The Food Problem in an Open Economy

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Abstract

This paper investigates how openness to trade reshapes our understanding of the Food Problem—the persistent specialization of low-income countries (LICs) in low labor-productivity agriculture. In closed-economy settings, these patterns are attributed to low agricultural TFP and to demand-side forces consistent with Engel's Law, which sustain high agricultural prices and a high labor-to-land ratio. The Food Problem is thus expected to ease with higher agricultural TFP or with trade openness through cheaper agricultural imports. I revisit these implications using a quantitative model of structural transformation and international trade. On the supply side, I infer relative TFPs from trade flows and a production technology that incorporates land. In this setting, the coexistence of low labor productivity and a high labor–land ratio in LICs implies relatively high agricultural TFP. On the demand side, I estimate income and substitution elasticities in an open economy. I perform counterfactual simulations to assess whether trade openness or higher agricultural TFP lowers agriculture's labor share in LICs, as predicted in the closed-economy literature. The results show the opposite: trade openness reinforces LICs' specialization in agriculture while higher agricultural TFP expands the sector by increasing its competitiveness.

Keywords: Food Problem; International Trade; Comparative Advantage; Structural Transformation; Agricultural Productivity; Land Endowments

JEL codes: F11, F16, L16, O13, O19, Q17

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1 Introduction

The "Food Problem" (Schultz, 1953) refers to the situation where Low-Income Countries (LICs) with low agricultural labor productivity allocate a large share of their workforce to agriculture to meet basic subsistence needs. Conventional explanations attribute this pattern to low agricultural Total Factor Productivity (TFP) and demand factors consistent with Engel's Law, whereby the share of income devoted to subsistence goods is larger at low income levels. Yet these analyses overlook the fact that most economies are open. With trade, domestic demand plays a smaller role in shaping specialization patterns. Despite this, LICs remain heavily specialized in agriculture. Understanding the Food Problem in an open economy remains a central challenge for development.

This paper investigates how openness to trade reshapes our understanding of the Food Problem and quantifies the mechanisms driving agricultural specialization in low-income countries. To do so, I develop and calibrate a general-equilibrium trade model that incorporates structural transformation.

The contribution of the paper is threefold. First, I show that once land is accounted for as a fixed factor in agriculture, LICs exhibit a high relative agricultural TFP, which explains the coexistence of relatively low labor productivity and a relatively high labor-to-land ratio. Second, I estimate income and substitution elasticities in an open-economy context with diminishing returns in agriculture, using the Non-Homothetic Constant Elasticity of Substitution (NHCES) demand system of Comin et al. (2021). Third, I combine the theoretical model and empirical estimates to conduct counterfactual simulations that assess the effects of trade openness and sectoral productivity on agricultural employment. While closed-economy models predict that trade or agricultural TFP growth should reduce agricultural labor shares, I find the opposite. In low-income countries, both openness and improvements in agricultural TFP reinforce agricultural specialization.

The theoretical framework underlying these results is a multi-country, multi-sector general equilibrium model of trade that captures how openness interacts with sectoral productivity, factor endowments, and consumption patterns to shape agricultural specialization. The model incorporates three central elements. First, non-homothetic preferences (Comin et al., 2021), potentially capturing the subsistence nature of agricultural consumption as income changes. Second, input–output linkages across sectors and countries, as in Caliendo and Parro (2015), allowing productivity and trade costs in one sector to transmit effects across sectors. Third, land as a fixed factor specific to agriculture, generating diminishing returns to labor in that sector, and thus an upward-sloping supply curve. The model also features Armington differentiation, with trade in both final and intermediate goods subject to iceberg trade costs.

I use cross-country data on production, trade, and factor endowments to estimate and calibrate the structural parameters that discipline the model and connect its mechanisms to observed patterns of sectoral specialization. The analysis draws on Organization for Economic Co-operation and Development (OECD) Inter-Country Input–Output (ICIO) tables and Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) data on agricultural employment and land use. The sample spans the development spectrum and includes 69 countries, accounting for over 80 percent of the world's population, together with a rest-of-world aggregate, across three broad sectors: agriculture, industry, and services.

The first step of my empirical strategy focuses on the supply side. I estimate revealed relative productivity from observed trade flows. This estimation incorporates both intermediate input linkages and land as a fixed factor in agriculture, as informed by the model. My strategy builds on Costinot et al. (2012). Their framework links observed trade flows to sectoral productivity but does not account for input linkages or fixed factors. My modification substantially alters relative productivity patterns by capturing cross-country differences in factor endowments. Omitting land as a factor of production can be misleading when comparing sectoral productivity across countries. Countries with scarce land and abundant agricultural labor, such as most LICs, may appear relatively more productive in non-agricultural sectors. By explicitly accounting for these endowment differences, the analysis reveals that LICs actually exhibit higher relative TFP in agriculture. Input–output linkages then propagate these effects throughout the economy.

In the second step, I turn to the demand side of the model. Trade openness alters the two main mechanisms shaping structural transformation in a closed economy: it changes relative price effects and decouples domestic production from expenditure patterns. To quantify the role of these mechanisms under openness, I discipline the demand-side channels by estimating the substitution and income elasticities of the non-homothetic CES demand system. I first construct sector-level relative prices by combining trade flows, input–output linkages, and the recovered productivity differences from the supply-side analysis above. I then estimate demand elasticities using an instrumental-variables strategy that exploits movements in sector-level TFP as instruments for relative price changes, assuming that TFP shocks are orthogonal to preference shifts. The estimation constitutes a methodological contribution by extending the approach of Comin et al. (2021). The resulting estimates align with the existing literature, indicating that the open-economy estimation delivers demand patterns consistent with standard empirical findings.

While the structural parameters shaping supply and demand help explain specialization, the extent to which countries can exploit comparative advantage also depends on trade costs. These frictions are particularly salient in low-income countries and especially pronounced in agriculture, affecting both sides of trade (Anderson and Van Wincoop, 2004; Waugh, 2010; Adamopoulos, 2011; Tombe, 2015). For importers, high trade costs hinder substitution away from domestic agricultural production even when foreign goods are cheaper; for exporters, they limit market access and constrain the gains from agricultural specialization.[1]

In LICs, agriculture combines a high labor–land ratio with a high revealed relative TFP, yet high trade costs restrict export capacity. Importantly, this mechanism operates purely on the supply side. This contrasts with much of the existing literature, which emphasizes demand-side forces, especially income-driven expenditure shifts shaped by non-homothetic preferences (Laitner, 2000; Kongsamut et al., 2001; Herrendorf et al., 2013; Boppart, 2014; Comin et al., 2021). At the same time, high import trade costs pose an additional constraint by limiting access to cheaper foreign goods. Whether trade openness reallocates labor out of agriculture through demand-side effects, or instead draws labor into agriculture through supply-side forces, is therefore a central and ultimately quantitative question.

To address this question, I use the calibrated model to conduct a series of counterfactual simulations. These experiments quantify how trade openness and sectoral productivity shape agricultural specialization by isolating individual mechanisms—labor–land ratios, demand preferences, production linkages, and trade frictions—while holding other factors constant. This approach allows me to disentangle the relative importance of supply- and demand-side channels in driving sectoral reallocation and welfare outcomes in low-income countries.

I first examine the overall effect of trade openness. Moving from autarky to observed trade patterns increases the agricultural employment share in LICs. Removing trade barriers reveals structural supply-side drivers that outweigh demand-side forces typically associated with structural transformation. To unpack these channels, I simulate uniform reductions in export and import trade costs, lowering each to the average level observed in advanced economies, corresponding to a 30 percent decrease. Reducing export barriers, operating primarily through the supply side, leads to a substantial expansion of agricultural production

[1] Following Novy (2013), in Appendix E, I estimate bilateral trade costs across sectors and countries, confirming this evidence. On average, agricultural trade costs are about 1.6 times higher for LICs than for advanced economies.

and increases the sector's labor share. In contrast, reducing import trade costs acts mainly through demand: it leads to a modest contraction in agriculture and generates limited welfare gains (about 0.3 percent on average), roughly a fifth of the gains from lower export barriers. By comparison, lowering import trade costs in the industrial sector yields much larger welfare gains (around 6.8 percent), as cheaper imported intermediates reduce production costs economy-wide through input–output linkages.

Next, I simulate increases in sectoral TFP, separately for agriculture and industry, to examine how productivity improvements interact with trade openness. These counterfactuals highlight a key distinction between closed and open economies. In a closed economy, higher agricultural TFP reduces the agricultural labor share by releasing workers into other sectors. In an open economy, the relationship reverses: trade amplifies specialization, and higher agricultural TFP draws more labor into agriculture. The resulting welfare and productivity gains are modest, about 2.4 percent on average, compared to those from higher industrial TFP, which is roughly twice as large due to stronger propagation through input–output linkages. Overall, agricultural TFP improvements reinforce existing specialization patterns, even in the presence of high trade costs.

Overall, my findings suggest that the Food Problem in an open economy reflects the specialization of low-income countries in their comparative advantage sector: agriculture. Starting from Schultz (1953), the Food Problem has long been central to the study of development and structural transformation. Gollin et al. (2007) and Restuccia et al. (2008) emphasize that the large agricultural employment share in low-income economies stems from low agricultural productivity and limited labor reallocation to more productive sectors. In their closed-economy settings, productivity gaps across sectors persistently drive low aggregate income. Tombe (2015) and Nath (2025) analyze the Food Problem in an open-economy context. Tombe (2015) shows that trade-cost reductions influence structural change mainly through labor-market frictions. In contrast, my results highlight that in low-income countries, relative labor-to-land endogenously drives agricultural specialization even in the absence of such frictions. Nath (2025) examines the effects of climate change on agricultural productivity in an open economy but abstracts from land and intermediate-input linkages. As a result, his framework implies a lower agricultural TFP for low-income countries. In my analysis, low-income economies instead display relatively high agricultural TFP under openness, indicating that agricultural specialization reflects comparative advantage rather than low productivity.

My results relate to a broad literature on trade and structural transformation. Previous studies emphasize how openness shapes comparative advantage and sectoral reallocation patterns. For example, Matsuyama (2009) and Uy et al. (2013) show that trade liberalization can accelerate industrialization, while Betts et al. (2017), Teignier (2018), and Sposi (2019) highlight that trade costs and sectoral linkages determine the speed and direction of structural change. Other research, such as Święcki (2017), Kehoe et al. (2018), Lewis et al. (2022), focuses on productivity growth and sector-biased technical change as the primary drivers of reallocation. In contrast, my findings show that agricultural specialization in low-income economies emerges endogenously from their relatively high labor–land ratio under openness, rather than from frictions or exogenous productivity differences.

Beyond trade frictions, TFP growth is central to development. Early work (Caselli, 2005; Restuccia et al., 2008; Gollin et al., 2002, 2004, 2014) highlights the fundamental importance of agricultural TFP for closing income gaps. In contrast, more recent research (Boppart et al., 2023) emphasizes the role of non-agricultural TFP growth. Within a closed-economy framework, I obtain results similar to those of Boppart et al. (2023): manufacturing TFP improvements generate larger welfare and reallocation effects through input linkages. Under openness, these effects are further strengthened, as international trade amplifies the diffusion of industrial productivity gains across sectors. A complementary perspective emphasizes that trade also interacts with cross-country differences in technology (Sampson, 2023). This pattern aligns with evidence that access to modern intermediates and capital goods is central to structural transformation (Hsieh and Klenow, 2007; Chen, 2020; Caunedo and Keller, 2021; Donovan, 2021; Adamopoulos and Restuccia, 2022). My results differ from these studies in two main respects. First, once the labor–land ratio is taken into account, low-income countries exhibit relatively high agricultural TFP. This differs from closed-economy interpretations, which treat high agricultural employment as evidence of low productivity. Second, under openness, agricultural TFP improvements expand agricultural exports and reinforce specialization.

This paper also contributes to the literature on revealed comparative advantage. To my knowledge, it is among the first to quantify how land endowments endogenously shape comparative advantage. In doing so, it contributes to the quantitative trade literature that measures revealed comparative advantage (Costinot et al., 2012; Levchenko and Zhang, 2016; Redding and Weinstein, 2024). This mechanism links to broader literature on the development effects of comparative advantage. Earlier studies emphasize the risks of resource-based development, such as slower growth (Sachs and Warner, 1995, 2001), persistent trade patterns (Hausmann et al., 2007; Tacchella et al., 2013), and natural-resource traps (Reinert, 2019; Dosi et al., 2021).

The paper proceeds as follows. Section 2 presents the model. Section 3 describes the data. Section 4 estimates revealed relative productivity. Section 5 presents the estimation of demand elasticities. Section 6 analyzes counterfactuals on trade costs and increases in productivity. Section 7 concludes.

2 Model

I develop a multi-sector quantitative trade model that explicitly incorporates agriculture alongside non-agricultural activities. Agricultural production exhibits decreasing returns to scale due to the presence of land as a sector-specific factor, which generates upward-sloping supply curves. Production is linked through an input–output structure as in Caliendo and Parro (2015). Goods are differentiated by country of origin under the Armington assumption, traded under perfect competition, and subject to iceberg trade costs.

2.1 Setup

The economy is composed of multiple countries indexed by $i, j, n = 1, ..., N$ and multiple sectors indexed by $k, s, l \in \mathcal{K} \equiv \{1, ..., K\}$. There are two types of sectors: agricultural, $k \in \mathcal{K}^A$, and non-agricultural sector, $k \notin \mathcal{K}^A$. In most cases, j denotes the country of consumption, while i and n represent countries of production.

Each country i is endowed with L_i units of labor and $Z_{i,k}$ units of land specific to agricultural sectors $k \in \mathcal{K}^A$. Labor is mobile across sectors within a country. All markets are perfectly competitive.

There is a representative agent in each economy who allocates all income, derived from labor earnings, land rents, and international transfers, to consumption. Preferences are Non-Homothetic CES (NHCES), following Comin et al. (2021),

$$1 = \sum_{k \in \mathcal{K}} (\gamma_{j,k})^{\frac{1}{\sigma}} \left(\frac{C_{j,k}}{(C_j)^{\nu_k}} \right)^{\frac{\sigma-1}{\sigma}}, \tag{1}$$

$\gamma_{j,k} > 0$ are preference shifters, $\sigma \in (0, 1) \cup (1, \infty)$ is the elasticity of substitution across goods, and $\nu_k \in [0, 1]$ is the non-homotheticity parameter, which governs how demand for sector k varies with real income. C_j denotes total consumption, and $C_{j,k}$ is consumption on good k.

Letting $\omega_{j,k} \in [0,1]$ denote the expenditure share on sector k, with $\sum_{k\in\mathcal{K}} \omega_{j,k} = 1$ for all j, utility maximization implies

$$\omega_{j,k} = \gamma_{j,k} \left(\frac{X_j^f}{P_{j,k}} \right)^{\sigma-1} (C_j)^{-\nu_k(\sigma-1)}, \tag{2}$$

where X_j^f denotes final expenditure and $P_{j,k}$ the sectoral price index; both will be defined in detail below.[2]

Within each sector $k \in \mathcal{K}$, Armington varieties from different countries are combined under a constant elasticity of substitution $(\varepsilon_k + 1)$, where $\varepsilon_k > 0$ denotes the trade elasticity. The resulting composite good is then consumed or used as an intermediate input in the production of goods $s \in \mathcal{K}$.

