Knowledge Capital, Product Differentiation and Market Structure: a Comparative Static CGE Analysis

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Abstract

This paper concerns the analysis of knowledge capital based product differentiation in a comparative static computable general equilibrium framework. Knowledge capital is measured as the value of copyrights, trademarks and patents and it is defined as the input in production that provides the basis for product differentiation. The first part of the paper describes the econometric estimation carried out in order to introduce knowledge capital in a computable general equilibrium framework. In the second part, we develop a Chamberlin-Heckscher-Ohlin type computable general equilibrium framework with monopolistic competition that explores the impacts of endowment of knowledge capital on product differentiation and comparative advantage. In addition, market structure matter

JEL Classification: **O30 L13 C68**

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1 Introduction

As pointed out in Chamberlin's (1933) theory of monopolistic competition, a general class of products is differentiated if there is any significant criterion for distinguishing products from one seller to the other. Differentiation may be based on characteristics of the product, such as patented features, trade-marks, quality, design and style or on conditions surrounding its sale, such as location, reputation of the seller, goodwill etc. If the differentiated product is unique and stands out from the rest of the products present on the market it confers its seller a first mover advantage and monopolistic power.

In this paper knowledge capital is defined as the input in production that provides the basis for product differentiation. Knowledge capital in this case does not represent knowledge in general but the one that is specific in nature; it is not a pure public good, but a measure of intangible capital that is non-rival and partially excludable; it is costly to develop but once developed it can be used at no additional cost. It follows that knowledge capital as defined here represents a fixed cost independent from the level of output and it is a source of increasing returns (Arrow, 1999). Examples of types of knowledge are copyrights, patents, licenses, trademarks and trade names, blueprints or building designs.

On the one hand, copyrights, patents or trade-marks have generally been considered as monopolies given that they grant their assignee for a limited period of time a set of exclusive rights[1]. On the other hand, there is certainly a competitive component to copyrights and patents: even if they confer their owner monopoly power with respect to specific product, few inventions have been as fundamental as to give their owner monopoly power over a whole class of products. Chamberlin (1933) argues that such an environment can be best represented by a monopolistically competitive behaviour with zero profits and monopoly pricing. In fact, we can argue that the degree of monopoly power conferred to the knowledge capital's owner depends not only on the degree of uniqueness of the product conferred to it by the embedded knowledge capital, but also on the substitution possibilities with other products that exist on the market.

[1] A non-tangible prerogative to perform an action or acquire a benefit and to permit or deny others the right to perform the same action or to acquire the same benefit (United States Patent and Trademark Office).

In addition to the industrial organisation considerations discussed above, we can complete the general equilibrium view by considering international trade in the presence of product differentiation, economies of scale and knowledge capital.

The traditional comparative advantage argument explains international trade patterns based on relative differences in factor endowments and technology. The Heckscher-Ohlin-Samuelson (HOS) model provides the theoretical framework that identifies labor and physical capital as primary sources of comparative advantage. In this paper we add knowledge capital as a determinant of patterns of international trade. We specify a Chamberlin-Heckscher-Ohlin type computable general equilibrium framework that explores the impacts of endowment with knowledge capital on product differentiation and comparative advantage.

Despite theoretical advance (reviewed in the section below), empirical analysis concerning knowledge capital is scarce to non-existent. There is nonetheless a body of empirical literature that concerns more comprehensive concepts such as technological change, innovation, spillovers or research and development.

The objective of this paper is to provide an empirical policy analysis of the impact of knowledge capital on product differentiation, market structure and trade flows. In contradiction with other studies that proxy knowledge capital with R&D expenditures, we measure knowledge capital directly based on firm-level data and specify a Chamberlin-Heckscher-Ohlin type computable general equilibrium model with parameters and value added shares estimated in an econometric framework that is consistent with the assumptions of the CGE model.

The first part of this paper describes the econometric estimation carried out in order to introduce knowledge capital in a computable general equilibrium framework, more specifically the comparative static GTAP model. We estimate a transcendental logarithmic (translog) production function with three inputs: labor, physical capital and knowledge capital using Seemingly Unrelated Regression techniques. The objective of the estimation is to provide parameters (elasticities of substitution between inputs) and value added shares estimated in a framework consistent with the assumptions of the CGE model. The dataset used in the econometric estimation has been built combining data from Standard and Poor's Compustat North America (for US and Canadian firms) and Compustat Global Fundamentals (for other 86 countries) and it contains a measure of knowledge capital as described in the paragraph above.

The second part presents the comparative static GTAP model with knowledge capital and increasing returns. Knowledge capital is defined as a factor of production in addition to labour and capital. The econometric estimation allows us to break down value added (based on fitted shares) and to define substitution possibilities between factors that now include knowledge capital. Based on Romer's specification knowledge is non-rival and partially excludable and it is modelled as fixed cost to production. We vary the degree of monopoly power conferred to the owner of the knowledge capital and implement two versions of the GTAP model with knowledge capital:

- Perfect competition with homogeneous products and constant returns: knowledge capital as an input in the production of a good does not give rise to a basis for product differentiation or market power;
- Chamberlinian monopolistic competition: each firm that uses knowledge capital as an input is able to differentiate its output and is conferred some monopoly power; entry drives monopoly profits to zero.

2 Literature review

Knowledge capital as a factor distinct from the traditional ones of labour, physical capital, land and natural resources has materialised over the years in mainstream economic theory.

