Domestic Value Chains and Development

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1 Introduction

Input-Output analysis has been a field of economics for long enough that one might think it would have fully explored the correlations of sectorial intermediate input linkages and the level of development. Indeed, in the early days of Leontief (1951, 1963) and Hirschman (1958), a series of promising research papers was devoted to finding out whether intermediate input use (or, rather, the lack thereof) was a proximate cause of low productivity and underdevelopment. This idea became known as the *linkage hypothesis*, and spurred some empirical work (Chenery and Watanabe, 1958, Yotopoulos and Nugent, 1973, Chenery, Robinson and Syrquin, 1986, and several others). While these were valiant efforts, the lack of suitable cross-country data meant that comparisons were typically limited to a small set of developed economies.

This chapter revisits the question on the relationship between vertical linkages and development using data that have been constructed in the recent decades, and that allows us to compare a much larger cross-section of countries at a finer level of disaggregation. I document that (1) vertical linkages across sectors are not the same across countries, (2) that they are correlated with the level of development, and (3), that the strength of linkages is varying in a systematic way to suggest that they are related to factors that affect the firm's sourcing decision. I then propose a model that allows us to think about these factors and rationalize the cross-country variation in vertical linkages. In this model, the firm's production activities are imperfect complements to each other, and it needs to decide for each of these activities whether to perform it in-house or to outsource it. The input-output share arises as an endogenous outcome of the relative costs of in-house production and outsourcing, and of the relative costs of different baskets of activities. Even though the model is written with a quantitative application in mind, such an endeavour would require solving several tough identification problems (such as distinguishing frictions to outsourcing from low supplier productivity), which we will not tackle in this chapter. Nevertheless, the model yields fairly simple expressions for welfare, and this allows us to get a sense for how much the aggregate economy is affected when there are distortions to the firm's sourcing decision and hence to the strength of vertical linkages.

The literature on linkages and development is vast. Most theoretical work focuses on why linkages matter for development.[1] In this chapter, I am more concerned to explain why linkages differ across countries in the first place. Hence, I assume neither strong complementarities nor increasing returns to scale, even though either may well be important. It it my hope that through understanding linkage formation, we will understand the firm's dependence on intermediate inputs, and that this in turn sheds light on the aggregate economy's reliance on intermediate inputs.

Before moving on, I would like to highlight some recent work that is similar in spirit to this chapter. Jones (2013) re-opened the debate on input-output relationships and misallocation by showing how they are theoretically linked. He compares the input-output tables of OECD economies, but does not further elaborate on the differences. The recent paper by Bartelme and Gorodnichenko (2015) emphasizes very clearly the positive empirical relationship between vertical linkages and aggregate total factor productivity.[2] To the extent of my knowledge, the only paper that attempts to tackle the fundamental identification problem (whether differences in input-output relationships are shaped by sectoral productivity differences or by distortions) is Boehm (2015). In that paper I show that in countries with poor contract enforcement institutions, input-output relationships are weaker when parties rely more heavily on formal contract enforcement (and controlling for sectoral productivity levels). This shows that institutions and the in-house production/outsourcing margin are reflected in input-output structures, and that the resulting amount of factor misallocation leads to large welfare reductions.

The chapter proceeds as follows. First, I describe the data used for the empirical exercise and define the variables that I describe. Then, I establish that input-ouput shares vary across countries, how much they vary (by sector-pair), and that they vary systematically with the level of development. I then describe a model that explains the sources of this variation, and finally discuss the sources of aggregate productivity loss in it.

2 Data

The main dataset used in this chapter is the set of input-output tables from the Global Trade Analysis Project (GTAP, Narayanan et al. (2012)). I use this dataset because of its vast coverage: GTAP contains input output tables for 109 countries, including a number of developing countries in Sub-Saharan Africa for which industrial statistics are typically scarce. Secondly, the tables have been harmonized using a common methodology in order to for them to be used in a single model.This means that the resulting tables should be comparable across countries–which is indeed the point of this chapter–but also means that the authors certainly had to

[1] There are two big literatures. One emphasizes the importance of linkages through the possibility of underdevelopment traps arising as multiple equilibria in models with increasing returns to scale (Murphy et al., 1989, Rodriguez-Clare, 1996, Ciccone, 2003), and is therefore closer to the Hirschman's linkage hypothesis. The other one emphasizes the complementarity between inputs (Kremer, 1993, Hausman and Hidalgo, 2009, Jones, 2010).

[2] Fadinger et al. (2015) also emphasize the cross-country variation in input-output tables, but take the view that input-output shares are exogenous technological parameters. Grobovsek (2015) conducts a development accounting exercise with country-specific input-output shares.

impute some data that are missing, or rely on strong assumptions in order to construct the necessary level of detail. The reader should have this caveat in mind throughout the presentation of the empirical results. One might speculate that data imputations may mean that the true cross-country variation in input-output tables is larger than what we observe in the constructed tables, but this is but one possible result.

The original dataset provides input-output data for 57 sectors in each country. I aggregate all agriculture-related industries up into one sector that covers agriculture, forestry, and fishing, and combine oil and gas into one sector. The resulting 35 sectors correspond roughly to two-digit ISIC categories. I exclude the countries on the Arabian peninsula (Saudi Arabia, Bahrain, Oman, Kuwait, UAE, Qatar) due to their heavy specialization on oil. Furthermore, I discard the input output table of Mongolia, which is clearly wrong. Most of the tables are for years in the early 2000s, although some are slightly older. See the GTAP documentation (Narayanan et al., 2012) for the source of each country's input-output table.

The GTAP input-output tables contain separate tables for domestically sourced and imported intermediate inputs. The main focus of my analysis will be on overall intermediate input expenditure shares, i.e. the sum of domestic and imported intermediates. I will report results whenever they are very different when using only domestically sourced intermediate inputs. More precisely, the main object of interest in my study is the expenditure of a sector n on intermediate inputs from sector i, as a fraction of gross output of sector n. In input-output analysis these shares are called the empirical technical input coefficients. I will denote them by M_{ni}/X_n, and will refer to them as the "intermediate input expenditure share", or sometimes "input-output share". In line with the expression from my model further below, I will denote the input-output shares on domestically sourced intermediate inputs by X_{ni}/X_n.