Non-agricultural production, in sector $k \notin \mathcal{K}^A$, has constant returns to scale, using $L_{i,k}$ units of labor and $Q_{i,sk}$ units of input from sector s according to

$$q_{i,k} = \Upsilon_{i,k} A_{i,k} (L_{i,k})^{\alpha_{i,k}} \prod_{s\in\mathcal{K}} (Q_{i,sk})^{\alpha_{i,sk}}, \tag{3}$$

where $\Upsilon_{i,k}$ is a constant,[3] and $A_{i,k}$ is total factor productivity (TFP) for sector k. The parameters $\alpha_{i,k}, \alpha_{i,sk} \in [0,1]$ are value added share and intermediate usage shares, respectively, satisfying $\alpha_{i,k} + \sum_{s\in\mathcal{K}} \alpha_{i,sk} = 1$.

The production of agricultural good $k \in \mathcal{K}^A$ in country i uses land $Z_{i,k}$, labor $L_{i,k}$, and $Q_{i,sk}$ units of input from sector s,

$$q_{i,k} = \Upsilon_{i,k} A_{i,k} (L_{i,k})^{\alpha_{i,k}\left(1-\zeta_{i,k}\right)} (Z_{i,k})^{\alpha_{i,k}\zeta_{i,k}} \prod_{s\in\mathcal{K}} (Q_{i,sk})^{\alpha_{i,sk}}, \tag{4}$$

where $\Upsilon_{i,k}$ is a constant, $Z_{i,k}$ denotes the land endowment specific to sector k. The parameter $\zeta_{i,k} \in [0,1]$ governs the allocation of the value added $\alpha_{i,k}$ between land and labor: $\alpha_{i,k}(1-\zeta_{i,k})$ is labor's share and $\alpha_{i,k}\zeta_{i,k}$ is land's share. This specification generates upward-sloping supply curves in agriculture, and implies that a share $\alpha_{i,k}\zeta_{i,k}$ of sales in sector k is collected as rents.

[2] Following Comin et al. (2021), the associated expenditure function is $X_j^f = \left(\sum_{k\in\mathcal{K}} \gamma_{j,k} (C_j)^{\nu_k(1-\sigma)} (P_{j,k})^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$ and the average cost index is simply $P_j = X_j^f / C_j$, thus $P_j = \left(\sum_{k\in\mathcal{K}} \gamma_{j,k} (C_j)^{(\nu_k-1)(1-\sigma)} (P_{j,k})^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$.

[3] Specifically, $\Upsilon_{i,k} \equiv \left[\alpha_{i,k}^{-\alpha_{i,k}} \prod_{s\in\mathcal{K}} \alpha_{i,sk}^{-\alpha_{i,sk}} \right]$ for all $k \notin \mathcal{K}^A$, and $\Upsilon_{i,k} \equiv \left[(\alpha_{i,k}(1-\zeta_{i,k}))^{-\alpha_{i,k}} \prod_{s\in\mathcal{K}} \alpha_{i,sk}^{-\alpha_{i,sk}} \right]$ for all $k \in \mathcal{K}^A$.

Varieties of any good $k \in \mathcal{K}$ are subject to iceberg trade costs: $\tau_{ij,k} \geq 1$ units of k need to be shipped from i so that one arrives in j. The triangular inequality holds, $\tau_{ij,k} \leq \tau_{in,k}\tau_{nj,k}$, for all i, j, n and $k \in \mathcal{K}$, and I assume that $\tau_{ii,k} = 1$ for all i and $k \in \mathcal{K}$.

2.2 Equilibrium

Let w_j denote the wage in country j. The supply curve of agricultural good $s \in \mathcal{K}^A$ in country j is

$$Y_{j,k} \equiv p_{j,k}q_{j,k} = Z_{j,k}\left(p_{j,k}A_{j,k}\left(w_j\right)^{-\alpha_{j,k}(1-\zeta_j)}\prod_{s\in\mathcal{K}}\left(P_{j,s}\right)^{-\alpha_{j,sk}}\right)^{1/\alpha_{j,k}\zeta_{j,k}}, \tag{5}$$

where $p_{j,k}$ is the producer unit cost and $P_{j,s}$ is the price index for good $k \in \mathcal{K}$ in country j and define, given the Armington assumption, as

$$P_{j,k}^{-\varepsilon_k} = \sum_{i=1}^{N}\left(\tau_{ij,k}p_{i,k}\right)^{-\varepsilon_k}. \tag{6}$$

For non-agriculture goods $k \notin \mathcal{K}^A$, the supply curve in country j is perfectly elastic and takes the form

$$p_{j,k} = A_{j,k}^{-1}\left(w_j\right)^{\alpha_{j,k}}\prod_{s\in\mathcal{K}}\left(P_{j,s}\right)^{\alpha_{j,sk}}. \tag{7}$$

For country j and sector k, the share of expenditure devoted to goods from country i is

$$\lambda_{ij,k} \equiv \frac{X_{ij,k}}{X_{j,k}} = \left(\frac{\tau_{ij,k}p_{i,k}}{P_{j,k}}\right)^{-\varepsilon_k}. \tag{8}$$

Perfect competition implies that unit cost of producing good $k \in \mathcal{K}$ must equalize the price index of good $k \in \mathcal{K}$ in country j, thus

$$\frac{P_{i,s}}{w_i} = \left(\frac{L_{i,a}}{Z_{i,a}}\right)^{\alpha_{i,a}\zeta_{i,a}\chi_{i,as}}\prod_{k\in\mathcal{K}}\left(\lambda_{ii,k}\right)^{\chi_{i,ks}/\varepsilon_k}\prod_{k\in\mathcal{K}}A_{i,k}^{-\chi_{i,ks}}, \tag{9}$$

where $\chi_{i,ks}$ is the (k, s) entry of the $K \times K$ Leontief inverse matrix, $\mathcal{L}_i \equiv (1 - \mathcal{A}_i)^{-1}$, with $\mathcal{A}_i$ having entries $\alpha_{i,sk}$. I consider $\mathcal{L}$ as the *forward linkage* matrix since $-\chi_{i,ks} = \partial \ln P_{i,s}/\partial \ln A_{i,k}$ is the elasticity of the sector-s price with respect to the TFP in sector k, $A_{i,k}$, holding trade shares, employment, and the wage fixed. $\mathcal{L}_i$ is well-defined given that $\sum_{s\in\mathcal{K}} \alpha_{i,sk} < 1$ for all k.

Expenditure on good s in country j combines final demand and intermediate use,

$$X_{j,s} = \omega_{j,s} X_j^f + \sum_{k \in \mathcal{K}} \alpha_{j,ks} Y_{j,k}. \tag{10}$$

Rents from land in sector $k \in \mathcal{K}^A$ and country j are given by the land share of revenues,

$$\Pi_{j,k} = \alpha_{j,k} \zeta_{j,k} Y_{j,k}. \tag{11}$$

Country j's GDP equals the sum of wages and total land rents across agricultural sectors:

$$GDP_j = w_j L_j + \sum_{k \in \mathcal{K}^a} \Pi_{j,k}. \tag{12}$$

Final expenditure is the sum of GDP and exogenous transfers (e.g., trade imbalances) from the rest of the world,

$$X_j^f = GDP_j + D_j, \tag{13}$$

where exogenous transfers sum to zero across countries, $\sum_{j=1}^{N} D_j = 0$.

Real consumption results $C_j = X_j^f / P_j$, while real GDP is GDP_j / P_j, where P_j is the price index associated with NHCES indirect utility in Equation (1).[4]

The market-clearing condition for any good $s \in \mathcal{K}$ produced in country i is

$$Y_{i,s} = \sum_{j=1}^{N} \lambda_{ij,s} X_{j,s}. \tag{14}$$

Labor market-clearing in country i requires

$$w_i L_i = \sum_{k \in \mathcal{K}^a} \alpha_{i,s} \left(1 - \zeta_{i,s}\right) Y_{i,s}. \tag{15}$$

Given parameters $\{\alpha_{i,s}, \alpha_{i,sk}, \zeta_{i,s}, \varepsilon_s, \gamma_{j,s}, \nu_s\}_{i,j=1,\ldots,N;s,k\in\mathcal{K}}$ and exogenous variables $\{A_{i,s}, \tau_{ij,s}, L_i, Z_{i,s} D_j\}_{i,j=1,\ldots,N;s,k\in\mathcal{K}}$, an equilibrium is a collection of producer unit costs and sectoral price indices, $\{p_{i,s}, P_{i,s}\}_{s\in\mathcal{K}}$, trade shares, $\{\lambda_{ij,s}\}_{i,s\in\mathcal{K}}$, total and final expenditures, gross output, and wages, $\left\{X_j^f, w_j, X_{j,s}, Y_{j,s}\right\}_{s\in\mathcal{K}}$, such that Equations (5)–(15) are satisfied.

[4]Specifically, $P_j = \left(\sum_{k\in\mathcal{K}} \gamma_{j,k} \left(C_j\right)^{(\nu_k - 1)(1-\sigma)} \left(P_{j,k}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$

3 Data

The empirical analysis draws on a set of variables that speak directly to the theoretical framework. In particular, I use bilateral trade flows, agricultural labor employment and agricultural land use.

My baseline empirical analysis relies on a set of variables that correspond directly to the key objects in the model. In particular, I use bilateral trade flows, agricultural labor employment and land use, GDP, and population. Tables I and II in Appendix C present the mapping of sectors and countries used in the empirical analysis that follows.

Bilateral Trade Flows. Data on bilateral trade flows are drawn from the OECD's ICIO tables, which report both domestic and international transactions across sectors and countries. The analysis focuses primarily on the 2005 cross-section, providing a consistent snapshot of global production and trade patterns. This benchmark year is widely adopted in the literature, facilitating comparability with related studies. For the estimation of demand parameters in Section 5, I exploit the full panel of available data spanning 1995–2020.

The sample includes 70 countries, including a rest-of-world aggregate, and three main aggregate sectors: agriculture, industry, and services. Accordingly, I define the set of sectors as $\mathcal{K} = \{ag, ind, ser\}$, with $\mathcal{K}^a = \{ag\}$ denoting the agricultural aggregate, which encompasses agriculture, hunting, forestry, fishing, and aquaculture. Tables I and II in Appendix C provide the detailed mapping of sectors and countries used in the empirical analysis.

Employment and Agricultural Land Use. Agricultural employment shares are obtained from the FAOSTAT, which reports the proportion of each country's labor force engaged in agriculture. These data provide a direct empirical counterpart to the model's sectoral allocation of labor.

Food and Agriculture Organization (FAO) data on agricultural land, measured in hectares, refer to total land used for agricultural purposes, including crop cultivation and animal husbandry. This measure serves as the empirical analog to the fixed factor in agricultural production. The ratio of agricultural employment to agricultural land captures cross-country differences in the labor–land ratio. It corresponds to the model's labor-to-land ratio, which plays an important role in determining agricultural productivity.

Country Classification. Countries are classified by income group following the World Bank Analytical Classifications reported in the World Development Indicators (WDI). The classification is based on Gross National Income (GNI) per capita, measured in current US dollars using the Atlas method for the year 2005. According to this criterion, economies with GNI per capita up to 875 US dollars are classified as LICs, and those with GNI per capita between 876 and 3,465 US dollars as Low-middle-Income Countries (LMICs). For my analysis, all countries with GNI per capita above this threshold (including upper-middle- and high-income economies) are grouped and referred to as High-Income Countries (HICs). The complete classification is reported in Table II in Appendix C.

These sources provide a rich cross-country dataset that enables a natural one-to-one mapping to the theoretical structure, allowing the empirical exercise to be interpreted directly through the lens of the model. Details on variable construction and data sources are reported in C, Table III. The next section discusses the calibration of the remaining model parameters.

3.1 Calibration

The model parameters are grouped into three categories: preferences, technology, and trade. Most are constructed from the ICIO tables or calibrated from existing studies, whereas a subset is estimated structurally in subsequent sections.

On the preference side, the sector–country specific shifters $\gamma_{j,k}$ play no role in the counterfactuals (Section 6), as they are held constant in the counterfactual equilibrium, under the Exact Hat Algebra equilibrium derived in Appendix B.1. The non-homotheticity parameters ν_k and the elasticity of substitution across goods σ are estimated in Section 5.

On the technology side, productivity terms $A_{i,k}$ are also estimated in Section 4, whereas value added shares $\alpha_{i,k}$, input–output shares $\alpha_{i,sk}$ are constructed directly from the ICIO tables. The land share in value added, $\zeta_{i,a}$, specific to agricultural production, is calibrated following Restuccia et al. (2008) and set uniformly to $\zeta_{i,a} = \zeta_a = 0.3$ across countries.

On the trade side, the sectoral trade elasticity is fixed at $\varepsilon_k 5$ for all k, consistent with standard values in the trade literature (Anderson and Van Wincoop, 2004; Costinot and Rodríguez-Clare, 2014; Head and Mayer, 2014). Bilateral iceberg trade costs $\tau_{ij,k}$ are inferred structurally from observed trade shares, as detailed in Appendix E.

4 Revealed Relative Productivity

In this section, I estimate relative sector–country TFP using data on bilateral exports, input–output linkages, agricultural labor employment, and land use, as described in Section 3. These fundamental productivities are inferred from observed bilateral exports, after accounting for land and intermediate input linkages. The estimation strategy extends the regression-based measure of Revealed Comparative Advantage (RCA) proposed by Costinot et al. (2012) to incorporate these additional factors.[5]

Starting from the model's expression for bilateral exports of good k from country i to importer j,

$$X_{ij,k} = \left(\frac{\tau_{ij,k} p_{i,k}}{P_{j,k}}\right)^{-\varepsilon} \omega_{j,k} X_j^f, \tag{16}$$

I derive an empirical specification that links observed exports to underlying productivity differences across countries and sectors. The estimating equation is

$$\ln \tilde{x}_{ij,k} = \delta_{j,k} + \delta_{ij} + \delta_{i,k} + u_{ij,k}, \tag{17}$$

where

$$\ln \tilde{x}_{ij,k} \equiv \ln X_{ij,k} - \sum_{l \in \mathcal{K}} \left(1_{\{l=k\}} - \chi_{i,lk}\right) \ln \lambda_{ii,l}. \tag{18}$$

The fixed effect $\delta_{j,k}$ captures importer-sector demand conditions, while δ_{ij} absorbs bilateral differences in aggregate demand and wages. In Equation (18), the correction term, $\sum_{l \in \mathcal{K}} \left(1_{\{l=k\}} - \chi_{i,lk}\right) \ln \lambda_{ii,l}$, nets out the effect of domestic expenditure shares ($\ln \lambda_{ii,l}$) on exporter–sector sales. The indicator $1_{\{l=k\}}$ corrects own-sector home bias, whereas the *forward linkages* $\chi_{i,lk}$ adjust for demand transmitted through the input–output network.[6] Consequently, the exporter–sector fixed effect $\delta_{i,k}$ reflects structural determinants of comparative advantage—sectoral productivity and the effect of country i's land–labor ratio through

[5] Compared with Balassa (1965)'s traditional index, which infers comparative advantage from export shares, the RCA measure of Costinot et al. (2012) has the advantage of being directly grounded in theory. While both methods rely on export data, only the regression-based approach is grounded in the Ricardian model and therefore interpretable as relative productivities. In contrast, Balassa's index conflates productivity with trade costs and demand conditions. My empirical analysis builds on this theoretical foundation. The model described in Section 2 shares the same assumptions as in Costinot et al. (2012), except for their assumption concerning Fréchet-distributed productivities. Nonetheless, their theoretical prediction, that relative productivity differences map into relative bilateral exports, continues to hold in my framework, allowing me to derive the same log-linear representation.

