CGIAR Initiative on *Rethinking Food Markets*

INITIATIVE ON Rethinking Food Markets

Measuring Employment and Job Quality in Agrifood Systems: A Comprehensive Approach

Erwin Corong, Madhur Gautam, Will Martin and Rob Vos

Date: 31 December 2024

Contents

Abstract

As the agricultural transformation associated with economic development proceeds, the economic fulcrum of the agrifood system moves from on-farm, or primary, production activities to activities that are increasingly non-farm sector based, such as agro-processing, food services, wholesale and retail trade, etc. Therefore, the traditional measures of farm employment and value-addition (or GDP) come to represent a smaller and smaller share of the total contribution of the agrifood system. Better quantification is important not only to appreciate the transformation within the agrifood system with economic development, but also to inform better policies and strategies to create more and better-quality jobs and accelerate structural transformation in developing economies. There are two broad approaches to measuring the size of the agrifood sector—tracking activity in agrifood sectors; and exploiting the full structure of the economy to assess the direct and indirect employment required to meet final demand for agrifood products. Both approaches are used in an analysis based on the global GTAP database and their results compared. The findings suggest that the final demand approach provides a more comprehensive assessment of the economic activities needed to meet final demand, with agrifood sector accounting for a much larger share of GDP, and the broader agrifood sector generating more and better-quality skilled jobs for both male and female workers. Another key aspect of the relationship is the resources needed to produce non-food products such as biofuels, clothing and leather products that rely on agricultural inputs. Including the resources needed to produce non-food agrifood outputs substantially increases the importance of the agrifood sector in overall activity and employment.

A key element of the agricultural transformation associated with economic development is a move away from a self-sufficient, subsistence farming sector to one in which much of the value added and employment involved in supplying agricultural products to final users occurs off farm. In this situation, employment and wages in primary agriculture substantially under-represent the value added and the employment opportunities created by the agrifood system. Thurlow et al (2023) show that a substantial part of agrifood value added and employment is in sectors such as food processing, input supply, food services, and the trade and transport associated with the marketing of agricultural products. Davis et al (2023) present similar findings for employment, including employment in downstream industries such as textiles.

But it is not just the number of jobs provided by the agrifood sector that matters. It is vitally important whether these jobs are available to both men and women; whether they involve skills that can be augmented over time; how the wage rates paid compare with those in employment generated by other sources of final demand, and whether jobs pay a "living wage". A key step in answering these questions is obtaining data on wages paid, and employment by level of skills and by gender. Fortunately, two major data collection efforts have made very substantial progress in providing the data needed to answer these questions. The first is the GTAP databases that disaggregate labor and employment (Weingarten and Tsigas 2010) The second is the Gender Disaggregated Labor Database developed by the World Bank (Jara Nercasseau et al 2020). Both of these are available in a form with the GTAP database as its organizing framework, providing data for the 65 GTAP sectors at a level of disaggregation that allows the variables of interest to be presented by sub-sector of the agrifood sector, and to be aggregated to an overall agrifood sector. The gender dimension of the GDLD database is a vitally important enhancement and, for that reason, we focus on that database in this paper.

After much reflection, we chose to use the GTAP database version 11 (Aguiar et al 2022) for our analysis. This required some major changes that required importing data from input-output tables produced at a higher level of disaggregation than the GTAP database. This allowed us to split the Accommodation and Food sector so we could focus on food services in total, rather than a composite sector including accommodation provision that has little link to agrifood. Another important change was to identify the margin services—such as transport and trade—that link food produced by the farm sector or the food processing sector to the final consumer.

But, before we can identify factor use and employment associated with agriculture, we need to consider carefully the scope of the sectors and products to be considered, and the relationships between them. In this paper, we take a broad view, considering the activities and outputs in agriculture, forestry and fisheries; food processing; food services; input supply to these sectors, including trade and transport; and forward linkages to processing agricultural outputs into non-food products such as biofuels, textiles, apparel, and wood products. We use the Leontief (1967) approach to capture the value-added in agriculture, food processing and food services and their input-supplying sectors and, the Ghosh (1958) forward-linkage approach to capture value added in downstream processing of non-food products derived from agricultural inputs.

The next section of this paper considers the fundamental methodological question of whether we should measure agrifood GDP and employment from the resources employed in a set of agrifood activities or from the resources employed to provide a set of agrifood products to final demand. The second section considers the boundaries of the agrifood sector. The third section deals with the selection and modification of the databases used in the analysis. The fourth section lays out the equations used for estimation. Section 5 presents results and Section 6 provides a summary and conclusions.

1. Activity or Final Demand Approaches?

Clearly, we cannot simply add up the outputs of different sectors—such as the agricultural sector, the food processing sector and the food services sector—to obtain an estimate of the total contribution of the agrifood sector to the economy. This would involve blatant double counting, with the output of the agricultural sector appearing once as the output of that sector and then as a contribution to the output of the food processing and food services sectors. Some sort of value-added approach is clearly needed before we can measure the value-added of the sector.

A key methodological concern is whether to estimate factor returns and employment in the agrifood sector using a production approach in which the resources used to produce agrifood products are estimated based on the activities in which they are engaged, or using an expenditure approach in which factor demand is estimated based on the resources needed to produce a set of agrifood products. The first approach, followed by Thurlow et al (2023) and Davis et al (2023) means measuring agrifood value added and employment on the basis of value added and employment in the total outputs of agri-food activities, while the second measures the value-added and employment needed to deliver final goods.

Measuring the factor inputs used in a specified set of agrifood activities has intuitive appeal and is likely more convenient than focusing on the factors used to deliver final goods to end users. All we need to do is to define a set of agrifood activities and measure the value added and employment in those activities. Because we are focusing on elements of value added, the resulting measures can be added across activities, which would involve double-counting if we were measuring gross outputs. With this approach, we measure the value added in the production of total output, irrespective of whether it is sold to final users, or used as intermediate inputs into production of other goods.

For agriculture, food processing and food services, we have well-defined final products and can use an alternative approach originally developed by Leontief (1967) for aggregating an individual activity with the activities supplying its inputs. In this case we focus on the total factor requirements—and particularly labor inputs—needed to produce a specified vector of final goods. This approach is similar to that used by Canning et al (2016) and Yi et al (2021) when estimating the farm share of final consumer expenditures on food. It requires using input-output techniques to identify all of the intermediate and factor inputs used—directly or indirectly—in producing the vector of final goods.

Both the activity and final demand approaches should give correct answers—to slightly different questions—if properly estimated, just as Gross Domestic Product (GDP) can be estimated by assessing the value of final goods, or the direct and indirect factor returns associated with the vector of final demands, or by simply adding the factor returns obtained in all sectors of the economy. However, there is no guarantee that this equivalence will hold for an individual sector or final demand such as agrifood. On the other hand, the gap between the two measures seems unlikely to be large. The activity-based approach estimates the factor returns to production of all designated agrifoods, whether they are final goods or intermediates in the production of other goods. But it does not take into account the value added in producing intermediate goods. By contrast, the approach based on final demands for agricultural goods omits the direct inputs into production of non-final goods but takes into account the direct and indirect factor use in the intermediate inputs to production of those final goods. An important question to be addressed will be what differences arise between measurement based on activities and measurement based on direct and indirect requirements for producing final goods.

One possible approach to extending the activity-based approach is to create additional sectors that supply intermediates to key agrifood subsectors such as primary agriculture and food processing. Implicitly, this creates additional agrifood subsectors (see, for example, Thurlow et al 2023). Under this approach, accountants who provide tax preparation services to farmers become agrifood accountants and their factor inputs are attributed to the agrifood sector. A challenge for this approach is that these subsectors are not recognizably “agrifood”. Another question that arises is whether it is sufficient to count only the direct factor inputs to agrifood? Since production of these inputs requires intermediate inputs whose production, in turn, requires factor inputs, should not an approach like the Leontief Inverse used in Canning et al (2016) be followed? But, given that the output of the sectors covered under this approach includes goods that are used as intermediates, there seems to be a risk of double counting. If this approach were extended to the economy as a whole, would the factor inputs used in producing intermediate inputs not be counted twice, once when considering the sectors in which they are produced and once when considering them as inputs into other sectors?

When we consider the resources used to produce non-food agriculture-derived products--such as biofuels, cotton or wool textiles or clothing, leather shoes, and wood products—we face a different problem. In this case, there are no data at the input-output level on final demand for these agrifood products. In most cases, these products are aggregated into broader categories such as fuels, textiles, footwear, paper products and construction materials.

The relevant activities might be arbitrarily defined based on the shares of total inputs for these sectors originating in agriculture. Simpler procedures, such as the treatment of all textiles as agriculture-derived in Davis et al (2023) raise serious questions given the importance of synthetic fibers in modern textiles and the fact that most sales to final users are largely of clothing rather than textiles. The solution that we have followed here is to use the forward linkage approach of Ghosh (1958) and Jones (1976) to estimate the value added in processing agrifood outputs into final outputs demanded in other sectors. This allows us to identify the contribution of agriculture to gross outputs of non-agrifood sectors, and the factors used in their production.

2. Boundaries of the Agrifood Sector

Some GTAP sectors clearly warrant inclusion in a broader measure of the agrifood sector. The sub-sectors of interest are shown in Table 1, drawing from the definitions of detailed list of sectors included in GTAP 10 and 11 databases (see Appendix 1 Table A.1).

Table 1: GTAP Sub-sectors of Interest

	GTAP Sectors
Primary Agriculture	1-14
Agricultural Processing	19-25, 26 (Beverages & Tobacco)
Other manufactures using agrifood inputs	27 (Textiles), 28 (Wearing Apparel), 29 (Leather products), 30 (Wood products), 31 (Paper and paper products)
Trade & Transport margins	50 (Wholesale & retail trade); 55 (Warehousing); 52-54 (Transport)
Food Services	51 (accommodation, food and services)

Source: Aguiar et al (2022).

The first question that arises from examination of Table 1 is where to draw the boundaries of the Agrifood Sector itself. A second is how to identify the factor inputs into the Trade and Transport margins on marketing of agricultural products. Each of these questions is addressed in turn in the following sections.

