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# Measuring Employment and Job Quality in Agrifood Systems

## Accounting for Backward and Forward Linkages

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## Abstract

As the agricultural transformation associated with economic development proceeds, the economic fulcrum of the agrifood system moves from primary production to nonfarm activities, such as input supply, food processing, food services, and wholesale and retail trade. Traditional measures of farm employment and value added (or GDP) represent a shrinking share of the agrifood system's total contribution. Better quantification is important not only to appreciate the role of agrifood system transformation in broader economic development, but also to inform policies that create more and better-quality jobs and accelerate structural transformation in developing economies.

This study considers two broad approaches to measuring the agrifood sector: (1) measuring agrifood activities, and (2) exploiting the economy's full input–output structure to measure the direct and indirect resources needed to meet final demands for agrifood products and to transform agrifood output into nonfood products such as biofuels and clothing. We apply both approaches using the Global Trade Analysis Project (GTAP) database and comparing their results. We then use the input–output approach to estimate the employment generated by the agrifood sector, including employment in backward and forward linkages. The findings suggest that the input–output approach provides a more comprehensive assessment, with the agrifood sector generating 15.2 percent (near one-sixth) of global GDP and one-third of global employment. The findings further show that the off-farm segments of the agrifood system provide better-quality jobs than the farm segments, particularly for women. These findings provide insights on the potential for improving welfare and reducing poverty and inequality through agrifood system transformation.

**Keywords**: Agrifood system, structural transformation, input–output approach, agrifood employment and job quality, gender inequality

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## 1. Introduction

A key element of agricultural transformation in economic development is the shift from self-sufficient, subsistence farming to a system that relies heavily on purchased inputs and whose outputs rely on extended value chains to reach final users. In this context, employment and wages in primary agriculture may substantially underrepresent the value added and employment opportunities generated by the agrifood system. Conventional statistics showing the rapidly declining importance of production agriculture may mislead policymakers into concluding that the agrifood sector is far less important than it actually is. Identifying the linkages between production agriculture and related agrifood sectors may help correct this impression and provide guidance on where and how policies might better create opportunities for income and employment growth.

Recent studies, such as Thurlow et al. (2023), examine the importance of the broader agrifood sector in terms of value added and employment. Yi et al. (2021) find that the major share of the resources used to meet consumer final demand for food are employed beyond the farmgate, in upstream and downstream segments of agrifood supply chains. Schneider et al. (2024) examine the shares of agrifood activity by component sector across 170 countries and track their evolution from 1995 to 2020. Davis et al. (2023) examine employment in agriculture and related sectors, including employment in downstream industries such as textiles, and Yi et al. (2024) examine the evolution of employment during structural transformation. These studies all show that a substantial share of agrifood value added and employment lies in sectors such as agrifood processing, input supply, food services, and the wholesale, retail, and transport activities involved in marketing agricultural products.

Except for Davis et al. (2023), who draw on data from national accounts and labor force surveys, all of the recent studies of the agrifood sector use input–output or supply-and-use tables for the whole economy to identify value added and/or employment. This approach makes it possible to identify employment and value added in sectors producing both final goods and intermediate inputs, and it facilitates estimation of the employment and/or GDP associated with forward and backward linkages from the core agrifood sectors of agriculture, food processing, and food services.

Available studies use one of two broad approaches—activity-based or input–output—to define and measure the agrifood sector's overall economic contribution. The activity approach begins by estimating value added in readily identifiable agrifood activities, such as agriculture, food processing, and food services. Some studies that use a value-added approach, such as Thurlow et al. (2023) and Schneider et al. (2024), also estimate the share of value added in adjacent sectors—such as input supply, trade, and transport—generated by core agrifood activities. Studies using input–output approaches (see, for example, Yi et al. 2021 and

2024) tend to rely on an aggregation approach developed by Leontief (1967) and later applied by Canning, Weersink, and Kelly (2016) to estimate employment and activity not only in adjacent sectors such as fertilizer supply, but also in all backward-linkage activities supplying inputs used in these activities.

Our study builds on this literature but extends it in two different dimensions. First, we use input–output techniques from Leontief (1967) to capture both *backward linkages* from final demand for agrifood products and from Ghosh (1958) to capture *forward linkages* involved in transforming nonfood agricultural outputs such as cotton into nonfood outputs such as cotton clothing. Second, we introduce new data to address key challenges in readily available but aggregated data and to estimate employment and wages disaggregated by gender and skill within the agrifood sector, including the contributions identified through backward and forward linkages. We then compare the results from our input–output approach—which extends beyond immediately adjacent sectors—with those from an activity approach limited to adjacent subsectors. We find that the input–output approach provides a more comprehensive measure of the resources employed in the agrifood sector.

Before we can identify factor use and employment associated with agriculture, we need to carefully consider the scope of the sectors and products included and the relationships among 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 nonfood products such as biofuels, textiles, apparel, and wood products. We then extend the database by, for instance, separating the hotel, restaurants, and food service sectors that are combined in the original input–output tables, which could otherwise overestimate the resources devoted to food services. We also allocate margin services, such as the trade and transport required to transfer agricultural products to final users, to those agrifood commodities.

We also use this approach to identify factor use in generating the value of agrifood system output, measured in terms of the numbers of jobs created and the quality of those jobs. We estimate these after linking the input–output estimation procedure to the World Bank's Gender Disaggregated Labor Database (GDLD) (Jara Nercasseau et al. 2020), which provides employment and wage information disaggregated by sector, gender, and skill level. This enables us to address questions such as whether agrifood system jobs are equally available to men and women, whether skill requirements increase with the development of agrifood value chains, how wages in the agrifood sector compare with those in other sectors and, in turn, whether the development of agrifood value chains will contribute to a process of inclusive growth.

The next section of this paper considers the fundamental methodological question of whether agrifood GDP and employment should be measured from the resources employed in a set of agrifood activities or from the resources used to meet final demand for agrifood products. The second section considers the boundaries of the agrifood sector. The third section discusses the selection and modification of the databases used in the analysis. The fourth section lays out the equations used for estimation. The fifth section presents the results, and the final section provides a summary and conclusions.

## 2. Methods: Activity or Input–Output Approaches?

### 2.1 Choosing methods

To estimate the total contribution of the agrifood sector to the economy, it would be a mistake to simply sum the outputs of the various subsectors within agrifood value chains. Such an approach would result in blatant double counting, as the output of the agriculture sector would appear once as its own output and again within the outputs of the food processing and food services sectors. A value-added approach is therefore needed before aggregating individual components into the value added of the entire agrifood sector.

A key methodological concern is whether to estimate factor returns and employment in the agrifood sector using a production approach—in which resources are estimated based on the activities in which they are engaged—or an expenditure approach, in which factor demand is estimated from the resources required to produce a set of agrifood products. The first approach, followed by Thurlow et al. (2023), Davis et al. (2023), and Schneider et al. (2024), measures agrifood value added and employment on the basis of total outputs of agrifood-related 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 simpler than focusing on the factors used to deliver final goods to end users. This approach requires defining a set of agrifood and agrifood-related activities and measuring the value added and the employment within them. With this approach, we measure the value added in production, regardless of whether the product is sold to final users or used as intermediate inputs in the production of other goods.

For agriculture, food processing, and food services, we have well-defined final products and can apply an alternative approach originally developed by Leontief (1967) for aggregating an individual activity with the activities supplying its inputs. In this case, the focus is on the total factor requirements—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) to estimate farm shares of final consumer expenditures on food, and by Yi et al. (2024) to estimate the evolution of employment and wages with economic development. It relies on input–output techniques to identify all intermediate and factor inputs used—directly or indirectly—in producing the vector of final agrifood goods. The method can be extended to account for the resources required to transform agricultural outputs such as cotton and animal skins into nonagrifood outputs such as clothing and footwear (Ghosh 1958). This estimation approach, which incorporates both backward and forward linkages, is one way of implementing a hypothetical extraction method of the type described by Hertwich et al. (2024). Cella (1984) and Duarte et al. (2002) propose alternative approaches, which we found to yield similar results to those reported in this paper.

If properly estimated, both the activity and final demand approaches could yield correct answers, albeit to slightly different questions. The expectation that their results should be similar follows from the fact that GDP can be estimated as (1) the value of final goods, (2) the direct and indirect factor returns required to produce final goods, or (3) the gross factor returns across all economic activities. While all three approaches give the same estimate for total GDP, there is no guarantee that this equivalence will hold for a particular subset of activities or final demands, such as those used to measure the economic size of the agrifood sector. Although the activity approach may seem to remove the need for complete input–output tables, these are in fact necessary to capture the backward and forward linkages that become increasingly important as economies develop.

