.001	1.03	-0.001	0.001	-1.65
γ_{33}	0.201	0.010	20.64	0.177	0.017	10.25
δ_{11}	0.095	0.012	7.81	0.111	0.019	5.73
δ_{21}	-0.068	0.008	-8.65	-0.048	0.009	-5.19
δ_{31}	-0.004	0.000	-10.71	-0.003	0.001	-4.94
δ_{12}	0.158	0.007	21.40	0.140	0.008	17.23
δ_{22}	0.122	0.008	14.45	0.110	0.008	13.94
δ_{32}	-0.002	0.000	-6.21	-0.001	0.000	-4.19
R^2_1	0.964			0.976		
R^2_2	0.979			0.902		
R^2_3	0.987			0.989		
R^2_4	0.988			0.988		
R^2_5	0.990			0.990		
R^2_6	0.991			0.991		
AR(1)						
ρ_1				0.480	0.081	5.92
ρ_2				0.316	0.091	3.46

Table 5.1b: Model I: Regression results with curvature restrictions

	ISUR			I3SLS		
Parameter	Estimate	Error	t-statistic	Estimate	Error	t-statistic
α_1	0.166	0.019	8.77	-0.099	2.311	-0.04
α_2	0.095	0.015	6.47	0.217	1.205	0.18
α_3	0.561	0.026	21.53	0.674	0.985	0.68
β_1	0.286	0.018	16.15	0.286	0.018	15.48
β_2	0.141	0.073	1.94	0.141	0.109	1.30
β_3	0.106	0.269	0.39	0.106	0.295	0.36
α_{11}	2.408	0.790	3.05	-840.658	259.186	-3.24
α_{12}	-0.798	0.418	-1.91	435.069	134.702	3.23
α_{13}	-0.301	0.489	-0.62	358.936	110.008	3.26
α_{22}	1.111	0.335	3.32	-224.364	70.014	-3.20
α_{23}	0.345	0.316	1.09	-185.588	57.165	-3.25
α_{33}	0.529	0.610	0.87	-152.455	46.704	-3.26
β_{11}	-0.212	0.101	-2.10	-0.211	0.088	-2.40
β_{12}	-0.013	0.068	-0.19	-0.013	0.050	-0.26
β_{13}	0.043	0.127	0.34	0.043	0.106	0.41
β_{22}	-0.734	0.135	-5.45	-0.733	0.184	-3.98
β_{23}	-0.886	0.269	-3.29	-0.885	0.336	-2.63
β_{33}	-5.095	0.960	-5.30	-5.096	0.967	-5.27
γ_{11}	0.103	0.144	0.71	7.844	2.284	3.43
γ_{12}	-0.384	0.206	-1.87	-18.716	6.172	-3.03
γ_{13}	0.347	0.144	2.41	14.652	8.054	1.82
γ_{21}	-0.066	0.099	-0.67	-3.874	1.156	-3.35
γ_{22}	0.630	0.165	3.81	10.009	3.214	3.11
γ_{23}	-0.532	0.135	-3.95	-7.649	4.184	-1.83
γ_{31}	-0.237	0.167	-1.42	-3.584	1.006	-3.56
γ_{32}	-0.211	0.186	-1.14	7.907	2.623	3.01
γ_{33}	0.454	0.200	2.27	-5.453	3.429	-1.59
δ_{11}	-0.006	0.001	-5.64	0.757	0.498	1.52
δ_{21}	-0.003	0.001	-3.21	-0.381	0.259	-1.47
δ_{31}	0.009	0.001	6.28	-0.281	0.211	-1.33
δ_{12}	0.002	0.001	1.84	-0.005	0.004	-1.21
δ_{22}	-0.007	0.005	-1.31	-0.064	0.020	-3.16
δ_{32}	-0.008	0.020	-0.41	-0.304	0.058	-5.26
R^2_1	0.979			0.213		
R^2_2	0.881			0.037		
R^2_3	0.979			0.261		
R^2_4	0.925			0.830		
R^2_5	0.178			0.371		
R^2_6	0.015			0.118		
AR(1)						
ρ_1	0.609	0.064	9.54	0.255	0.062	4.11
ρ_2	0.584	0.067	8.67	0.212	0.063	3.37