Which Agrifood Subsectors to Include?

While the Primary Agriculture sub-sectors are relatively well defined, with perhaps the only major controversy being whether to include fishing and forestry. Most of the GTAP Agricultural Processing subsectors—such as those milling rice and producing meat or dairy products— also clearly belong to a broader agrifood sector. Beverages and tobacco clearly rely strongly on agricultural products, with many of these products produced on farm in subsistence economies and moving to the manufacturing sector as the agricultural transformation proceeds, although other products such as soda water or sweetened carbonated beverages, often have little or no link to agriculture. Food services are clearly highly relevant to what is normally thought of as the agrifood sector and the main challenge is that these are typically (and certainly in the case of GTAP) included within a broader sector such as Accommodation, Food and Services (GTAP Sector 51).

A key question is whether to include the manufacturing sectors that draw heavily on agriculture for their intermediate inputs. While Thurlow et al (2023) do not include these activities in their measures of agrifood GDP and employment, Davis et al (2023) include all of textiles (13), leather products (15), wood products (16) and paper (17). The dividing line with respect to textiles is challenging, with some textiles--such as bolts of cotton cloth—heavily derived from agriculture while others, such as synthetic tire cord, have no tangible link to agriculture. Another problem is that, particularly within the advanced economies, only a small share of textile output is sold directly to consumers, with most textile output used as intermediate inputs into wearing apparel and other sectors. If textiles are to be included, then it seems likely to be important to include wearing apparel as well. But does including activity in the design and manufacture of clothing—or at least the share of it that involves agricultural inputs—stretch the boundary of the agrifood sector too far? Similar issues arise in the wood products sector, where much of the output is intermediate goods, such as wood used in housing and in construction. But does including all or part of the housing sector extend the boundaries of the agrifood sector beyond reasonable limits?

As long as we have input-output information, an appealing alternative to the activity-based approach for non-food products using agricultural inputs is the forward linkages approach of Ghosh (1958) and Jones (1976). This approach measures the contributions to gross outputs of non-agrifood sectors resulting from processing agricultural outputs into non-food products such as biofuels, clothing and leather goods. From this information on gross output changes, it is possible to infer the value-added associated with production of products that rely on agrifood inputs.

Trade and Transport Margins

Estimation of the factor use associated with Trade and Transport margins on outputs and incorporating them into an input-output structure for analysis poses a different set of challenges. These do not arise on the production side of the agrifood sector, but on the marketing side. Where agrifood sectors use trade and transport as intermediate inputs—as when a farmer hires a trucking company to transport hay to feed to animals, these are correctly recorded as intermediate inputs from the transport sector to the agrifood sector. On the marketing side, however, when trade and transport inputs are used to transfer and/or transform farm products for use by final demanders, these inputs are recorded as direct sales by trade and transport to the final users in any input-output table presented at basic prices. As a consequence, the link between these trade and transport inputs and sales of agrifood products is lost. By contrast, when an input-output table is presented at purchasers' prices, data on the costs of providing margin services have generally been used to convert basic prices into producer prices.

While the GTAP input-output data are presented at both basic prices and at purchasers' prices, the allowance for trade and transport margins is very small because it focuses only on international trade margins. All of the domestic margin services are allocated to composite trade and transport activities, without distinguishing the value of these services applying to Agrifood products. One option for filling this lacuna is to use a simple rule, such as the rule that these services are used in proportion to the share of agrifood in total employment excluding margin services (Davis et al 2023, p11). Alternatively, where data on margin expenditures are available (as in Thurlow et al 2023), the share of these services in the total availability of margin services might be used to apportion the outputs of these sectors between margin services used for agriculture and those for other activities. The data collected by Peterson (2006) for a version of GTAP 6 including margin services provides a more detailed source of margin data per unit of output. New data collected for the next version of the GTAP database provide much more detailed information to deal with this problem.

Dixon et al (1982, p151) provide an illustration of the way an input-output table may be reformulated—while preserving its usability for IO analysis using equation (5)—to allocate margins to specific agrifood products. They do this by adding rows reflecting margin expenses attributable to specific products as additional rows of intermediate inputs. Expenditures on these margin services for domestically produced goods then contribute to the purchasers' prices for these goods and the analysis can proceed exactly as before, while now correctly attributing the factor inputs associated with those margin services to the agrifood sector, rather than to final sales by the trade and transport service sectors.

3. Selection and Enhancement of Databases

The ideal database for this project would be comprehensive in country and regional coverage; distinguish between domestic and imported inputs; provide detailed disaggregation of the agricultural, forestry and fisheries sectors and divide the accommodation and food services into two (likely very distinct) sectors; and identify the trade and transport costs associated with marketing agricultural and agriculture-derived products to final users. It would also be frequently updated to allow tracing structural changes over time.

Comprehensive coverage is important because of our interest in the evolution of agriculture-related activities with economic development. Detailed disaggregation of the agricultural, forestry and fishing sectors is important because their input-output and forward linkages differ substantially. The common practice of consolidating hotels and food service into a single sector is of particular concern both because their input structure is likely very different, with provision of accommodation involving much more limited backward linkages with agriculture than provision of food services. Separating inputs into domestic and imported is important because both forward and backward linkages are primarily associated with use of domestic inputs (Jones 1976). When a domestically-produced input is used, it is important to consider the factors used to produce that input; when an imported input is used, those factors are part of GDP in another country.

As previously noted, identifying the domestic trade and transport activities associated with delivering goods and services to final users is important. If input-output tables are presented at basic prices, then these services are treated as being delivered by stand-alone sectors, with no identification of which services are associated with delivering final goods to their purchasers (Peterson 2006; Peterson and Lin 2009).

Given our interest in global coverage, we sought existing databases with global coverage. Two promising databases for this exercise were the GLORIA Multi-Regional IO table (Lenzen 2021) and the GTAP global database. The GLORIA database has the advantage of being comprehensive in its coverage of agriculture and of providing a time series of observations (1990-2019). Unfortunately, it does not disaggregate domestic and imported intermediate use and nor does it separate hotels and restaurant services. The GTAP database has been updated every few years since the early 1990s, has a disaggregated agricultural sector and disaggregates intermediates between domestic and imported. Where it falls short for our purposes was that its product flows are measured at basic prices so that, for example, a purchase of a bottle of milk is recorded as one purchase of milk at farm prices and entirely separate purchases of trade and transport services from those sectors. Like most MRIO tables, it also fails to separate hotels and food services.

We ultimately decided to undertake the analysis using the GTAP dataset, with extensive modifications that draw on additional input-output tables collected as part of the GTAP exercise. This required allocating trade and transport services to the commodity flows with which they are associated, and additionally classifying margins into direct and indirect margin uses following Corong (2018) and detailed information from input-output tables listed in Appendix Table A.2. Similarly, accommodation and food service sectors were separated from a set of input-output tables listed in Appendix Table A.3 that provide this information. In particular, detailed production and sales structures from these input-output tables were used as input to the SplitCom routine which facilitates disaggregation of GTAP sectors.

This database is compatible with the World Bank's Gender Disaggregated Labor Database, which provides data on both employment and wages by GTAP sector. This, in turn, allows estimation of the wage rates received by workers in different activities. Details of this database are available from https://datatopics.worldbank.org/gdld/.

4. Approaches to Estimation

For the activity approach, we simply added the value added and employment information for the three subsectors that produce food outputs: agriculture, forestry and fisheries; food processing and food services. To capture value added and employment in input sectors, we divided each input sector into two based on the share of total output used as intermediate inputs into the three food sub-sectors above. We did not attempt to use this approach to identify value added or employment in downstream sectors producing non-food products because of the challenges involved in identifying the share of employment and output in these sub-sectors. These challenges are particularly intense in cases such as the yarn-textile-fiber value chain, where agricultural products pass through several processing stages—and Input-output sectors—between farm output and final demand.

Identifying Direct and Indirect Factor Requirements

Under the Input-Output approach, we used two main approaches to measuring the total factor requirements for production of agrifood products. The first follows the approach Leontief's (1967) of working back from identifiable final demands for a set of identified products. The second uses the approach of Ghosh (1958) and Jones (1976) to identify the factor employment involved in transforming agricultural goods into non-food products such as biofuels, textiles and clothing; leather goods; wood and paper products. A key difference between the backward linkage case and the forward linkage case is that, in the forward linkage case, we frequently have little information on the products that are produced using agrifood inputs. Because it can be confusing to identify the right matrix operations, the Appendix contains simple derivations in the two by two case to illustrate the approach to inference and the meaning of individual coefficients.

Backward Linkages—The Leontief Approach

When we have information on a clearly defined set of agrifood products, the Leontief (1967) approach to assessing the factor inputs needed to produce them uses an open-economy input-output model. A useful exposition of this model is given in OECD (2018, p162), beginning with two simple equations:

(1) $X = A^D X + f^D$

(2) $m = A^M X + f^M$

where the first equation is the supply-demand equation for domestic goods and the second for imported goods. The term **X** is a vector of gross outputs of domestic products; A^D is a matrix of intermediate use for domestic products, with each element specified as the value of an intermediate input in that row as a share of the gross output value of the good represented in the column; f^D is a vector of final demands for domestically produced outputs, including exports. The term m is a vector of imports; A^M is a matrix of coefficients of intermediate use of imported goods; and f^M a vector of imports used to meet final demands.

Equation (3) allows us to identify the vector of gross outputs required to produce any given vector of gross outputs for domestic goods:

(3) $X = (I - A^D)^{-1} f^D$

Where A^D is the proportion of the total value of output, including domestic and imported intermediates and factor use; and **X** is the vector of final demands for both domestic uses and exports of the *n* domestically-produced goods. When—as in our case—the f^D vector under consideration only includes some commodities with the others represented by zeros, the Leontief matrix $(I - A^D)^{-1}$ could be partitioned, as in Leontief (1967) and Canning et al (2016), but this impedes comprehension and is no longer computationally necessarily.