The activity-based approach estimates the factor returns to production of all designated agrifood activities, whether they produce final goods or intermediates used in the production of other goods. However, it does not directly account for either the value added in producing the intermediate goods used in their production, or in transforming them into nonagricultural final goods. In contrast, the final demand approach counts only the inputs into production of final goods but adds the values of direct and indirect factor use in the intermediate inputs required to produce those goods. An important question, then, is how measurement based on activities compares with measurement based on the direct and indirect requirements for producing final goods.

One possible approach to extending the activity-based approach is to identify some of the resources used to supply intermediates to agrifood subsectors such as primary agriculture and food processing. This implicitly creates additional agrifood subsectors (see, for example, Thurlow et al. 2023). With this approach, the part of the chemical sector that supplies fertilizer to farmers becomes part of the agrifood sector. Schneider et al. (2024) introduce forward linkages by attributing factor use in certain downstream sectors to the agrifood sector. For instance, if cotton from the farm sector accounts for 10 percent of the total costs of the textile sector, then 10 percent of the factors employed in the textile sector are attributed to the agrifood sector.

A key problem with these extensions of the activity approach, as highlighted by Leontief (1967), is their dependence on the degree of aggregation in the input–output data used. For example, if all raw cotton is sold to a ginning sector, activity-based estimates of forward linkages derived from an input–output table that includes a cotton ginning activity will capture only the factors used in that activity. But if the estimates are based on an input–output table with a more aggregated "cotton textile" sector that combines cotton ginning, spinning, weaving, and clothing, the estimated factor use in forward linkages will be much larger. The source of this problem is that the activity approach to backward and forward linkages does not extend beyond immediately adjacent sectors.

When estimating the value added generated in the production of inputs under the activity approach, we use the row-shares method described in Schneider et al. (2024). That is, we calculate the share of a product's gross output used as an input into agrifood and apply that same share of the product's value added to the agrifood sector. If, for example, intermediate use of manufactures in agrifood is 10 percent of manufacturing gross output, then 10 percent of manufacturing value added contributes to the agrifood sector. This activity-based approach, however, is likely to understate the true use of inputs in agrifood production, as it omits the value added generated in earlier stages, such as the production of natural gas used in fertilizer production but not sold directly to farmers.

When considering the resources used to produce nonfood agriculture-derived products—such as cereals or sugar used for biofuels; cotton, leather, wool, or plant-based materials used for textiles, clothing and footwear or wood used for housing—we face different problems. At the input–output level, there are no data on final demand for these agrifood-derived products. Instead, they are typically aggregated into broader categories such as fuels, textiles, footwear, paper products, and construction materials. This means that the Leontief (1967) approach that works backwards from final demands cannot be applied in these cases.

Simple solutions to this problem, such as treating all textiles as agriculture-derived, as in Davis et al. (2023), raise serious concerns, given the importance of synthetic fibers in modern textiles and the fact that most sales to final users are of clothing rather than textiles. Relevant activities might be defined, as in Schneider et al.'s (2024) column-share approach, by attributing part of factor employment in adjacent sectors based on the share of their inputs coming from core agrifood sectors. But again, this omits the value added in producing clothing demanded by final users unless the textile and clothing sectors are aggregated. The solution we adopt is to use the forward-linkage approach of Ghosh (1958) and Jones (1976) to estimate the value added in processing agrifood outputs into the final outputs of other sectors. This approach enables us to identify agriculture's contribution to the outputs of nonagrifood sectors and the factors used in their production.

## 2.2 Boundaries of the agrifood sector

A useful way of defining the boundaries of the agrifood sector is to consider individual sectors and commodities from a global input–output database. For this purpose, we used the subsectors of interest shown in Table 1, drawing from the definitions of the detailed list of sectors included in the Global Trade Analysis Project (GTAP) 11 database (see Appendix A.1, Table A1.1). These boundaries do not include the many input-supplying sectors to the agrifood subsectors, which are addressed separately in the analysis.

### Table 1: GTAP subsectors of interest

| Agrifood sectors | GTAP sectors |
|---|---|
| Primary agriculture | 1–14 |
| Food processing | 19–25, 26 (beverages and tobacco) |
| Other manufacturers using agrifood inputs | 27 (textiles), 28 (wearing apparel), 29 (leather products), 30 (wood products), 31 (paper and paper products) |
| Trade and transport margins | 50 (wholesale and retail trade), 55 (warehousing), 52–54 (transport) |
| Food services | 51 (accommodation, food, and services) |

**Source:** Global Trade Analysis Project, www.gtap.org
**Note:** GTAP = Global Trade Analysis Project.

The first question that arises from examination of Table 1 is where to draw the boundaries of the agrifood sector itself. A second question is how to identify the factor inputs embedded in the trade and transport margins on marketing of agricultural products. We address each of these questions in turn in the following subsections.

## 2.3 Which agrifood subsectors to include?

While the primary agriculture subsectors are relatively well-defined, with perhaps the only major controversy being whether to include fishing and forestry, most of the GTAP food processing subsectors—such as those milling rice and producing meat or dairy products—also clearly belong to the broader agrifood sector. Beverages and tobacco rely heavily on agricultural products, many of which are produced on-farm in subsistence economies and later move into the manufacturing sector as agricultural transformation proceeds. Other products, however, such as soda water or sweetened carbonated beverages, may have little or no link to agriculture. Food services are also highly relevant to what is normally considered part of the agrifood sector, but the main challenge is that these are typically (and certainly in the case of GTAP) included within a broader subsector, such as accommodation, food, and services (GTAP Sector 51).

A key question is whether to include the nonfood manufacturing activities that draw heavily on agricultural products 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 textiles (13), leather products (15), wood products (16), and paper (17). The dividing line for textiles is challenging: Some textiles—such as bolts of cotton cloth—rely heavily on agricultural inputs, while others—such as synthetic tire cord—have no tangible link to agriculture. Another problem is that, particularly within 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 important to include wearing apparel as well. But does including activity in the design and manufacture of clothing—or at least the share 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 construction. But does including all or part of the housing sector extend the boundaries of the agrifood sector beyond reasonable limits?

## 2.4 Trade and transport margins

Estimating 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 issues 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 be used as animal feed—these are correctly recorded as intermediate inputs from the transport sector to the agrifood sector. Although these purchases are not allocated to specific inputs, this poses no problem for our analysis, as we are interested in the total trade and transport inputs used in aggregate agrifood production. On the marketing side, however, when trade and transport inputs are used to transfer and/or transform farm products for use by final demanders, they are recorded as direct sales by trade and transport to the final users in any input–output table presented at basic prices. As a result, the link between these trade and transport inputs and sales of agrifood products is lost.

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 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 gap is to use a simple rule, such as assuming that these services are used in proportion to the share of agrifood in total employment, excluding margin services (Davis et al. 2023, p. 11). Alternatively, where data on margin expenditures are available (as in Thurlow et al. 2023), the share of these services in total margin services can be used to apportion factor inputs between those used for agriculture and those used for other activities. For this project, we draw on input–output tables that directly identify the services used to deliver agrifood goods to sources of final demand.

## 3. Data

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; 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 enable tracing structural changes over time. Unfortunately, databases for the vast majority of countries do not provide this level of detail.

Comprehensive coverage is important because of our interest in the evolution of agriculture-related activities with economic development. Detailed disaggregation of the agriculture, forestry, and fishing sectors is important, as 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 because the input structure of hotels is very different from that of food services: The former tends to have much more limited backward linkages with agriculture than the latter. Separating inputs into domestic and imported is important because both forward and backward linkages are primarily associated with the use of domestic inputs (Jones 1976). When a domestically produced input is used, it is important to consider the factors involved in producing 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. When input–output tables are presented at basic prices, these services are treated as being delivered by stand-alone sectors, without identifying which services are associated with delivering final goods to purchasers (Peterson 2006; Peterson and Lee 2009).

Given our interest in global coverage, we sought databases with global coverage. Two promising databases for this exercise were the Global Resource Input Output Assessment (GLORIA) multiregional supply-use 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 separate hotel and restaurant services, and it uses synthetic data for many countries without adequate input–output data.

The GTAP database has been updated roughly every three years since the early 1990s, has a disaggregated agriculture sector, and disaggregates intermediate inputs between domestic and imported sources. It incorporates both developing and developed countries and is based on actual input–output tables obtained from a wide variety of sources. Its main limitation for our purposes is that product flows are measured product flows at basic prices. For example, the 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, with no indication of how much of each margin service is relevant to each aspect of final demand. Like most multiregional input–output tables, it also does not separate hotel and food services.