3 The cross-country variation in input-output shares

3.1 Input-output shares do vary a lot across countries

The literature in input-output analysis typically assumes that the input-output shares ("technical coefficients") are constant and reflect the technological aspects of the sector's production process (see, for example, Miller and Blair (2009)). The assumption is that $20,000 of output of the car industry require, say, $500 of inputs from the tyre industry, $2000 of inputs from the electronics industry, and $1000 of inputs from the R&D industry. While assumptions like these make it relatively easy to study the spread of sectoral shocks throughout the economy, the flaws are apparent from the example. What if the price of tyres declines, but the quantity of tyres required to produce a car remains unchanged? Most likely the input-output share of cars on tyres will go down.[3] What if high-tech electronics components are prohibitively expensive

[3] In fact, much of Leontief's original work was formulated based on fixed *quantity* shares, as opposed to value shares (see, e.g. Leontief 1951). This, however, has proven relatively unpopular for standard (i.e. except environment and energy) applications since it would require measurement of prices. Data for input-output tables come almost exclusively in values, i.e. prices times quantities.

or unavailable, so that car producers decide to substitute away from electronics inputs, and produce low-tech cars? And finally, the decision wheter or not to outsource services such as R&D to another company will decide whether they are priced and hence show up in the company's accounts under consumption of intermediates.[4] All these considerations would suggest that input-output shares are not predetermined parameters, but are the outcome of agents' decisions.

Let's start our empirical investigation by establishing that input-output shares are far from constant across countries. We do this by looking at the fraction of the variance of two-digit by two-digit input-output shares M_{ni}^c/X_n^c that is explained by sector-pair dummies, i.e. the R^2 of a regression

$$M_{ni}^c/X_n^c = \alpha_{ni} + \varepsilon_{ni}^c. \tag{1}$$

Here, n is the downstream (buying) sector, i is the upstream (selling) sector, and c is the country. Table 1 shows the R^2 from regression (1) along with summary statistics. The sector-pair dummies explain less than half of the total variation in the level or log of input-output shares. The independent variables together explain around 5% more of the variation in the log input-output shares when one includes country dummies as well. If one includes upstream sector × country fixed effects, the fraction of explained variation rises to 54% for the level and 65% of the log input share. Nevertheless, a lot of the variation remains unexplained. Some of it will certainly be due to mismeasurement of economic aggregates. But, on the whole, the table challenges the standard view that input-output matrices directly show a set of immutable parameters; indeed, in some countries they are systematically higher than in others.

Table 1: Summary statistics and variance decomposition for input-output shares.

	M_{ni}^c/X_n^c	X_{ni}^c/X_n^c	$\log(M_{ni}^c/X_n^c)$	$\log(X_{ni}^c/X_n^c)$
Sample Size	124,950	124,950	124,950	124,950
Mean	.017	.011	-7.34	-8.16
Std. Dev.	.056	.041	4.17	4.55
R^2 in (1)	.46	.33	.46	.48
R^2 in (1), with α_c	.46	.34	.52	.55
R^2 in (1), with α_{ci}	.54	.46	.65	.70

Note: Table shows summary statistics for expenditure shares on intermediate inputs at the two-digit sector-pair-country level, as well as the R^2 of estimating (1) and specifications with additional fixed effects using ordinary least squares. Source: author's calculations using GTAP data.

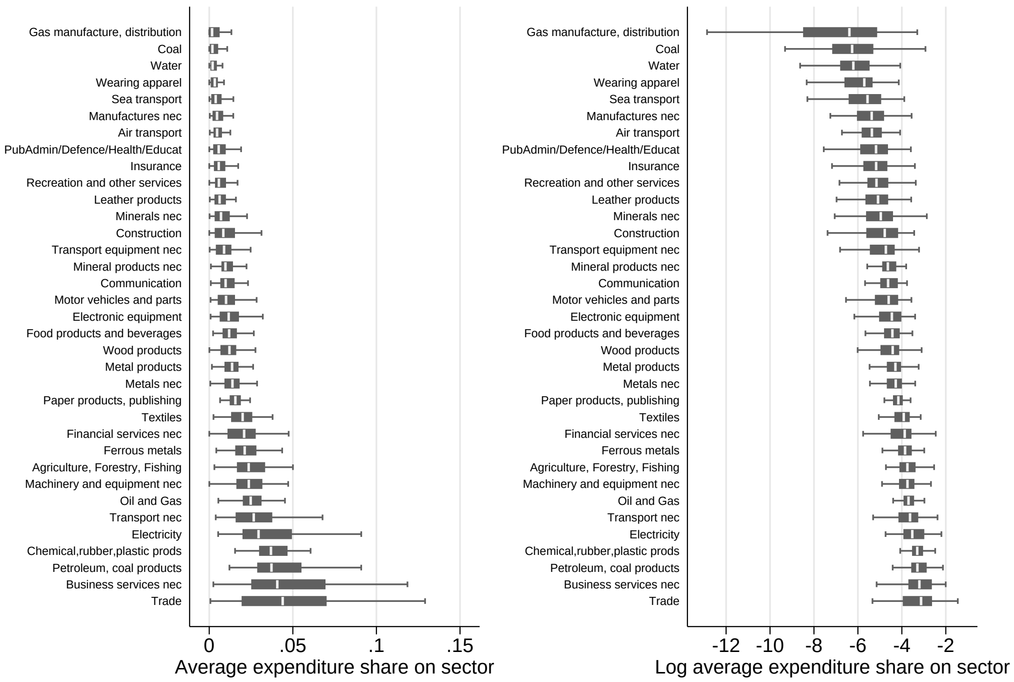
[4] Note that the input-output tables in my sample are based on the 1993 system of national accounts, which treats R&D as consumption, and not capital formation.

3.2 Some input-output shares vary more across countries than others

Let's now take a closer look at the cross-country variation in input-output shares separately for each sector and sector-pair. The left panel of Figure 1 shows the distribution of the average (across downstream sectors, within the same country) input-output share on intermediate inputs from the row sector. The right panel shows the distribution of the log of the corresponding average expenditure share. From the left panel we see that on average, the cross-country dispersion in the input-output share generally increases with the average input share: sectors that are, on average, used more heavily as intermediate inputs will also see countries differ more widely in their use of them. But this relationship does not seem to be linear: some sectors that account for a very low fraction of input expenditures have a cross-country dispersion that is disproportionately high (Gas, Coal, Water, etc; top part of right panel). Because of their limited use as intermediate inputs, these sectors are not very interesting to us. The bottom part of the right panel, however, reveals that there are some sectors where countries differ particularly strongly in their use as intermediate inputs: trade (including retail), business services, electricity supply, transportation by land, and financial services all have a relatively high dispersion in input expenditure shares compared to their mean. In another paper (Boehm, 2015), I show that this dispersion cannot alone be explained through cross-country variation in sectoral productivity levels. Some of the variation comes from differences in the quality of judicial institutions, which help resolve hold-up problems between suppliers from these sectors and their buyers. Indeed, these sectors (and services sectors more generally) are particularly prone to hold-up problems due to the nature of their products: one the service has been performed, it cannot be re-sold to a third party.