[6] This generalizes the openness correction in Costinot et al. (2012), who adjust only for domestic absorption by subtracting $\ln \lambda_{ii,k}$. My specification preserves the same econometric structure, but the exporter–sector fixed effects are now mapped to fundamental productivities in a way that is consistent with my model.

input–output linkages—rather than openness or market size. Finally, $u_{ij,k}$ denotes the error term capturing exogenous changes in trade costs. A detailed derivation of this specification is provided in Appendix D.

Under the assumption that variable trade costs, and other components captured in $u_{ij,k}$, are orthogonal to sectoral productivity, Ordinary Least Squares (OLS) estimation of Equation (17) yields unbiased estimates of the exporter–sector fixed effects $\delta_{i,k}$.

Fundamental sectoral productivities are recovered from the estimated exporter–sector fixed effects, $\delta_{i,k}$, by exploiting the structure of the model. Using FAOSTAT data on the labor-to-land ratio in agriculture, $L_{i,a}/Z_{i,a}$, together with the calibrated parameters $\theta, \alpha_{i,a}, \zeta_{i,a}, \{\chi_{i,lk}\}_{l,k\in\mathcal{K}}$, I solve a system of equations, for each country i, linking fixed effects to technology levels.

Specifically, for each country i and sector k, fundamental productivity $A_{i,l}$ is identified from

$$\delta_{i,k}/\theta = \sum_{l\in\mathcal{K}} \chi_{i,lk} \ln A_{i,l} - \alpha_{i,a}\zeta_{i,a}\chi_{i,ak} \ln\left(\frac{L_{i,a}}{Z_{i,a}}\right). \tag{19}$$

This system maps reduced-form exporter–sector effects into structural productivity terms, while accounting for input–output linkages and the role of labor and land allocated in agriculture production. Importantly, the recovery of fundamental sectoral TFP under the Cobb–Douglas production structure requires only bilateral export data and the labor-land ratio in agriculture, together with the parameters governing value-added shares, input–output shares, and the trade elasticity.

A high labor–land ratio thus reflects a high level of TFP in agriculture. When economic models fail to distinguish between land as a fixed factor and productivity, particularly in standard closed-economy frameworks, countries with a high labor–land ratio and large agricultural employment are mistakenly assigned low measured agricultural TFP. As a result, these models underestimate the fundamental TFP of high-labor-to-land economies, attributing high labor share in agriculture to technological inefficiency rather than to underlying differences in resource endowments.

Using the estimated productivities, I construct a Revealed Relative Productivity (RRP) index to compare sectoral TFP across countries. This measure expresses each country's productivity in sector k relative to a base sector (agriculture) and a benchmark country

(USA):[7]

$$RRP_{i,k} = \frac{A_{i,k}}{A_{USA,k}} \frac{A_{USA,ag}}{A_{i,ag}}. \tag{20}$$

While the differences-in-differences identified by the fixed-effect regression,

$$\left(\delta_{i,k} - \delta_{i,ag}\right) - \left(\delta_{USA,k} - \delta_{USA,ag}\right),$$

capture the essence of Ricardian comparative advantage, the $RRP_{i,k}$ index measures relative TFP efficiency across sectors and countries, controlling for differences in the labor–land ratio, the number of workers in agriculture per unit of available land.

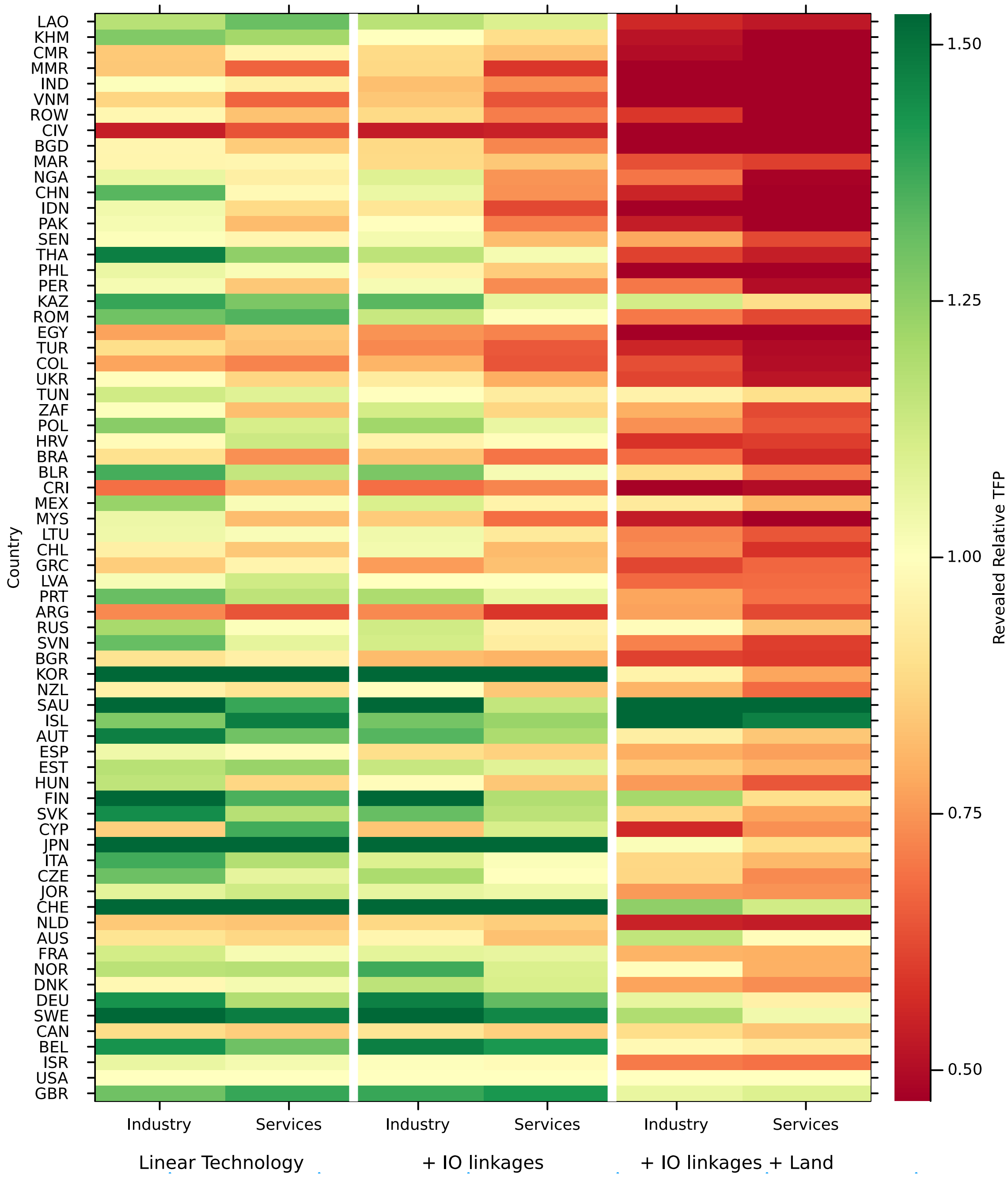
It should be noted, however, that the productivity ratios in Equation (20) are not themselves measures of comparative advantage. In the presence of land and input–output linkages, autarky prices, and hence comparative advantage, depend not only on technology but also on land abundance and sectoral linkages. The $RRP_{i,k}$ index, therefore, isolates the relative TFP component that drives comparative advantage, net of the equilibrium effects of relative labor-to-land and intermediate demand.

Figure 1 reports the estimated $RRP_{i,k}$ values under three alternative model variants: (i) a linear technology using labor only; (ii) a specification incorporating intermediate input linkages; and (iii) a specification combining input–output linkages with a fixed land factor in agriculture, which corresponds to the benchmark model described in Section 2. Countries are ordered by their labor share in agriculture, providing a natural way to interpret differences in relative productivities. The color gradient represents the strength of revealed comparative advantage, computed as a double difference relative to agriculture and to the United States, with greener shades indicating stronger comparative advantage and deeper red shades indicating stronger comparative disadvantage. The linear model reproduces the measure in Costinot et al. (2012) and serves as a benchmark.[8]

[7]The general formula is $RP_{i,k} = \frac{A_{i,k}}{A_{n,k}} \frac{A_{n,b}}{A_{i,b}}$ where sector b refers to the base sector and country n to the benchmark country.

[8]Costinot et al. (2012) estimate their model using bilateral trade and productivity data for a sample of mainly high-income countries (see their Table 1), covering 12 manufacturing and food-processing industries, including Food, Textiles, Chemicals, and Machinery. By contrast, my analysis relies on a three-sector aggregation—agriculture, industry, and services—and a broader set of countries, including many low-income economies. Although the econometric specification is identical, these differences in sectoral detail and country coverage are important for interpreting the patterns of comparative advantage.

Figure 1: **Revealed Relative Productivity Across Specifications**



Notes: The figure reports RRP estimates by country and sector for 2005, as defined in Equation (20), using data from the OECD ICIO database. Three specifications are shown: (i) linear unit costs; (ii) unit costs including intermediate input linkages; and (iii) unit costs incorporating both input linkages and land in agriculture. Derivations of the first two models are provided in Appendix D. Countries are ordered by their agricultural labor share. The color gradient represents the strength of revealed comparative advantage, computed as a double difference relative to agriculture and to the United States, with greener shades indicating stronger comparative advantage and deeper red shades indicating stronger comparative disadvantage.

When intermediate inputs and land abundance are ignored, no systematic pattern in relative productivity ratios across countries emerges. Some low-income economies appear relatively more productive in industry or services, while others display higher relative productivity in agriculture.

When input linkages and the fixed factor are incorporated, a clear pattern emerges: poor countries exhibit relatively high TFP in agriculture compared with richer economies. Thus, low-income countries are not characterized by low agricultural TFP but by a relative productivity advantage in agriculture. This contrasts with the conventional interpretation of the agricultural productivity gap, which attributes cross-country differences to low agricultural TFP (i.e. Restuccia et al., 2008; Gollin, 2010; Gollin et al., 2014). The observed gap instead reflects differences in land availability and the transmission of these effects through input linkages. Accounting for these structural features reveals a key result: poorer economies are relatively more efficient in agriculture.

This result complements the trade and development literature on endowment-driven specialization. Classical models associate resource abundance with structural stagnation (Matsuyama, 1992; Sachs and Warner, 1995, 2001; Reinert, 2019; Dosi et al., 2021), while empirical work shows that export concentration and resource booms can hinder diversification (Hausmann et al., 2007; Harding and Venables, 2016; Coniglio et al., 2021; Tacchella et al., 2013). Here, by contrast, specialization emerges endogenously from relative labor-to-land rather than from low productivity or policy distortions, offering a complementary perspective on the "resource curse" mechanism.

5 Estimation of NHCES parameters

The estimation exploits country–sector variation over time in the OECD-ICIO tables, which provide harmonized information on expenditure patterns and trade flows. A single cross-section provides only one realization of expenditure shares and relative prices, which is insufficient to disentangle structural elasticities from persistent cross-country and cross-sector heterogeneity. Observing the same country–sector pairs across multiple years allows comparison of how expenditure shares adjust as income levels and relative prices change. This framework allows me to identify income and price elasticities implied by the NHCES structure described in Section 2, while explicitly accounting for openness and inter-sectoral linkages.

To clarify the analytical approach, I index all variables by year t. By taking logarithms to Equation (9) and substituting into the logarithm of Equation (2), the log expenditure share in country j on sector k at time t is given by

$$\ln \omega_{j,k,t} = (\sigma - 1) \ln X^f_{j,t} - (\sigma - 1) \ln P_{j,k,t} - \nu_k (\sigma - 1) \ln (C_{j,t}) + \ln \gamma_{j,k,t}. \tag{21}$$

To estimate both σ and ν_k, I adopt a normalization imposing $\frac{1}{K}\sum_{k\in\mathcal{K}} \nu_k = 1$, so income elasticities are identified relative to the cross-sector average. For any variable $a_{j,k,t}$, let $\overline{\ln a_{j,t}} = \frac{1}{K}\sum_{k\in\mathcal{K}} \ln a_{j,k,t}$ denote the within-country-time log mean. Applying this to Equation (21) yields:

$$\overline{\ln \omega_{j,t}} = (\sigma - 1) \ln X^f_{j,t} - (\sigma - 1) \overline{\ln P_{j,t}} - (\sigma - 1) \ln C_{j,t} + \overline{\ln \gamma_{j,t}}.$$

Substituting this expression back into Equation (21) gives:

$$\begin{aligned}\ln \omega_{j,k,t} = (\sigma - 1)(1 - \nu_k)\left(\ln X^f_{j,t} - \overline{\ln P_{j,t}}\right) - (\sigma - 1)\left(\ln P_{j,k,t} - \overline{\ln P_{j,t}}\right) \\ + \nu_k \overline{\ln \omega_{j,t}} + \left(\ln \gamma_{j,k,t} - \nu_k \overline{\ln \gamma_{j,t}}\right).\end{aligned} \tag{22}$$

Direct data on relative prices $P_{j,s,t}$ are not available in the ICIO tables. Nevertheless, using the structural relationship in Equation (9) together with the expression for sectoral productivity in Equation (19), the model implies that equilibrium producer prices can be written as a function of (i) domestic absorption terms transmitted through input–output linkages and (ii) a country–sector productivity component. Specifically, combining these equations yields the following model-consistent relative price proxy:

$$\ln \tilde{P}_{i,k,t} = \sum_{l\in\mathcal{K}} \chi_{i,lk,t} \frac{\ln \lambda_{ii,l,t}}{\varepsilon} - \frac{\delta_{i,k,t}}{\varepsilon}, \tag{23}$$

where $\lambda_{ii,l,t}$ is domestic absorption, $\chi_{i,lk,t}$ denotes the input–output forward linkages, and $\delta_{i,k,t}$ are exporter–sector fixed effects obtained from Equation (17) for each year t.

This price index preserves the model's core mechanism: conditional on technology, higher domestic absorption raises sectoral marginal costs and, through input–output linkages, sectoral prices, while higher exporter–sector technology ($\delta_{i,k,t}$) lowers prices by increasing productivity. The trade elasticity ε disciplines the steepness of this relationship. This mapping parallels the welfare-gains formula in Arkolakis et al. (2012), where $P_{i,k,t} \propto \lambda^{1/\varepsilon}_{ii,k,t}$. Here, input–output forward linkages $\chi_{i,lk,t}$ transmit cost changes across sectors, and $\delta_{i,k,t}/\varepsilon$ provides a country–sector–year measure of technological competitiveness consistent with the model. The full derivation of Equations (22) and (23) is provided in Appendix F.

A central identification challenge arises because equilibrium prices embed endogenous movements in agricultural labor shares: labor allocated to agriculture responds to demand conditions, so relative prices reflect both supply-driven cost variation and demand-driven shocks. This simultaneity means that observed prices cannot be used directly to identify the demand elasticities. The model, however, provides the analog of knowing the supply elasticity in a simple supply–demand system: Equation (9) delivers an explicit mapping from sectoral TFP to producer prices. I exploit this supply-side relationship to construct an instrument based on the effect of TFP, calculated in Equation (19), on prices, thereby isolating the component of price variation driven solely by supply TFP fundamentals rather than by unobserved demand or taste shocks.