Initially, knowledge capital has been identified as a part of the endogenous growth literature with the seminal articles of Solow (1956, 1957) as a part of an aggregate growth model with exogenous technical change. Subsequently, Romer (1986, 1990) identifies knowledge as a separate input in production with increasing marginal productivity. Later, knowledge capital became a part of theoretical trade literature with Grossman and Helpman (1991, 1990) that examine the link between trade regimes and knowledge spillovers. The multinational firms theory as pioneered by Markusen (2004), Carr et al. (2001), Markusen and Maskus (2001) describes knowledge based assets as the main reason firms undertake foreign direct investment.

On the other hand, product differentiation and increasing returns has been a popular topics of the economic literature the starting with Chamberlin's (1933) theory of monopolistic competition. Dixit and Stiglitz (1977) in their seminal article first formulated a Chamberlinian monopolistic competition model that captured the main aspects of Chamberlin's model. Later, monopolistic competition has been introduced to the mainstream theoretical trade literature with Krugman (1980), Ethier (1982), Grossman (1994).

Despite theoretical advance, empirical analysis concerning knowledge capital is scarce to non-existent. Most economic models tend to ignore knowledge capital as factor or include it in the residual. There is nonetheless a considerable body of empirical literature that concerns more comprehensive concepts such as technological change, innovation, spillovers or research and development. Data limitations in quantifying an intangible resource such as knowledge has forced applied researchers to approximate knowledge capital with R&D expenditures. For instance, studies such as Coe and Helpman (1995), Bayoumi et al. (1999), Lejour and Nahuis (2005) examine the linkages between technological change, openness and R&D expenditures.

As emphasised by Freeman (1994) "it is often unsatisfactory to use R&D expenditure statistics as a surrogate for all those activities at the level of the firm which are directed towards knowledge accumulation, technical change and innovation. We have measures of capital-intensity, energy-intensity, but not of knowledge intensity."

There are several applied CGE models that include some specification of product differentiation and imperfect competition. Examples of such models include Harris (1984) with his pioneering study that describes the first applied general equilibrium model of the Canadian economy with imperfect competition, Cox and Harris (1985), Cory and Horridge (1985), Hertel (1992) the SALTER model, Brown (1994) the Michigan model, Abayasiri-Silva and Horridge (1996) the ORANI model, Swaminathan and Hertel (1996) the GTAP model, Harrison et al. (1997), Bchir et al. (2002) the MIRAGE model. In these models increasing returns are motivated with the presence of fixed production costs, nevertheless fixed costs are not linked to any specific factor.

The purpose of this paper is to conceptualise knowledge capital and to fill the gap in the empirical literature. The next two sections describe the source data and the econometric estimation carried out to introduce knowledge capital in the comparative static GTAP model.

3 Description of the data

The dataset used in the econometric estimation has been built combining data from Standard&Poor's Compustat North America (for US and Canadian firms) and Compustat Global Fundamentals (for other 86 countries). The resulting dataset describes 6,341 publicly traded individual firms for 2004.

Summary statistics for the main variables used in the regressions are presented in Table (1). Output is measured as net sales or value added, physical capital is listed as Compustat item "Property, plant and equipment-Total (net)", labor is "Staff expense-Total" and knowledge capital is approximated by Compustat variable "Intangible assets-Total".

Intangibles assets in the Compustat database are a measure of the value of patents, copyrights, trademarks and trade names, blueprints or building designs, licenses, operating rights, covenants not to compete, design costs, subscription lists, distribution rights and agreements, easements, engineering drawings, excess of cost or premium on acquisition, franchise costs, goodwill (except on unconsolidated subsidiaries), import quotas, lease hold costs, organisational expense, transportation company route acquisition costs (Zambon, 2003).

For the purposes of this paper we specify a sectoral/regional aggregation that is later linked with the aggregation used in the CGE model. Accordingly, we define three sectors (agriculture, manufacturing, services) and three regions (high, middle and low income).

Figure (1) presents bivariate scatter plots of output versus knowledge capital represented for each region-sector pair. In each case we find significant and positive relationship, suggesting that output increases with knowledge capital. On the overall, the magnitude of the response of output to changes in knowledge capital is bigger in high income countries and the services sector.

To measure the importance of knowledge capital in production, boxplots of knowledge capital as a share of value added are provided in Figure (2). A preliminary analysis reveals that there is a distinct pattern that emerges in all three of these boxplots: among sectors, on average knowledge capital plays the most important role in the production services, while across regions on average knowledge capital plays represents a more significant share of value added in high income countries (HIC) compared to middle and low income countries. In addition, the length of the interquartile box for high income countries also points toward the significance of knowledge capital in production.

4 Econometric estimation

Consider the production function of the form:

$$Y = f(X; i, r) \tag{1}$$

where Y is output and X is a vector of inputs comprised of physical capital (C), labour (L) and knowledge capital (K). In addition to inputs, the production function may also vary with differences in the industry (i), country (r) in which the firm operates.

Suppose the production function (1) is approximated by a translog form:

$$\ln Y = \alpha_0 + \sum_i \alpha_i \ln X_i + 1/2 \sum_i \sum_j \beta_{ij} \ln X_i \ln X_j, \quad i, j = K, C, L \tag{2}$$

The translog (or transcendental logarithmic) production function (Christensen et al., 1973) specified above is an appealing functional form mainly due to its empirical tractability and because of its properties as a flexible functional form. It has been often used to examine the substitution between factors of production (Griliches and Ringstad, 1971; Berndt and Christensen, 1973; Brynjolfsson and Hitt, 1995; Dewan and Min, 1997), relative productive efficiency (Lau and Yotopoulos, 1971; Kim, 1992) and other methodological issues (Tzouvelekas, 2000).