The matrix of factor demands by sector and factor needed to produce the vector f^D are obtained by first diagonalizing **X** and then performing the matrix multiplication:

(4) $W^D = W_{\cdot}\mathrm{Diag}(X)$

Where W^D is the $q*n$ matrix of *q* factor demands for production of each of *n* domestic gross outputs needed to produce the final outputs of agrifood products ; and $W_{\cdot}$ is the matrix of direct factor demand shares of total output associated with the *n* vector of gross outputs.

If we used the complete vector of gross outputs for domestic goods, the resulting matrix would include all factor demands in the economy. Because we consider only part of the gross output vector—the final demands for specified agrifood outputs—the equation returns the matrix of factor inputs (and hence value added) needed to produce those outputs. Where our matrix of direct factor input requirements allows us to identify particular categories of workers (eg male/female or skilled/unskilled), this matrix allows us to identify the total employment and sectors of employment needed to produce the specified agrifood commodities. This estimate, like Leontief's (1967) estimate, covers the value added in both the agrifood sector and in its input-supplying sectors. Subtracting the value added used directly in agrifood sectors yields an estimate of the value added generated in sectors supplying inputs to agrifood.

One minor omission with this procedure is value adding in the intermediate inputs used to produce agrifood outputs that are not used in production of final agrifood products. Value added in production of cotton, for example, is not included in the value added attributed to final outputs from the agrifood sectors. To deal with this challenge, we scaled up the estimate of value added in intermediate inputs by the ratio of total value added in agrifood to the agrifood value added needed to produce final agrifood outputs.

Forward Linkages—The Ghosh Approach

The Ghosh approach to forward linkages assumes that each using sector continues to use the same share of the gross output of each good. This assumption contrasts with the Leontief assumption of a fixed share of each input in gross output of the using sector. It implies that an increase in the output of an agricultural product such as cotton requires an increase in the output of cotton-using sectors such as textiles to absorb the increase in cotton output.

In this discussion, we drop the ^{D} superscript but continue to use only domestic flows. The Ghosh approach uses a matrix ***B*** similar to the matrix ***A*** used in the Leontief approach. Jones (1976) shows that, where the matrix *A* is derived by postmultiplying the matrix of intermediate flows by the inverse of **Diag(X),** the matrix ***B*** is obtained by premultiplication, as in:

(5) $\boldsymbol{B = (Diag(X))^{-1}F}$

where ***F*** is the matrix of interindustry flows of domestic products.

The fundamental equation for this model is:

(6) $\mathbf{X' - X'B = V'}$

Where ***V*** is a vector of total factor returns in each sector. In turn, this allows us to identify the gross output vector associated with either the total vector of factor returns, ***V,*** or with a subset of sectors such as our agrifood sectors:

(7) $\boldsymbol{X' = V'(I\text{-}B)^{-1}}$

Intuitively, equation (7) estimates the gross outputs of commodities associated with either the full vector of factor returns in the economy or with a subset of those returns. In our context—because the V matrix we use covers only the agrifood sectors—it measures the gross outputs of all products resulting from the presence of the agrifood industries in the economy—such as the outputs of clothing that are based on agrifood outputs such as cotton. Information on the magnitude of these gross outputs allows us to infer the factor inputs used to produce these outputs using equation (6).

5. Results

A stylized application

A stylized application of this formula to GTAP 11 data for high-income countries yields some interesting and surprising results. For simplicity, it considers three sectors: Primary agriculture; Food Processing and Accommodation and Food Services (without splitting Food Services from Accommodation). The purpose of this analysis is primarily to investigate whether measuring agrifood employment and value added differs whether measured from the factors needed to deliver final goods or from factor use in the designated activities. In this preliminary analysis, we use the original GTAP11 database, without partitioning Accommodation and Food or mapping trade and transport to the food products they deliver to consumers.

When we measure factor returns in value terms, considering only the activities in which these factors are engaged, we obtain the results in Table 2.

Table 2: Share of Factor Returns by Sector, %

	Agriculture	Processed Food	Accommodation & Food	"Agrifood total"
Land	49.7	0	0	49.7
Labor	1.3	1.8	4.5	7.6
Capital	1.3	2.2	2.9	6.4

Source: GTAP 11 database. Aguiar et al (2022).

When we measure factor returns taking into account the value-added factors needed to deliver these products to final demand (including export demand), we obtain the quite different set of results seen in Table 3.

Table 3: Share of Factor Returns Generated Supplying Agrifood Goods to Final Demand, %

	Agric	Processed Food	Accommodation & Food	"Agrifood Total"
Land	22.3	19.3	5.9	47.5
Labor	0.9	3.9	8.3	13.2
Capital	1.0	4.4	6.8	12.1

Source: Authors' calculations.

Table 3 shows that the share of labor and capital needed to meet final demands for food in high income countries is much higher than the share directly employed in the activities directly supplying those products. This striking finding needs careful interpretation if it is to be understood and accepted. It is, of course, important to recall that much of the factor use in the "Agrifood total" is not in activities identified as agrifood. An accountant providing services to a farmer who sells food to final demand is, for example, counted.

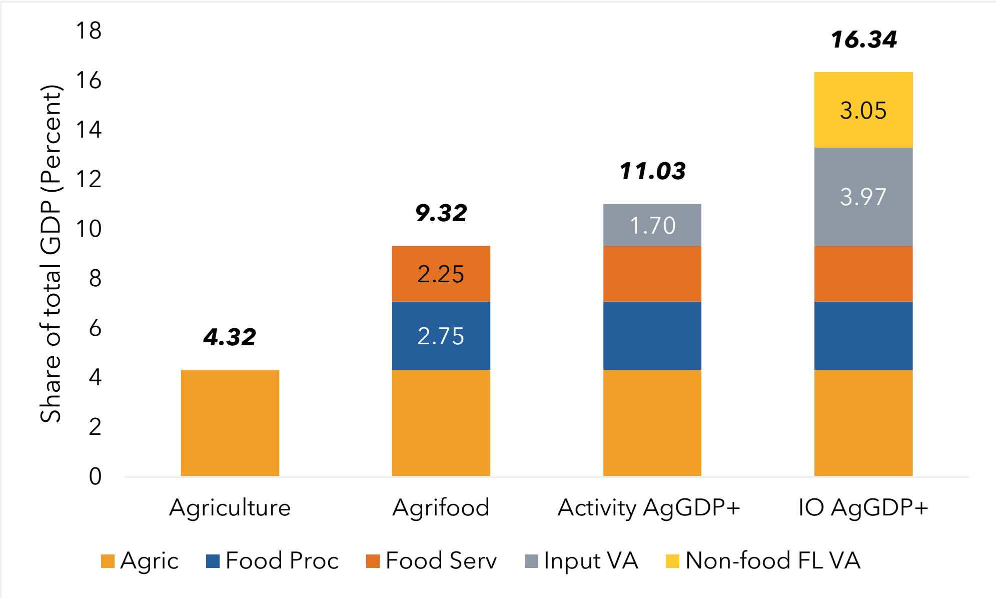
Interestingly, the higher share of factor use in agrifood is not seen to be the case for primary agriculture, but is strongly the case for Processed Food and for Accommodation and Food. In the case of primary agriculture, the fact that the final demand approach measures only factors used in producing products sold directly from agriculture to final users sharply reduces the estimated importance of factor use in agriculture, relative to the sector-of-employment approach. This is compensated for to some degree when employment in sectors supplying intermediates to agriculture is considered. But, because agriculture uses a relatively small share of intermediate inputs (51 percent vs 76 percent in food processing) and sells a relatively small share of its output directly to final demand, its employment share on this measure is smaller than its share of direct employment. Processed Food and Accommodation and Food Services, by contrast, sell far higher shares of their output to final demand, and use far higher shares of intermediate inputs, including, of course, from agriculture.

These results are extremely preliminary. The share of employment in agrifood will certainly decline when it becomes possible to separate Food Services from Accommodation. And will certainly increase when we are able to adequately account for the margin services needed to transfer food from producers to its consumers. What they do show, however, is the fact that the share of factors needed to supply final agrifood goods may differ substantially from the share of factors needed to supply final agrifood goods to final demand.

Size of the Agrifood System

Applying the two approaches using the modified GTAP11 database, a key finding is that the activity-based measures of the size of the agrifood system provide a significant underestimation of its contribution to the overall economy. The results indicate that primary agriculture alone accounts for only about 25 percent of total value added in the agrifood system. Figure 1 summarizes the estimates using the activity based and the final demand (or IO based) approaches for the world as a whole.

Figure 1: Size and Components of the Agrifood System



Sources: Authors' calculations.

The first striking finding from Figure 1 is that while agriculture is the foundation of the agrifood system, ignoring the non-farm segments of the agrifood system leads to gross underestimation of its importance to the overall economy. Even within the food domain, which dominates the agrifood system (with agrifood defined to include both food and non-food components of primary agriculture and their linked upstream and downstream segments in other sectors), it is important to note that including just the food-processing and food services activities more than doubles the economic size of the global agrifood system. Further adjusting for only the direct intermediate inputs used in the agriculture, food processing and food services (labelled as Activity AgGDP+ in Figure 1) further raises the value addition generated by the agrifood system by another 18 percent of the contribution of 3 principal components of the agrifood system.