We ultimately decided to undertake the analysis using the GTAP dataset (Aguiar et al. 2022), with extensive modifications that draw on additional input–output tables collected as part of the GTAP database development exercise. This required allocating trade and transport services to the final demand flows with which they are associated and classifying margins into direct and indirect margin uses, following Corong (2018) and using detailed information from the input–output tables listed in Appendix A.2, Table A2.2. Similarly, accommodation and food service sectors are separated from a set of input–output tables listed in Appendix Table A2.3 that provide this information. In particular, we use detailed production and sales structures from these tables as input to the SplitCom routine (Horridge 2008), which facilitates the disaggregation of GTAP sectors. Appendix A.2 provides further details on these data modifications.

An important feature of the GTAP database for our purposes is its compatibility with the World Bank's GDLD, which provides data on both employment and wages by GTAP sector for skilled and unskilled workers by gender. This, in turn, allows us to estimate the wage rates received by workers in different activities (Jara Nercasseau et al. 2020). Because this dataset is provided with the GTAP database as its organizing framework, it supplies data for the 65 GTAP sectors at a level of disaggregation that allows the variables of interest to be presented by agrifood subsector and aggregated to the overall agrifood sector. The gender dimension of the GDLD database is a vitally important enhancement, and for that reason, we focus on this database in our paper.

## 4. Estimation Procedures

While our primary focus is on the input–output approach, we first investigate the simpler activity approach to enable comparisons. For the activity approach, we first aggregate the value added and employment information for the three subsectors that produce food outputs: agriculture, forestry, and fisheries; food processing; and food services. Then, to capture value added and employment in input sectors, we divide each input sector into two based on the share of total output used as intermediate inputs into the three food subsectors above. For forward linkages, we follow Schneider et al. (2024) in allocating the value added of the using sector in proportion to the share of inputs from agrifood in the total costs of the using sector.

As previously noted, a key feature of the activity approach is that it measures only the resources used in sectors directly proximate to the agrifood sector. For example, if farmers purchase 10 percent of the output of the "chemical" sector in the form of fertilizer and pesticides, the approach attributes 10 percent of the value added in the chemical sector to value added in the agrifood sector. But it ignores value added in sectors such as natural gas, phosphate, and potassium mining that supply inputs to fertilizer production, unless the “chemical” sector is aggregated with those input-supplying sectors. As emphasized by Leontief (1967), this approach to aggregation creates two major problems: (1) It wastes valuable information, and (2) it makes the results vulnerable to arbitrary choices about aggregation.

### 4.1 Identifying direct and indirect factor requirements

Under the input–output approach, we use two procedures to measure the total factor requirements for the production of agrifood products. The first follows Leontief’s (1967) approach 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 use of labor in transforming agricultural goods into nonfood products such as biofuels; textiles and clothing; leather goods; and wood and paper products. In applying this forward-linkage approach, we encounter the problem of limited information about the products with agrifood inputs. Appendix A.2 spells out the proxy procedure used to overcome this limitation.

The input–output approach has a key advantage in addressing the critical problem of aggregation that arises with the activity approach. In the fertilizer case considered above, the Leontief (1967) approach traces value added back—through multiple sectoral linkages if needed—to count the full contribution of resources employed in what Leontief terms the subcontracting sectors to aggregate the sector of interest (Leontief 1967). The Ghosh (1958) approach has a similar advantage in tracing forward linkages through the stages required to measure all the resources used. For instance, if cotton is first ginned to remove seed, then spun into thread, then woven into cloth, and finally sewn into a shirt, the forward linkage approach will capture the value added needed to transform the raw cotton into products for final demand.

### 4.2 Backward linkages: The Leontief approach

When we have information on a clearly defined set of agrifood products, the Leontief (1967) approach for estimating the factor inputs needed to produce them uses an open-economy input–output model. A useful exposition of this model is provided in OECD (2018, p. 162), beginning with two simple equations:

$$x = A^{D}x + f^{D} \tag{1}$$

$$m = A^{M}x + f^{M} \tag{2}$$

where the first equation is the supply–demand balance for domestic goods, and the second is 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; and $f^{D}$ 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 $f^M$ is 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 final demands for domestic goods:

$$x = (\mathrm{I} - A^D)^{-1} f^D \tag{3}$$

where $A^D$ is a matrix showing proportions 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 $n$ domestically produced goods. When—as in our case—the $f^D$ vector under consideration includes only some commodities (with the others represented by zeros), the Leontief matrix $(\mathrm{I} - A^D)^{-1}$ could be partitioned, as in Leontief (1967) and Canning et al (2016), but this is not necessary for our purposes.

Equation (3) allows us to estimate the gross output vector, $x^a$, needed to produce the vector of agrifood final demands, $f^{Da}$.

The matrix of factor demands by sector and factor needed to produce $f^{Da}$ is given by:

$$V^{Da} = V\mathrm{diag}(x^a) \tag{4}$$

where $V^{Da}$ is the $q \times n$ matrix of $q$ factor demands for production of each of $n$ domestic gross outputs needed to produce the final outputs of agrifood products; and $V$ is the matrix of factor demand shares of total output associated with the $n$ vector of gross outputs.

If we use the complete vector of gross outputs for domestic goods, the resulting matrix includes all factor demands in the economy. Because we consider only part of the gross output vector—that is, the final demands for specified agrifood outputs and the margin services used directly to deliver them to final users—the equation yields the matrix of factor inputs used (and, hence, the value added generated) in agrifood production. Where our matrix of direct factor input requirements identifies particular categories of workers (for example, male/female or skilled/unskilled), this matrix identifies the *total* employment and sectors of employment needed to produce the specified agrifood commodities. As in the Leontief model, this procedure captures the value added in both the agrifood sector and 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.

Because the Leontief procedure is applied to measure the resources needed to meet final demand for food products, it omits the value added in agrifood outputs not used in production of final nonfood products. For example, the value added in production of cotton and other outputs that do not contribute to final sales from agrifood is not included in the value added attributed to final outputs from the agrifood sectors. The Leontief procedure estimates that about 92 percent of total value added in agrifood sectors is needed to produce final food products, with the remainder contributing to other final outputs, such as biofuels from corn or clothing from cotton. We can measure the value added directly in production of cotton because it is included in the reported value added for agriculture. But we cannot directly measure the value added in the intermediate inputs used to produce agricultural outputs like cotton. To address this challenge, we scale up the estimate of value added in intermediate inputs used for food production by the ratio of total value added in food-related agricultural output to the total agricultural value added. This makes the reasonable assumption that the intermediate input intensity of nonfood agricultural outputs is, in the aggregate, the same as for the outputs contributing to final demand for food products.

### 4.3 Forward linkages: The Ghosh approach

The Ghosh approach to forward linkages assumes that each sector's output is allocated to different uses in fixed proportions. This assumption contrasts with the Leontief assumption of a fixed share of each input in the gross output of the using sector. The Ghosh procedure starts from primary factor inputs to the agrifood sectors and determines how these affect sectoral outputs and hence demands for factors in other sectors.

In the formal specification of this procedure, we simplify notation by dropping the $^{D}$ superscript, as we focus only on domestic commodity 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 post-multiplying the matrix of intermediate flows by the inverse of *diag(x),* the matrix $B$ is obtained by pre-multiplication, as in:

$$B = (diag(x))^{-1}F \qquad (5)$$

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

The use of the row shares of the input–output matrix in the Ghosh approach is broadly similar to the direct allocation approach of Schneider et al. (2024, Equation 3). They use shares of the gross output of the input sector when considering the share of value added in the input-supplying sectors to be allocated to the agrifood sector. The Ghosh approach has an advantage in tracing impacts through multi-stage production processes, such as fiber–textile–clothing value chains, where later stages, such as clothing, do not directly use outputs from the agrifood sectors. It also avoids a possible ambiguity in the direct approach to allocating shares of the value added in downstream sectors. If, for instance, the textile sector uses 50 percent cotton and 50 percent chemical fibers, should 50 percent of the value added in the textile sector be allocated to agrifood, or should this allocation be based on the likely much smaller share of cotton in the total output value of the textile sector?

The fundamental equation for the Ghosh model is:

$$x' - x'B = v' \tag{6}$$

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 our vector of agrifood value added:

$$x^{a\,\prime} = v^{a\,\prime}(I - B)^{-1} \tag{7}$$

Intuitively, we know that 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 $v^{a\,\prime}$ vector we use covers only the agrifood sector—it measures the gross outputs of all products resulting from the presence of the agrifood industries in the economy, such as clothing output based on agrifood outputs such as cotton. Importantly, in contrast with the Leontief (1967) approach for backward linkages, the Ghosh approach does not require information on the final demand for the goods that embed agrifood inputs to unknown degrees.