Given its flexible nature, the translog (2) imposes no *a priori* restrictions on the structure of production, the value of the elasticities of substitution or returns to scale. Our objective is to provide parameters estimated in a framework consistent with the assumptions of the CGE model these parameters will be feeding. As a result, we impose restrictions that yield a production function that respects the assumptions of homogeneity, constant returns to scale and symmetry. This implies that the following restrictions on the parameters of the translog are imposed:

$$\sum_i \alpha_i = 1; \quad \sum_j \beta_{ij} = 0; \quad \beta_{ij} = \beta_{ji} (i \neq j) \tag{3}$$

One may denote the marginal product of knowledge capital as:

$$f_K = \frac{Y}{X_K} (\alpha_K + \sum_j \beta_{Kj} \ln X_j), \quad j = K, C, L \tag{4}$$

Assuming that both input and output markets are competitive, the first order conditions of profit maximization are:

$$f_i = p_i, \quad i = K, C, L \tag{5}$$

where p_i is the price of the i^{th} input relative to the price of output. Substituting (5) into (4) results in the equality:

$$\frac{\partial Y}{\partial X_i}\frac{X_i}{Y} = \frac{\partial \ln Y}{\partial \ln X_i} = \frac{p_i X_i}{Y}, \quad i = K, C, L \tag{6}$$

Thus, differentiating the translog production function (2) with respect to input i results in the cost share equation:

$$S_i = \alpha_i + \sum_j \beta_{ij} \ln X_j, \quad i = K, C, L \tag{7}$$

As shown by Kim (1992), the translog production function could not be efficiently estimated without considering the cost share equations that embed important information about the structure of production, i.e. the first order conditions that approximate inverse input demand equations. As a result, the translog parameters should be determined by jointly estimating (2) and (7).

This framework allows us to analyze input substitution possibilities where the elasticities vary with the values of relative input shares. We calculate Allen partial elasticities of subsitution (Allen, 1971) directly from the production function:

$$\sigma_{ij} = \sum_i \frac{f_i X_i}{X_i X_j} \frac{|\bar{F_{ij}}|}{|\bar{F}|} \tag{8}$$

where $\bar{F}$ is the determinant of the bordered Hessian matrix and $\bar{F_{ij}}$ is the cofactor in F_{ij} of the bordered Hessian (Berndt and Christensen, 1973; Humphrey and Moroney, 1975).

In the three-input translog specified above further yields elasticities defined as:

$$\sigma_{ij} = \frac{|\bar{G_{ij}}|}{|\bar{G}|} \tag{9}$$

where $|\bar{G}|$ is the determinant of

$$G = \begin{bmatrix} 0 & S_K & S_C & S_L \\ S_K & \beta_{KK} + S_K^2 - S_K & \beta_{KC} + S_K S_C & \beta_{KL} + S_K S_L \\ S_C & \beta_{KC} + S_K S_C & \beta_{CC} + S_C^2 - S_C & \beta_{CL} + S_C S_L \\ S_L & \beta_{KL} + S_K S_L & \beta_{CL} + S_C S_L & \beta_{LL} + S_L^2 - S_L \end{bmatrix}$$

The set of equations consisting of the production function and two of the cost share[2] equations were estimated using a SUR (seemingly unrelated regression) system using R package systemfit (Henningsen and Hamann, 2007).

Results of the estimation are reported in Table (2) in the Appendix. In Table (3) we report the estimated Allen partial elasticities of substitution both for the overall sample and separately for each region/sector pair of our aggregation. For the overall sample, we find significant substitution possibilities between labor and knowledge capital ($\sigma_{KL} = 1.63$), and slightly lower between physical capital and knowledge capital ($\sigma_{KC} = 0.19$) and labor and physical capital ($\sigma_{LC} = 0.61$). Elasticities estimated for region/sector pairs provide interesting insights with respect to substitution possibilities in different sectors and regions.

5 GTAP with knowledge capital

The standard GTAP model is a multi-region, multi-sector comparative static CGE model that follows the theoretical structure of most standard CGE models with perfectly competitive input and output markets and constant returns to scale in production (for a detailed description see Hertel (1999)).

In the standard version the representative consumer allocates income among private consumption, government consumption and savings (Cobb-Douglas). Demand for private goods is governed by Constant Difference of Elasticities (CDE) that implies a non-homothetic character of the private consumption bundle. The production side is described by Leontief technology with fixed production coefficients between primary and intermediate inputs. Primary factors are defined to be mobile across sectors, their degree of mobility being described by the Constant Elasticity of Transformation function.

The next subsections describe how the standard GTAP model has been extended to include the explicit modeling of knowledge capital. The econometric estimation

[2]Factor shares sum to unity by construction.

described above allows us to split total value added into three components (labor, physical capital and knowledge capital) and to define substitution possibilities between these factors. We implement two versions of the GTAP model with knowledge capital: in the first version, knowledge capital is a factor input in production, but it does not give rise to a basis for product differentiation or market power, i.e. the model is defined by perfect competition and constant returns to scale; the second version is governed Chamberlinian monopolistic competition: each firm that uses knowledge capital as an input is able to differentiate its output and is conferred monopolistic power; entry drives monopoly profits to zero.