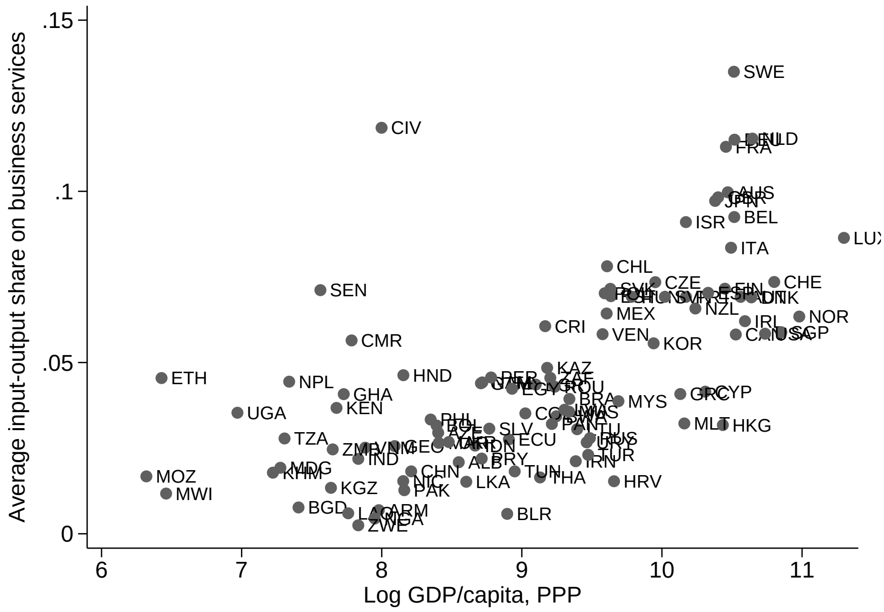
I have mentioned business services as one of the sectors where countries vary a lot in their use of it. Figure 2 shows these differences in a striking way by plotting, the average (within a country, across downstream sectors) input-output share on business services against log GDP per capita of that country. Sectors in countries like Sweden, France, Germany, and the Netherlands spend on average more than ten percent of their sales revenue on business services, whereas in sectors in Pakistan, Zimbabwe, Bangladesh, and Malawi the corresponding share is less than two percent. Note that the "average" in the input-ouput expenditure share is not weighted by sector size, hence the cross-country differences do not arise because of different industrial composition! The input expenditure share on business services is strongly correlated with development. This, of course, relates to a sizable and growing literature in industrial development, which has studied the importance of services inputs in raising firm productivity in developing countries (Arnold et al., 2008, 2011, Arnold et al., 2015, Bloom et al., 2013). I should mention that, in this definition, business services comprise real estate, renting, computer services, and professional services (legal, technical, advertising, etc.). Financial and insurance services are not part of it.

Figure 1: First and second moments of average input expenditure shares



Note: The graph shows the distribution of the average (left panel; log of average on right panel) intermediate input expenditure share on the row sector. Averages are taken across downstream sectors within the same country. Graph excludes outliers. Source: Author's calculations from GTAP data.

Figure 2: Average input-output share on business services



Note: The figure shows each country's average input-output share on business services (vertical axis) against that country's log GDP per capita (PPP adjusted; horizontal axis). Business services include real estate & renting, computer services, and professional services (legal, technical, advertising, etc.). Source: Author's calculations from GTAP data.

3.3 Input-output shares are correlated with development

We have already shown for the case of business services that input-output shares are correlated with the level of development. Let's do this more systematically. Divide the economy into three broad sectors: agriculture and mining, manufacturing, and services. We will look at correlations between expenditure shares on these broad baskets of intermediate inputs and the level of development. Factor intensities will vary across sectors, so we need to compare the expenditure shares of the same sector across countries. Hence, define the "country components" α_c of an input-output share as the coefficients on country dummies in a least-squares regression of the input-output share on downstream sector dummies and country dummies:

$$\frac{X_{ni}^c}{X_n} = \alpha_c + \alpha_n + \varepsilon_n^c. \tag{2}$$

In this regression, n is the index of the 35 two-digit downstream sectors, and c is the country index. We run this regression separately for each $i \in$ {Agriculture + Mining, Manufacturing, Services}. Countries with a positive country component α_c would have higher-than-average input-output shares on the broad sector i.

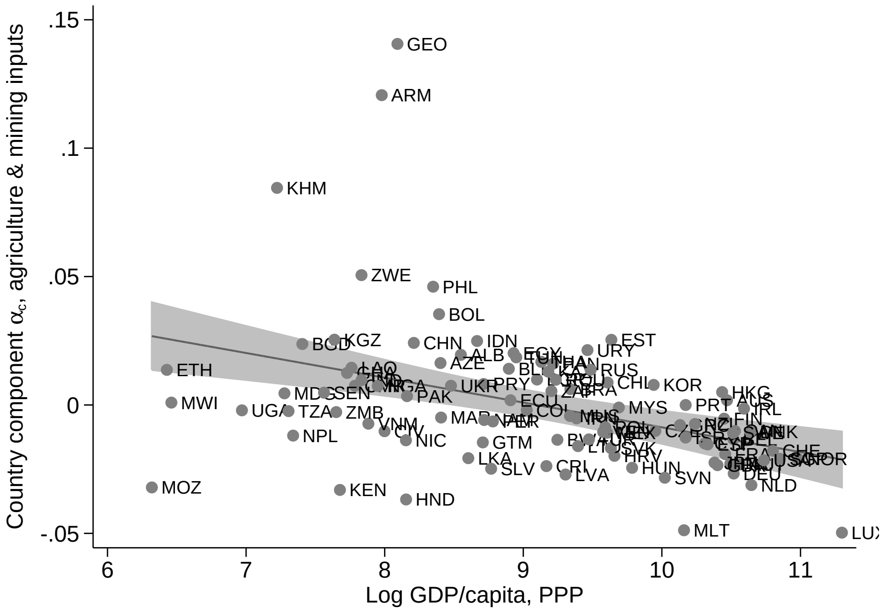
Figures 3 to 5 show the correlation of the country component with development, separately for expenditure shares on agriculture and mining, manufacturing, and services (where services are broadly defined and include utilities, transportation, and retail). My measure of development is log GDP per capita in the year 2000, in international (PPP) dollars, and comes from the World Bank's World Development Indicators.