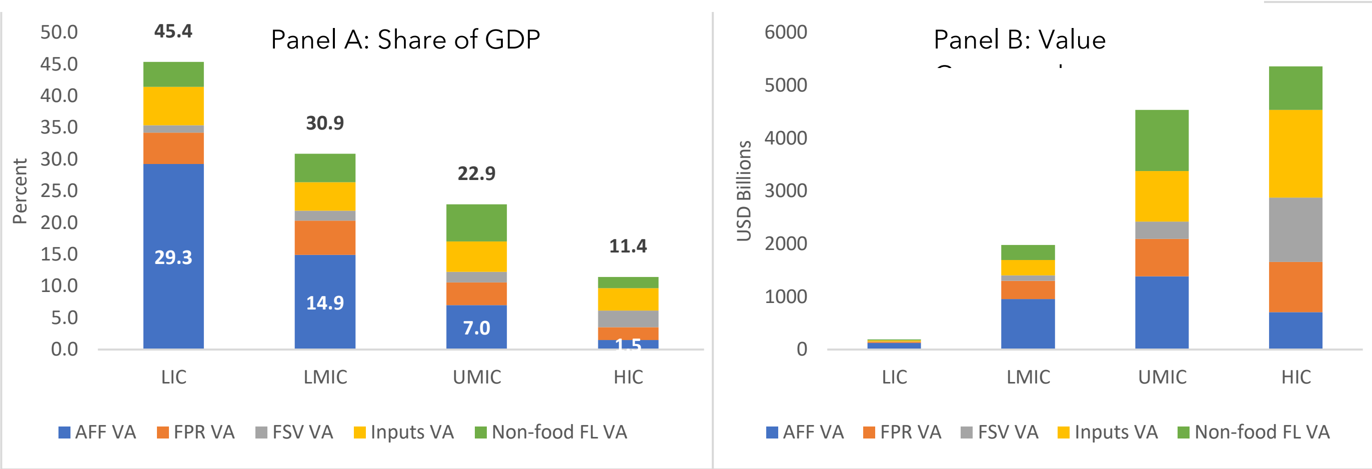
Exploiting the full information contained in the IO tables provides further insights into the indirect contributions of the agrifood system to the economy (labelled as the IO AgGDP+ in Figure 1). One contribution of this approach is a more precise measurement of the economic value created by industries and services that provide both direct and indirect intermediate inputs to the agrifood system – on farm as well as along the associated value chains to final demand. And the estimates indicate that it outweighs the value addition in either the food services or the food processing sectors alone. Strikingly, it is almost as high as the value created on farm itself.

A second important contribution of the final demand approach is the typically ignored (or grossly mismeasured) contribution of the non-food products from agriculture that are essential inputs for the production of non-food goods demanded by consumers. Since typically accessible national accounts data, as summarized in IO tables, do not provide estimates of agrifood based non-food consumer demand, preventing the application of the Leontief approach to estimate the non-food contributions of the agrifood system, an alternative is to apply the Ghosh approach which helps identify forward linkages for agrifood products used as intermediate inputs to other (non-food related) sectors. Applying this approach suggests that another 3.5 percent of the world economy is accounted for by the non-food forward linkages through the rest of the economy.

An important stylized fact of structural transformation as economies develop is the declining share of agriculture in the overall economy. The estimates in Panel A of Figure 2 confirm that this share falls steadily with income, from an average of about 29 percent in low-income countries (LIC) to 1.5 on average for high income countries (HIC). Accounting for the broader agrifood system related activities, the downward trend still holds but shows that even in HICs a substantial share, over 11 percent on average, of the overall economy is dependent on the agrifood system – significantly higher than the 1.5 percent of the primary agricultural economy and perhaps explaining the heft of the farm lobby in many countries.

The declining share of agriculture and the agrifood system in the overall economy is often interpreted as a sign of the decline in the importance of the food system. Quite to the contrary, Panel B of Figure 2 shows the total value, in billions of US Dollars, generated by the agrifood system. The figure shows that even as its share of the economy falls dramatically, in value terms the agrifood system rises even more dramatically – from an average of $0.2 trillion in LICs to over $5 trillion in HICs – nearly a 28-fold increase.

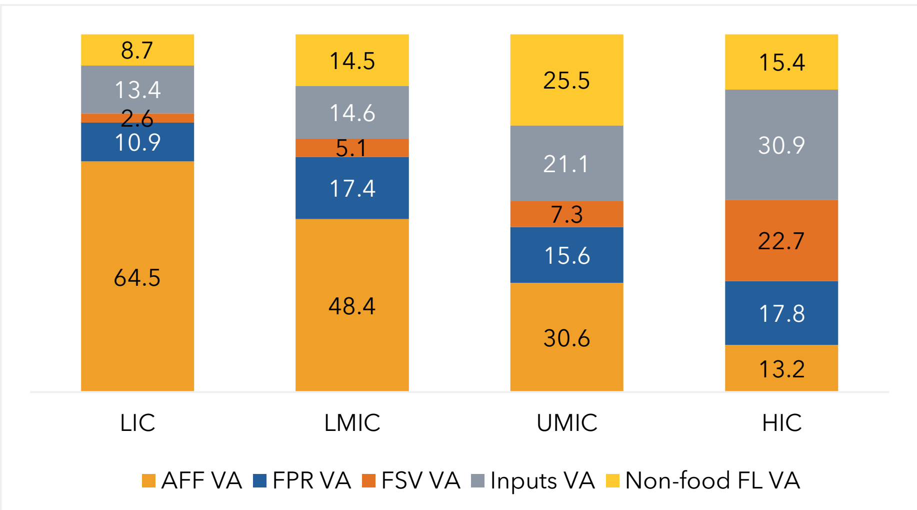
Figure 2: Size and Structure of the Agrifood System by Income Level



Sources: Authors' calculations.

A final point to note is that the economic fulcrum of the agrifood system shifts from on-farm, or primary, production-based activities in LICs to activities that are progressively more non-farm, or manufacturing and services, based in lower-middle income (LMIC), upper-middle income (UMIC) and HICs. This is shown more clearly in Figure 3, which shows the shares of each component within the agrifood system by income category (in contrast to Figure 1 Panel A which shows them as shares of the overall economy). As expected, the share of primary agriculture withing the agrifood system itself falls sharply with income, falling to a low of 13.2 percent for HICs. The increase in food processing is not as dramatic as the rise in food services in the post-farm segments of the agrifood economy. Processing dominates food services in LICs, but the balance shifts dramatically to food services in HICs. This likely reflects the dominance of basic processing activities in LICs but sharp increases in the importance of restaurants and food establishments as food away from home and prepared foods start to play a much larger role with rising incomes. Another important insight is the dramatic increase in role of input industries with rising income levels. They account for the largest share of the agrifood economy in HICs. Interestingly, while the non-food processing and downstream value addition rises with income levels from LICs to LMICs to UMICs, it falls sharply for HICs. This may reflect the globalization of these largely labor-intensive sectors, that have shifted offshore from HICs to more labor-abundant countries (as in the case of apparel, textiles, and footwear).

Figure 3: Composition of the Agrifood System, by Income Level (% shares)



Sources: Authors' calculations.

Employment and Job Quality Across Sectors

Disaggregated Activity Based Analysis

Given the uniqueness and detailed disaggregation of employment by sector in the GDLD, before moving to the IO based approach to estimate the full scope of employment and job quality in the broader agrifood system, the analysis in this section exploits the GDLD database to identify the share of total labor employment by gender and skill level (non-skilled and skilled) in each sector. This unique database provides an unprecedented opportunity to do cross country analyses on both the quantity and quality of jobs. The quantitative analysis is based on shares of total employment in each sector and the qualitative analysis relies on the trends in relative wages across sectors. GDLD estimates wages using numerous micro-surveys from various countries, and as such are considered more reliable than estimates from national account statistics. To facilitate cross-country comparisons, we estimate wage premia in defined sectors relative to primary agriculture.

The GDLD database provides detailed estimates on the volume of labor and wages by gender and skill level for 64 "activities" in GTAP terminology, which roughly translates to 64 distinct sectors or sub-sectors of the economy in common terminology. For tractability, these 64 activities were aggregated into 14 distinct "sectors" as defined earlier to allow flexibility in subsequent definitions of direct and indirect (apportioned as discussed above) uses of agri-food products. The 14 sectors were defined as follows:

1. AGF: Primary agriculture – including all activities related to crop and livestock products.
2. FFS: Forestry and fishing – typically included in primary agriculture in national accounts
3. FPR: Food processing – processing of all final food and beverage products
4. NPR: Non-food processing – processing of non-food agricultural products such as textiles, leather, etc.
5. AFS: Accommodation and food services – as per GTAP accounts from which food services yet to be apportioned out.
6. CNS: Construction activities
7. TPT: Transport – from which agri-food shares yet to be estimated
8. TRW: Trade and warehousing/support services of which agri-food shares yet to be estimated
9. EXT: Extractive industries (coal, oil, gas, mineral, etc.)
10. MGF: Manufacturing - chemical, metal, plastic, rubber products, machinery and transport vehicles, etc. from which agricultural chemicals, machinery, vehicles, etc. yet to be estimated
11. MFX: Petroleum, coal, basic pharmaceutical, paper products and publishing
12. EEQ: Computers, electronics, electric and optimal products/equipment
13. UTL: Utilities – electricity/water/gas manufacture and distribution
14. SVS: Services – all other services broadly defined.

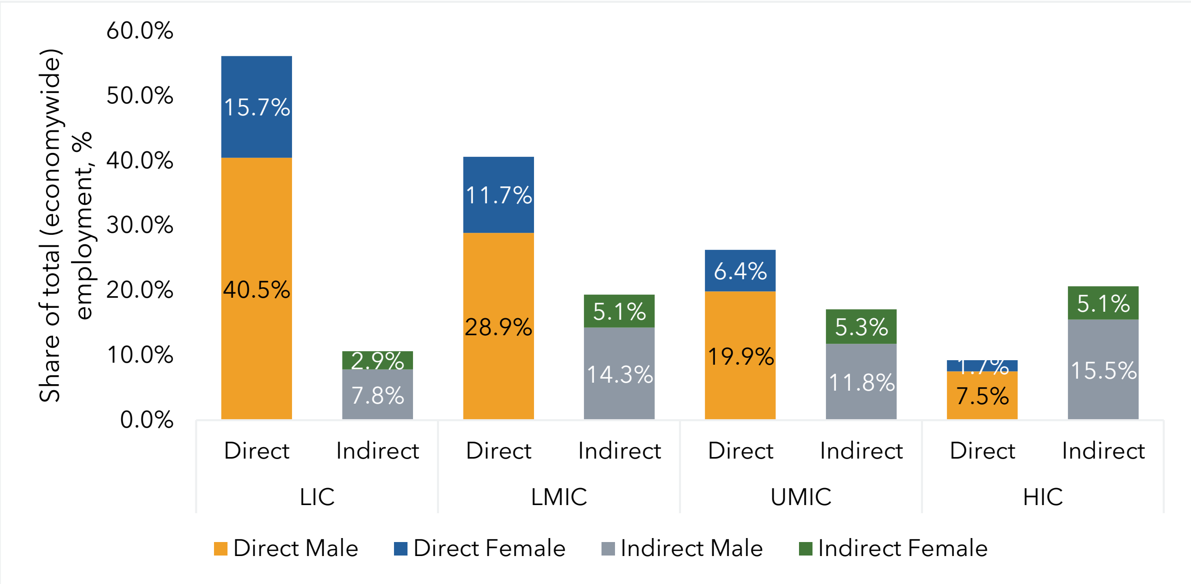
It is important to note that this initial analysis is based on the raw GTAP sectoral data, with AGF, FFS and NPR considered as agri-food sectors in totality. The indirect factor requirements in other sectors that use agri-food products as intermediate inputs, or the shares of margin industries related to the agri-food system are estimated in a later section. This section provides a benchmark, using traditional sector definitions, against the results of the following analysis that examines the share of indirect employment sectors linked to both food and non-food final goods derived from the agrifood sector.