5.1 Perfect competition with knowledge capital

The starting framework has been the current version (v6.2) of the comparative static GTAP model. In this version of the model knowledge capital is specified as a value added input into production in addition to the traditional labour and capital. Knowledge capital is described as imperfectly immobile across sectors (with sector specific return to knowledge), and immobile internationally (there is no international market of knowledge). At this initial stage, the supply of knowledge capital is exogenous.

5.2 Chamberlinian monopolistic competition

In this version, our goal is to introduce monopolistic competition and product differentiation into the current version of the GTAP model. We build on Swaminathan and Hertel (1996) that describes a version of the GTAP model with monopolistic competition. Nevertheless, our specification differs significantly in two main aspects:

- Armington preferences are kept and complemented with an additional Krugman love of variety nest where the consumer is differentiates between horizontally differentiated varieties described by CES preferences;

- Fixed costs are associated only with knowledge capital that is described to be an input into production and that gives rise to economies of scale.

All equations describing the monopolistic competition extension are listed in the Appendix as implemented in the model in linearized percent change form.

5.2.1 Supply side

Following Dixit and Stiglitz (1977) and Krugman (1979) we specify a market in which each industry defined by monopolistic competition consists of N identical firms, each producing a different variety using the same technology and cost structure (symmetry assumption). Increasing returns to production arise from fixed costs associated with knowledge capital. The profit maximising firms set price above marginal cost according to the Lerner formula that describes markup behaviour:

$$P_{irs} = MC_{ir}/(1 + PE_{irs}) \tag{10}$$

where PE_{irs} is the perceived elasticity of demand of firm i in region r in market s; MC_{ir} is marginal cost of variety i in region r. Following the Chamberlinian large group hypothesis we assume away from strategic interactions and find that markup γ is constant as the elasticity faced by the firm reduces to the Dixit-Stiglitz elasticity of substitution between varieties σ_{irs}.

$$\gamma_{irs} = \frac{P_{irs}}{MC_{ir}} = \frac{\sigma_{irs}}{\sigma_{irs} - 1} \tag{11}$$

Total production costs are composed of fixed and variable costs, where fixed costs are associated with costs with knowledge capital as an input into the production of the differentiated good. This is an important difference with respect to the specification of fixed costs in the literature that assumes fixed costs to be a constant share of total or value added costs.

$$TC_{ir} = VC_{ir} + FC_{ir} \tag{12}$$

$$FC_{ir} = Knowledgecapital_{ir} \tag{13}$$

With free entry and exit (long run equilibrium), the endogenous number of firms is determined by the zero profit condition. Due to the symmetry assumption, industry output is defined as the product between the number of firms and the output per firm in the industry. Output per firm adjusts in order to equalise the firm's fixed costs with the excess sales revenue over variable costs.

$$Y_{i,r} = n_{i,r} \cdot y_{i,r} \tag{14}$$

For a graphical representation of the supply with extended with product differentiation see Figure (3) in the Appendix.

5.2.2 Demand side

At the cornerstone of most applied CGE models lies Armington's (1969) seminal paper that defines varieties to be differentiated only by the country of origin and thus sets the number of varieties to be fixed. The love of variety models specified in the spirit of Dixit and Stiglitz (1977) and Krugman (1980) allow for an endogenous number of varieties and an associated variation in consumers' utility. Here we specify a more general CES preference structure that complements the traditional Armington preferences at an additional level of love of variety CES nesting. The representative household's subutility from consuming a good is positively related with the number of varieties of that good available:

$$U = \sum (n \cdot Q^{\sigma-1/\sigma})^{\sigma/\sigma-1} \tag{15}$$

Further, we can describe an associated unit expenditure function that increases with the price of individual varieties but decreases with the number of varieties, i.e. given prices and expenditure, the representative household's utility increases with the number of varieties available.

$$P = (\sum n \cdot P_n^{\sigma-1})^{1/1-\sigma} \tag{16}$$

The new demand side extended with product differentiation and the love of variety assumption is graphically depicted in Figure (4) in the Appendix.

6 Policy application

The model is calibrated on the GDyn 7 database with 2004 as the base year. The aggregation is a 3x3 specifically created to match the level of aggregation of the econometric estimation. Regions have been aggregated into 3 composite ones into HIC (high income countries), MIC (middle income countries) and LIC (low income countries). The sectoral aggregation contains 3 sectors: agriculture, manufacturing and services.

In the first version of the model with perfect competition all sectors are perfectly competitive, while in the monopolistic competition version manufacturing and services are defined by increasing returns to scale, while agriculture is assumed to be perfectly competitive.

The simulation carried out here is of stylized nature aimed to illustrate features of the GTAP model with monopolistic competition and knowledge capital and to highlight differences in results when compared to the perfectly competitive model. We carry out a trade policy liberalization experiment that entails the elimination of barriers to trade in the manufacturing sector in all regions of the model.

Selective results with respect to variables of concern are reported in Table (4) in percent change.

In the GTAP model with monopolistic competition, the output per firm of the imperfectly competitive sectors is determined by the relative changes between the average total cost at constant scale and the average variable cost. As the change in average total cost at constant scale is bigger than the change in average variable cost, output per firm must increase.