The matrix of factors needed beyond the agrifood sector to process the intermediate inputs provided by the agrifood sector to other sectors is then estimated as:

$$V^a = V diag(x^a) \tag{8}$$

## 5. Results

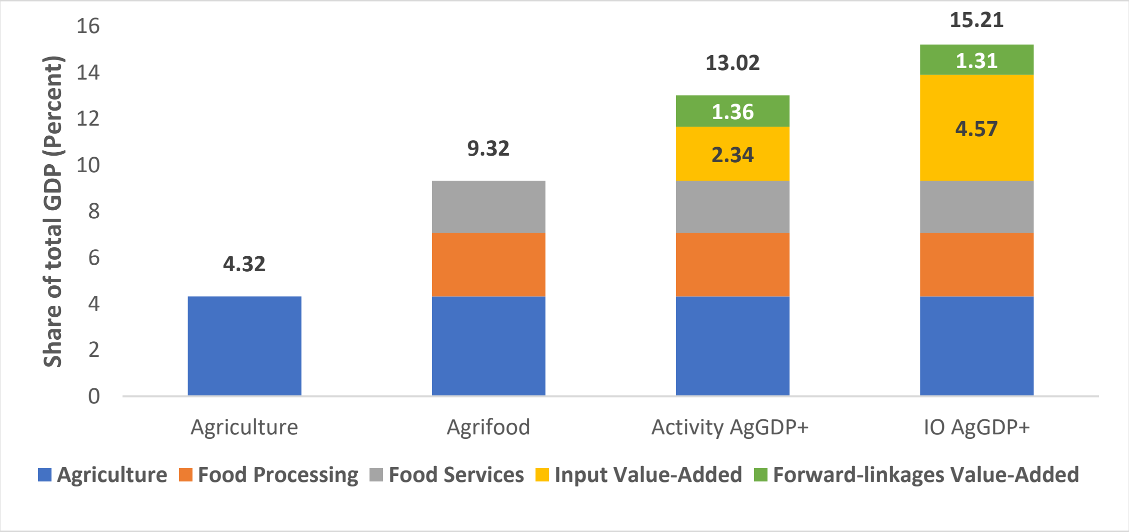
In this section, we first measure total agrifood GDP and then turn to more detailed questions of employment and wages. The sectoral disaggregation used for the analysis and its relationship to the GTAP sectors are given in Appendix A.1. Please note that the reference year for all data presented below is 2017.

### 5.1 Economic importance of the agrifood system

When applying the two approaches using the modified GTAP 11 database, a key finding is that the activity-based measures of the size of the agrifood system substantially underestimate its contribution to the overall economy. The results indicate that, globally, primary agriculture alone accounts for only about 28 percent of total value added in the agrifood system. Figure 1 summarizes the estimates using the activity-based and final-demand (or input–output-based) approaches for the world as a whole.

A first striking finding from Figure 1 is that while agriculture is the foundation of the agrifood system (with agrifood defined to include both food and nonfood components of primary agriculture, along with their linked upstream and downstream segments in other sectors), ignoring the nonfarm segments of the agrifood system leads to gross underestimation of its importance to the overall economy. Applying the activity-based approach—even within the food domain, which dominates the agrifood system—adding food-processing and food services activities more than doubles the economic size of the global agrifood system, to 9.3 percent of global GDP. Including direct intermediate inputs used in agriculture, food processing, and food services (labeled as Activity AgGDP+ in Figure 1) raises the share of global GDP to 11.6 percent. Accounting for the indirect value added by downstream or forward linkage activities involving nonfood outputs from agrifood further raises the agrifood contributions to nearly one-sixth of the global economy (13.0 percent). As previously noted, using the HEM approach of Duarte et al. (2002) yields very similar results to the approach applied in this paper.

**Figure 1: Size and components of the global agrifood system in 2017**



**Source:** Authors' estimations based on the GTAP 11 database.
**Note:** Activity AgGDP+ = GDP in Agrifood plus a share of GDP in direct input-supplying or direct using activities ; IO AgGDP+ = GDP in Agrifood plus backward and forward linkage GDP

Exploiting the full information contained in the input–output tables provides further insights into the agrifood system's indirect contributions to the economy (labeled as IO AgGDP+ in Figure 1). An important contribution of this approach is its ability to better measure 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. Accordingly, we estimate that the agrifood system contributes almost one-sixth (15.2 percent) to global GDP. The estimates further indicate that—at 4.6 percent of global GDP—the value added by intermediate inputs outweighs the value addition in either the food-service or the food-processing sectors alone. Strikingly, it is slightly higher than the value created on-farm itself.

A second important contribution of the final-demand approach is capturing the typically ignored (or grossly mismeasured) contribution of nonfood products from agriculture that serve as essential inputs for the production of nonfood goods demanded by consumers. Typically, accessible national accounts data, as summarized in input–output tables, do not provide separate estimates of final demands for agrifood-based nonfood products such as biofuels, cotton clothing, leather goods, and wooden houses. These products are usually subsumed under broader aggregates such as textiles, clothing, and fuels. Without estimates of final demands for these goods, we cannot use the Leontief approach to estimate their contributions to overall value added and employment. The alternative used in this paper is the Ghosh (1958) approach, which helps identify forward linkages for agrifood products used as intermediate inputs to other (nonfood-related) sectors. Applying this approach suggests that another 1.3 percent of the world economy is accounted for by nonfood-forward linkages through the rest of the economy.

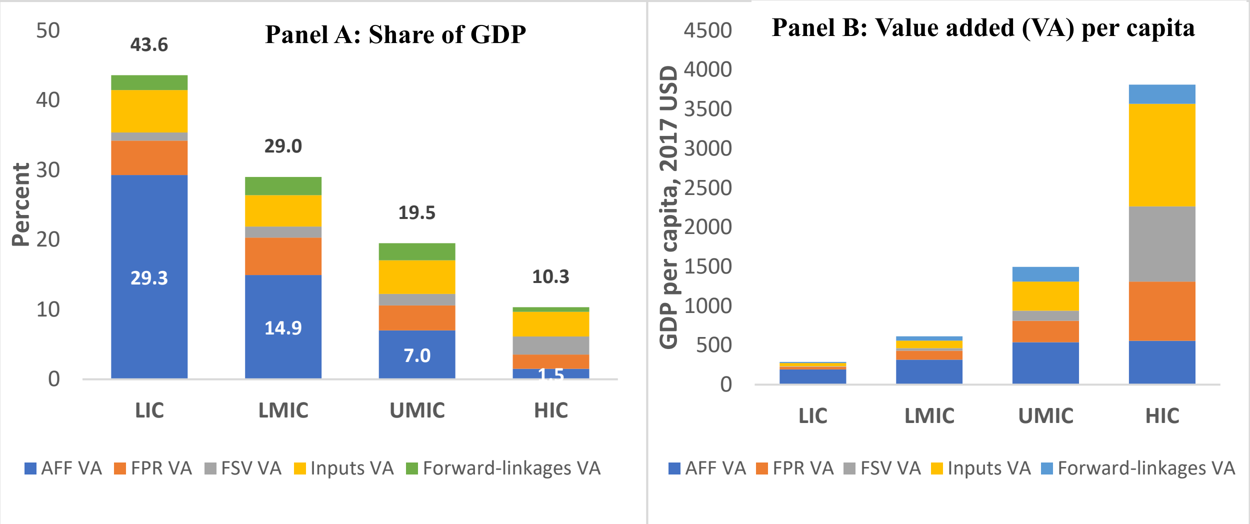
The result using the Ghosh approach is slightly smaller than the 1.4 percent of world output measured with the activity approach. This is likely because we used a relatively aggregated 11-sector classification for ease of computation as we developed the methodology applied for this study. Had we instead used the full 65 sectors available in the GTAP input–output tables, the activity-based estimate may have been lower because only the resources used in the first post-farm activity would have been counted. For the plant-based fibers, for example, this would have meant counting the resources used in the textile sector but not those used in the clothing sector. The input–output approach used in the Ghosh estimate is likely to be much more robust to differences in aggregation than the activity approach.