I therefore use an Instrumental Variables (IV) procedure in which the instruments for $\ln \tilde{P}_{i,k,t}$ are constructed from the implied TFP index that aggregates technology across upstream sectors. In particular, supply fundamentals feed into prices through the weighted sum

$$\ln \tilde{A}_{i,k,t} \equiv \sum_{l \in \mathcal{K}} \chi_{i,lk,t} \ln A_{i,l,t}, \tag{24}$$

where the input–output coefficients $\chi_{i,lk,t}$ capture the forward-linkage exposure of sector k to productivity in sector l. I use this model-consistent TFP index $\ln \tilde{A}_{i,k,t}$ as the source of exogenous variation in the first stage for $\ln \tilde{P}_{i,k,t}$, providing the supply-driven price movements required to identify the demand elasticities.

I estimate the elasticity of substitution σ and the non-homothetic parameters ν_k via the following specification

$$\begin{aligned} \ln \omega_{j,k,t} = \phi_{j,k} &+ (\sigma - 1)(1 - \nu_k)\left(\ln X^f_{j,t} - \overline{\ln P_{j,t}}\right) \\ &- (\sigma - 1)\left(\ln \tilde{P}_{j,k,t} - \overline{\ln P_{j,t}}\right) + \nu_k \overline{\ln \omega_{j,t}} + \upsilon_{j,k,t}, \end{aligned} \tag{25}$$

where $\phi_{j,k}$ denotes a country–sector fixed effect capturing all time-invariant preference heterogeneity in $\upsilon_{j,k,t}$. In particular, it reflects persistent differences in preference tastes that do not vary over time. The structural error term $\upsilon_{j,k,t}$ then represents the remaining time-varying, idiosyncratic preference shock, after removing country and sector means, as detailed in Appendix F.

I estimate Equation (25) using Generalized Method of Moments (GMM), instrumenting $\ln \tilde{P}_{j,k,t}$ with the model-implied productivity index $\ln \tilde{A}_{j,k,t}$ described above. The validity of this instrument relies on the assumption that innovations in sectoral TFP are orthogonal to the unobserved preference shocks $\upsilon_{j,k,t}$ in the demand equation. Formally, the exclusion restriction requires

$$E\left[\ln \tilde{A}_{j,k,t} \upsilon_{j,k,t} \middle| j, k, t\right] = 0.$$

This holds under the interpretation of $\ln \tilde{A}_{j,k,t}$ as a supply-side fundamental determined by technological conditions rather than by destination-specific taste shocks. Because $\upsilon_{j,k,t}$ reflects purely demand-side variation in expenditure shares, there is no mechanism in the model linking it to productivity innovations. Under this restriction, the variation in $\ln \tilde{A}_{j,k,t}$ isolates the supply-driven component of price movements, yielding consistent GMM estimates of σ and ν_k.

Since $\overline{\ln P_{j,t}}$ enters the regression both in the income term and in the relative-price term, I also instrument $\overline{\ln P_{j,t}}$, using the corresponding country–year average of the productivity index, $\overline{\ln \tilde{A}_{j,t}} = \frac{1}{K}\sum_{k\in\mathcal{K}} \ln \tilde{A}_{j,k,t}$. The associated exclusion restriction, $E\left[\overline{\ln \tilde{A}_{j,t}} \upsilon_{j,k,t} \middle| j, k, t\right] = 0$, follows from the same supply-side argument as above: changes in $\overline{\ln \tilde{A}_{j,t}}$ reflect aggregate technology shocks rather than sector-specific preference shocks. By contrast, $\ln X^f_{j,t}$ and $\overline{\ln \omega_{j,t}}$ are treated as exogenous country–year controls that shift the overall level and demand composition but are assumed orthogonal to the residual, sector-specific taste shocks, i.e.

$$E\left[\upsilon_{j,k,t} \middle| \ln X^f_{j,t}, \overline{\ln \omega_{j,t}}\right] = 0.$$

Economically, this means that country–year shifts in total expenditure or in average expenditure shares affect the overall level of demand but do not generate relative demand shocks across sectors k beyond what is already absorbed by the country–sector fixed effect $\phi_{j,k}$.

Table 1 presents the estimates of Equation (25) for 70 countries using the OECD's ICIO data over 1995–2020. The IV estimates of the non-homotheticity parameters ν_k are very close to the GMM results without instrumentation, with agriculture below one ($\nu_{ag} = 0.638$), industry near a unitary elasticity ($\nu_{ind} = 1.042$), and services above one ($\nu_{ser} = 1.332$). The elasticity of substitution is lower under IV estimation, reflecting the removal of the upward bias induced by the possible endogeneity in relative prices. The IV estimated is $\sigma = 0.136$, indicating that broad sectors are gross complements. I therefore use the IV estimates in the analysis that follows. In Appendix F.3 I compute the implied income elasticities across income groups, which follow the same ordering implied by the ν_k estimates and are consistent with Engel's law, identifying agriculture as a necessity and services as a luxury.

Table 1: **Estimates of NHCES Parameters** (σ,ν_k)

	GMM (OLS) (1)	GMM (IV) (2)
σ	0.259	0.136
	[0.008, 0.475]	[0.006, 0.389]
ν_{ag}	0.619	0.638
	[0.472, 0.841]	[0.480, 0.808]
ν_{ind}	1.073	1.042
	[0.932, 1.241]	[0.910, 1.171]
ν_{ser}	1.322	1.332
	[1.230, 1.428]	[1.236, 1.473]
Country-Sector FE	Yes	Yes
Observations	1,820	1,820

Notes: Estimates are obtained by two-step GMM. Bootstrapped 95% confidence intervals, clustered at the country level, are reported in square brackets (computed from 50 bootstrap samples with replacement). The sample covers 70 countries and three aggregate sectors (agriculture, industry, services) over the period 1995–2020, using ICIO tables. Column (1) reports GMM estimates without instrumentation, while column (2) reports GMM estimates using the TFP-based instrument described in Equation (24).

Discussion. The estimates reproduce the expected sectoral hierarchy. Comin et al. (2021)'s estimates are $\sigma = 0.57$ for the elasticity of substitution, $\nu_{ag} = 0.02$ for agriculture, and $\nu_{ser} = 1.17$ for services, with industry normalized as the base sector ($\nu_{ind} = 1$). Nath (2025), using a simulated method of moments on sectoral GDP shares, obtains closely related preference parameters: $\sigma = 0.27$, $\nu_{ag} = 0.29$, $\nu_{ind} = 1$, and $\nu_{ser} = 1.15$. Quantitatively, my estimates for agriculture and services are somewhat larger, while the estimated elasticity of substitution is lower. This suggests that, once trade is explicitly accounted for using ICIO data, the demand for sectors with higher income elasticities becomes stronger and broad sectors behave as close complements.

A further point of interest concerns the estimated substitution elasticity, $\sigma = 0.136$. This value lies below the range typically reported in the literature. Comin et al. (2021) obtain values between 0.25 and 0.63 depending on the specification. Herrendorf et al. (2013) report estimates close to 0.80 using US consumption data. Bartelme et al. (2025), focusing on manufacturing sectors within the ICIO data, find an elasticity of 0.87. At a finer level of disaggregation, Oberfield and Raval (2021) obtain values between 0.86 and 1.27 across 2-digit sectors, and Redding and Weinstein (2024) report $\sigma = 1.36$ at the 4-digit level.

My estimate of σ therefore lies at the lower end of the existing evidence, reinforcing the interpretation that broad sectors are strong complements. A plausible explanation is that the inclusion of intermediate input linkages and trade in the ICIO framework reduces the effective substitutability across aggregate sectors relative to closed-economy estimates.

The lower value obtained here likely reflects several factors. The higher level of aggregation across broad sectors naturally limits substitution possibilities in final demand. The open-economy setting, with cross-border production linkages, also reduces sectoral substitutability relative to closed-economy estimates. In addition, the use of the constructed prices captures technological differences that compress relative price variation compared with studies using observed prices alone.

5.1 Sensitivity to alternative samples and specifications

Before turning to model simulations using the estimated parameters $\{\sigma, \nu_k\}$, it is important to examine their robustness to alternative samples and specifications. I therefore conduct two sets of exercises: (i) re-estimating the model over different time spans, and (ii) estimating the model separately for OECD and non-OECD countries, mirroring the sensitivity analysis in Comin et al. (2021). These exercises allow me to assess whether the patterns of sectoral complementarity and non-homotheticity documented above are driven by specific periods or particular subsets of countries.

Heterogeneity Over Time. As a first robustness check, I re-estimate the parameters $\{\sigma, \nu_k\}$ over different sample windows: 1995–2010, 1995–2015, 2000–2015, and 2000–2020, in addition to the full 1995–2020 period. The resulting estimates, reported in Table V in the Appendix, are stable across periods. In each window, agriculture consistently appears as a necessity, industry remains close to unitary elasticity, and services display income elasticities above unity. The substitution elasticity σ remains well below one in all specifications. The close similarity of estimates across decades indicates that the core patterns of non-homotheticity and complementarity are not driven by any particular period.

Comparison with Comin et al. (2021). I also explore heterogeneity across country groups by estimating the model separately for OECD and non-OECD economies, following

Comin et al. (2021).[9] This split tests whether differences in income levels or openness affect the parameter estimates. As shown in Table VI in the Appendix, the results are similar across groups: agriculture remains a subsistence good, industry stays close to unitary elasticity, and services continue to display income elasticities above one. The substitution elasticity σ also remains low in both samples. These patterns indicate that systematic cross-country differences in income or trade-integration levels do not drive the core empirical relationships.

6 Quantitative Analysis

This section quantifies how openness and sectoral productivity shape welfare and specialization in an economy with land constraints and trade. Empirically, low-income countries display high revealed relative TFP in agriculture once labor-to-land ratios are taken into account. At the same time, demand estimates indicate that agriculture is a subsistence sector and that broad sectors are strong complements. These patterns point to offsetting forces linking trade, productivity, and agricultural employment, whose net effects and magnitudes cannot be determined analytically. Quantitative counterfactuals are therefore required to assess how changes in trade costs and technology translate into employment reallocation and welfare outcomes. In particular, these counterfactuals assess whether the mechanisms commonly invoked in the literature to explain reductions in agricultural employment in closed economies still apply in open economies.

To conduct these counterfactual exercises, I apply exact hat algebra (Dekle et al. 2008; Costinot and Rodríguez-Clare 2014) to express the equilibrium conditions in proportional changes, as derived in B.1. The model is solved using a fast fixed-point algorithm in the spirit of Alvarez and Lucas Jr (2007), described in Appendix B.3.[10]

I consider four sets of counterfactual experiments designed to isolate the mechanisms through which openness and productivity affect specialization and welfare. The first counterfactual imposes autarky by shutting down international trade, quantifying the welfare cost of isolation. The second and third counterfactuals reduce import and export trade costs, respectively, to the levels observed in advanced economies, distinguishing between agricultural and

[9]Specifically, I replicate Comin et al. (2021, Table III, p. 336) using the methodology describe in this section.

[10]I convert the equilibrium conditions 1–15 from levels to hat changes, as derived in Appendix B.1. Given baseline values for $\left\{\alpha_{i,ks}, \alpha_{i,k}, \lambda_{ij,k}, Y_{i,k}, X_j^f, \omega_{j,k}, \ell_{j,a}, Z_j\right\}$ and the shocks of interest, the algorithm, describe in Appendix B.3, delivers counterfactual changes for $\left\{\hat{\ell}_{j,k}, \hat{\omega}_{j,k}, \hat{P}_{j,s}, \hat{\lambda}_{ij,k}, \hat{X}_{j,s}, \hat{Y}_{i,k}, \hat{X}_j^f, \widehat{GDP}_j, \widehat{P}_j\right\}$, where $\hat{x} \equiv x'/x$ denote the proportional change between the initial equilibrium x and the counterfactual x'.

industrial sectors. These experiments separate the effects of foreign demand access from those of import competition. The fourth counterfactual simulates a 10 percent increase in sectoral TFP in either agriculture or industry, under both closed- and open-economy conditions, to examine how productivity improvements interact with trade and land constraints in shaping specialization patterns.

6.1 The Effects of Openness

6.1.1 Autarky Counterfactual

To establish a baseline for understanding the role of trade openness, I first quantify the welfare cost of shutting down all international trade. Although autarky represents an extreme and unrealistic scenario, it serves as a standard benchmark in the quantitative trade literature (Arkolakis et al., 2012) and provides a transparent illustration of the model's core mechanisms. This exercise is particularly valuable for assessing how trade affects welfare across countries and how structural features—such as non-homothetic preferences, input–output linkages, and land allocations—shape the magnitude of the gains from trade.

Letting $\hat{x} \equiv x'/x$ denotes the proportional change between the initial equilibrium x and the counterfactual equilibrium x', welfare changes are measured by the hat change in real GDP, defined as $\widehat{W}_j = \widehat{GDP}_j/\widehat{P}_j$.[11] Accordingly, the gains from trade are defined as

$$\widehat{GT}_j = 1 - \widehat{W}_j,$$

which captures the percentage decline in real income under autarky relative to the observed equilibrium.

Figure 2 displays the welfare gains for all countries in the sample. The distribution exhibits substantial cross-country variation, ranging from approximately 2 percent in the United States to over 17 percent in Cambodia. Low-income countries (in green) experience positive gains throughout the distribution, without a clear income-related pattern. Despite heterogeneity in gains from trade, countries within similar income ranges share comparable structural characteristics, including sectoral composition, trade costs, and patterns of specialization. Hence, grouping by income provides a useful summary of the model's implications.

[11] Because real GDP and real consumption differ due to exogenous international transfers, D_j, I report changes in real GDP to ensure that trade imbalances do not substantially distort the results (Costinot and Rodríguez-Clare, 2014).

To characterize the mechanisms underlying these welfare effects, I focus on three outcome variables: (i) percentage-point changes in expenditure shares,

$$\Delta\omega_{j,k} = \left(\omega'_{j,k} - \omega_{j,k}\right) \times 100,$$

(ii) percentage-point changes in labor shares,

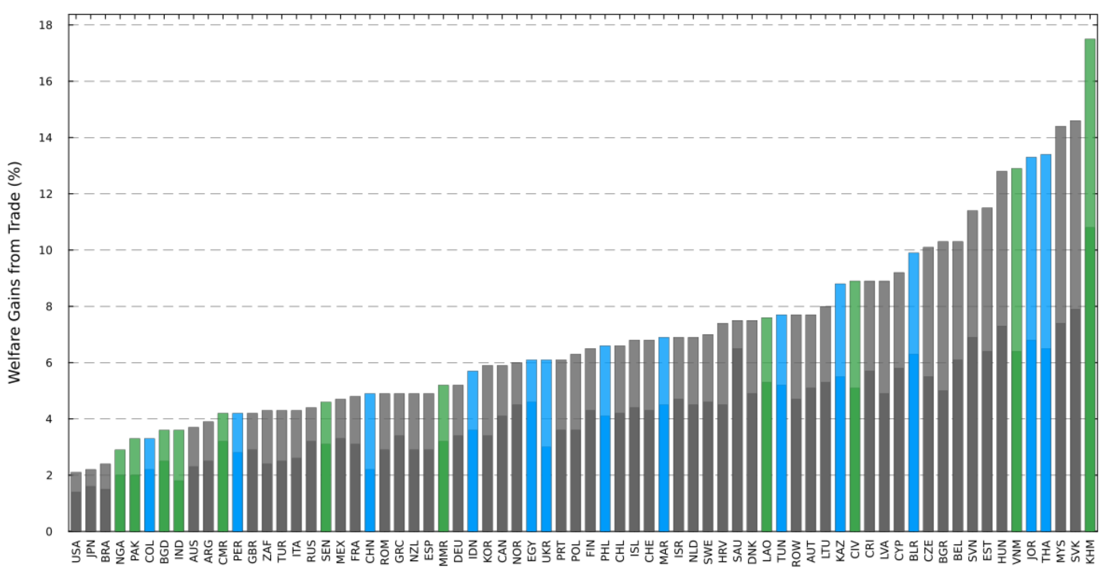
$$\Delta\ell_{j,k} = \left(\ell'_{j,k} - \ell_{j,k}\right) \times 100,$$

where $\ell_{j,k} = \alpha_{j,k}\left(1 - \zeta_{j,k}\right) Y_{j,k}/w_j L_j$, and (iii) hat changes in labor productivity,

$$\hat{\Lambda}_{j,k} = \frac{\hat{Y}_{j,k}}{\hat{P}_{j,k}} \frac{\hat{\lambda}_{jj,k}^{1/\varepsilon_k}}{\hat{L}_{j,k}},$$

whose derivation is provided in Appendix B.2.