As a result of the liberalization of the manufacturing sector, industry output in the monopolistically competitive sectors expands. The increase in output per firm in both manufacturing and services however exceeds the increase of total industry output in these sectors, and thus firms are forced to exit the industry. For instance, we find that output per firm in manufacturing in LIC countries increases by 6.85% relative to the manufacturing industry output that expands by only 1.61%. As a results, manufacturing firms in LIC countries exit the industry and the associated number of manufacturing varieties decreases by -4.9%. The same mechanisms operate with respect to other regions and monopolistically competitive sectors in the model. Real GDP in MIC and LIC increases as a result of a more efficient allocation of resources.

When comparing the impact of trade liberalization of the GTAP model with perfect competition and that with monopolistic competition, our findings are in line with that emphasized by the mainstream applied trade policy literature. Accordingly, it has been pointed out that general equilibrium analysis that does not incorporates scale economies and imperfect competition tends to understate the impact of trade liberalization. Most notably, Harris (1984) found that static long run gains of trade liberalization on the Canadian economy were 8-12% larger in a model that incorporated imperfect competition. Our results confirm this finding, as utility gains and increase in real GDP are found to be systematically higher in the GTAP model with monopolistic competition.

7 Conclusion

This paper is aimed at developing original research in quantifying knowledge capital and analyzing knowledge capital based product differentiation in the context of a Chamberlin-Heckscher-Ohlin type computable general equilibrium model.

Compared to other studies that proxy knowledge capital with R&D expenditures, we measure knowledge capital directly based on firm-level data. This data allows us to carry out econometric estimation of parameters (Allen elasticities of substitution) and value added shares that feed the computable general equilibrium model. We implement two versions of the comparative static GTAP model with knowledge capital: in the first version, knowledge capital is an input in production but does not give rise to a basis for product differentiation or market power; the second version is governed Chamberlinian monopolistic competition, i.e. each firm that uses knowledge capital as an input is able to differentiate its output and is conferred monopolistic power. A stylized trade liberalization scenario highlights mechanism of these models and further re-iterates findings of previous trade literature according to which in the absence of imperfect competition features CGE models tend to understate the impact of trade liberalization.

8 Appendix: Monopolistic competition extension in GTAP

Private consumption

$$
\begin{aligned}
qpdv_{ir} &= qpd_{ir} + n_{ir} + \sigma_i \cdot (ppd_{ir} - ppdv_{ir}) \\
qpmv_{ir} &= qpm_{ir} + n_{ir} + \sigma_i \cdot (ppm_{ir} - ppmv_{ir}) \\
ppdv_{ir} &= ppd_{ir} - [1/(\sigma_i - 1)] \cdot n_{ir} \\
ppmv_{ir} &= ppm_{ir} - [1/(\sigma_i - 1)] \cdot n_{ir}
\end{aligned}
$$

Government consumption

$$
\begin{aligned}
qgdv_{ir} &= qgd_{ir} + n_{ir} + \sigma_i \cdot (pgd_{ir} - pgdv_{ir}) \\
qgmv_{ir} &= qgm_{ir} + n_{ir} + \sigma_i \cdot (pgm_{ir} - pgmv_{ir}) \\
pgdv_{ir} &= pgd_{ir} - [1/(\sigma_i - 1)] \cdot n_{ir} \\
pgmv_{ir} &= pgm_{ir} - [1/(\sigma_i - 1)] \cdot n_{ir}
\end{aligned}
$$

Production

$$
\begin{aligned}
qfdv_{ijr} &= qfd_{ijr} + n_{ir} - \sigma_i \cdot (pfdv_{ijr} - pfd_{ijr}) \\
qfmv_{ijr} &= qfm_{ijr} + n_{ir} - \sigma_i \cdot (pfmv_{ijr} - pfm_{ijr}) \\
pfdv_{ijr} &= pfd_{ijr} - [1/(\sigma_i - 1)] \cdot n_{ir} \\
pfmv_{ijr} &= pfm_{ijr} - [1/(\sigma_i - 1)] \cdot n_{ir} \\
qvaf_{ir} &= n_{ir} + ao_{ir} \\
qva_{ir} &= VAV_{ir}/VA_{ir} \cdot qvav_{ir} + VAF_{ir}/VA_{ir} \cdot qvaf_{ir} \\
qvav_{ir} &= qo_{ir} \\
ps_{ir} &= avc_{ir} + mkupslack_{ir} \\
qo_{ir} &= qof_{ir} + n_{ir}
\end{aligned}
$$

$$VC_{ir} \cdot avc_{ir} = \sum_i VFA_{ijr} \cdot pf_{ijr} + VAV_{ir} \cdot pva_{ir}$$

$$VOA_{ir} \cdot scatc_{ir} = \sum_i VFA_{ijr} \cdot pf_{ijr} + VA_{ir} \cdot pva_{ir}$$

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Table 1: Descriptive statistics

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Y	0.00	61.45	290.60	57740.00	1717.00	132000000
K	0.00	2.41	15.90	2524.00	113.90	5411000
L	0.00	11.34	46.81	5704.00	257.10	11940000
C	0.00	10.19	63.46	35330.00	497.70	75290000
S_K	0.00	0.03	0.11	0.20	0.31	1.00
S_L	0.00	0.16	0.33	0.35	0.51	1.00
S_C	0.00	0.20	0.43	0.45	0.69	1.00