Figures 3 and 4 show that developing countries tend to have higher input-output shares on inputs from agriculture and mining sectors and lower input-output shares on manufacturing inputs. The average input-output share on agriculture and mining is 6.7% and on manufacturing is 28.1%, which means that countries' input-output shares are distributed in the ballpark of -50% to +50% of the average share; a large variation.[5] The most interesting fact, however, is that services input shares and development exhibit a U-shaped relationship: they are high for low-income countries; low for middle-income countries, and at intermediate levels for high-income countries (Figure 5). Again, relative to the average services expenditure share (25.8%), the variation in the country component is large.

The cross-country variation in input-output shares make sense when linked to facts about relative productivity levels. Assuming that broad input baskets are complements, the fact that the relative price of agriculture decreases with development and the relative price of manufacturing increases with development (Duarte and Restuccia, 2010) explains the negative correlation in Figure 3 and the positive correlation in Figure 4. Recent evidence using data from international comparisons of price has also shown that the relative price of some services

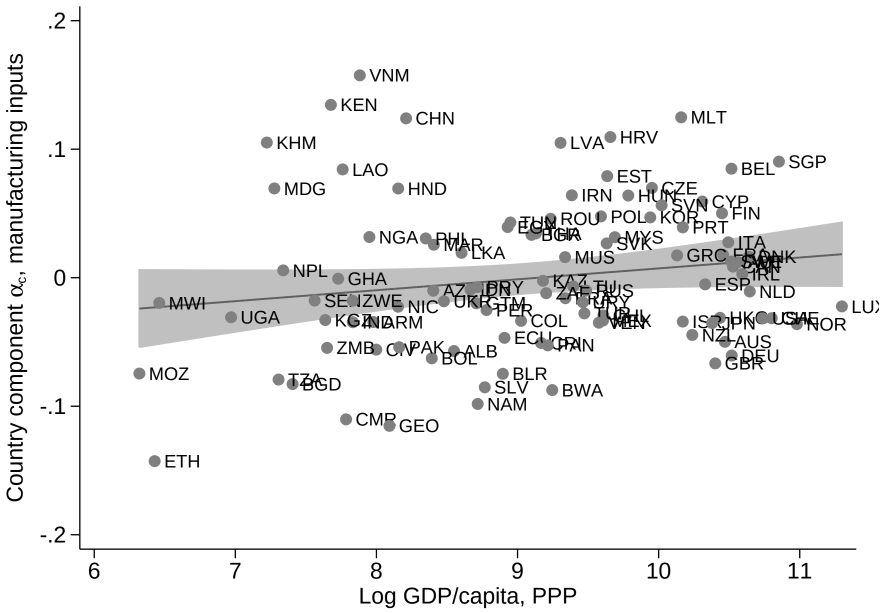
[5] Results are very similar when using the log of intermediate input shares to calculate the country components.

Figure 3: Country components of input-output shares on agriculture/mining



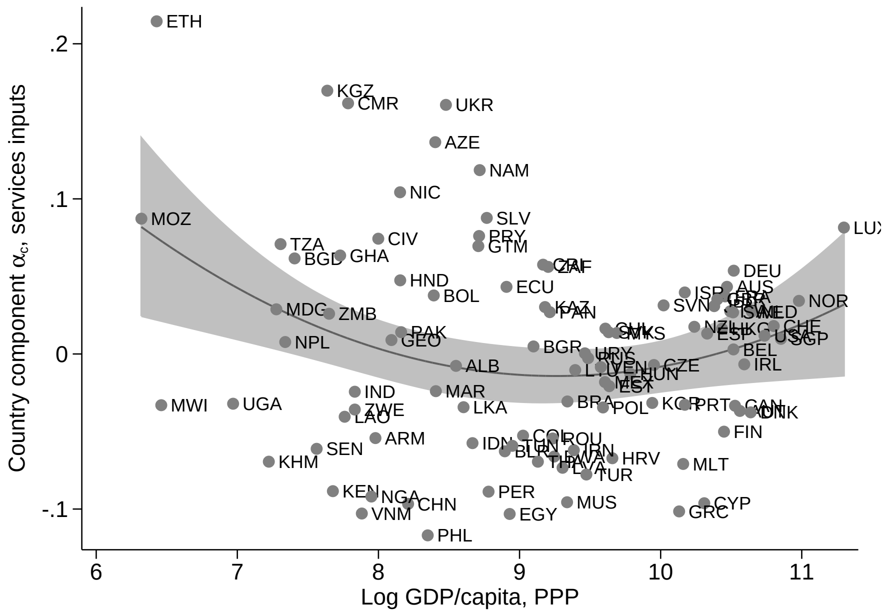
Note: The variable on the y-axis is the coefficient on country dummies in a regression of input-output shares on agriculture and mining inputs on downstream sector and country dummies (equation (2)). The horizontal axis shows the country's log GDP per capita (PPP).

Figure 4: Country components of input-output shares on manufacturing



Note: The variable on the y-axis is the coefficient on country dummies in a regression of input-output shares on manufacturing inputs on downstream sector and country dummies (equation (2)). The horizontal axis shows the country's log GDP per capita (PPP).

Figure 5: Country components of input-output shares on services



Note: The variable on the y-axis is the coefficient on country dummies in a regression of input-output shares on services inputs on downstream sector and country dummies (equation (2)). The horizontal axis shows the country's log GDP per capita (PPP).