Trends in agri-food employment: quantity trends

The initial set of results on employment, using standard national accounts classification of sectors (essentially derived from the traditional view of the economy broadly divided by primary, secondary and tertiary sectors) is unsurprising in that the share of the agri-food sector in total employment declines with development, proxied here by the World Bank classification of countries by income (the World Bank uses gross national income per capita thresholds to classify countries by income level as low, lower-middle income, upper-middle income, and high-income countries). Using these groupings, Figure 4 shows total employment in primary agriculture (AGR+FFS) and agricultural processing sectors (APR+NPR) falls progressively as countries transition from low to high income status.

The shares of sectors with indirect employment related to the agri-food sector are not readily available in typical IO tables so cannot be estimated with any accuracy. Instead, employment in the accommodation and food services (AFS), transport (TPT) and trade and warehousing (TRW) are instead used as a crude proxy indicators to see the trends in such indirect employment. This does show a rising trend, but is less dramatic. As noted, these crude estimates of indirect employment are, on the one hand, an overestimate. On the other, these estimates miss the indirect employment stimulated by the agrifood value chains in other sectors, underestimating employment in those sectors. These three broadly defined sectors overestimate the shares of agri-food related to these sectors because they also deliver other goods and services (e.g. accommodation in addition to food services in AFS, and transport of non agri-food goods in TPT). On the other hand, indirect employment is underestimated to the extent that current estimates do not include employment in economic activities that provide intermediate inputs to primary agriculture (e.g., fertilizers or farm machinery) or in sectors where agri-food goods may be used as intermediate inputs (e.g, cassava starch or plant based products used as industrial inputs). The refinement of the estimates with more accurate measurement of indirect sectors and proper accounting for the "hidden" indirect contribution of the agri-food sector is undertaken in the following section.

Figure 4: Share of agri-food employment in total employment by country income classification.



Source: Authors' estimates using GDLD database, World Bank. *Note:* LIC refers to Low-income countries; LMIC to Lower-middle income countries; UMIC to Upper-middle income countries; and HIC to High-income countries as defined by the World Bank.

The second point to note is that both the direct and indirect employment are dominated by males. The share of female labor is not trivial, but is significantly less than the share of male employment in each sector (direct or indirect) and income classification. While this pattern is consistent across countries, it is notable that the share of males in direct agricultural employment rises consistently from LIC to HIC status. Indirect employment shows a more stable share across income classes.

Finally, the pattern by skill levels (with the GDLD defining non-skilled workers as those with less than nine years of education, and skilled workers otherwise) provides some interesting important insights. Within direct agri-food employment, the share of non-skilled workers declines steadily from LIC to HIC but the share of skilled employment shows a non-linear pattern. As countries transition from low to lower-middle income status, the shares of skilled workers rise substantially from 7 percent of the total workforce in LICs to 13 percent in LMICs, before falling sharply to 4 percent in UMICs and 1.5 percent in HICs. Within direct agri-food employment, employment rises somewhat in primary agriculture (from 6 to 8 percent) but is more pronounced in the processing sectors (from 2 percent to 5 percent). These trends suggest two points: as education levels increase in low-income countries, agri-food processing provides an important opportunity for skilled labor to transition out of primary agriculture. Yet, the trends in primary agricultural employment suggest some friction in the labor markets. Some of the educated workers appear to remain in primary agriculture, which may reflect frictions in labor mobility – including insufficient skilled job opportunities to transition to, or other factor policies. With sustained development, skilled workers appear to find opportunities in other sectors, transitioning rapidly out of agri-food into other sectors. This pattern is also seen in the gross indirect agri-food employment patterns but more refined estimates for these sectors (as discussed above) to meaningfully interpret the employment trends.

Trends in wage premia: quality trends

The GDLD provides an unprecedented opportunity to also study the trends in wages across sectors. As noted earlier, these wages/income estimates are estimated using micro-surveys from various countries, and as such are considered more reliable than estimates from national account statistics. To facilitate cross-country comparisons, we estimate relative wage premia, defined as are sector wages (derived as weighted average of all activities that are aggregated into each of the 14 final sectors of analysis) relative to the wage in primary agriculture. These premia are estimated for both genders (male and female) and skill levels (non-skilled and skilled). The main results are summarized in Figure 5.

The first thing that jumps out from the figure is that all sectors, other than primary agriculture (AGR and FFS) show a substantial wage-premium relative to agriculture. This large premium in all sectors outside primary agriculture, including the agri-food processing sectors, however needs some further to be interpreted with caution because of concerns raised in the agricultural wage-gap literature that points to substantial measurement errors in national accounts and aggregated statistics when it comes to estimates of agricultural workers. Since agriculture frequently does not employ workers full time, except perhaps during short "peak" periods (sowing or harvesting), the blunt classification of workers their stated primary occupation (as is the convention in national accounts) is likely problematic. A second concern is the need for correction of wages to real wages to provide a more meaningful comparison of the standard of living they permit. Most non-agricultural wages related to urban jobs whereas most agricultural wages are for rural based jobs. Given large differences in the cost of living between rural and urban areas, a proper comparison requires adjusting the wages appropriately. A third potential source of confusion arises the importance of family labor in agriculture—and other activities dominated by unincorporated enterprises--relative to sectors dominated by incorporated enterprises. Family labor in agriculture is often remunerated from gross operating surplus that incorporates returns to skill and capital as well as labor. Wage labor in agriculture is often only a small share of employment and the total return to agriculture and is frequently concentrated in the more routinized and lower-paid activities. Gollin et al (2014) recognize and adjust for the importance of the first and second concerns, and still finds that hourly returns to labor of the same skill level are below those in other sectors.

Figure 5: Wage Premia by Sector: Averages Across Country Income Groups

Source: Authors' estimates using GDLD database, World Bank.

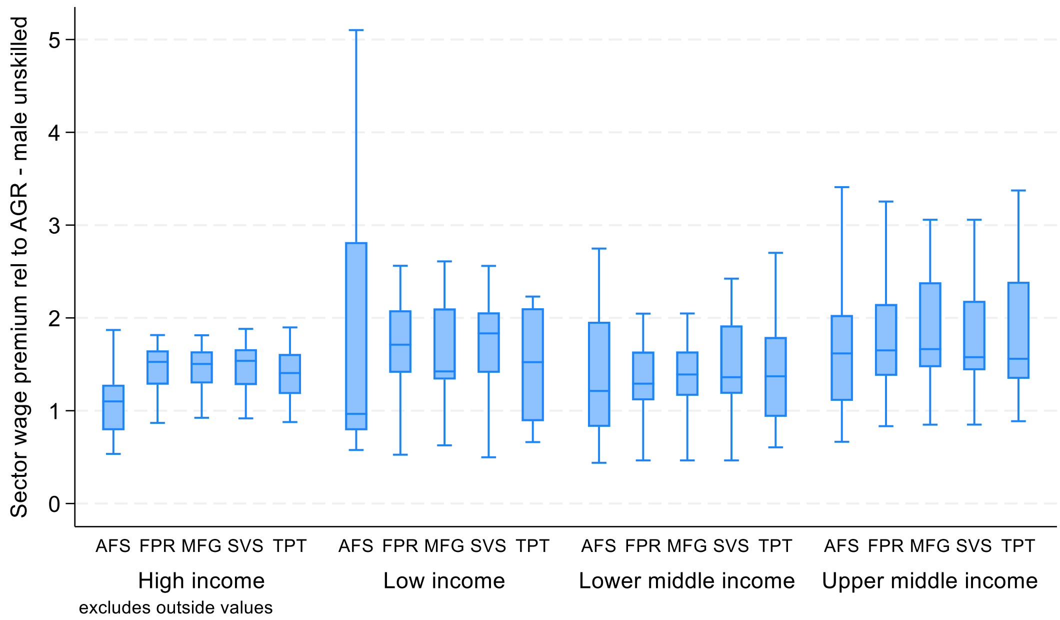
Note: Sector definitions in the figure are as follow: AGR=Agriculture; FFS=Forestry and Fisheries; FPR=Food processing; NPR=Non-food agricultural products processing; AFS=Accommodation and food services; CNS=Construction; TPT=Transport; TRW=Trading and Warehousing services; EXT=Extractive industries; MGF=Manufacturing; MFX=other industry including petroleum, coal, basic pharmaceutical, paper products and publishing; EEQ= Computers, electronics, electric and optimal products/equipment; UTL=Utilities, including electricity/water/gas manufacture and distribution; SVS=Services – all other services broadly defined.

Leaving aside the differences in agriculture vs non-agricultural wages, an important finding from Figure 5 is the consistency of the wage premium across sectors. The wage premia are more varied in LIC but tend to converge as income level rises (the one notable exception being the extractive industries in UMICs). The higher variability in LICs needs more detailed analysis but, a priori, it may reflect the process of development, with some sectors (such asAFS or construction) being "first movers" in absorbing labor from primary agriculture. Analysis using median premia by country income groups (not shown here) indicates a more stable premium across sectors suggesting country specific factors, including the structural characteristics of the economy, are important beyond income classification into broad groups. Such idiosyncratic factors are evident in the sample graph in Figure 6, which shows the relative wage premium unskilled for selected sectors for male unskilled labor.