Caution is needed when comparing results in Figure 1 with those from other studies, as both the underlying data and the methodologies used differ. Nevertheless, it is reassuring that the 13.1 percent of global GDP estimated using the activity approach is very close to the 12.6 percent of global GDP reported by Thurlow et al. (2023, p. 7). The 15.2 percent estimate obtained using the input–output approach is close to the 15.5 percent reported by Schneider et al. (2024), despite their use of the activity approach.

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 a country's average income level, from an average of about 29 percent in low-income countries (LICs) to an average of 1.5 in high-income countries (HICs). When the broader agrifood-system-related activities are taken into account, the downward trend still holds, but even in HICs, a substantial share—more than 10 percent on average—of the overall economy depends on the agrifood system. This figure is significantly higher than the 1.5 percent for the primary agricultural economy alone and perhaps explains 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 diminishing importance of the food system. Quite to the contrary, Panel B of Figure 2 shows agrifood GDP per capita at different income levels in 2017 prices. 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 about US$290 per capita in LICs to more than US$3,800 in HICs—a more than 13-fold increase.

**Figure 2: Size and structure of the agrifood system by income level, 2017 data**



Panel A: Share of GDP

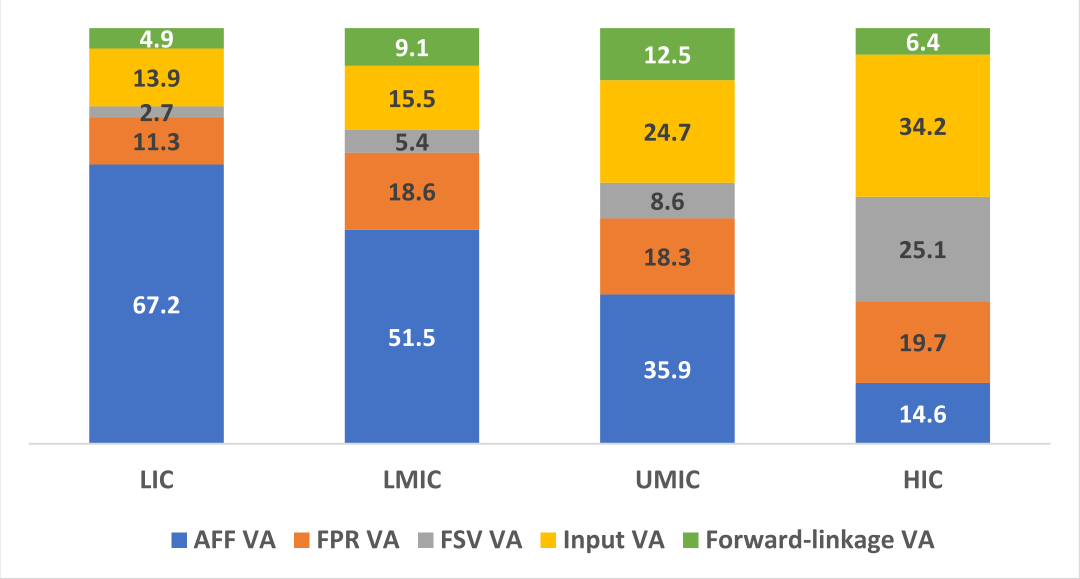
Panel B: Value added (VA) per capita

**Source:** Authors' estimations based on the GTAP 11 database.
**Note:** Country income groups follow the World Bank income classification, with LICs = low-income countries; LMICs = lower-middle-income countries; UMICs = upper-middle-income countries; and HICs = high-income countries. VA = value added. Contributing activities are grouped as AFF = agriculture, fisheries, and forestry; FPR = food processing; FSV = food services; inputs = an aggregate of all intermediate inputs; and forward linkages = all downstream activities along the nonfood value chains linked to agrifood inputs.

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 increasingly nonfarm, or manufacturing- and services-based, in lower-middle-income countries (LMICs), upper-middle-income countries (UMICs) and HICs. This is shown more clearly in Figure 3, which depicts the shares of each component within the agrifood system by income category (in contrast to Panel A in Figure 2, which shows them as shares of the overall economy).

As expected, the share of primary agriculture within the agrifood system itself falls sharply with income, to a low of 14.6 percent on average 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 and the sharp increase in the importance of restaurants and food establishments as food away from home and prepared foods become more prominent with rising incomes. Another important insight is the dramatic increase in the role of input–supplying industries with rising income levels; they account for the largest share of the agrifood economy in HICs. Interestingly, while nonfood processing and downstream value addition rise with income levels from LICs to LMICs to UMICs, they fall sharply in HICs. This may reflect the globalization of these mainly labor-intensive sectors, which have largely 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 (percentage shares of agrifood system GDP)**



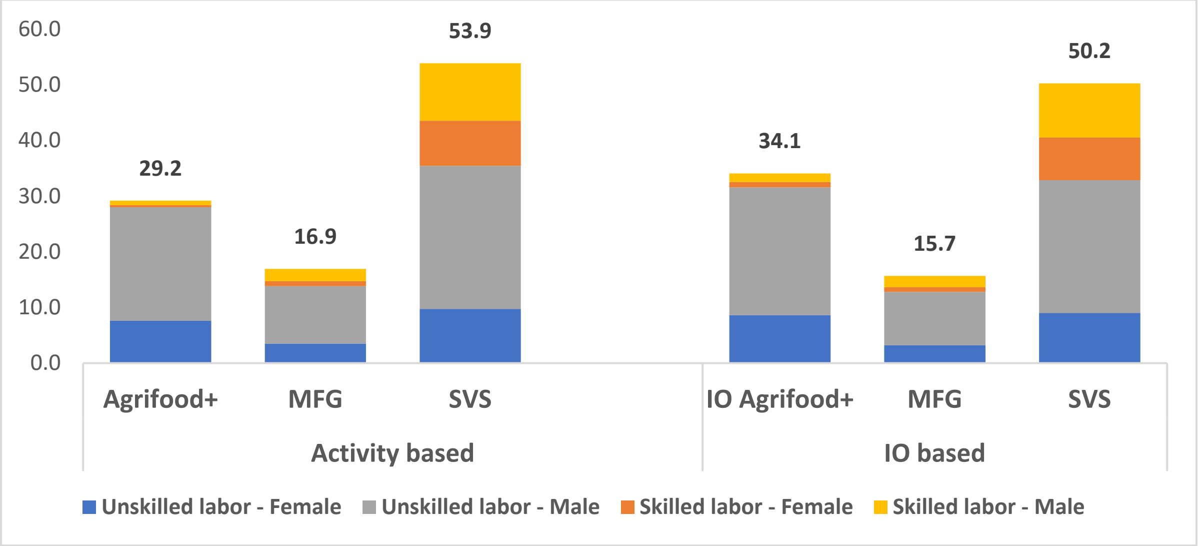
**Source:** Authors' estimations based on the GTAP 11 database.
**Note:** See Figure 2 for an explanation of the abbreviations.

## 5.2 Employment, wage gaps, and job quality across the agrifood system

As previously noted, the analysis in this section draws on the GDLD database (Jara Nercasseau et al. 2020) to identify the share of total labor employment by gender and skill level (unskilled and skilled) in each sector. This unique database, aligned with the 2017 sectoral data in the GTAP 11c database, is built from more than 2,000 household and labor force surveys—including surveys that report wages paid to farmworkers—and provides an unprecedented opportunity to conduct cross-country analyses of both the quantity and quality of jobs. In the GDLD, unskilled workers are defined as those with fewer than nine years of education, and skilled workers as those with nine years or more. While this cutoff is necessarily arbitrary, it is applied consistently across countries.

Figure 4 shows the share of the total global labor force, by gender and skill level, in the agrifood system relative to employment in manufactures and services. The first three stacked columns present activity-based estimates of employment in agrifood compared with employment in manufacturing and services. The last three columns show the input–output-based estimates for the same breakdown, capturing the full direct and indirect employment generated in meeting final food and nonfood demands for agrifood products. Accounting for intermediate inputs used in the agrifood system raises the input–output-based estimates of employment in agrifood and correspondingly reduces the estimates for manufacturing and services. Unskilled labor, particularly unskilled male labor, dominates across all estimates. The agrifood system is clearly a major employer of unskilled labor, but an even greater share of unskilled labor, both male and female, is in the services sector. The majority of the skilled labor force, male and female alike, is also engaged in services, reflecting the heterogeneity of this broadly defined sector. The next highest shares of skilled workers are in the agrifood system and manufacturing.