Figure 2: **Gains from Trade**



Notes: Bars show model-implied welfare gains from trade, measured as $(100 \times (1 - \hat{W}_j))$ in percent, by country. Countries are ordered from the smallest to the largest welfare gain. Green bars denote low-income countries, blue bars denote lower-middle-income countries, and gray bars denote all other countries. Darker share bars denote welfare gains without any mechanisms (no NHCES, sectoral linkages, or fixed factor). The classification of countries is reported in Appendix C.

Table 2 reports the average effects of moving from the open-economy equilibrium to autarky across income groups.[12] For LICs, moving to autarky leads to a decline in the agricultural labor share of 2.1 p.p., indicating that trade openness increases agricultural employment

[12]Detailed country-level welfare gains from trade are reported in Appendix G.1, Table VII.

rather than reducing it. This result is consistent with the high relative agricultural TFP documented in Section 4: when trade is allowed, resources shift toward the sector in which countries are most efficient. Expenditure shares show a similar pattern, with agriculture contracting by about 0.6 p.p. and industry expanding by 1.7 p.p., while services decline modestly. Agricultural labor productivity increases by 1.6 percent as labor moves out of agriculture, reflecting diminishing returns within the sector. At the same time, openness substantially raises productivity in non-agricultural sectors, reflecting gains through input linkages.

Table 2: **Effects of Trade**

	LIC	LMIC	HIC
Gains from trade	6.75	7.45	6.87
Changes in Expenditure share (p.p.)			
Agriculture	-0.57	0.09	0.06
Industry	1.72	1.72	1.94
Services	-1.16	-1.80	-2.00
Changes in Labor share (p.p.)			
Agriculture	-2.13	0.24	0.01
Industry	2.63	0.61	1.46
Services	-0.50	-0.85	-1.47
Changes in Labor Productivity (%)			
Agriculture	1.64	-4.52	-5.67
Industry	-5.18	-7.17	-7.61
Services	-3.44	-4.06	-3.87

Notes: Table reports model-implied effects of moving to autarky under the benchmark model described in Section 2. Values show percentage-point (p.p.) or percent changes relative to the baseline open-economy equilibrium. 'Gains from trade' denote the welfare gains from moving out of autarky, expressed in percent terms. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported by income group (LIC, LMIC, HIC), as defined in Appendix C.

In contrast, LMICs and HICs exhibit opposite but smaller changes in the agricultural sector, consistent with lower relative agricultural TFP. As income rises, trade openness leads to an expansion of the services sector and a contraction of manufacturing, consistent with standard patterns of structural transformation.

To uncover the mechanisms driving these results, Table 3 reports outcomes for low-income countries under alternative model specifications, where individual features are removed in turn. The full model, combining non-homothetic preferences, land as a fixed factor, and input–output linkages, serves as the benchmark.[13]

Table 3: **Effects of Trade across Different Specifications - LICs**

	Benchmark	w.o. NHCES	w.o. FF	w.o. NHCES-FF	w.o. Linkages	w.o. Linkages-NHCES	w.o. Linkages-FF	w.o. Linkages-NHCES-FF
Gains from trade	6.75	7.67	6.63	7.51	3.85	4.28	3.70	4.13
Changes in Expenditure share (p.p.)								
Agriculture	-0.57	-1.07	-0.25	-0.70	-0.70	-1.02	-0.24	-0.49
Industry	1.72	1.60	1.64	1.51	1.45	1.42	1.24	1.19
Services	-1.16	-0.53	-1.39	-0.81	-0.75	-0.40	-1.00	-0.70
Changes in Labor share (p.p.)								
Agriculture	-2.13	-2.48	-2.32	-2.70	-1.96	-2.22	-1.98	-2.23
Industry	2.63	2.55	2.59	2.55	3.00	2.93	2.88	2.82
Services	-0.50	-0.07	-0.27	0.14	-1.04	-0.71	-0.90	-0.58
Changes in Labor Productivity (%)								
Agriculture	1.64	2.28	-2.10	-2.10	6.14	6.97	0.00	0.00
Industry	-5.18	-5.10	-5.54	-5.54	0.00	0.00	0.00	0.00
Services	-3.44	-3.41	-3.58	-3.58	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of moving to autarky under alternative model specifications. Values show percentage-point (p.p.) or percent changes relative to the corresponding open-economy equilibrium under each specification. 'Benchmark' denotes the model described in Section 2; 'w.o. NHCES' assumes $\nu_k = 1$ for all k (homothetic preferences); 'w.o. FF' sets $\zeta_j = 0$ (no fixed factor in agricultural production); 'w.o. NHCES–FF' combines both assumptions; 'w.o. Linkages' removes input–output linkages; 'w.o. Linkages–FF' removes linkages and the fixed factor; w.o. Linkages–NHCES' removes linkages and non-homothetic preferences; and 'w.o. Linkages–NHCES–FF' excludes all three features simultaneously. 'Gains from trade' denote the welfare gains from moving out of autarky, expressed as a percentage. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported as averages across income group (LIC, LMIC, HIC), as defined in Appendix C.

Across all specifications, the agricultural labor share falls under autarky, indicating that trade openness raises agricultural employment in low-income countries. With land and linkages, this reflects high relative agricultural TFP. Without them, the effect persists mainly because agriculture is initially more closed: shutting trade redirects expenditure toward industrial goods, reducing agricultural employment. The decline is smaller under non-homothetic preferences but remains negative; removing them amplifies the response. Eliminating the land constraint removes diminishing returns, so labor reallocation no longer raises agricultural productivity. Consequently, the productivity gain observed in the benchmark model vanishes.

[13] Results for LMICs and HICs are reported in Tables VIII and IX, in Appendix G.1.

Closing the economy also raises intermediate input prices, leading to a roughly 5 percent productivity decline in industry across all specifications with linkages.

Removing input–output linkages produces a distinct pattern: welfare gains decline sharply, while agricultural productivity rises mechanically as sectors adjust in isolation. Further removing non-homothetic preferences or the fixed factor has little additional effect. Only when the fixed factor is included does agricultural labor productivity increase; without it, productivity remains unchanged relative to the open-economy equilibrium.

Overall, in low-income countries, trade openness increases agricultural employment on average. However, the autarky simulation yields an opposite conclusion to the conventional explanation that these countries should increase their labor share in agriculture due to income effects. This discrepancy suggests a role for both sector-specific productivity and trade frictions in shaping labor allocation, which requires further examination. To address this, the next section examines how targeted reductions in trade costs affect sectoral outcomes, aiming to clarify the mechanisms underlying changes in labor share.

6.1.2 Unilateral Reduction of Trade Costs

In Appendix E, I show that low-income countries systematically face higher trade barriers than advanced economies. To understand why these countries experience an increase in labor share when they open to trade, I examine the consequences of a unilateral reduction in import and export trade costs, considered separately.

In these simulations, low-income countries are assigned the fixed trade costs of high-income countries, resulting in an average reduction of about 30 percent—an adjustment that effectively closes the average trade-cost gap between low- and high-income economies. For each scenario, I apply the reduction first to agriculture and then to manufacturing, enabling a comparison of how sector-specific liberalization affects welfare, labor productivity, and factor allocation. The first experiment reduces import costs while holding export barriers constant, highlighting the impact of cheaper foreign inputs on domestic outcomes. The second experiment lowers export costs while maintaining existing import frictions, capturing the effects of improved market access abroad.

Table 4 reports the effects of a unilateral 30 percent reduction in import trade costs. When applied to agriculture, welfare gains are modest, around 0.2 to 0.3 percent across specifications, and accompanied by a small decline in agricultural employment due to import competition and a mild rise in agricultural productivity, mainly driven by the presence of the fixed factor. These effects remain largely confined to agriculture, as the sector contributes few intermediates to the rest of the economy.

When the same reduction is applied to manufacturing, the effects are considerably larger. Welfare increases from approximately 4.5 percent in the simplest specification to nearly 7 percent in the Benchmark model. Without intermediate linkages, a small share of labor reallocation occurs toward agriculture; with linkages, the response of agricultural employment is almost null, and the main shift occurs from industry to services, consistent with structural transformation patterns. Introducing non-homothetic preferences reinforces this pattern, as rising income shifts demand toward services. Productivity rises across all sectors when input–output linkages are included.

In summary, reductions in agricultural import barriers yield small, sector-specific gains. In contrast, reductions in industrial trade costs generate broader productivity improvements that rely critically on production networks and are moderated by the presence of non-homothetic preferences.

Table 5 summarizes the effects of a unilateral 30 percent reduction in export trade costs. When applied to agriculture, welfare gains are noticeably larger than in the import experiment, ranging from 1.4 to 1.7 percent in specifications with intermediate linkages and around 0.9 percent without them. The rise in welfare reflects the expansion of the agricultural sector following improved export access: with lower barriers abroad, low-income countries specialize further in their relatively high-TFP sector. However, agricultural productivity declines because the presence of a fixed factor in production generates diminishing returns to labor. These effects weaken, though remain positive, when linkages are removed, as fewer sectors benefit indirectly from the agricultural expansion.

When the reduction targets industrial exports, welfare gains are again sizable, around 3 to 5 percent across specifications, and broadly comparable to those in the import experiment. Employment shifts markedly from services to industry, while agricultural employment declines, an effect that becomes stronger under non-homothetic preferences. Better access to external markets also raises productivity across all sectors, reflecting the influence of intermediate linkages. As labor exits agriculture, the fixed-factor constraint amplifies the productivity gains within the sector.

In summary, reductions in export trade costs lead to larger absolute changes in agricultural employment than comparable reductions in import trade costs, particularly in agriculture. Lower export costs increase foreign demand for domestic agricultural goods and shift labor

Table 4: **Effects of a Unilateral 30% reduction in Import Trade Costs in LICs**

	Benchmark	w.o. NHCES	w.o. FF	w.o. NHCES-FF	w.o. Linkages	w.o. Linkages-NHCES	w.o. Linkages-FF	w.o. Linkages-NHCES-FF
Trade Costs Reduction in Agriculture								
Welfare changes (%)	0.27	0.30	0.29	0.34	0.15	0.17	0.18	0.20
Changes in Expenditure share (p.p.)								
Agriculture	-0.47	-0.44	-0.31	-0.29	-0.51	-0.49	-0.29	-0.27
Industry	0.10	0.10	0.09	0.09	0.23	0.22	0.14	0.14
Services	0.36	0.34	0.22	0.20	0.29	0.27	0.14	0.13
Changes in Labor share (p.p.)								
Agriculture	-1.25	-1.22	-1.91	-1.88	-1.02	-1.00	-1.63	-1.61
Industry	0.77	0.76	0.99	0.98	0.63	0.63	1.00	1.00
Services	0.48	0.46	0.92	0.90	0.39	0.37	0.63	0.61
Changes in Labor Productivity (%)								
Agriculture	2.55	2.50	0.31	0.31	2.96	2.89	0.00	0.00
Industry	0.63	0.62	0.27	0.27	0.00	0.00	0.00	0.00
Services	0.15	0.15	0.02	0.02	0.00	0.00	0.00	0.00
Trade Costs Reduction in Industry								
Welfare changes (%)	6.77	7.81	6.77	7.80	3.96	4.46	3.96	4.45
Changes in Expenditure share (p.p.)								
Agriculture	0.27	0.76	0.28	0.73	0.56	0.87	0.36	0.62
Industry	-2.83	-2.72	-2.83	-2.72	-2.78	-2.74	-2.72	-2.66
Services	2.56	1.96	2.55	1.99	2.22	1.87	2.36	2.04
Changes in Labor share (p.p.)								
Agriculture	-0.03	0.24	-0.02	0.33	0.91	1.12	1.28	1.54
Industry	-4.53	-4.49	-4.23	-4.22	-7.13	-7.05	-6.97	-6.94
Services	4.56	4.25	4.25	3.89	6.21	5.94	5.69	5.40
Changes in Labor Productivity (%)								
Agriculture	2.55	2.16	2.45	2.45	-1.96	-2.38	0.00	0.00
Industry	7.31	7.25	7.29	7.30	0.00	0.00	0.00	0.00
Services	3.93	3.90	3.92	3.92	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of unilateral reductions in import trade costs of a 30 percent under alternative model specifications. Values show percentage-point (p.p.) or percent changes relative to the corresponding open-economy equilibrium under each specification. 'Benchmark' denotes the model described in Section 2; 'w.o. NHCES' assumes $\nu_k = 1$ for all k (homothetic preferences); 'w.o. FF' sets $\zeta_j = 0$ (no fixed factor in agricultural production); 'w.o. NHCES–FF' combines both assumptions; 'w.o. Linkages' removes input–output linkages; 'w.o. Linkages–FF' removes linkages and the fixed factor; w.o. Linkages–NHCES' removes linkages and non-homothetic preferences; and 'w.o. Linkages–NHCES–FF' excludes all three features simultaneously. Separate results are reported for reductions applied to agriculture and to industry. 'Welfare Changes (%)' denotes the change in real GDP, expressed in percentage terms. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported as averages across low-income countries (LICs), as defined in Appendix C.