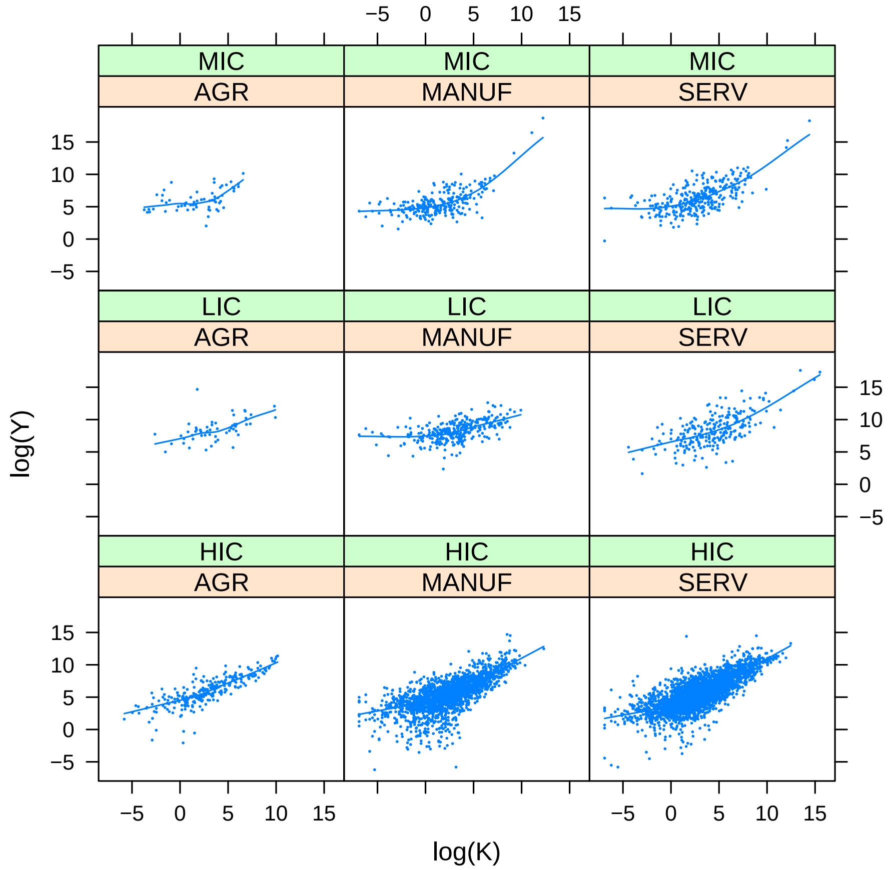
Source: Author's calculations based on Compustat data

Table 2: Overall regression results

	Estimate	Std. Error	t value	Pr(>|t|)
intercept	1.70	0.01	140.75	0.00
α_K	0.24	0.00	92.06	0.00
α_L	0.42	0.00	141.88	0.00
α_C	0.34	0.00	88.93	0.00
β_{KK}	0.03	0.00	80.27	0.00
β_{LL}	0.02	0.00	44.59	0.00
β_{CC}	0.13	0.00	155.18	0.00
β_{KL}	0.04	0.00	98.30	0.00
β_{KC}	−0.07	0.00	−191.75	0.00
β_{LC}	−0.06	0.00	−107.06	0.00