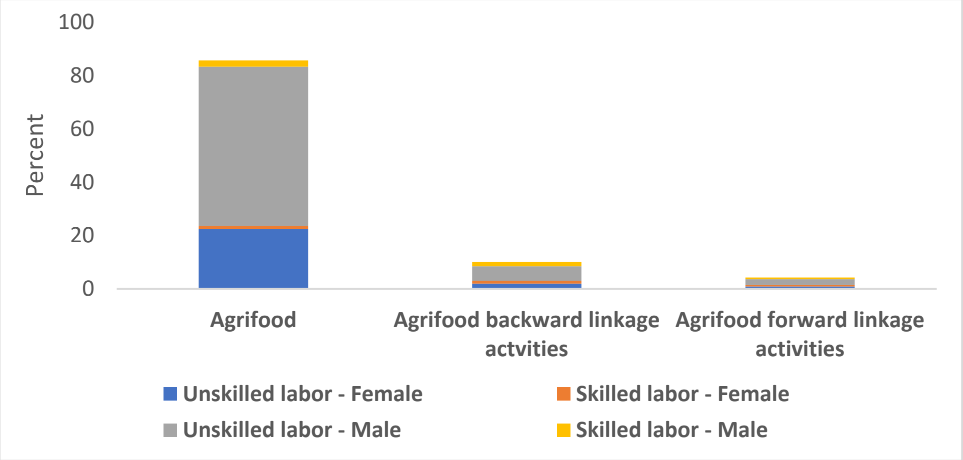
**Figure 4: Share of global agrifood employment by gender and skill level, according to activity- and input–output-based measurements, 2017**



**Source:** Authors' estimations based on the GTAP 11 and GDLD databases.
**Note:** Agrifood+ and IO [input–output] Agrifood+ = total agrifood system; MFG = manufacturing; SVS = services.

Within the agrifood system, the composition of employment in the agrifood sectors (agriculture, food processing and food services), and through their forward and backward linkages is shown in Figure 5. Agrifood employment is heavily concentrated on-farm, much of it consisting of unskilled male labor. Most employment generated by forward and backward linkages is in agrifood backward linkage activities associated with meeting the final demand for food products, which account for 10.1 percent of total agrifood employment, followed by forward linkage activities associated with nonfood products, which employ about 4.3 percent of agrifood workers. The shares of skilled workers, both male and female, are considerably higher in nonfarm activities than in primary agriculture. Nevertheless, skilled workers still account for only a minor share of total employment in food and nonfood value chains.

**Figure 5: Distribution of global agrifood employment across farm and nonfarm segments, 2017 (percentage of total labor force)**



**Source:** Authors' estimations based on the GTAP 11 and GDLD databases.

A key finding of the analysis is that nonfarm parts of the agrifood sector provide much better-paid jobs, especially for female workers. As expected, across all sources of employment—including on-farm jobs where the few skilled workers are concentrated, skilled workers command a substantial wage premium over unskilled workers, as shown in Figure 6. The figure compares wages for unskilled and skilled male and female workers in primary agriculture; in agrifood (a weighted average of agriculture, food processing, and food services); and in intermediate inputs and downstream activities of the food and nonfood segments of the food system. Nonfarm activities, both food- and nonfood-related, pay considerably higher average wages than the agrifood system and notably higher than primary agriculture.

**Figure 6: Average wage by gender and skill level in the agrifood system, 2017 (US$ per worker, per year)**

**Source:** Authors' estimations based on the GTAP 11 and GDLD databases.

An indicator of job quality for female workers is the wage premium earned by male workers relative to their female counterparts. Table 2 reports these wage premia by skill level and segment of the agrifood sector where the workers are employed. The highest premium is among unskilled farmworkers, with men earning a substantial 45 percent more than women. For skilled farmworkers, the premium is lower but still sizeable at 25 percent. A wage gap persists when considering the agrifood system, with food processing and food services included, though it is considerably smaller for both skilled and unskilled workers. Gender disparities are also narrower in the backward linkage activities providing inputs to agrifood and the forward linkage activities transforming agrifood outputs like cotton and timber into nonfood products (the last two columns of Table 2). These findings suggest that facilitating off-farm agrifood employment opportunities helps create better-paid jobs for both skilled and unskilled workers, but especially for female workers in both categories.

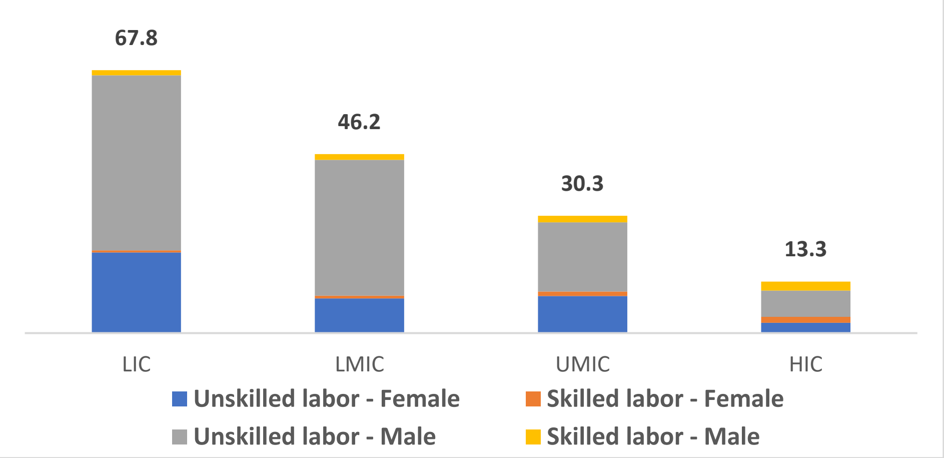
**Table 2: Wage premia for male workers relative to female workers**

| Skill level | Agriculture | Agrifood | Agrifood backward linkage activities | Agrifood forward linkage activities |
|---|---|---|---|---|
| Unskilled | 1.45 | 1.24 | 1.28 | 1.24 |
| Skilled | 1.25 | 1.10 | 1.14 | 1.11 |

**Source:** Authors' estimations based on the GTAP 11 and GDLD databases. Note: Agrifood backward linkage activities refer to the labor used in producing inputs to agrifood final outputs. Agrifood forward linkage activities refer to labor used to transform agrifood products like cotton into nonfood outputs such as textiles.

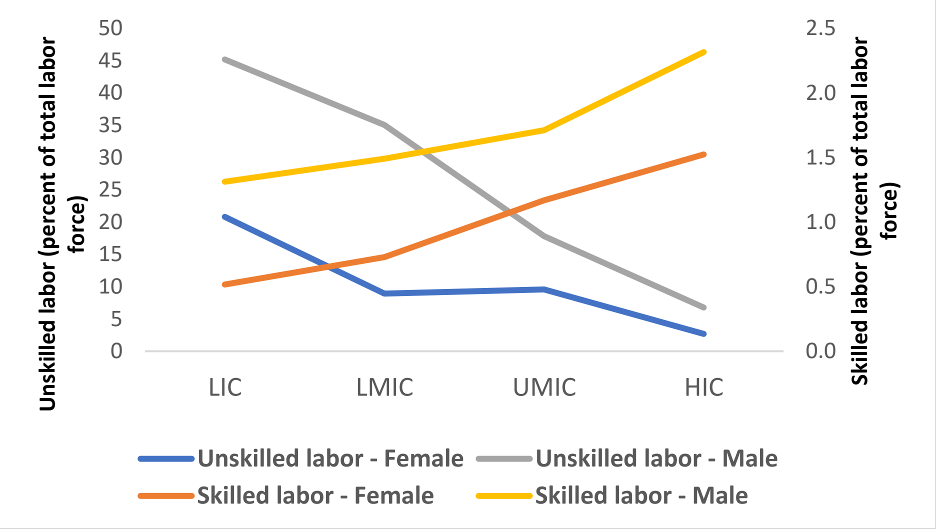
We turn next to changes in the agrifood system labor force with overall economic development. Figure 7 shows a substantial exit of workers from the agrifood sector as they transition to nonagrifood-related activities in other sectors. Within this broad trend are also changes in the composition of the agrifood labor force itself (Figure 8). This is seen in the sharp decline in the share of unskilled workers (in the total labor force) employed in 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 transition more rapidly between the LMIC and UMIC stages. At the same time, the shares of skilled workers rise consistently 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 emerge 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 LMIC and UMIC stages, before slowing again. The increase in skilled male workers in the agrifood system is progressively faster, with the largest increase occurring between UMIC and HIC.

**Figure 7: Share of agrifood workers in total labor force by income level**



**Source:** Authors' estimations based on the GTAP 11 and GDLD databases.
**Note:** The abbreviations for country income groups are defined in Figure 2.