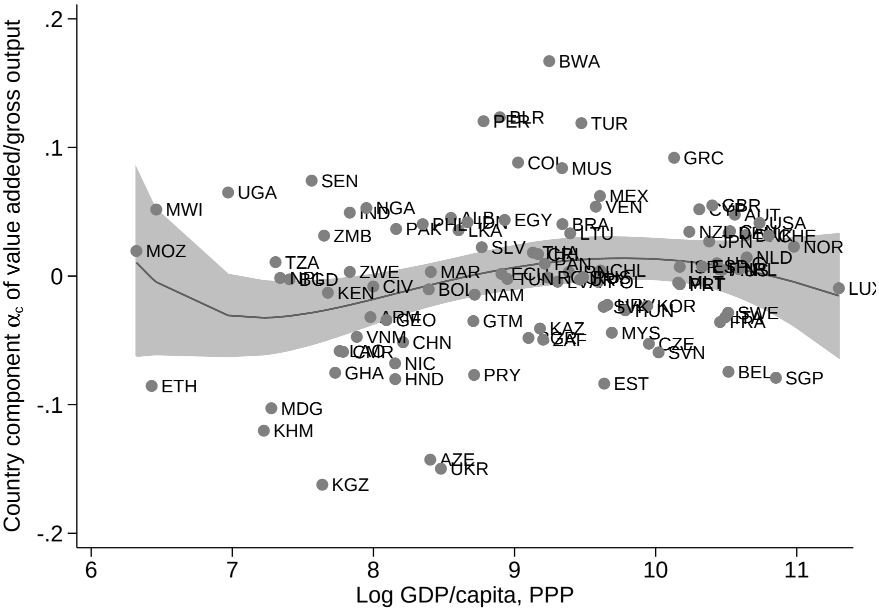
decreases with development, whereas the relative price of others increase with development. The authors, Duarte and Restuccia (2015), call the former "non-traditional services" , and the latter "traditional services". The vast majority of the services inputs in my broad definition are non-traditional services; hence the services input prices story support the upward-sloping part of the relationship in Figure 5.[6] This explains why middle-income countries have lower services input shares than low-income countries. But then why do we observe an increase in that share as we move from middle to high income countries?

Figure 6 shows the country components not for input shares, but for the share of value added in gross output. Again we find the U-shape, but this time in inverted form: on average, high-income countries use more intermediate inputs than middle-income countries. This suggests that there is some kind of substitution between value added and services inputs going on: in high-income countries, firms prefer to use services inputs as a substitute for activities that would be performed in-house (or not at all) in middle-income countries.[7] We now turn to a model that captures this mechanism.

[6]Indeed, when I restrict attention to non-traditional services inputs only, the U-share remains as in Figure 5. For traditional services inputs, the expenditure share is increasing with income.

[7]See Berlingieri (2013) for evidence on this phenomenon in the time dimension.

Figure 6: Country components of value added share



Note: The variable on the y-axis is the coefficient on country dummies in a regression of the value added share in gross output on sector and country dummies. The horizontal axis shows the country's log GDP per capita (PPP).

4 Model

The model is a generalization of Boehm's (2015) model of input sourcing in a domestic economy, which in turn builds on Eaton and Kortum's (2002) way of modeling the discrete sourcing problem using extreme value distributions. The purpose of the model is to give a framework which can be used to study the determinants of cross-country differences in input-output tables, as well as their quantiative importance. Input-output shares are endogenous outcomes of the firm's cost minimization problem. The production function features a constant (possibly nonunitary) elasticity of substitution across broad input baskets. The novelty of the model is the view that production involves a large number of different tasks, which may be performed by the firm itself, or outsourced to a specialized supplier. Since each of these ancillary activities correspond to a relatively small amount of value added, the sectoral classification of the firm will remain unchanged, regardless of whether the individual tasks have been done in-house or whether they have been outsourced. The relative cost of outsourcing activites may be different across countries, partly because the productivities of specialized suppliers may be different, and partly because the transaction costs associated with outsourcing may be different. Hence, cross-country differences in the technical input-output matrix arise both from different relative prices of input baskets, and also from different degrees of outsourcing of ancillary activities. Since the overall amount of ancillary activities may be a sizable fraction of gross output, the distortions that account for the cross-country variation in input-output tables can have large effects on aggregate productivity.

The model describes a closed economy consisting of N sectors with homogenous firms in each sector. Firms in sector n have production function

$$y_n = \left(\sum_{i=1}^{N} \gamma_{ni}^{1/\rho} \left(\int_0^1 q(n,i,j)^{(\sigma_n-1)/\sigma_n} dj \right)^{\frac{\sigma_n}{\sigma_n-1}\frac{\rho-1}{\rho}} \right)^{\rho/(\rho-1)},$$

$$y_n = \left(\sum_{i=1}^{N} \gamma_{ni}^{1/\rho} q_i^{\frac{\rho-1}{\rho}} \right)^{\rho/(\rho-1)}$$

The baskets indexed by (n, i) correspond to the broad bundles of tasks or activities in the production process of sector n firms that may be outsourced to sector i, or performed in-house by the firm. The varieties indexed by (n, i, j), correspond to the individual tasks within each basket (j runs from zero to one in each basket (n, i)). The outer elasticity ρ governs the substitutability of broad input baskets, whereas the inner elastiticities σ_n govern the substitutability of tasks within each broad input basket.

For each variety (n, i, j), firms decide whether to perform it in-house, or to outsource it to sector i. In-house production is done entirely using labor, whereas outsourcing it means that it is produced using y_i. This gives rise to input-output linkages between sectors.

4.1 In-house production

The production function for activity (n, i, j) under in-house production is linear in labor,

$$q(n, i, j) = s(n, i, j)l(n, i, j).$$

$s(n, i, j)$ is a stochastic variety-specific productivity draw coming from a Frechet distribution

$$P(s(n, i, j) < z) = e^{-S_{ni} z^{-\theta}}$$

with scale parameter S_{ni} and shape parameter θ. The cost of producing one unit of activity (n, i, j) is therefore the wage w divided by the technology draw, $p^l(n, i, j) = w/s(n, i, j)$.

4.2 Outsourcing

The production function for activity (n, i, j) under outsourcing is linear in the output of sector i,

$$q(n, i, j) = z(n, i, j)y_i(n, i, j)$$

where, again, $z(n, i, j)$ is a variety-specific Frechet-distributed productivity draw

$$P\left(z(n, i, j) < z\right) = e^{-T_{ni} z^{-\theta}}.$$

$T_{ni} > 0$ is the scale parameter of the productivity draw distribution, and $\theta > 1$ is the shape parameter. To obtain well-defined price indices, I also assume that $\theta > \sigma - 1$. I assume that suppliers are perfectly competitive and hence price their products at marginal cost, but that there is a proportional "iceberg" transaction cost of $\tau_{ni} - 1 \geq 0$ units per unit of outsourced good (n, i, j). The unit cost of variety (n, i, j) under outsourcing is then $p^x(n, i, j) = \tau_{ni} p_i / z(n, i, j)$, where p_i denotes the cost of producing one unit of sector i's output good.

Given the pefect substitutability of in-house production and outsourcing, the cost of procuring one unit of variety (n, i, j) is

$$p(n, i, j) = \min(p^x(n, i, j), p^l(n, i, j)).$$

4.3 Households

There is a representative household with a utility function that is Cobb-Douglass in the sectoral output goods,

$$U = \prod_{i=1}^{N} c_i^{\eta_i},$$

with $\sum_i \eta_i = 1$. The household inelastically supplies L units of labor and hence receives labor income wL. Finally, I set the wage to be the numeraire, $w = 1$.