The ISUR and I3SLS estimate in Table 5.1a yield generally similar results although that are some notables exceptions. A Sargan-type test on the validity of overidentying restrictions was rejected for all combinations of the available instruments suggesting that for the moment it might be better to rely on the ISUR estimates than on the I3SLS estimates. For the system of nonlinear equations in Table 5.1b the problems associated with the use of I3SLS are exacerbated due to nonlinearities and the lack of convergence.

The interpretation of the results is not straightforward due to the fact that the right-hand side variable are in natural logarithms whereas the dependent variables are not. Results will therefore be discussed on the basis of the estimated price and quantity elasticities. Unfortunately, results in Table 5.1a are not economically meaningful, while the results reported in Table 5.1b are not invariant to the equation dropped due to the failure to achieve convergence. It is not clear which of the two problems is the most serious. Table 5.2 reports the corresponding Stolper-Samuelson elasticities of the results obtained with ISUR reported in Table 5.1a and b.[11]

Table 5.2: Stolper-Samuelson elasticities

	ISUR (Table 5.1a)			ISUR (Table 5.1b)		
	1976	1987	1999	1976	1987	1999
ES11	0.113	0.076	0.068	0.925	0.649	0.519
ES12	0.492	0.381	0.285	-0.336	-0.202	-0.174
ES13	0.197	0.323	0.489	-1.505	-0.877	-0.455
ES14	0.261	0.264	0.193	1.916	1.431	1.110
ES21	0.501	0.450	0.463	-0.244	-0.601	-0.896
ES22	0.183	0.226	0.227	1.816	2.530	3.206
ES23	-0.051	-0.090	-0.076	0.472	0.648	0.878
ES24	0.261	0.264	0.193	-1.043	-1.577	-2.188
ES31	0.395	0.308	0.274	0.973	1.251	1.398
ES32	-0.243	-0.447	-0.589	0.103	0.116	0.083
ES33	0.713	1.081	1.368	2.082	3.313	4.030
ES34	0.261	0.264	0.193	-2.158	-3.680	-4.511
ES41	0.359	0.250	0.205	0.220	0.142	0.099
ES42	0.094	0.101	0.065	-1.113	-0.834	-0.854
ES43	0.285	0.385	0.538	-0.193	0.014	0.173
ES44	0.261	0.264	0.193	0.261	0.264	0.193

[11] As the computation of the standard errors is not straightforward they are omitted. However in order to get some idea of the significance of the estimated elasticities one might refer back to the t-statistic of the associated parameter in tables 5.1a and b.

The qualitative pattern is stable over time, although the magnitudes might differ quite substantially. The elasticities that correspond with Table 5.1a shows surprisingly large effects of changes in the sum of prices and TFP on factor prices. If anything, the elasticities for nontradable effective prices exceed those for tradable effective prices which suggests that the standard HOS-model might be too restrictive a way of modelling the actual economy, although the present result could also be due to interactions between the tradable and nontradable sector. In addition, the reported elasticities suggest that changes in relative goods prices and sector-biased productivity growth are unlikely to explain a substantial part of the increase in wage inequality.

6. Conclusion

The aim of this paper was to estimate a GNP function for the United Kingdom using data for the period 1975-1999. The GNP approach uses duality to analyse the impact of trade on the economy. Consistent with standard trade theory a GNP function is estimated which treats factor supplies and goods prices as exogenous and factor prices and outputs supplies as endogenous. As such the methodology allows one to evaluate the role of sector bias effects in the form of relative price changes and productivity growth, factor bias effects and factor supplies on factor prices in one single framework.