Table 5: **Effects of a Unilateral 30% reduction in Export Trade Costs in LICs**

	Benchmark	w.o. NHCES	w.o. FF	w.o. NHCES-FF	w.o. Linkages	w.o. Linkages-NHCES	w.o. Linkages-FF	w.o. Linkages-NHCES-FF
Trade Costs Reduction in Agriculture								
Welfare changes (%)	1.46	1.68	1.51	1.73	0.79	0.90	0.81	0.92
Changes in Expenditure share (p.p.)								
Agriculture	0.54	0.65	0.05	0.16	0.68	0.74	0.05	0.10
Industry	-0.32	-0.30	-0.28	-0.26	-0.42	-0.41	-0.23	-0.22
Services	-0.22	-0.35	0.23	0.10	-0.26	-0.33	0.18	0.11
Changes in Labor share (p.p.)								
Agriculture	4.49	4.57	7.04	7.12	3.45	3.51	6.03	6.08
Industry	-2.43	-2.44	-3.28	-3.28	-2.23	-2.23	-3.59	-3.60
Services	-2.06	-2.13	-3.77	-3.84	-1.22	-1.28	-2.43	-2.49
Changes in Labor Productivity (%)								
Agriculture	-4.97	-5.08	0.42	0.42	-6.27	-6.39	0.00	0.00
Industry	0.02	0.01	1.20	1.20	0.00	0.00	0.00	0.00
Services	0.24	0.24	0.79	0.79	0.00	0.00	0.00	0.00
Trade Costs Reduction in Industry								
Welfare changes (%)	4.86	5.58	4.89	5.61	2.83	3.17	2.86	3.20
Changes in Expenditure share (p.p.)								
Agriculture	0.06	0.41	0.14	0.47	-0.05	0.18	0.17	0.37
Industry	-0.84	-0.77	-0.86	-0.78	-0.65	-0.63	-0.74	-0.71
Services	0.79	0.36	0.72	0.31	0.71	0.46	0.57	0.34
Changes in Labor share (p.p.)								
Agriculture	-0.69	-0.50	-1.00	-0.77	-1.01	-0.86	-1.40	-1.22
Industry	8.82	8.83	8.40	8.38	8.34	8.36	8.19	8.18
Services	-8.14	-8.33	-7.39	-7.62	-7.33	-7.50	-6.78	-6.96
Changes in Labor Productivity (%)								
Agriculture	2.57	2.29	1.52	1.53	2.54	2.20	0.00	0.00
Industry	3.99	3.95	3.87	3.88	0.00	0.00	0.00	0.00
Services	2.56	2.54	2.49	2.50	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of unilateral reductions in export trade costs of a 30 percent under alternative model specifications. Values show percentage-point (p.p.) or percent changes relative to the corresponding open-economy equilibrium under each specification. 'Benchmark' denotes the model described in Section 2; 'w.o. NHCES' assumes $\nu_k = 1$ for all k (homothetic preferences); 'w.o. FF' sets $\zeta_j = 0$ (no fixed factor in agricultural production); 'w.o. NHCES–FF' combines both assumptions; 'w.o. Linkages' removes input–output linkages; 'w.o. Linkages–FF' removes linkages and the fixed factor; w.o. Linkages–NHCES' removes linkages and non-homothetic preferences; and 'w.o. Linkages–NHCES–FF' excludes all three features simultaneously. Separate results are reported for reductions applied to agriculture and to industry. 'Welfare Changes (%)' denotes the change in real GDP, expressed in percentage terms. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported as averages across low-income countries (LICs), as defined in Appendix C.

allocation toward the sector, whereas lower import costs reduce agricultural employment by intensifying import competition. This asymmetry helps explain the autarky results in the previous subsection: shutting down trade eliminates export demand and therefore lowers agricultural labor shares, even though technology and land constraints remain unchanged. By contrast, reductions in industrial trade costs generate broader welfare gains through input–output linkages, while their effects on agricultural employment are limited and mainly involve reallocation toward services.

6.2 The Effects of TFP Improvements

A long-standing debate concerns whether productivity growth in agriculture or in non-agriculture is more effective in narrowing income differences across countries. Much of the existing literature emphasizes agricultural TFP as a central determinant of cross-country income differences and structural transformation, while noting that observed labor-productivity gaps often reflect differences in input intensity rather than technology (Caselli, 2005; Restuccia et al., 2008; Gollin et al., 2002, 2004, 2014). More recent work highlights the dominant role of non-agricultural TFP, particularly in investment and intermediate sectors, in driving income convergence as economies develop (Donovan, 2021; Caunedo and Keller, 2021; Boppart et al., 2023).

This debate has largely been conducted within closed-economy frameworks. As a result, it abstracts from the interaction between productivity growth, trade, and sectoral specialization in economies with fixed factors. In an open economy with land constraints and input–output linkages, productivity improvements affect export demand, relative prices, and labor allocation across sectors. This section uses counterfactual TFP shocks to quantify how the effects of agricultural and industrial productivity growth differ between closed and open economies, and how these differences shape welfare and agricultural specialization in low-income countries.

Table 6 addresses this question for low-income countries by comparing sector-specific 10% increases in TFP across alternative model specifications. These specifications sequentially remove non-homothetic preferences, the fixed factor in agriculture, and production linkages, under both closed- and open-economy conditions.[14]

A key difference arises in labor allocation across regimes. In a closed economy, higher agricultural productivity reduces the sector's labor share as workers reallocate to non-agriculture, thereby amplifying the rise in labor productivity. In contrast, in the open

[14] Corresponding results for LMICs and HICs are reported in Appendix G.2, Tables XI and XII.

economy, low-income countries specialize further in their relatively high-TFP agricultural sector, leading to an increase in the agricultural labor share. An effect that strengthens when non-homothetic preferences or the fixed factor are removed. This pattern is consistent with the traditional view that raising agricultural productivity enhances overall labor productivity and helps narrow income gaps with advanced economies. However, it highlights a distinct mechanism: in open economies, TFP growth reinforces specialization in agriculture rather than inducing labor to move out of it.

A 10% increase in agricultural TFP yields robust welfare gains of 1.5-3 percent across specifications, with slightly higher values under openness. The inclusion of non-homothetic preferences and the fixed factor modestly dampens the aggregate effect, as both mechanisms limit income responses and constrain sectoral reallocation. Removing input–output linkages reduces welfare gains by almost half, confirming that intermediate input spillovers are the main channel through which agricultural productivity improvements translate into aggregate welfare. The agricultural expenditure share decreases by roughly 1 percentage point in all scenarios. However, the magnitude of this adjustment is slightly smaller once trade is introduced, as part of the productivity gain is transmitted externally rather than absorbed domestically. Across all cases, agricultural labor productivity increases sharply by 10-13 percent, whereas cross-sector spillovers disappear when linkages are suppressed.

On the other hand, a 10% increase in industrial TFP yields substantially larger welfare gains than an agricultural one, ranging from 3 to 5 percent across specifications, with slightly smaller magnitudes under openness than in autarky. In a closed economy, higher industrial productivity reduces the sector's labor share, as workers reallocate primarily to services. When income effects are removed, however, a marginal increase in agricultural employment emerges. Under openness, this pattern reverses: labor shifts into industry from both agriculture and services, reflecting the sector's greater competitiveness in global markets. The rise in industrial labor productivity declines from around 16 percent to the original 10% increase when linkages are suppressed, while modest spillovers to agriculture persist due to the fixed factor.

Taken together, the results indicate two distinct patterns in agricultural employment. Under openness, increases in agricultural TFP raise labor productivity but also expand agricultural employment in low-income countries, reinforcing specialization rather than releasing labor from the sector, as occurs in a closed economy. By contrast, increases in industrial TFP lead to only modest reductions in agricultural employment, while generating larger welfare gains through intermediate input linkages that propagate productivity improvements across

Table 6: **Effects of a 10% increase in TFP across Different Specifications - LICs**

	Benchmark		w.o. NHCES		w.o. FF		w.o. NHCES-FF		w.o. Linkages		w.o. Linkages-NHCES		w.o. Linkages-FF		w.o. Linkages-NHCES-FF	
	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open
TFP improvement in Agriculture																
Welfare changes (%)	2.38	2.58	2.72	2.95	2.42	2.56	2.76	2.93	1.33	1.48	1.48	1.65	1.38	1.47	1.53	1.63
Changes in Expenditure share (p.p.)																
Agriculture	-1.37	-1.18	-1.18	-0.98	-1.25	-1.21	-1.08	-1.03	-1.43	-1.16	-1.30	-1.03	-1.15	-1.12	-1.05	-1.01
Industry	0.14	0.12	0.17	0.15	0.12	0.12	0.16	0.16	0.53	0.39	0.53	0.40	0.41	0.37	0.43	0.38
Services	1.23	1.06	1.01	0.82	1.13	1.09	0.92	0.87	0.90	0.78	0.77	0.64	0.74	0.75	0.62	0.62
Changes in Labor share (p.p.)																
Agriculture	-0.88	0.37	-0.75	0.49	-0.99	0.65	-0.85	0.79	-1.12	-0.08	-1.02	0.01	-1.15	0.11	-1.05	0.21
Industry	0.07	-0.18	0.09	-0.17	0.14	-0.27	0.15	-0.27	0.40	-0.27	0.42	-0.25	0.41	-0.34	0.43	-0.33
Services	0.80	-0.19	0.66	-0.32	0.85	-0.38	0.70	-0.52	0.72	0.35	0.60	0.24	0.74	0.23	0.62	0.12
Changes in Labor Productivity (%)																
Agriculture	13.59	11.38	13.37	11.20	11.93	11.93	11.93	11.93	13.36	10.23	13.11	10.02	10.00	10.00	10.00	10.00
Industry	2.29	2.02	2.25	2.00	2.03	2.10	2.03	2.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Services	0.84	0.80	0.83	0.79	0.75	0.83	0.75	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TFP improvement in Industry																
Welfare changes (%)	5.39	5.02	6.24	5.81	5.39	5.04	6.23	5.83	2.86	2.76	3.22	3.10	2.85	2.77	3.21	3.11
Changes in Expenditure share (p.p.)																
Agriculture	0.20	0.12	0.58	0.47	0.20	0.17	0.55	0.49	0.30	0.16	0.54	0.38	0.24	0.21	0.43	0.40
Industry	-2.15	-1.67	-2.05	-1.58	-2.14	-1.68	-2.04	-1.58	-1.82	-1.42	-1.80	-1.39	-1.79	-1.44	-1.74	-1.40
Services	1.95	1.54	1.47	1.11	1.94	1.51	1.49	1.09	1.52	1.26	1.25	1.02	1.55	1.23	1.31	1.00
Changes in Labor share (p.p.)																
Agriculture	-0.02	-0.37	0.23	-0.18	-0.03	-0.55	0.25	-0.31	0.24	-0.28	0.43	-0.14	0.24	-0.43	0.43	-0.25
Industry	-1.20	3.12	-1.15	3.15	-1.12	2.99	-1.10	3.00	-1.88	2.05	-1.83	2.10	-1.79	2.03	-1.74	2.05
Services	1.23	-2.75	0.92	-2.97	1.16	-2.44	0.84	-2.69	1.64	-1.77	1.40	-1.96	1.55	-1.60	1.31	-1.80
Changes in Labor Productivity (%)																
Agriculture	2.02	2.28	1.59	1.99	1.95	1.74	1.95	1.74	-0.60	0.67	-1.09	0.34	0.00	0.00	0.00	0.00
Industry	16.42	15.62	16.33	15.56	16.39	15.54	16.39	15.55	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Services	3.02	2.74	3.00	2.72	3.02	2.71	3.02	2.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of a 10 percent increase in sectoral total factor productivity (TFP) under alternative model specifications. Values show percentage-point (p.p.) or percent changes relative to the corresponding open-economy equilibrium under each specification. 'Benchmark' denotes the model described in Section 2; 'w.o. NHCES' assumes $\nu_k = 1$ for all k (homothetic preferences); 'w.o. FF' sets $\zeta_j = 0$ (no fixed factor in agricultural production); 'w.o. NHCES–FF' combines both assumptions; 'w.o. Linkages' removes input–output linkages; 'w.o. Linkages–FF' removes linkages and the fixed factor; w.o. Linkages–NHCES' removes linkages and non-homothetic preferences; and 'w.o. Linkages–NHCES–FF' excludes all three features simultaneously. Separate results are shown for agricultural and industrial TFP improvements, and for both closed- and open-economy environments. 'Welfare Changes (%)' denotes the change in real GDP, expressed in percentage terms. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported as averages across low-income countries (LICs), as defined in Appendix C.

sectors.

7 Conclusion

The macro development literature refers to the Food Problem as the persistent concentration of labor in low-productivity agriculture in low-income countries. This paper revisits this phenomenon in an open-economy framework that includes trade, input–output linkages, and land as a fixed factor in agriculture. Here, production is not tied to domestic expenditure. As a result, observed agricultural employment shares and labor productivity differ from those in closed-economy models.

On the supply side, bilateral trade flows, input–output linkages, and the agricultural labor-to-land ratio together identify sectoral technology. When labor-to-land ratios are accounted for, low-income countries exhibit high revealed relative TFP in agriculture. Despite this, measured labor productivity remains low because land scarcity depresses output per worker. This implies that a high agricultural employment share can be consistent with strong agricultural technology when land is a fixed factor, and labor is abundant.

On the demand side, this paper is the first to estimate non-homothetic CES preferences in an open-economy environment with diminishing returns to labor in agriculture. The parameters are identified using an instrumental variables strategy that exploits sector-level TFP variation. The estimates indicate strong complementarity across broad sectors and systematic income effects, which are consistent with Engel-type expenditure patterns. These estimates shape how expenditure responds to income growth and relative price changes in the quantitative analysis.

Standard closed-economy models predict that higher agricultural TFP or greater trade openness should reduce agricultural employment, either through increased productivity or import competition. In an open economy, however, trade unties domestic production from domestic expenditure. As a result, the effects of productivity growth and trade on agricultural specialization are not clear a priori. This motivates counterfactual simulations that quantify the effects of changes in trade costs and sectoral productivity on sectoral employment, labor productivity, and welfare.

The counterfactual simulations show that both trade openness and higher agricultural TFP increase agricultural specialization in low-income countries. Improvements in market access raise foreign demand for agricultural goods and draw labor into agriculture, whereas domestic demand plays a limited role in shaping production patterns. By contrast, increases in industrial TFP or reductions in trade costs for manufactures generate larger welfare gains, primarily through input–output linkages that lower production costs across the economy and reduce labor in agriculture.

Taken together, these results offer a reinterpretation of the Food Problem in an open economy. Persistent agricultural employment in low-income countries need not signal weak agricultural technology. Instead, it can arise from the interaction of land scarcity, diminishing returns to labor, and access to foreign demand under trade. Openness and agricultural productivity growth can therefore reinforce agricultural specialization. Therefore, the Food Problem in an open economy departs from the closed-economy interpretation, as trade openness shapes agricultural employment patterns.

Future work can extend the empirical coverage and sharpen the sectoral detail. A natural next step is to incorporate more low-income economies with consistent trade and land-use data. Another step is to disaggregate agriculture and distinguish between land-intensive and labor-intensive activities, refining the mapping from endowments to inferred technology. Finally, introducing shocks to land suitability would allow a quantitative assessment of how climate-driven changes in effective land endowments alter specialization patterns and welfare under trade.

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A The Food Problem

A persistent feature of low-income countries is the concentration of labor in low-productivity agriculture, a phenomenon known as the "Food Problem" (Schultz, 1953). Figure I illustrates three related patterns. Panel (a) plots agricultural employment shares against GDP per worker and shows that poorer countries remain highly specialized in agriculture. Panel (b) plots relative agricultural labor productivity, defined as the ratio of value added per worker in agriculture to value added per worker in non-agriculture, and shows that this specialization coexists with low relative productivity. The Food Problem is not only about employment and productivity but also about welfare: panel (c) shows a strong negative association between food security and the agricultural employment share, indicating that countries in which most workers remain in agriculture also face greater risks of undernourishment. Taken together, these patterns suggest that agricultural specialization persists even when it is associated with low productivity and poor food outcomes, raising the question of which structural forces sustain this equilibrium in low-income countries.