4.4 Equilibrium

Under cost minimization of the sector n firms, the price levels for the sectoral goods, $(p_i)_{i=1,\ldots,N}$, have to satisfy

$$p_n = \left(\sum_{i=1}^{N} \gamma_{ni} \left(\alpha_n \left(S_{ni} + T_{ni} \left(\tau_{ni} p_i \right)^{-\theta} \right)^{-\frac{1}{\theta}} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{3}$$

where $\alpha_n = \Gamma\left(\frac{1-\sigma_n}{\theta} + 1\right)^{1/(1-\sigma_n)}$ (see the Appendix for proofs). Furthermore, the sectoral expenditure shares on outsourced intermediate inputs (i.e. the input-output shares) are

$$\begin{aligned} \frac{X_{ni}}{X_n} &= \gamma_{ni} \left(\frac{\alpha_n}{p_n} \right)^{1-\rho} \frac{T_{ni} \left(\tau_{ni} p_i \right)^{-\theta}}{\left(S_{ni} + T_{ni} \left(\tau_{ni} p_i \right)^{-\theta} \right)^{1+\frac{1-\rho}{\theta}}} \\ &= \gamma_{ni} \left(\frac{\alpha_n \left(S_{ni} + T_{ni} \left(\tau_{ni} p_i \right)^{-\theta} \right)^{-\frac{1}{\theta}}}{p_n} \right)^{1-\rho} \frac{T_{ni} \left(\tau_{ni} p_i \right)^{-\theta}}{S_{ni} + T_{ni} \left(\tau_{ni} p_i \right)^{-\theta}} \end{aligned} \tag{4}$$

Let's interpret the components of this expression. Naturally, the input-output shares are increasing in γ_{ni}: a car requires a lot of steel in the production process, therefore the input-output share of car on steel will be higher. The second term in (4), the large bracket, arises because of the complementarity between broad input baskets. It is the cost of (n, i) inputs divided by the cost of the output of sector n, raised to a power that depends on the degree of complementarity.

If the production function were Cobb-Douglass in broad input baskets, $\rho = 1$, then this term would disappear. Finally, the third term is the fraction of outsourced (n, i)-varieties, and also the fraction of expenditure on outsourced (n, i)-varieties. It is increasing in the relative productivity of outsourcing versus in-house production, T_{ni}/S_{ni}, decreasing in the cost of producing the sector i output, p_i, and decreasing in the transaction cost τ_{ni}.

Formally, an equilibrium of the economy is a price vector $(p_i)_{i=1,\dots,N}$ that satisfies (3). All other prices and quantities are uniquely pinned down given the equilibrium price vector. Determining the existence and uniqueness of equilibria is far from trivial, but one can derive a set of sufficient conditions to guarantee it:

Proposition 1 *Let Ξ be the matrix with elements $\Xi_{ni} = \alpha_n^{-\theta} \gamma_{ni}^{\theta/(\rho-1)} T_{ni} d_{ni}^{-\theta}$, and assume that*

1. *$\theta/(\rho - 1) < 1$, and*
2. *either $\theta/(\rho-1) > 0$ and the spectral radius of Ξ is strictly less than one, or $\theta/(\rho-1) < 0$ and the spectral radius of Ξ is strictly greater than one,*

then an equilibrium price vector $p = (p_i)_{i=1,\dots,N}$ exists and is unique.

The condition on the spectral radius of Ξ rules out infinite loops in the value chain, where one basket of sectoral output can be used to produce more than one unit of the same good. Note that even though the theorem does not explicitly allow for the Cobb-Douglass case $\rho = 1$, it is straightforward to prove equilibrium existence and uniqueness in that case.

A beautiful feature of the model is that the input-output expenditure shares arise as an elasticity of the sectoral cost functions:

Lemma 2 *Write the system of equations that determine the price level, (3), as*

$$p = f(p)$$

with $p = (p_i)_{i=1,\dots,N}$ and $f = (f_n)_{n=1,\dots,N}$, then we have that

$$\frac{X_{ni}}{X_n} = \frac{\partial \log f_n}{\partial \log p_i}$$

4.5 Welfare properties

Our measure of welfare is real income per capita. Since labor supply is fixed and the wage is the numeraire, changes in welfare come about from changes in the consumer's price index $P = \prod_i p_i^{\eta_i}$,

$$\frac{Y}{PL} = \frac{wL}{PL} = \frac{1}{P}$$

Taking the total differential of the log price levels, and holding constant the productivity parameter vectors S and T, we get

$$\log P = \sum_i \eta_i \log p_i$$

where changes in the sectoral price levels are given by

$$d \log p_n = \sum_i \frac{X_{ni}}{X_n} \left(d \log p_i + d \log \tau_{ni} \right). \tag{5}$$

Let $X_{ni}^l / X_n = \gamma_{ni} \left(\alpha_n \left(S_{ni} + T_{ni} \left(\tau_{ni} p_i \right)^{-\theta} \right)^{-\frac{1}{\theta}} / p_n \right)^{1-\rho} S_{ni} / \left(S_{ni} + T_{ni} \left(\tau_{ni} p_i \right)^{-\theta} \right)$ be the expenditure on in-house produced varieties of type (n, i), then $\left(X_{ni}^l / X_n \right) / \left(X_{ni} / X_n \right) = S_{ni} / \left(T_{ni} \left(\tau_{ni} p_i \right)^{-\theta} \right)$ and hence $d \log \left(X_{ni}^l / X_n \right) - d \log \left(X_{ni} / X_n \right) = \theta \left(d \log p_i + d \log \tau_{ni} \right)$. From (5) we get

$$d \log p_n = \frac{1}{\theta} \sum_i \frac{X_{ni}}{X_n} \left(d \log \left(X_{ni}^l / X_n \right) - d \log \left(X_{ni} / X_n \right) \right).$$