In the present study estimated a GNP function approach distinguishing between four inputs and four outputs. The present model concentrates explicitly on the role of nontradables but does not explicitly address the role of international trade. It is the first application of the GNP approach to the United Kingdom.

At the present stage result seem to indicate that the standard HOS model might be too a restrictive representation of the UK economy. Moreover, the role of effective prices in explaining the increase in wage inequality seems at best very limited. More promising explanations seem to be capital accumulation and skill-biased technological change. Although these explanations can also be examined in the present framework these are left to a later stage.

References

Aw, B.Y. and M.J. Roberts (1985), “The Role of Imports from the Newly-Industrializing Countries in U.S. Production”, *Review of Economics and Statistics*, Vol. 67, Iss. 1, pp. 108-117.

Berman, E., J. Bound, and Z. Griliches (1994), “Changes in the Demand for Skilled Labor within U.S. Manufacturing: Evidence from the Annual Survey of Manufacturers”, *Quarterly Journal of Economics*, Vol. 109, pp. 367-397.

Berndt, E.R. and D.O. Wood (1975), “Technology, Prices, and the Derived Demand for Energy”, *Review of Economics and Statistics*, Vol. 57, Iss. 3, pp. 259-268.

Berndt, E.R. and D.O. Wood (1981), “Engineering and Econometric Interpretations of Energy-Capital Complementarity: Reply and Further Results”, *American Economic Review*, Vol. 71, Iss. 5, pp. 1105-1110.

Burgess, D.F. (1974a), “A Cost Minimization Approach to Import Demand Equations”, *Review of Economics and Statistics*, Vol. 56, Iss. 2, pp. 225-234.

Burgess, D.F. (1974b), “Production Theory and the Derived Demand for Imports”, *Journal of International Economics*, Vol. 4, No.2, pp. 103-117.

Christensen, L.R., D.W. Jorgenson and L.J Lawrence (1973), “Transcendental logarithmic production frontiers”, *Review of Economics and Statistics*, Vol. 55, pp. 28-45.

Dixit, A.K. and V.D. Norman (1980), *Theory of International Trade: A Dual, General Equilibrium Approach*, Cambridge: University Press.

Feenstra, R.C. and G.H. Hanson (2001), “Global Production Sharing and Rising Wage Inequality”, *NBER Working Paper*, No. 8372.

Harrigan, J. and R. Balaban (1999), “U.S. Wages in General Equilibrium: The Effect of Prices, Technology, and Factor Supplies, 1963-1991”, *NBER Working Paper*, No. 6981.

Harrigan, J. (2000), “International Trade and American Wages in General Equilibrium, 1967-1995”, in R.C. Feenstra (ed.), *The Impact of International Trade on Wages*, University of Chicago Press: Chicago.

Kohli, U. (1991), *Technology, Duality and Foreign Trade: The GNP Function Approach to Modelling Imports and Exports*, Harvester Wheatsheaf: Hemel Hempstead.

O’Mahony, M. (1999), *Britain’s productivity performance 1950-1996: An international perspective*, NIESR.

Murphy, K.M. and F. Welch (1992), “The Structure of Wages”, *Quarterly Journal of Economics*, Vol. 107, No.1, pp. 285-326.

Ryan, D.L. and T.J. Wales (2000), “Imposing Local Concavity in the Translog and Generalized Leontief Cost Funtcions”, *Economics Letters*, Vol. 67, pp. 253-260.

Samuelson, P.A. (1953), “Prices of Factors and Goods in General Equilibrium”, *Review of Economic Studies*, Vol. 21, pp. 310-317.

Tombazos, C.G. (1998), “U.S. Production Technology and the Effects of Imports on the Demand for Primari Imports”, *Review of Economics and Statistics*, Vol. 80, No. 3, pp. 480-483.

Tombazos, C.G. (2003), “A Production Theory Approach to the Imports and Wage Inequality Nexus”, *Economic Inquiry*, Vol. 41, No. 1, pp. 42-61.