B Model

B.1 Exact Hat Algebra

For any variable x, denote its counterfactual change by $\hat{x} \equiv x'/x$. Exogenous variables are time-invariant unless explicitly shocked (e.g. $\hat{\tau}_{ij,k} \neq 1$, $\hat{A}_{i,k} \neq 1$, $\hat{L}_i \neq 1$, $\hat{Z}_{i,k} \neq 1$, $\hat{D}_j \neq 1$) while the remain parameters $\{\alpha_{i,s}, \alpha_{i,sk}, \zeta_{i,s}, \varepsilon_s, \gamma_{j,s}, \nu_s\}_{i,j=1,\ldots,N;s,k\in\mathcal{K}}\}$ does not vary.

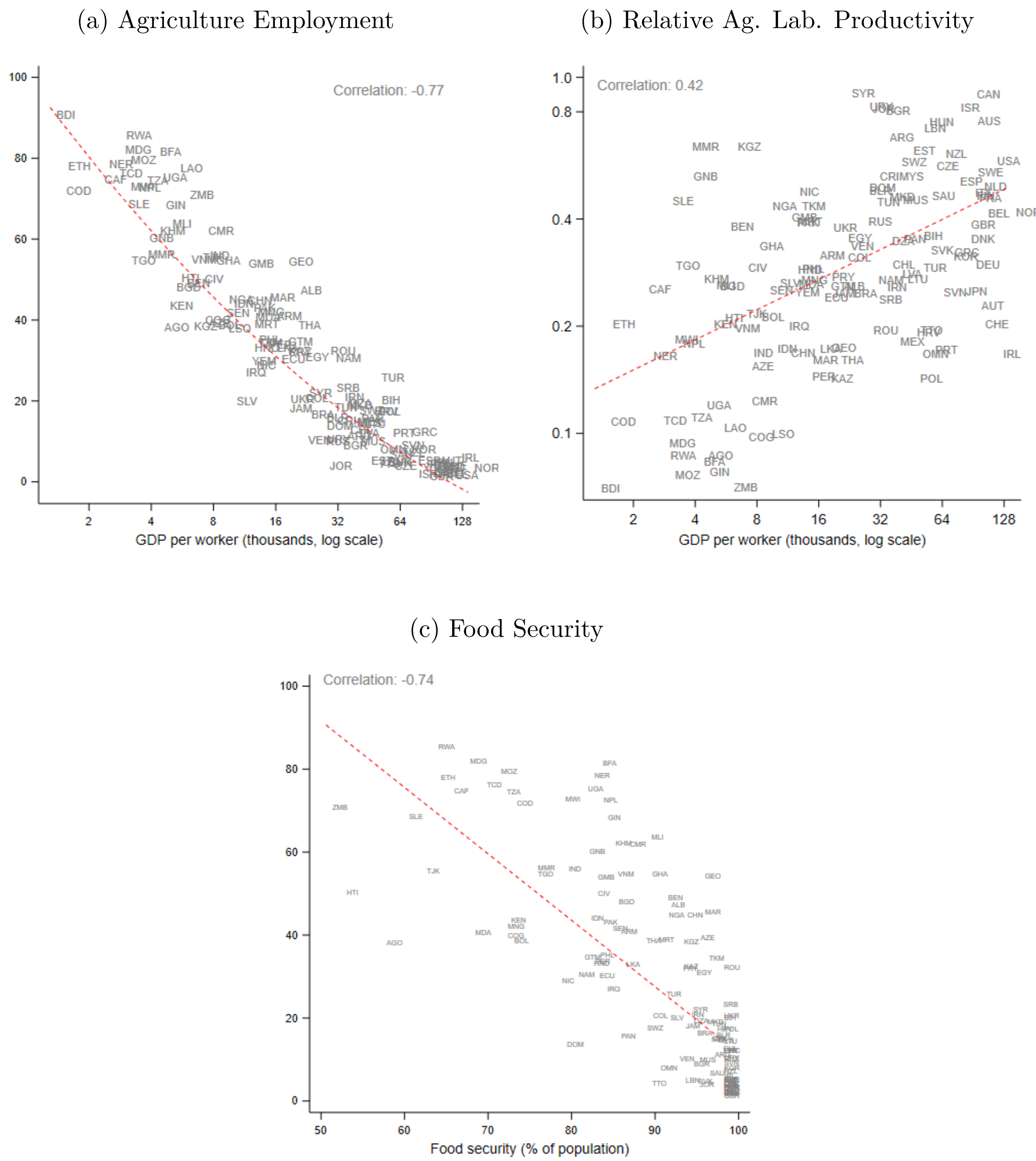
Non-Homothetic CES (NHCES) preferences results

$$1 = \sum_{k=1}^{\mathcal{K}} \omega_{j,k} \left(\frac{\hat{C}_{j,k}}{\left(\hat{C}_j\right)^{\nu_k}} \right)^{\frac{\sigma-1}{\sigma}}, \tag{26}$$

implying

$$\hat{\omega}_{j,k} = \left(\frac{\hat{X}_j^f}{\hat{P}_{j,k}} \right)^{\sigma-1} \left(\hat{C}_j\right)^{-\nu_k(\sigma-1)}. \tag{27}$$

Figure I: The Food Problem



Notes: Each panel plots country-level data for 2005. Panel (a) shows agricultural employment shares (% of total employment) against log GDP per worker from the Penn World Table (PWT) 10.01. Panel (b) shows log relative agricultural labor productivity, defined as the log ratio of value added per worker in agriculture to value added per worker in non-agriculture. Panel (c) shows agricultural employment shares against log food security, measured as the log share of the population with adequate caloric intake (100 minus the prevalence of undernourishment, % of population). Red dashed lines plot fitted linear relationships, with correlation coefficients reported above each panel. Country codes denote individual observations.

The supply curve of agricultural good $s \in \mathcal{K}^A$ in country j is

$$\hat{Y}_{j,k} = \hat{Z}_j \left(\hat{p}_{j,k} \hat{A}_{j,k} \left(\hat{w}_j\right)^{-\alpha_{j,k}(1-\zeta_j)} \prod_{s \in \mathcal{K}} \left(\hat{P}_{j,s}\right)^{-\alpha_{j,sk}} \right)^{1/\alpha_{j,k}\zeta_{j,k}}, \tag{28}$$

and for non-agricultural goods $s \notin \mathcal{K}^A$, hat changes in the supply curve in country in country j is

$$\hat{p}_{j,k} = \hat{A}_{j,k}^{-1} \left(\hat{w}_j\right)^{\alpha_{j,k}} \prod_{s \in \mathcal{K}} \left(\hat{P}_{j,s}\right)^{\alpha_{j,sk}}, \tag{29}$$

where $\hat{p}_{j,k}$ is the hat change of the producer unit cost and $\hat{P}_{j,s}$ the hat change of the sectoral price indices, given the Armington assumption, is defined as

$$\left(\hat{P}_{j,k}\right)^{-\varepsilon_k} = \sum_{i=1}^{N} \lambda_{ij,k} \left(\hat{p}_{ij,k}\right)^{-\varepsilon_k}, \tag{30}$$

where

$$\hat{\lambda}_{ij,k} = \left(\frac{\hat{p}_{ij,k}}{\hat{P}_{j,k}}\right)^{-\varepsilon_k}. \tag{31}$$

By perfect competition, changes in the unit cost of producing good $k \in \mathcal{K}$ must equalize the change in the price index of good $k \in \mathcal{K}$ in country j, thus

$$\frac{\hat{P}_{i,s}}{\hat{w}_i} = \left(\frac{\hat{L}_{i,a}}{\hat{Z}_{i,a}}\right)^{\alpha_{i,a}\zeta_{i,a}\chi_{i,as}} \prod_{l \in \mathcal{K}} \left(\hat{\lambda}_{ii,l}\right)^{\chi_{i,ls}/\varepsilon_k} \prod_{l \in \mathcal{K}} \hat{A}_{i,l}^{-\chi_{i,ls}},$$

where $\chi_{i,ks}$ is the (k, s) entry of the *forward linkage* matrix, $\mathcal{L}$.

Hat changes in total rents from land are:

$$\hat{\Pi}_j = \sum_{k \in \mathcal{K}^A} \frac{\alpha_{j,k}\zeta_{j,k} Y_{j,k}}{\Pi_j} \hat{Y}_{j,k}, \tag{32}$$

while hat change in sectoral wage are

$$\hat{w}_j \hat{L}_{j,k} = \hat{Y}_{j,k}, \tag{33}$$

thus final expenditure equals

$$\hat{X}_j^f = \frac{w_j L_j}{X_j^f} \hat{w}_j \hat{L}_j + \frac{\Pi_j}{X_j^f} \hat{\Pi}_j + \frac{D_j}{X_j^f} \hat{D}_j = \sum_{k \in \mathcal{K}} \frac{\alpha_{j,k} Y_{j,k}}{X_j^f} \hat{Y}_{j,k} + \frac{D_j}{X_j^f} \hat{D}_j. \tag{34}$$

The market clearing condition for any good $s \in \mathcal{K}$ produced in country i results

$$\hat{Y}_{i,s} = \sum_{j=1}^{N} \frac{\lambda_{ij,s} X_{j,s}}{Y_{i,s}} \hat{\lambda}_{ij,s} \hat{X}_{j,s}, \tag{35}$$

with changes in expenditure on good s in country j as

$$\hat{X}_{j,s} = \frac{\omega_{j,s} X_j^f}{X_{j,s}} \hat{\omega}_{j,s} \hat{X}_j^f + \sum_{k \in \mathcal{K}} \frac{\alpha_{j,ks} Y_{j,k}}{X_{j,s}} \hat{Y}_{j,k}. \tag{36}$$

Labor market clearing in country i requires

$$\hat{L}_j = \sum_{k \in \mathcal{K}} \ell_{j,k} \hat{L}_{j,k}. \tag{37}$$

Finally, real GDP is

$$\widehat{GDP}_j = \frac{w_j L_j \hat{w}_j \hat{L}_j / \hat{P}_j}{w_j L_j + \sum_{s \in \mathcal{K}^a} \Pi_{j,k}} + \sum_{s \in \mathcal{K}^a} \frac{\Pi_{j,k} \hat{\Pi}_{j,k} / \hat{P}_j}{w_j L_j + \sum_{s \in \mathcal{K}^a} \Pi_{j,k}}, \tag{38}$$

where

$$\left(\hat{P}_j\right)^{1-\sigma} = \sum_{k \in \mathcal{K}} \omega_{j,k} \left(\hat{C}_j\right)^{(1-\nu_k)(\sigma-1)} \left(\hat{P}_{j,k}\right)^{1-\sigma}.$$

Given parameters $\{\alpha_{i,s}, \alpha_{i,sk}, \zeta_{i,s}, \varepsilon_s, \gamma_{j,s}, \nu_s\}_{j=1,\ldots,N; s,k \in \mathcal{K}}$, hat change in exogenous variables $\left\{\hat{A}_{i,s}, \hat{\tau}_{ij,s}, \hat{L}_i, \hat{Z}_{i,s}, \hat{D}_j\right\}_{i,j=1,\ldots,N; s,k \in \mathcal{K}}\}$ an counterfactual equilibrium is a collection of hat change in producer unit costs and sectoral price indices, $\left\{\hat{p}_{i,s}, \hat{P}_{i,s}\right\}_{s \in \mathcal{K}}$, trade shares, $\left\{\hat{\lambda}_{ij,s}\right\}_{i,s \in \mathcal{K}}$, total and final expenditures, gross output, and wages, $\left\{\hat{X}_j^f, \hat{w}_j, \hat{X}_{j,s}, \hat{Y}_{j,s}\right\}_{s \in \mathcal{K}}$, such that Equations (26)–(38) are satisfied.

B.2 Derivation of Labor Productivity

Sectoral labor productivity in country j and sector k is defined as real output per worker:

$$\Lambda_{j,k} \equiv \frac{Y_{j,k}}{p_{j,k}} \frac{1}{L_{j,k}}.$$

Following Equation (8), under Armington with domestic trade costs $\tau_{jj,k} = 1$, the home expenditure share satisfies $\lambda_{jj,k} = \left(\frac{p_{j,k}}{P_{j,k}}\right)^{-\varepsilon_k}$, thus

$$p_{j,k} = \lambda_{jj,k}^{-1/\varepsilon_k} P_{j,k}.$$

Substituting,

$$\Lambda_{j,k} = \frac{Y_{j,k}}{P_{j,k}} \frac{\lambda_{jj,k}^{1/\varepsilon_k}}{L_{j,k}}. \tag{39}$$

By 4 and 3, the labor share of revenue equals $\alpha_{j,k}(1-\zeta_{j,k})$ with $\zeta_{j,k} = 0$ for all $s \notin \mathcal{K}^A$, hence $w_j L_{j,k} = \alpha_{j,k}\left(1-\zeta_{j,k}\right) Y_{j,k}$, thus

$$\frac{Y_{j,k}}{L_{j,k}} = \frac{w_j}{\alpha_{j,k}\left(1-\zeta_{j,k}\right)},$$

and therefore,

$$\Lambda_{j,k} = \frac{w_j}{P_{j,k}} \frac{\lambda_{jj,k}^{1/\varepsilon_k}}{L_{j,k}} \frac{1}{\alpha_{j,k}(1-\zeta_{j,k})}.$$

For any variable x, denote its counterfactual change by $\hat{x} \equiv x'/x$. From the previous definition, I get:

$$\hat{\Lambda}_{j,k} = \frac{\hat{Y}_{j,k}}{\hat{P}_{j,k}} \frac{\hat{\lambda}_{jj,k}^{1/\varepsilon_k}}{\hat{L}_{j,k}}. \tag{40}$$

B.3 Algorithm Procedure

I apply exact hat algebra (Dekle et al. 2008; Costinot and Rodríguez-Clare 2014) to convert the equilibrium conditions 1–15 from levels to hat changes, as derived in Appendix B.1. Let $\hat{x} \equiv x'/x$ denote the proportional change between the initial equilibrium, x, and the counterfactual, x'. Given baseline values for $\left\{\alpha_{i,ks}, \alpha_{i,k}, \lambda_{ij,k}, Y_{i,k}, X_j^f, \omega_{j,k}, \ell_{j,a}, Z_j\right\}$ and the shocks of interest, the method delivers counterfactual changes for $\left\{\hat{P}_{j,s}, \hat{\lambda}_{ij,k}, \hat{X}_{j,s}, \hat{Y}_{i,k}, \hat{X}_j^f, \hat{C}_j, \hat{\ell}_{j,k}, \hat{\omega}_{j,k}, \hat{P}_{i,k}\right\}$.

The counterfactual equilibrium is obtained via an iterative fixed-point algorithm that updates prices, trade shares, and quantities until convergence. World GDP is normalized as the *numéraire*, which allows the model to be solved using a fast algorithm in the spirit of Alvarez and Lucas Jr (2007). The procedure follows these steps:

1. **Initialization**: Guess hat changes for agricultural prices and wages, and load baseline data on production, trade shares, and parameters.

2. **Sectoral Price Indices**: Compute agricultural price indices from trade shares, trade costs, and current prices; then solve for non-agricultural price indices using a nested fixed-point loop.

3. **Trade Shares**: Update bilateral trade shares using the CES import demand system, conditional on current prices, trade costs, and technology.

4. **Sectoral Output**: Update sectoral outputs using the production functions, incorporating changes in prices, wages, technology, and (for agriculture) land.

5. **Final Expenditure**: Compute total country expenditure, combining household income from wages and land rents.

6. **Welfare and expenditure shares**: Derive welfare changes from price indices and total expenditure; then update sectoral expenditure shares.

7. **Demand System:** Solve demand across sectors and countries, accounting for changes in expenditure shares and intermediate input demand.