Hence, changes in a sector's price index are determined by changes in the expenditure share on in-house produced varieties, and changes in the input-output share. Unfortunately we do not observe expenditure on in-house produced varieties separately for each input basket. Hence, we need to continue by approximating:

$$\begin{aligned} d \log p_n &= \frac{1}{\theta} \sum_i \frac{X_{ni}}{X_n} d \log \frac{X_{ni}^l}{X_n} - \frac{1}{\theta} \sum_i \frac{X_{ni}}{X_n} d \log \frac{X_{ni}}{X_n} \\ &\approx \frac{1}{\theta} \left(1 - \frac{X_n^l}{X_n} \right) d \log \frac{X_n^l}{X_n} - \frac{1}{\theta} \sum_i \frac{X_{ni}}{X_n} d \log \frac{X_{ni}}{X_n} \end{aligned} \tag{6}$$

which is exact iff the share of outsourced varieties by sector-pair is constant across upstream sectors,

$$\frac{X_{ni}^l}{X_n} / \frac{X_{ni}}{X_n} \approx \left(\sum_i \frac{X_{ni}^l}{X_n} \right) / \left(\sum_i \frac{X_{ni}}{X_n} \right).$$

Note that this approximation would hold exactly in a model where each variety could be sourced from any of the N sectors, and produced in-house, at varying costs, with no distinction between broad input baskets. Then, integrating the differential equation (6) from c' to c (i.e. two countries with the same S and T but possibly different τ's), we get

$$\begin{aligned} \log p_n^c - \log p_n^{c'} &= \frac{1}{\theta} \left(\left(\log \frac{X_n^l}{X_n} - \frac{X_n^l}{X_n} \right)_c - \left(\log \frac{X_n^l}{X_n} - \frac{X_n^l}{X_n} \right)_{c'} \right) - \frac{1}{\theta} \sum_i \left(\left(\frac{X_{ni}}{X_n} \right)_c - \left(\frac{X_{ni}}{X_n} \right)_{c'} \right) \\ &= \frac{1}{\theta} \left(\left(\log \frac{X_n^l}{X_n} \right)_c - \left(\log \frac{X_n^l}{X_n} \right)_{c'} \right) \end{aligned} \tag{7}$$

Similar to how the gains from trade in a Ricardian trade model can be written as a function of the trade share and a trade elasticity (Arkolakis et al., 2012), the setup here allows us to express sectoral price level changes as a function of the elasticity θ and the change in the share of value added in gross output. The elasticity of substitution across broad input baskets, ρ, enters implicitly through the change in the value added share: with a high ρ, a reduction in transaction costs τ would have a smaller impact on the value added share.

4.6 A quantitative exercise

A serious, formal quantification exercise would require taking a stance on whether cross-country differences in input-output shares are shaped more by differences in productivity or by differences in transaction costs, and is beyond the scope of this chapter. Nevertheless, we can discuss by which orders of magnitude prices would change when the in-house production/outsourcing margin would be changed. I will look at the percentage variation in value added shares across countries, and will link it to counterfactual changes in the sector's production cost using equation (7).

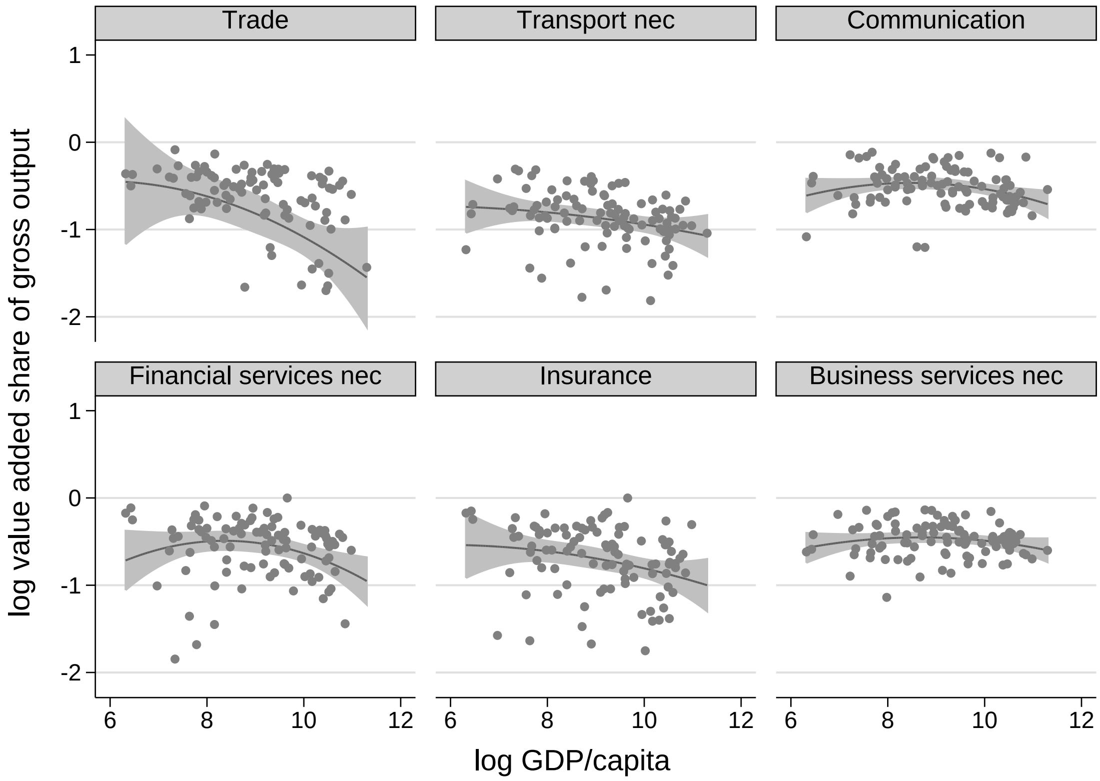
The parameter θ is similar to the elasticity of trade flows with respect to iceberg trade costs in international trade. It arises, just like in the Eaton and Kortum (2002) model, as the shape parameter of a Frechet distribution of productivity realizations. I set it to $\theta = 4$, a value that many recent papers that estimate it find (see Head and Mayer (2015) for a summary). In Boehm (2015), I estimate it to be around $\theta = 3$ (while at the same time assuming $\rho = 1$), so a value of four may be too conservative.

How much does the value added share vary? Figure 7 shows the log of the value added share for several services sectors. These sectors naturally have a relatively high share of intermediate inputs from the services sectors, and it is plausible that they face the outsourcing decision for a relatively large range of tasks. All these sectors have their value added share decline with income for high levels of income. For some sectors like trade/retail, finance, and insurance, the decline is particularly steep. If high-income countries outsource more than middle-income countries, and this leads to a 20% lower value added share of services sectors (a relatively small part of the overall cross-country variation in the value added share of the services sectors), then this would correspond to a 5% lower price level of these sectors (holding constant the productivity vectors T and S). Hence, transaction costs could explain a large fraction of cross-country TFP differences.