**Figure 8: Shares of skilled and unskilled workers by gender and country income level**



**Source:** Authors' estimations based on the GTAP 11 and GDLD databases.
**Note:** The abbreviations for country income groups are defined in Figure 2.

Finally, trends in job quality by income level in the food segments of the agrifood system are shown in Figure 9. The trends for the nonfood segments are similar and therefore not presented here for brevity. The figure illustrates how 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. Male workers receive significantly higher wages at all income levels, with the notable exception of skilled workers in LICs. The GDLD data show that female workers earn relatively higher wages than male workers, bucking the trend for all other income levels and for both skilled and unskilled workers.

**Figure 9: Wage levels by gender, skill, and country income level, 2017 (US$ per worker, per year)**

**Source:** Authors' estimations based on the GTAP 11 and GDLD databases.
**Note:** The abbreviations for country income groups are defined in Figure 2.

## 6. Summary and Conclusions

It is well-known that the share of agriculture in economic activity and employment declines dramatically during economic growth and development. Part of this decline, however, reflects structural transformation, under which many activities move off-farm as economic agents specialize and processes become more complex. An important question in this context 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 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, assessments of the magnitude of the agrifood sector cannot be done by simply aggregating the output values of the sectors involved in producing these goods, as this would result in substantial double counting. For instance, the output value of wheat would be counted at least three times—once as raw wheat, once as milled wheat flour, and once as wheat flower used in bread or pasta. Double counting can be avoided by focusing on the value added at each production stage of the agrifood value chain. Applying this approach is straightforward for production segments that generate recognizable agrifood products, such as agriculture, food processing, and food services. It becomes more challenging when dealing with inputs—such as inorganic fertilizers—that clearly contribute to agricultural production but whose economic activity is generally attributed to other sectors (for example, the chemical industry) that generate many other products. Similar measurement difficulties also arise for agrifood outputs such as cotton that contribute to nonfood outputs like clothing. Capturing the contribution of nonfood outputs to the agrifood system's GDP and employment is particularly challenging when working with relatively aggregated input–output data that combine output of textiles and clothing that may be produced from synthetic or natural fibers (or both).

To address these challenges, we used approaches that rely heavily on input–output methods. 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 nonfood agricultural outputs such as clothing and textiles, we used an approach developed by Ghosh (1958) and Jones (1976) to measure the value added from processing agrifood outputs such as cotton into these final products. We contribute to the existing literature by combining the backward and forward linkage approaches, thereby also capturing the nonfood contributions to the economic value of the agrifood system. Our preferred input–output approach yields larger estimates of agrifood GDP than activity-based approaches using the same data. The estimate of 15.2 percent of global GDP is higher than that of Thurlow et al (2023) and slightly lower than the Schneider et al. (2024) estimate of 15.5 percent.

We apply this approach using an extended version of the GTAP 11 database for 2017. Two key adaptations to the database were (1) disaggregation of the composite accommodation and food services sector to focus on food services alone, and (2) transformation of the data on final demands 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. Another important innovation in our analysis is the use of the World Bank's GDLD database to identify employment and job quality by gender and skill level and align these measures with agrifood system GDP.

The empirical application of our approach yields a substantially larger global agrifood sector than estimated through other methods. At a global level, we estimate that total agrifood GDP is close to four times that of primary production in agriculture, forestry, and fishing. This ratio is larger than the factor of three found by, for instance, Thurlow et al. (2022) using an "activity approach." Replicating the activity approach with our dataset also yields an estimate of around three. By including agrifood-related production of nonfood final goods such as cotton textiles and clothing using the Ghosh approach, we arrive at a global estimate that the agrifood system contributes nearly one-sixth (15.2 percent) to the global economy.

Notwithstanding the difference in the estimation of the total size of the agrifood system, our results confirm the key finding of other related studies: The share of agricultural GDP declines relative to total agrifood value added as incomes rise and more activity moves off-farm, and the share of the agrifood system in total GDP falls with increasing levels of economic development.

A further contribution of this paper is the gender- and skill-disaggregation of total employment in the agrifood sector. Our findings show that, under our broad definition, the agrifood system generates one-third of overall employment. Most of this employment remains on-farm, reflecting the still-large agricultural workforces in populous low-income countries. Farm employment is dominated by unskilled male labor. With the development of off-farm activities and rising average incomes, however, the share of farm employment declines in favor of better-paid nonfarm jobs in the agrifood sector, which are more accessible to women and require higher skill levels. As a result, wage gaps between men and women in the agrifood sector narrow with the development of agrifood value chains. This indicates that agrifood system development and integration has the potential for reducing poverty and inequality.

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## Appendix A.1 Sector Detail

Our analysis was conducted using an 11-sector aggregation of the GTAP 11 database, as documented in Aguiar et al. (2022).

**Table A1.1: Sectors used for the analysis**

| No. | Code | Description |
|---|---|---|
| 1 | AFF | Agriculture, Forestry and Fisheries |
| 2 | FPR | Food processing |
| 3 | NPR | Non-food processing |
| 4 | EXT | Other mining |
| 5 | MFG | Heavy manufacturing |
| 6 | ACM | Accommodation |
| 7 | FSV | Food services |
| 8 | TRD | Trade and Warehousing |
| 9 | TRN | Transport |
| 10 | SVS | Services - all |
| 11 | ENE | Energy/extractives (other than oxt) |

**Table A1.2: The relationship between these sectors and the GTAP sectors**

| No. | Code | Description | Concordance |
|---|---|---|---|
| 1 | pdr | Paddy rice | AFF |
| 2 | wht | Wheat | AFF |
| 3 | gro | Cereal grains not elsewhere classified (nec) | AFF |
| 4 | v_f | Vegetables, fruit, nuts | AFF |
| 5 | osd | Oilseeds | AFF |
| 6 | c_b | Sugarcane, sugar beet | AFF |
| 7 | pfb | Plant-based fibers | AFF |
| 8 | ocr | Crops nec | AFF |
| 9 | ctl | Bovine cattle, sheep and goats, horses | AFF |
| 10 | oap | Animal products nec | AFF |
| 11 | rmk | Raw milk | AFF |
| 12 | wol | Wool, silkworm cocoons | AFF |
| 13 | frs | Forestry | AFF |
| 14 | fsh | Fishing | AFF |
| 15 | coa | Coal | ENE |
| 16 | oil | Oil | ENE |
| 17 | gas | Gas | ENE |
| 18 | oxt | Other extraction (formerly omn minerals nec) | EXT |
| 19 | cmt | Bovine meat products | FPR |
| 20 | omt | Meat products nec | FPR |
| 21 | vol | Vegetable oils and fats | FPR |
| 22 | mil | Dairy products | FPR |
| 23 | pcr | Processed rice | FPR |
| 24 | sgr | Sugar | FPR |
| 25 | ofd | Food products nec | FPR |
| 26 | b_t | Beverages and tobacco products | FPR |
| 27 | tex | Textiles | NPR |
| 28 | wap | Wearing apparel | NPR |
| 29 | lea | Leather products | NPR |
| 30 | lum | Wood products | NPR |
| 31 | ppp | Paper products, publishing | MFG |
| 32 | p_c | Petroleum, coal products | MFG |
| 33 | chm | Chemical products | MFG |
| 34 | bph | Basic pharmaceutical products | MFG |
| 35 | rpp | Rubber and plastic products | MFG |
| 36 | nmm | Mineral products nec | MFG |
| 37 | i_s | Ferrous metals | MFG |
| 38 | nfm | Metals nec | MFG |

| **No.** | **Code** | **Description** | **Concordance** |
|---|---|---|---|
| 39 | fmp | Metal products | MFG |
| 40 | ele | Computer, electronic, and optical products | MFG |
| 41 | eeq | Electrical equipment | MFG |
| 42 | ome | Machinery and equipment nec | MFG |
| 43 | mvh | Motor vehicles and parts | MFG |
| 44 | otn | Transport equipment nec | MFG |
| 45 | omf | Manufactures nec | MFG |
| 46 | ely | Electricity | MFG |
| 47 | gdt | Gas manufacture, distribution | MFG |
| 48 | wtr | Water | MFG |
| 49 | cns | Construction | SVS |
| 50 | trd | Trade | TRD |
| 51 | acm | Accommodation* | ACM |
| 52 | res | Restaurants* | FSV |
| 53 | otp | Transport nec | TRN |
| 54 | wtp | Water transport | TRN |
| 55 | atp | Air transport | TRN |
| 56 | whs | Warehousing and support activities | TRD |
| 57 | cmn | Communication | SVS |
| 58 | ofi | Financial services nec | SVS |
| 59 | ins | Insurance (formerly isr) | SVS |
| 60 | rsa | Real estate activities | SVS |
| 61 | obs | Business services nec | SVS |
| 62 | ros | Recreational and other services | SVS |
| 63 | osg | Public administration and defense | SVS |
| 64 | edu | Education | SVS |
| 65 | hht | Human health and social work activities | SVS |
| 66 | dwe | Dwellings | SVS |

**Note:** * Split from accommodation, food, and services in the GTAP dataset.

## Appendix A.2 GTAP Data Processing

The initial GTAP input–output tables assume that intermediate and final users buy services such as transportation and wholesale and retail trade without any connection to particular goods. In this format, a consumer who buys a dozen eggs is treated as making two separate purchases: the eggs themselves, valued at their farmgate price, and the services involved in transforming them into the consumer-ready product. This approach fails to distinguish between (1) domestic margin services associated with delivering goods (for example, the eggs and the trade and transport services between farm and store) and (2) direct purchases of similar services unrelated to purchases of agrifood commodities (for example, a bus fare to visit relatives in the city). For our purposes—measuring the full agrifood sector—this is problematic, since the margin services required to deliver a carton of milk to a consumer are essential to the agrifood sector, while a bus fare is not.