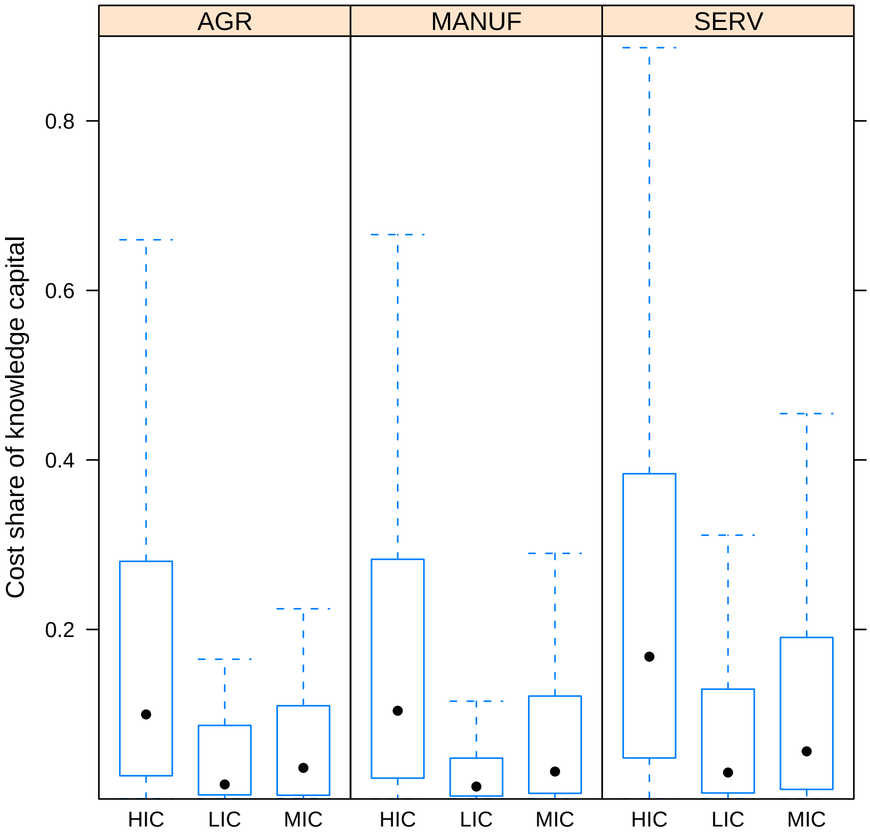
Source: Regression estimates

Figure 1: Relationship Between log(Y) and log(K) by region-sector pairs



Source: Author's calculations based on Compustat data

Figure 2: Boxplot of the Cost Share of Knowledge Capital



Source: Author's calculations based on Compustat data

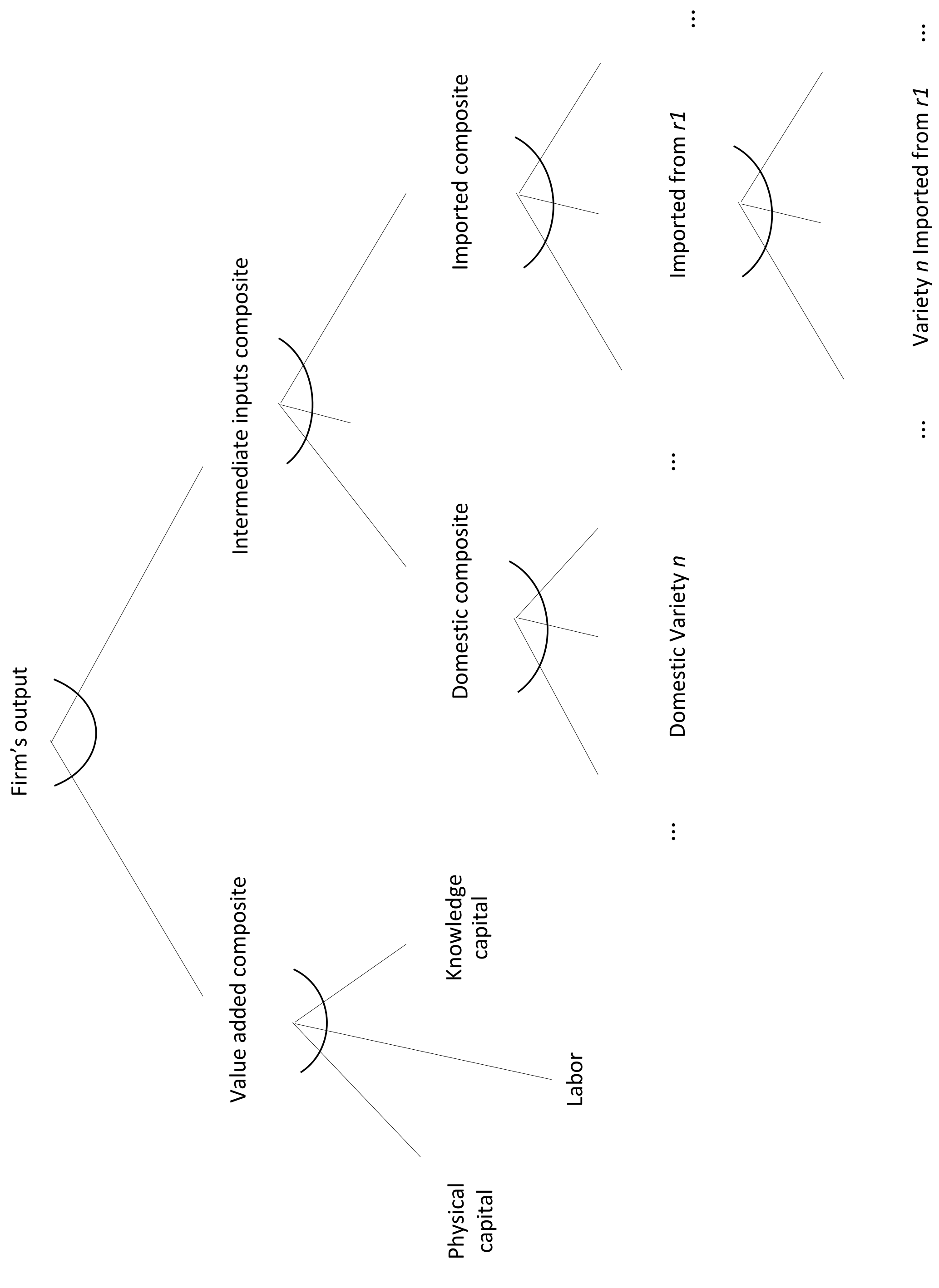


Figure 3: Supply with product differentiation

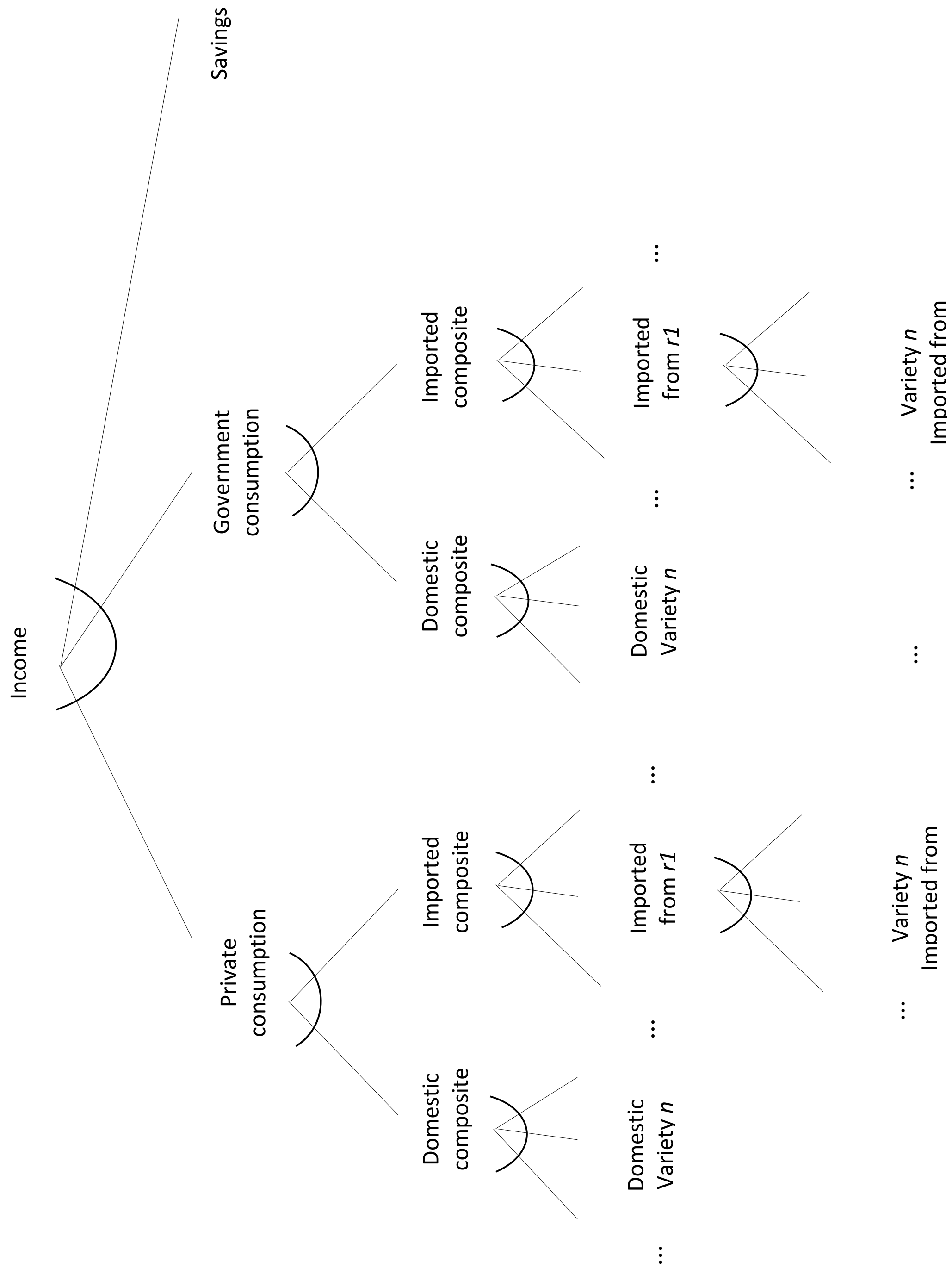


Figure 4: Demand with product differentiation

Table 3: Estimated Allen partial elasticities of substitution, translog CRTS 3-input function

	Overall	AGR HIC	AGR MIC	AGR LIC	MANUF HIC	MANUF MIC	MANUF LIC	SERV HIC	SERV MIC	SERV LIC
σ_{KL}	1.63	2.23	5.14	5.49	1.71	4.17	5.37	1.44	1.76	2.84
σ_{KC}	0.19	0.13	0.16	−0.58	−0.01	−0.08	−0.57	0.19	0.29	0.02
σ_{LC}	0.61	0.50	0.38	0.51	0.57	0.49	0.66	0.57	0.69	0.59
σ_{KK}	−3.31	−3.67	−7.22	−9.06	−3.52	−7.34	−10.14	−2.61	−3.76	−5.34