5 Conclusion

During the last few years both macroeconomists and trade economists have shown renewed interest in input-output linkages across sectors. However, the vast majority of models treat

Figure 7: Value added shares of six services sectors



Note: The figure shows the log shares of value added in gross output (vertical axis) and log GDP per capita (PPP adjusted, horizontal axis) for each country in the sample. Source: Author's calculations from GTAP data.

the strength of these linkages as exogenous: the typical setup is one where the firm's production function is Cobb-Douglass in labor and capital and in the inputs from different sectors, and the exponents of the sectoral inputs are taken directly from the expenditure shares in the input-output tables. This chapter has shown that these input-output shares vary substantially across countries, that they are correlated with the level of development, and that they are most likely dependent on input prices. Hence, the Cobb-Douglass is not the correct specification. Empiricists should also take heed. There are many papers that use the United States' input-output table to proxy for interindustry linkages in other countries. This may bias the results in unexpected ways. Actual input-output linkages are the endogenous outcomes of firms' decisions, and they are shaped by the economic and institutional environment in a similar way as international trade shares.

6 Appendix

6.1 Proof of Proposition 1

Different possibility to show existence and uniqueness of fixed point: use Kennan (1999)'s FPT.

Lemma 3 *Suppose*

$$f_n(z) = \sum_i^N \left(a_{ni} + b_{ni} z_i^{\eta}\right)^{\frac{1}{\eta}}$$

with $1 > \eta$ *and* $\eta \neq 0$, *and either* $\rho(B^{1/\eta}) < 1$ *if* $\eta > 0$, *or* $\rho(B^{1/\eta}) > 1$ *and* $\eta < 0$, *where* $B^{1/\eta} = \left(b_{ni}^{1/\eta}\right)_{n,i}$ *and* $\rho(\cdot)$ *is the spectral radius (or the Perron-Frobenius root). Then* $f(z)$ *has a unique fixed point* z^*.

Proof. The Jacobian is

$$\begin{aligned}
\frac{\partial f_n}{\partial z_i} &= \left(a_{ni} + b_{ni} z_i^{\eta}\right)^{\frac{1}{\eta}-1} b_{ni} z_i^{\eta-1} = \frac{b_{ni}}{\left(a_{ni} + b_{ni} z_i^{\eta}\right)^{1-1/\eta} z^{1-\eta}} = \frac{b_{ni}}{\left(a_{ni} z_i^{-\eta} + b_{ni}\right)^{1-1/\eta}} \\
&= \left(b_{ni}^{\frac{\eta}{1-\eta}} a_{ni} z_i^{-\eta} + b_{ni}^{\frac{1}{1-\eta}}\right)^{1/\eta-1} = \left(b_{ni}^{-1} a_{ni} z_i^{-\eta} + 1\right)^{1/\eta-1} b_{ni}^{\frac{1}{\eta}} > 0
\end{aligned}$$

We have that, if $0 < \eta < 1$

$$\lim_{z_i \to 0} \frac{\partial f_n}{\partial z_i} = \infty, \qquad \lim_{z_i \to \infty} \frac{\partial f_n}{\partial z_i} = b_{ni}^{1/\eta}$$

and, if $\eta < 0$,

$$\lim_{z_i \to 0} \frac{\partial f_n}{\partial z_i} = b_{ni}^{\frac{1}{\eta}}, \qquad \lim_{z_i \to \infty} \frac{\partial f_n}{\partial z_i} = 0$$

The second derivatives are

$$\frac{\partial^2 f_n}{\partial z_i^2} = -\eta \left(1/\eta - 1\right) \left(b_{ni}^{-1} a_{ni} z_i^{-\eta} + 1\right)^{1/\eta-2} b_{ni}^{-1} z_i^{-\eta-1} a_{ni} b_{ni}^{\frac{1}{\eta}} < 0$$

and 0 for the cross derivatives, thus f_n is strictly concave and increasing. Now it is easy to show existence and uniqueness of a fixed point using Kennan's (2001) fixed point theorem. First we need to find an $a > 0$ such that $f(a) > a$. We can find one in a neighborhood of zero. This is guaranteed by the fact that $\lim_{z_i \to 0} \frac{\partial f_n}{\partial z_i} = \infty$ (if $\eta > 0$) or, in the case of $\eta < 0$, the fact that $\lim_{z_i \to 0} \frac{\partial f_n}{\partial z_i} = b_{ni}^{\frac{1}{\eta}}$ and the Perron-Frobenius root of this matrix being greater than one (pick a vector sufficiently close to zero in the eigenspace of the Perron-Frobenius root). It remains to show that there is a $b > a$ such that $f(b) < b$. In the case where $\eta < 0$, this is trivial, since $f^{(n)}$ is bounded above by $\sum_i a_{ni}^{1/\eta}$ (pick a sufficiently large point). In the case $\eta > 0$, the function becomes asymptotically linear since the Jacobian converges uniformly to $B^{1/\eta}$. The fact that this matrix has a Perron-Frobenius root strictly less than one means that we can find a large enough vector b such that $f(b) < b$. ■

Proposition 4 *Let* $R = \rho\left(\gamma_{ni}^{\theta/(\rho-1)} \alpha_n^{-\theta} T_{ni} d_{ni}^{-\theta}\right)$. *Assume that* $\theta/(\rho-1) < 1$ *and that either* $\theta/(\rho-1) > 0$ *and* $R < 1$, *or* $\theta/(\rho-1) < 0$ *and* $R > 1$. *Then an equilibrium price vector* p *exists and is unique.*

Proof. The price vector satisfies the system of equations

$$p_n \equiv \alpha_n \left(\sum_{i=1}^{N} \gamma_{ni} \left(\left(S_{ni} w^{-\theta} + T_{ni} \left(p_i d_{ni}\right)^{-\theta} \right)^{-1/\theta} \right)^{1-\rho} \right)^{1/(1-\rho)} \tag{8}$$

which can be rewritten

$$z_n \equiv \sum_{i=1}^{N} \left(\gamma_{ni}^{\theta/(\rho-1)} \alpha_n^{-\theta} S_{ni} w^{-\theta} + \gamma_{ni}^{\theta/(\rho-1)} \alpha_n^{-\theta} T_{ni} d_{ni}^{-\theta} z_i^{\eta} \right)^{1/\eta} \tag{9}$$

with $z_n = p_n^{1-\rho}$ and $\eta = \frac{\theta}{\rho-1}$. By Lemma 3 there exists a unique z that satisfies (9) and thus a unique p that satisfies (8). ■

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