Notably the premium in agri-food processing sectors is comparable to other sectors, such as manufacturing and services for most countries. The premia seem to be the highest in LICs but to decline as income levels rise.

Two main conclusions arise from this analysis. Shining the light only on primary agriculture significantly underestimates its contribution to the overall economy in terms of both value added, the number of jobs as well as the quality of jobs it directly or indirectly creates throughout the economy. Secondly, as the composition of the broader agri-food system changes from primary agriculture to becoming more processing and service oriented with development, the contribution of the agri-food sector to the overall value added in the economy and to employment, especially the quality of employment, also increases.

Figure 6: Variations in Wage Premia within Country Groupings



Source: Authors' estimates using GDLD database, World Bank.

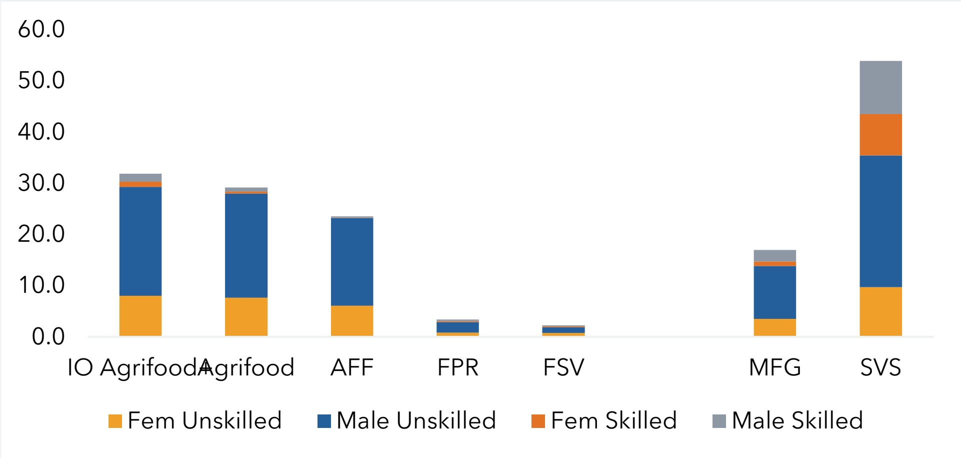
Note: Sector definitions are the same as in Figure 5.

IO Based Analysis

As a first step, given the similarities across certain groups of sector, the next step of the analysis aggregates the 64 sectors or subsectors in the GDLD database to 11 sectors to apply the Leontief and Ghosh approaches to measuring the key employment indicators. Among these, for the sake of brevity, the discussion presented below further focuses on selected sectors and sub-sectors to highlight the main findings.

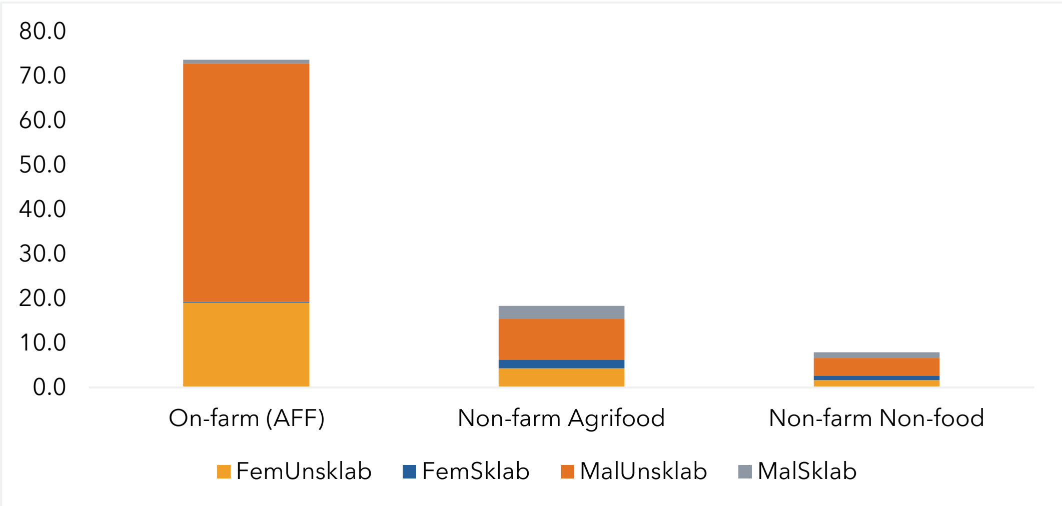
Figure 7 shows the share of the total global labor force, by gender and skill level, occupied in the different parts of the agrifood system. The first stacked column shows the IO based estimate that accounts for the full direct and indirect employment created in meeting the final demand for agrifood products. This estimate is compared with the agrifood estimate based on the activity approach (second column) and the employment in each of the three main segments of the agrifood system – primary agriculture, food processing, and food services. On the right side of Figure 7 are the employment shares of non-agrifood related manufacturing and services. Unskilled labor, and within that unskilled male labor, dominate all estimates. The agrifood system is clearly a major employer of unskilled labor but even a greater share of the unskilled labor is in the services sector. The majority of the skilled labor force, both for males and females, is also engaged in services indicating the heterogeneity of the broadly defined services sector. The next highest shares of skilled workers are in manufacturing, and the agrifood system but primarily through the indirect effects.

Figure 7: Share of Global Employment by Gender and Skill level



Source: Authors' estimates.

Figure 8: Distribution of Global Agrifood Employment across Farm and Non-farm

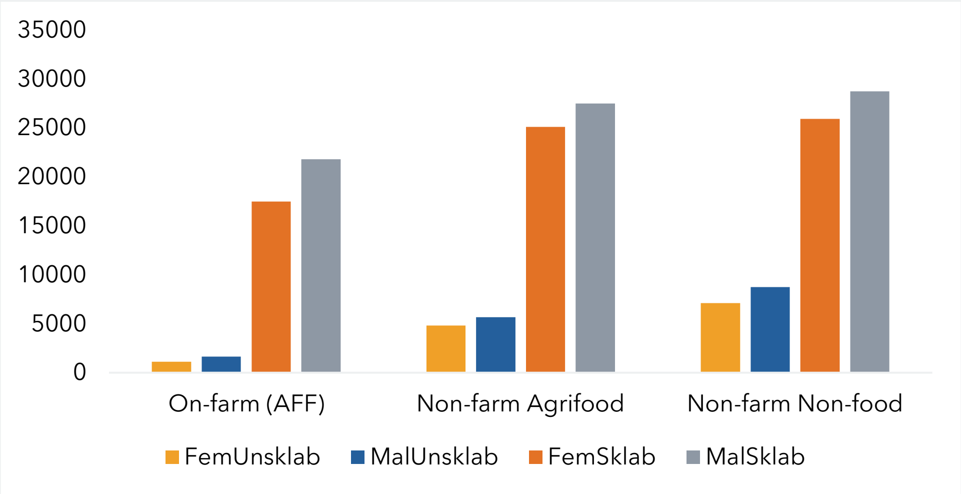


Source: Authors' estimates.

Within the agrifood system, the composition of employment in the farm and non-farm segments of the food system are shown in Figure 8. Employment is heavily concentrated on farms, much of it being unskilled male labor. Most of the off-farm employment is in the food value chains, accounting for 18.4 percent of total agrifood employment, followed by the non-food value chains employing about 7.9 percent of the agrifood workers. The shares of skilled workers, both males and females, are significantly higher in the non-farm activities than in primary agriculture, but overall remain a minor share of the employment in those segments.

An important insight from the analysis is the much higher quality of jobs provided by the non-farm sectors, especially for female workers. As expected, across all sources of employment, including on-farm where the few skilled workers are employed, they command a significant premium over unskilled workers in terms of wages as shown in Figure 9. Average wages are higher for non-farm activities with non-food related downstream activities paying relatively better than in the downstream food segments of the agrifood system.

Figure 9: Average Wage by Gender and Skill Level in the Agrifood System



Source: Authors' estimates.

An important indicator of the quality of jobs for female workers is the extent of wage premium that male workers get relative to female workers. The wage premia, by skill and segment of agrifood sector where the workers are employed, are given in Table 4. The highest premium is for unskilled on-farm workers, with males earning a substantial 45 percent higher wages than unskilled female farm workers. The premium is lower for on-farm skilled workers, but still significant at 25 percent. While the wage premium persists in the off-farm food segments of the agrifood system, they are relatively more equitable with the wage premium falling for both skilled and unskilled workers, with the food value chains performing better than the non-food. These findings suggest that promoting the creation of non-farm agrifood system jobs offers a promising avenue for better quality jobs for both skilled and unskilled workers, but especially for female workers in both categories.

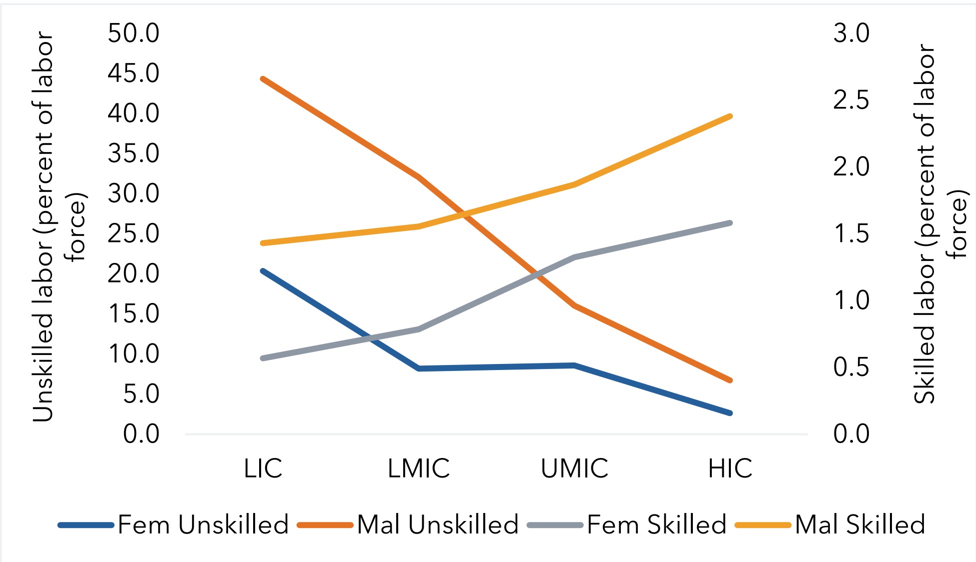
Table 4: Male/female wage premium

	On-farm	Off-farm Agrifood	Off-farm Non-food
Unskilled	1.45	1.18	1.23
Skilled	1.25	1.09	1.11

Source: Authors' estimates.