Following Corong (2014; 2018), the margin component associated with delivering commodity inputs is first determined in Equation (A2.1) using the share of margin, $m$, in total margin use for each intermediate and final user, $u$, in the economy. This calculated margin component is then deducted from the vector of total domestic margin purchases in the original input–output table ($ORIGUSE_{m,"dom",u}$) as shown in Equation (A2.2), thereby leaving direct purchases of margins in the revised Use table. The matrix detailing the amount of trade and transport margins required to deliver a unit of commodity, $c$, to each intermediate and final user, $u$, from either domestic and imported sources, $s$, is calculated in Equation (A2.3) by prorating the value of margin sales to the value of purchases by all intermediate and final users. Note that we assume that margins used to deliver commodities are domestically produced and cannot be imported. Therefore, delivering imported goods from a country's port of entry to all domestic users will require the use of domestically produced trade and transport margin commodities.

$$MARGINMU_{m,u} = marshare_{m} * INITUSE_{m,"dom",u} \tag{A2.1}$$

$$USE_{m,"dom",u} = ORIGUSE_{m,"dom",u} - MARGINMU_{m,u} \tag{A2.2}$$

$$Margin_{c,s,u,m} = MARGINMU_{m,u} * \frac{USE_{c,s,u}}{\sum_{c,s} USE_{c,s,u}} \tag{A2.3}$$

The accommodation and food service sectors were separated from the set of input–output tables listed in Appendix Table A2.3. In particular, detailed production and sales structures are used as weights to the SplitCom (Horridge 2008) routine, which is publicly available and facilitates the disaggregation of GTAP sectors. As shown in Appendix Figure A2.1, the file SPLITSEC.har is created by SplitCom once the original GTAP sector to be disaggregated is identified (that is, accommodation and food services, afs), and the names of new sectors to be created have been specified (that is, acm and res, representing accommodation and restaurants, respectively). The USERWGT.HAR file is then populated with information on either production or sales shares of acm and res from the 41 countries detailed in Appendix Table A2.3, while the average acm and res shares from these 41 countries are applied to the remaining GTAP countries/regions. After these two steps, the SPLITBAT.BAT routine is executed to run the various SplitCom programs and generate a new database with acm and res sectors disaggregated from the original afs sector.

## Table A2.2: Input–output tables with detailed trade and transport margins

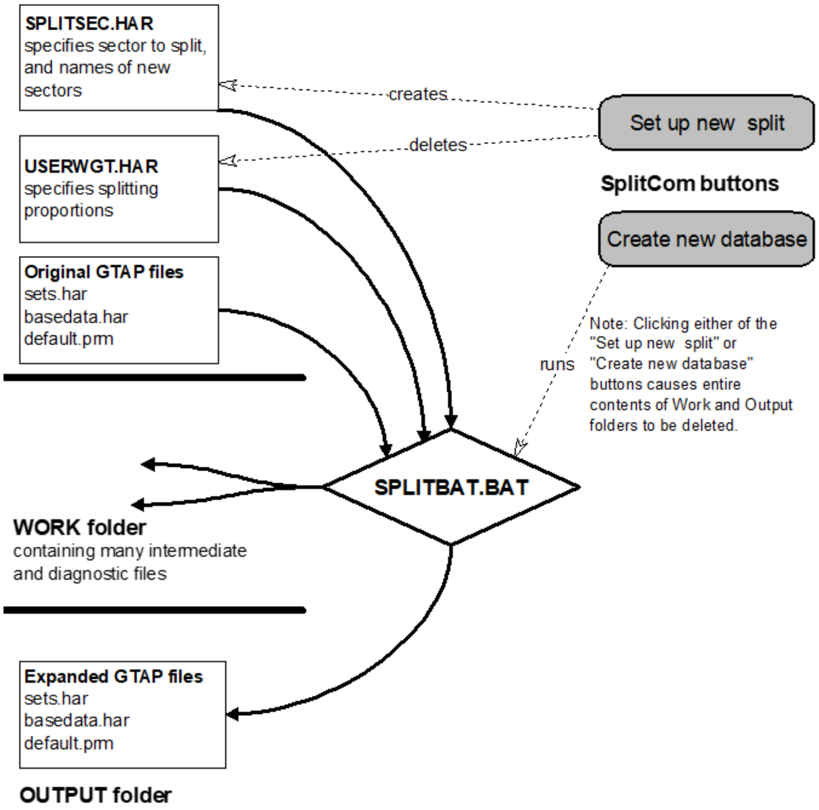
| | | |
|---|---|---|
| 1 | aus | Australia |
| 2 | nzl | New Zealand |
| 3 | jpn | Japan |
| 4 | mng | Mongolia |
| 5 | usa | United States of America |
| 6 | aut | Austria |
| 7 | bel | Belgium |
| 8 | bgr | Bulgaria |
| 9 | cze | Czechia |
| 10 | dnk | Denmark |
| 11 | est | Estonia |
| 12 | fin | 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 A2.3: 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 |

**Figure A2.1: SplitCom routine**



**Source:** Horridge (2008).

## Appendix A.3 Derivation of Backward and Forward Linkages

In the equation below, we verify the matrix operations used to derive the backward and forward linkages between sectors of the economy. While we build on the approach used in OECD (2018), we adapt it here to identify the total resources needed for the agrifood sector and where these resources are employed.

***Backward linkages***

We use a 2 × 2 example to identify the matrix operations that yield the desired results. The Leontief equation is:

(A3.1)

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

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, which ensures the correct dimensionality later. However, the elements do not yield the results we want. Diagonalizing *y* gives 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 it addresses a different question from the one we want to solve—how much total output of $x_1$ will rise as a consequence of demands for both elements of *y*. To obtain this, we keep *y* as a vector at the first step and derive the gross output vector: $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$.

To reach the answer we want, the diagonalization must occur at the next stage, where we pre-multiply a diagonalized *x* vector by the factor shares to obtain factor use by sector and factor:

$$\text{A3.2} \qquad \begin{bmatrix} v_{11} & v_{21} \\ v_{12} & v_{22} \end{bmatrix} = \begin{bmatrix} s_{11} & s_{21} \\ s_{12} & s_{22} \end{bmatrix} \begin{bmatrix} x_1 & 0 \\ 0 & x_2 \end{bmatrix} = \begin{bmatrix} s_{11}x_1 & s_{12}x_2 \\ s_{12}x_1 & s_{22}x_2 \end{bmatrix}$$

***Forward linkages***

The critical equation for this approach is:

$$\text{(A3.3)} \qquad x' - x'B = v'$$

The logic of this equation becomes evident when recalling the definition of *B*. In the 2 × 2 case, Equation (A3.3) is:

$$x' - x' \begin{pmatrix} \frac{1}{X_1} & 0 \\ 0 & \frac{1}{X_2} \end{pmatrix} \begin{pmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{pmatrix} = v' \tag{A3.4}$$

or

$$x' - (x_1 \quad x_2) \begin{pmatrix} \frac{F_{11}}{x_1} & \frac{F_{12}}{x_1} \\ \frac{F_{21}}{x_2} & \frac{F_{22}}{x_2} \end{pmatrix} = v'$$

(A3.5)

or

$$(X_1 \quad X_2) - (F_{11} + F_{21} \quad F_{12} + F_{22}) = V', \tag{A3.6}$$

which explains the posited relationship.

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