σ_{LL}	−1.70	−2.58	−6.97	−3.89	−1.42	−4.16	−4.27	−1.41	−3.13	−3.39
σ_{CC}	−0.57	−0.28	−0.07	−0.08	−0.55	−0.11	−0.12	−0.74	−0.32	−0.19

Table 4: Simulation results

	Perfect competition			Monop. competition		
	HIC	MIC	LIC	HIC	MIC	LIC
Industry output						
AGR	1.39	-1.87	-2.25	1.47	-1.73	-2.05
MANUF	-0.04	0.64	1.20	0.05	0.85	1.61
SERV	-0.06	0.10	0.53	0.00	0.41	1.17
Output per firm						
MANUF	...	...	...	0.70	3.54	6.85
SERV	...	...	...	0.19	1.86	4.02
Number of varieties						
MANUF	...	...	...	-0.64	-2.60	-4.90
SERV	...	...	...	-0.19	-1.42	-2.74
Average variable cost						
MANUF	...	...	...	-2.19	1.90	1.77
SERV	...	...	...	-1.70	3.55	4.53
Avr. cost at constant scale						
MANUF	...	...	...	-2.15	1.95	1.87
SERV	...	...	...	-1.67	3.75	4.99
Private consumption						
AGR	-0.72	0.93	1.34	-0.67	1.08	1.66
MANUF	0.18	2.43	3.10	0.29	2.69	3.60
SERV	-0.66	1.39	2.07	-0.58	1.72	2.67
Real GDP	-0.11	0.30	0.81	-0.04	0.56	1.30
Utility	-0.48	1.66	1.94	-0.40	1.94	2.45