Turning next to the trends in employment as incomes rise, Figure 10 shows how the shares of skilled and unskilled male and female workers change with income level. Overall, there is substantial exit of workers from the agrifood sector with development, as they transition out of primary agriculture to other sectors and to non-agrifood related activities. This is seen as sharp decline in the share of unskilled workers (in total labor force) employed in the agrifood activities as incomes rise, for both male and female workers. Unskilled female workers transition out at a relatively faster pace at lower levels of development (from LIC to LMIC) while unskilled males make the transition at a faster pace between LMIC and UMIC stages. At the same time, shares of skilled workers rise consistently at with rising incomes. While the overall shares of skilled labor remain relatively small compared to the exit of unskilled labor, indicating a net decline in overall agrifood employment, some interesting patterns can be seen in the rising skilled worker trends. As incomes rise, the increase in skilled female workers is slow initially (from LIC to LMIC) but accelerates sharply between the stages of LMIC and UMIC, before slowing down again. The increase in male skilled workers in the agrifood system is progressively faster, with the highest increase between UMIC and HIC.

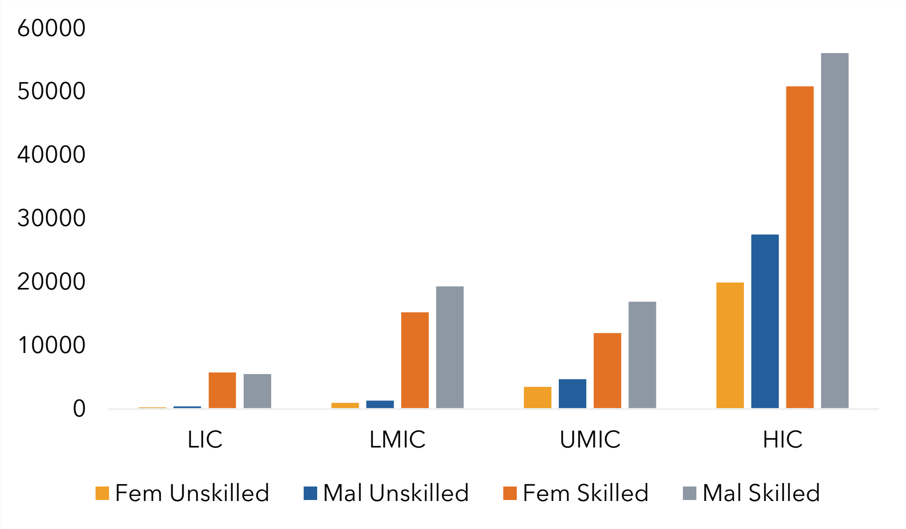
Figure 10: Shares of Skilled and Unskilled Workers by Gender and Income level



Source: Authors' estimates.

Finally, trends in job quality by income level in the food segments of the agrifood system are shown in Figure 11. The trends for non-food part of the agrifood system are similar, so not presented for brevity. The figure shows how the weighted average wage rates by gender and skill level change with income level. At all income levels, skilled labor commands a substantial premium, though this premium falls in percentage terms relative to unskilled labor. Males get significantly higher wages at all income levels with the notable exception of skilled workers in LICs. The GDLD data show that female workers get relatively higher wages than men, bucking the trend for all other income levels and for skilled and unskilled workers.

Figure 11: Wage levels by Gender, Skill and Income level



Source: Authors' estimates.

6. Summary and Conclusions

It is well known that the share of agriculture in economic activity and employment declines dramatically during the process of economic growth and development. But part of this decline is due to the structural transformation under which many activities move off farm as economic agents specialize and processes become more complex. An important question in this situation is the extent to which the share of agrifood activities declines during this process of growth and structural transformation.

This study examines the magnitude of economic activity and employment in the broad agrifood sector, taking into account the expansion of the food processing and food services, the trade and transport services that support agrifood-related activities, and the processing and sale of nonfood products that rely on agriculture, such as cotton wearing apparel.

Clearly, assessment of the magnitude of the agrifood sector this cannot be done by adding up the outputs from the sectors involved in producing these goods. This would involve enormous amounts of double counting with the same wheat, for example, being counted at least three times—once as raw wheat, once as flour, and finally as bread. However, an attractive approach to measuring the scope of the agricultural sector is to add up the value added in each of the production stages involved in agrifood value chains.

Adding up value added under an activity approach is attractive when there multiple activities—such as production agriculture; food processing and food services— that recognizably produce agrifood products. This approach becomes challenging is with inputs—such as fertilizer—that recognizably contribute to agricultural production but whose economic activity is generally attributed to another sector with many other outputs. It also encounters severe difficulties when considering agrifood outputs such as cotton that contribute to nonfood outputs such as clothing. The challenge with nonfood outputs is particularly challenging when working with aggregated information from input-output tables where sectors such as textiles and clothing generate a large share of their output from processes such as production of synthetic fibers and clothing that does not rely on agricultural inputs.

In this paper we relied primarily on alternative approaches that build heavily on the input-output literature. To capture the importance of inputs such as fertilizer, we used the Leontief (1967) approach to identify the importance of backward linkages and estimate the economic activity and employment needed to produce agrifood final outputs such as raw and processed foods and meals away from home. For non-food agricultural outputs such as clothing and textiles, we used an approach developed by Ghosh (1958) and Jones (1976) to measure the value added generated in processing agrifood outputs such as cotton into these final products.

For this analysis we used an extended version of the GTAP11 database for 2017. Two key adaptations to the database were disaggregation of the composite Accommodation and Food Services sector to allow us to focus on the food services sector alone, and transformation of the data from basic prices to purchasers' prices so that the trade and transport services required to deliver products to final users are associated with the use of those products. By contrast, under the basic prices approach, a consumer purchase of a bottle of milk is recorded as two transactions—the first being a purchase of milk from the food processing sector and the second being unrelated purchases from the trade and transport sectors. Another important element of the analysis was the use of the World Bank's Gender Disaggregated Labor Database to identify employment and job quality by gender and skill level.

Our analysis dramatically increases the measured importance of the global agrifood sector. At a global level, it implies that total agrifood GDP is about four times that of agriculture, forestry and fishing. This is larger than the factor of three multiple than found by Thurlow et al (2022) using an activity approach. Part of the difference appears to be due to the use of activity approach, which yields a lower estimate of this multiple when applied to our dataset. Another part of the difference is our inclusion of the forward linkage to production of non-food final goods such as cotton textiles and clothing using the Ghosh approach. Our analysis finds reassuringly similar findings to Thurlow et al (2022) with the share of agriculture declining relative to total agrifood value added as incomes rise, and more activity moves off farm.

The analysis also reveals important patterns in employment and the quality of jobs related to the agrifood sector. While production agriculture is a small share of agrifood GDP, it makes up a much larger share of employment, completely dominating total employment in agriculture. Male employment is much larger than female in this sector. Very consistently, employment in agriculture has the lowest wages for both male and female workers, although skilled workers' earnings are only modestly lower than those in other sectors.

References

Aguiar, A., M. Chepeliev, E. Corong, R. McDougall and D. van der Mensbrugghe (2022), 'The GTAP Data Base Version 11'. *Journal of Global Economic Analysis 7:2*

Canning, P., Weersink, A. and Kelly, J. (2016), 'Farm share of the food dollar: an IO approach for the United States and Canada' *Agricultural Economics* 47:505-12.

Corong, E. (2018), 'GTAP Data Base 10 with Domestic Margins' *Center for Global Trade Analysis, Purdue University. https://gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5609*

Davis, B., Mane, E., Gurbuzer, L.Y., Caivano, G., Piedrahita, N., Schneider, K., Azhar, N., Benali, M., Chaudhary, N., Rivera, R., Ambikapathi, R. and Winters, P. (2023) Estimating global and country-level employment in agrifood systems. FAO Statistics Working Paper Series, No. 23-34. Rome, FAO. https://doi.org/10.4060/cc4337en

Dixon, P., Parmenter, B., Sutton, J. and Vincent, D. (1982), *ORANI: A Multisectoral Model of the Australian Economy,* Contributions to Economic Analysis 142, North-Holland, Amsterdam.

Ghosh, A. (1958), 'Input-Output Approach in an Allocation System' *Economica* 25(97): 58-64.

Gollin, D., Lagakos, D. and Waugh, M. (2014) 'The Agricultural Productivity Gap' *Quarterly Journal of Economics* 129(2): 939–993.

Jones, L. (1976), 'The Measurement of Hirschmanian Linkages' *Quarterly Journal of Economics* LXXXVII 157-72.

Lenzen, M. (2021), 'Global Resource Input Output Assessment (GLORIA) database: Technical Documentation', University of Sydney.

Lenzen, M., Moran, D., Kanemoto, K. and Geschke, A. (2013), 'Building EORA: A Global Multi-region Input-Output Database at High Country and Sector Resolution' Economic Systems Research 25(1): 20–49, http://dx.doi.org/10.1080/09535314.2013.769938

Leontief, W. (1967), 'An Alternative to Aggregation in Input-Output Analysis and National Accounts' *Review of Economics and Statistics* 49,(3): 412-419.

Nercasseau, C., Maliszewska, M., Montenegro, C., Osorio Rodarte, I. Petersen Muga, J., Smith Mayer, J. and Zhang, H. (2020), Gender Disaggregated Labor Database, World Bank Macroeconomics, Trade and Investment Group, 6 April. https://datatopics.worldbank.org/gdld/

OECD (2018), *Australian Services Trade in the Global Economy,* OECD, Paris. https://doi.org/10.1787/9789264303911-en

Peterson, E. (2006), GTAP-M: A GTAP Model and Data Base that Incorporates Domestic Margins Technical Paper No. 26, https://www.gtap.agecon.purdue.edu/ Domestic Margins, GTAP

Peterson, E. and Lee, H. (2008), 'Implications of incorporating domestic margins into analyses of energy taxation and climate change policies' *Economic Modelling* 26: 370–378.

Thurlow, J., Holtemeyer, B., Pauw, K. and Randriamamonjy, J. (2023), 'Measuring Agrifood Systems: New Indicators and Global Estimates', Mimeo, International Food Policy Research Institute, Washington DC.

Walmsley, T. and Carrico, C. (2013), 'Disaggregating Labor Payments', https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4560

Weingarden, A. and Tsigas, M. (2010), 'Labor Statistics for the GTAP Database' https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3248

Yi, Jing, Meemken, E., Mazariegos-Anastassiou, V., Liu, Jiali, Kim, E., Gómez, M., Canning, P., Barrett, C. (2021), 'Post-farmgate food value chains make up most of consumer food expenditures globally' Nature Food 2: 417–425, June.

Appendix 1

Table A.1 Sectors Represented in GTAP 10 and 11

1	pdr	Rice: seed, paddy (not husked)
2	wht	Wheat: seed, other
3	gro	Other Grains: maize (corn), sorghum, barley, rye, oats, millets, other cereals
4	v_f	Veg & Fruit: vegetables, fruit and nuts, edible roots and tubers, pulses
5	osd	Oil Seeds: oil seeds and oleaginous fruit
6	c_b	Cane & Beet: sugar crops
7	pfb	Fibre crops
8	ocr	Other Crops
9	ctl	Cattle: bovine animals, live, other ruminants, horses and other equines, bovine semen
10	oap	Other Animal Products:
11	rmk	Raw milk
12	wol	Wool: wool, silk, and other raw animal materials used in textile
13	frs	Forestry: forestry, logging and related service activities
14	fsh	Fishing: hunting, trapping and game propagation
15	coa	Coal: mining and agglomeration of hard coal, lignite and peat
16	oil	Oil: extraction of crude petroleum, service activities incidental to oil and gas extraction
17	gas	Gas: extraction of natural gas, service activities incidental to oil and gas extraction
18	oxt	Other Mining Extraction (formerly omn): mining of metal ores; other mining and quarrying
19	cmt	Cattle Meat:
20	omt	Other Meat:
21	vol	Vegetable Oils
22	mil	Milk: dairy products
23	pcr	Processed Rice: semi- or wholly milled, or husked
24	sgr	Sugar and molasses
25	ofd	Other food

Table A.1 Sectors Represented in GTAP 10 and 11

26	b_t	Beverages and Tobacco products
27	tex	Manufacture of textiles
28	wap	Manufacture of wearing apparel
29	lea	Manufacture of leather and related products
30	lum	Lumber: manufacture of wood and of products of wood and cork, except furniture;
31	ppp	Paper & Paper Products: includes printing and reproduction of recorded media
32	p_c	Petroleum & Coke: manufacture of coke and refined petroleum products
33	chm	Manufacture of chemicals and chemical products
34	bph	Manufacture of pharmaceuticals, medicinal chemical and botanical products
35	rpp	Manufacture of rubber and plastics products
36	nmm	Manufacture of other non-metallic mineral products
37	i_s	Iron & Steel: basic production and casting
38	nfm	Non-Ferrous Metals:
39	fmp	Manufacture of fabricated metal products, except machinery and equipment
40	ele	Manufacture of computer, electronic and optical products
41	eeq	Manufacture of electrical equipment
42	ome	Manufacture of machinery and equipment n.e.c.
43	mvh	Manufacture of motor vehicles, trailers and semi-trailers
44	otn	Manufacture of other transport equipment
45	omf	Other Manufacturing: includes furniture
46	ely	Electricity; steam and air conditioning supply
47	gdt	Gas manufacture, distribution
48	wtr	Water supply; sewerage, waste management and remediation activities
49	cns	Construction: building houses factories offices and roads
50	trd	Wholesale and retail trade; repair of motor vehicles and motorcycles
51	afs	Accommodation, Food and service activities
52	otp	Land transport and transport via pipelines

Table A.1 Sectors Represented in GTAP 10 and 11

53	wtp	Water transport
54	atp	Air transport
55	whs	Warehousing and support activities
56	cmn	Information and communication
57	ofi	Other Financial Intermediation:
58	ins	Insurance (formerly isr):
59	rsa	Real estate activities
60	obs	Other Business Services nec
61	ros	Recreation & Other Services:
62	osg	Other Services (Government)
63	edu	Education
64	hht	Human health and social work
65	dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)

Table A.2 Input Output Tables with Detailed Trade and Transport Margins

1	aus	Australia
2	nzl	New Zealand
3	jpn	Japan
4	mng	Mongolia
5	usa	United States of America
6	aut	Austria
7	bel	Belgium
8	bgr	Bulgaria
9	cze	Czechia
10	dnk	Denmark
11	est	Estonia
12	fin	Finland
13	fra	France
14	deu	Germany
15	grc	Greece
16	hun	Hungary
17	irl	Ireland
18	ita	Italy
19	lva	Latvia
20	ltu	Lithuania
21	nld	Netherlands
22	pol	Poland
23	prt	Portugal
24	rou	Romania
25	svk	Slovakia
26	svn	Slovenia
27	esp	Spain

28	swe	Sweden
29	gbr	United Kingdom of Great Britain and Northern Ireland
30	nor	Norway

Table A.3 Input Output Tables with Disaggregated Accommodation and Food Services Sectors

1	aus	Australia
2	nzl	New Zealand
3	jpn	Japan
4	kor	Republic of Korea
5	mng	Mongolia
6	twn	Taiwan Province of China
7	idn	Indonesia
8	mys	Malaysia
9	phl	Philippines
10	sgp	Singapore
11	tha	Thailand
12	vnm	Viet Nam
13	ind	India
14	can	Canada
15	usa	United States of America
16	mex	Mexico
17	arg	Argentina
18	bra	Brazil
19	chl	Chile
20	ecu	Ecuador
21	per	Peru
22	cri	Costa Rica
23	pan	Panama

24	dnk	Denmark
25	irl	Ireland
26	nld	Netherlands
27	pol	Poland
28	prt	Portugal
29	gbr	United Kingdom of Great Britain and Northern Ireland
30	che	Switzerland
31	kaz	Kazakhstan
32	uzb	Uzbekistan
33	aze	Azerbaijan
34	irn	Iran (Islamic Republic of)
35	jor	Jordan
36	tun	Tunisia
37	bfa	Burkina Faso
38	xac	South-Central Africa
39	tza	United Republic of Tanzania
40	swz	Eswatini
41	zaf	South Africa

Appendix 2

Verifying Matrix Operations for Backward and Forward Linkages

Backward Linkages

Here we use a 2*2 example to identify the matrix operations that yield the desired answers. The Leontief equation is:

(A.1)

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$$

Where **y** is final demand; **X** is gross output and the a_{ij} terms are elements of the Leontief inverse.

The OECD approach diagonalizes the **y** vector at this point. This gives us the right dimensionality later.   But the elements do not yield the results we want. Diagonalizing **y**, gives us the product:

$$\begin{bmatrix} a_{11}y_1 & a_{12}y_2 \\ a_{12}y_1 & a_{22}y_2 \end{bmatrix}$$

Note that element (1,1) in this matrix is the amount of X_1 associated with final demand element y_1 (and so on). This is an interesting answer but to a different question from what we want. We need to know how much output of $x_1$will rise in total, as a consequence of demands for both elements of **y**. To get that, we keep the **y** vector as a vector at the first step and get the gross output vector $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$.

To get the answer we want, we need to do the diagonalization at the next stage, where we pre-multiply a diagonalized **X** vector by the factor shares to get factor use by sector and factor:

A.2 $$\begin{bmatrix} v_{11} & v_{21} \\ v_{12} & v_{22} \end{bmatrix} = \begin{bmatrix} s_{11} & s_{21} \\ s_{12} & s_{22} \end{bmatrix} \begin{bmatrix} x_1 & 0 \\ 0 & x_2 \end{bmatrix} = \begin{bmatrix} s_{11}x_1 & s_{12}x_2 \\ s_{12}x_1 & s_{22}x_2 \end{bmatrix}$$

Forward Linkages

The critical equation for this approach is:

(A.3) $\mathbf{X}' - \mathbf{X}'\mathbf{B} = \mathbf{V}'$

The logic of this equation becomes evident when recalling the definition of ***B***. In the 2*2 case, equation (A.3) is:

(A.4) $$\boldsymbol{X}' - \boldsymbol{X}' \begin{pmatrix} \frac{1}{X_1} & 0 \\ 0 & \frac{1}{X_2} \end{pmatrix} \begin{pmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{pmatrix} = \boldsymbol{V}'$$

or

(A.5) $$X' - (X_1 \quad X_2) \begin{pmatrix} \frac{F_{11}}{X_1} & \frac{F_{12}}{X_1} \\ \frac{F_{21}}{X_2} & \frac{F_{22}}{X_2} \end{pmatrix} = \boldsymbol{V}'$$

or

(A.6) $$(X_1 \quad X_2) - (F_{11} + F_{21} \quad F_{12} + F_{22}) = \boldsymbol{V}'$$

Which explains the posited relationship.

Erwin Corong is Principal Research Economist at the Center for Global Trade Analysis, Purdue University. Madhur Gautam, Will Martin and Rob Vos are Senior Research Fellows at IFPRI

Measuring Employment and Job Quality in Agrifood Systems

We would like to thank all funders who support this research through their contributions to the CGIAR Trust Fund: www.cgiar.org/funders.

To learn more about this Initiative, please visit this webpage.

To learn more about this and other Initiatives in the CGIAR Research Portfolio, please visit www.cgiar.org/cgiar-portfolio

INITIATIVE ON
Rethinking
Food Markets