8. **Output Allocation**: Compute sectoral output levels from the updated final and intermediate demand.

9. **Updating:** Adjust wages and agricultural prices via a *tâtonnement* rule so that factor and goods markets approach equilibrium, with smaller adjustment steps as convergence improves.

10. **Convergence Check**: Stop if the maximum change across wages, prices, and quantities is below a tolerance threshold; otherwise, return to step 2.

C Data Description

I use the sectoral classification from the OECD Inter-Country Input–Output (ICIO) tables. For the analysis, the detailed sectors reported in the ICIO are aggregated into three broad categories: agriculture, industry, and services. This aggregation provides a parsimonious structure that aligns with the model while preserving the essential features of production and trade. The mapping from the original ICIO sectors into these three aggregates is presented in Table I.

The ICIO database covers a wide set of countries. Table II presents the description of country coverage. To simplify the analysis and avoid overweighting very small but highly open economies, I group Brunei Darussalam, Hong Kong, Ireland, Luxembourg, Malta, Singapore, and Chinese Taipei with the "Rest of the World" (ROW). This treatment ensures that these economies remain represented in the data without introducing disproportionate variation relative to their economic size. Countries are further categorized by OECD membership, which provides a natural benchmark for distinguishing advanced economies from non-members.

In addition, I classify countries by income group according to the World Bank Analytical Classifications, as reported in the *World Development Indicators*. These classifications are based on Gross National Income (GNI) per capita, measured in current US dollars using the Atlas methodology for the calendar year 2005. According to this criterion, countries with a GNI per capita of up to 875 US dollars are classified as low-income countries (LICs). In comparison, those with incomes between 876 and 3,465 US dollars are classified as lower-middle-income countries (LMICs). A few country-specific adjustments are required for consistency. Cameroon is classified as a LIC, despite having crossed into lower-middle-income status in 2005, to preserve comparability with its historical classification. Conversely, Bulgaria and Brazil are moving to the HIC category, since they transitioned to upper-middle-income status after 2005. These adjustments have no material effect on the results, which remain robust to alternative groupings.

To illustrate how the ICIO country sample is distributed along the global income–agriculture relationship, Figure II shows the relationship between agricultural employment and income from Figure I (panel a), confirming that the ICIO countries are representative of the broader cross-country association between income levels and agricultural specialization.

The model variables map directly to observable data counterparts. Table III summarizes the notation, description, and sources.

D Revealed Relative Productivity: Derivations

For expositional convenience, I first present the general case with intermediate inputs and a fixed factor, and then show how to obtain the remaining specifications.

Agriculture is the only sector using a fixed factor (land), $\mathcal{K}^A = \{a\}$. The unit cost in any

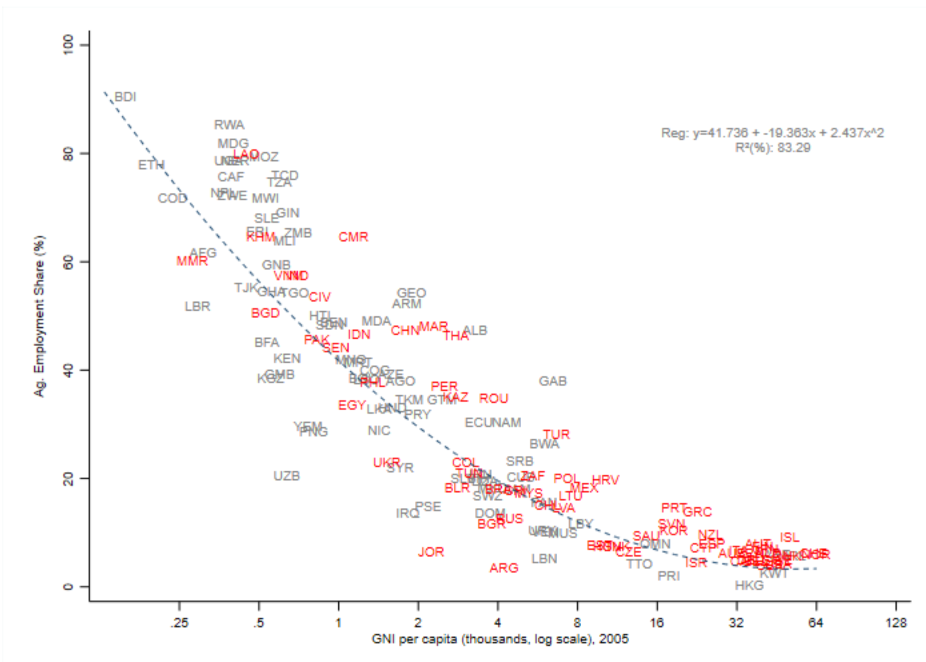
Table I: Sector Aggregation

Main Aggregation	Sector Name	ISIC Rev.4 Code
Agriculture	Agriculture, hunting, forestry	A01_02
	Fishing and aquaculture	A03
Industry	Mining and quarrying, energy producing products	B05_06
	Mining and quarrying, non-energy producing products	B07_08
	Mining support service activities	B09
	Food products, beverages and tobacco	C10T12
	Textiles, textile products, leather and footwear	C13T15
	Wood and products of wood and cork	C16
	Paper products and printing	C17_18
	Coke and refined petroleum products	C19
	Chemical and chemical products	C20
	Pharmaceuticals, medicinal chemical and botanical products	C21
	Rubber and plastics products	C22
	Other non-metallic mineral products	C23
	Basic metals	C24
	Fabricated metal products	C25
	Computer, electronic and optical equipment	C26
	Electrical equipment	C27
	Machinery and equipment, nec.	C28
	Motor vehicles, trailers and semi-trailers	C29
	Other transport equipment	C30
	Industry nec; repair and installation of machinery and equipment	C31T33
Services	Electricity, gas, steam and air conditioning supply	D
	Water supply; sewerage, waste management and remediation activities	E
	Construction	F
	Wholesale and retail trade; repair of motor vehicles	G
	Land transport and transport via pipelines	H49
	Water transport	H50
	Air transport	H51
	Warehousing and support activities for transportation	H52
	Postal and courier activities	H53
	Accommodation and food service activities	I
	Publishing, audiovisual and broadcasting activities	J58T60
	Telecommunications	J61
	IT and other information services	J62_63
	Financial and insurance activities	K
	Real estate activities	L
	Professional, scientific and technical activities	M
	Administrative and support services	N
	Public administration and defense; compulsory social security	O
	Education	P
	Human health and social work activities	Q
	Arts, entertainment and recreation	R
	Other service activities	S
	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T

Table II: Country Description

Country Code	Country Name	OECD member	Income Group	Country Code	Country Name	OECD member	Income Group
ARG	Argentina	No	HIC	JPN	Japan	Yes	HIC
AUS	Australia	Yes	HIC	KAZ	Kazakhstan	No	LMIC
AUT	Austria	Yes	HIC	KHM	Cambodia	No	LIC
BEL	Belgium	Yes	HIC	KOR	Korea (South)	Yes	HIC
BGD	Bangladesh	No	LIC	LAO	Lao (PDR)	No	LIC
BGR	Bulgaria	No	HIC	LTU	Lithuania	Yes	HIC
BLR	Belarus	No	LMIC	LVA	Latvia	Yes	HIC
BRA	Brazil	No	HIC	MAR	Morocco	No	LMIC
CAN	Canada	Yes	HIC	MEX	Mexico	Yes	HIC
CHE	Switzerland	Yes	HIC	MMR	Myanmar	No	LIC
CHL	Chile	Yes	HIC	MYS	Malaysia	No	HIC
CHN	China	No	LMIC	NGA	Nigeria	No	LIC
CIV	Côte d'Ivoire	No	LIC	NLD	Netherlands	Yes	HIC
CMR	Cameroon	No	LIC	NOR	Norway	Yes	HIC
COL	Colombia	Yes	LMIC	NZL	New Zealand	Yes	HIC
CRI	Costa Rica	Yes	HIC	PAK	Pakistan	No	LIC
CYP	Cyprus	No	HIC	PER	Peru	No	LMIC
CZE	Czechia	Yes	HIC	PHL	Philippines	No	LMIC
DEU	Germany	Yes	HIC	POL	Poland	Yes	HIC
DNK	Denmark	Yes	HIC	PRT	Portugal	Yes	HIC
EGY	Egypt	No	LMIC	ROU	Romania	Yes	HIC
ESP	Spain	Yes	HIC	RUS	Russian Federation	No	HIC
EST	Estonia	Yes	HIC	SAU	Saudi Arabia	No	HIC
FIN	Finland	Yes	HIC	SEN	Senegal	No	LIC
FRA	France	Yes	HIC	SVK	Slovakia	Yes	HIC
GBR	United Kingdom	Yes	HIC	SVN	Slovenia	Yes	HIC
GRC	Greece	Yes	HIC	SWE	Sweden	Yes	HIC
HRV	Croatia	No	HIC	THA	Thailand	No	LMIC
HUN	Hungary	Yes	HIC	TUN	Tunisia	No	LMIC
IDN	Indonesia	No	LMIC	TUR	Türkiye	Yes	HIC
IND	India	No	LIC	UKR	Ukraine	No	LMIC
ISL	Iceland	Yes	HIC	USA	United States	Yes	HIC
ISR	Israel	Yes	HIC	VNM	Viet Nam	No	LIC
ITA	Italy	Yes	HIC	ZAF	South Africa	No	HIC
JOR	Jordan	No	LMIC	ROW	Rest of the World	No	HIC

Figure II: Country Coverage



Notes: The figure replicates panel (a) of Figure I, plotting agricultural employment shares (% of total employment) against the log of GNI per capita (Atlas method, current US$) in 2005, using World Bank World Development Indicators. Countries included in the ICIO database are shown in red, while the others are shown in gray. The fitted quadratic regression line is displayed with the corresponding R^2.

Table III: Mapping of Variables with the Data

Variable	Description	Source
$\{i,j,n\}$	Country indices	Table II
$\{k,s,l\}$	Sector indices; $k \in \mathcal{K}^A$ for agriculture, $k \notin \mathcal{K}^A$ for non-agriculture	Table I
Variables		
$Z_{i,k}$	Agricultural land in country i, sector $k \in \mathcal{K}^A$	FAO Agricultural Land Use
L_i	Total labor endowment of country i	PWT 10.01
$L_{i,ag}$	Employment in agriculture of country i	FAO Agricultural Employment Share
$X_{ij,k}$	Bilateral expenditure by j on goods from i in sector k	OECD ICIO tables
X_j^f	Final expenditure in country j	OECD ICIO tables
$Y_{i,k}$	Total sales of country i in sector k	OECD ICIO tables
P_j	Aggregate consumer price index in country j	Constructed
$P_{j,k}$	Price index of good k in country j	Constructed, see Section 5
$\lambda_{ij,k}$	Import share of j from i in sector k	OECD ICIO tables
$\omega_{j,k}$	Expenditure share on good k in country j	OECD ICIO tables
$w_i L_i$	Wage bill in country i	Constructed from OECD ICIO tables
$\Pi_{j,k}$	Rents from land in country j, sector $k \in \mathcal{K}^A$	Constructed from OECD ICIO tables
Parameters		
$\gamma_{j,k}$	Preference shifter for sector k in country j	
ν_k	Non-homotheticity parameter for good k	Estimated, see Section 5
σ	Elasticity of substitution across goods	Estimated, see Section 5
θ	Trade elasticity	Externally calibrated
$A_{i,k}$	TFP in sector k of country i	Estimated, see Section 5
$\alpha_{i,k}$	Value added share in production in country i, sector k	Constructed from OECD ICIO tables
$\alpha_{i,sk}$	Input share of sector s in production of k in country i	Constructed from OECD ICIO tables
$\chi_{i,ks}$	Forward linkage elasticity of sector s with respect to productivity in sector k	Constructed from OECD ICIO tables
$\zeta_{i,k}$	Land share in value added, only for agricultural production in country i, sector k	Externally calibrated
$\tau_{ij,k}$	Iceberg trade costs from i to j for good k	Estimated, see Section E

sector $k \in \mathcal{K}$ in country i is

$$\frac{p_{i,k}}{w_i} = A_{i,k}^{-1} \left(\frac{L_{i,k}}{Z_{i,k}} \right)^{\alpha_{i,k}(1-\zeta_{i,k})} \prod_{s \in \mathcal{K}} \left(\frac{P_{i,s}}{w_i} \right)^{\alpha_{i,sk}},$$

where

$$\frac{P_{i,s}}{w_i} = \left(\frac{L_{i,a}}{Z_{i,a}} \right)^{\alpha_{j,a}\zeta_{j,a}\chi_{j,as}} \prod_{l \in \mathcal{K}} \lambda_{ii,l}^{\chi_{i,ls}/\varepsilon_l} \prod_{l \in \mathcal{K}} A_{i,l}^{-\chi_{i,ls}}.$$

Substituting yields

$$\frac{p_{i,k}}{w_i} = \left(\frac{L_{i,a}}{Z_{i,a}} \right)^{\alpha_{j,a}\zeta_{j,a}\chi_{j,ak}} \prod_{l \in \mathcal{K}} \lambda_{ii,l}^{(\chi_{i,lk} - 1_{\{l=k\}})/\varepsilon_l} \prod_{l \in \mathcal{K}} A_{i,l}^{-\chi_{i,lk}}.$$

Taking logs and inserting into Equation (16) gives

$$\begin{aligned} \ln X_{ij,k} = -\varepsilon \ln \tau_{ij,k} + \ln \left(X_j^f / w_i^\varepsilon \right) + \sum_{l \in \mathcal{K}} \left(1_{\{l=k\}} - \chi_{i,lk} \right) \ln \lambda_{ii,l} \\ + \varepsilon \left(\sum_{l \in \mathcal{K}} \chi_{i,lk} \ln A_{i,l} - \alpha_{j,a}\zeta_{j,a}\chi_{j,ak} \ln \left(\tfrac{L_{i,a}}{Z_{i,a}} \right) \right) + \ln \left(P_{j,k}^\varepsilon \omega_{j,k} \right). \end{aligned}$$

Define the corrected dependent variable

$$\ln \tilde{x}_{ij,k} \equiv \ln X_{ij,k} - \sum_{l \in \mathcal{K}} \left(1_{\{l=k\}} - \chi_{i,lk} \right) \ln \lambda_{ii,l},$$

and fixed effects

$$\begin{aligned} \delta_{ij} &\equiv \ln \left(X_j^f / w_i^\varepsilon \right), \\ \delta_{j,k} &\equiv \ln \left(P_{j,k}^\varepsilon \omega_{j,k} \right), \\ \delta_{i,k} &\equiv \varepsilon \left(\sum_{l \in \mathcal{K}} \chi_{i,lk} \ln A_{i,l} - \alpha_{j,a}\zeta_{j,a}\chi_{j,ak} \ln \left(\frac{L_{i,a}}{Z_{i,a}} \right) \right), \end{aligned}$$

defining the error term as

$$u_{ij,k} \equiv -\varepsilon \ln \tau_{ij,k}.$$

The estimating equation is then

$$\ln \tilde{x}_{ij,k} = \delta_{j,k} + \delta_{ij} + \delta_{i,k} + u_{ij,k}.$$

From the estimated exporter-sector fixed effects, $\delta_{i,k}$, using FAOSTAT data for $L_{i,a}/Z_{i,a}$ for each country i, and with the calibrated parameters $\{\chi_{i,lk}, \alpha_{i,a}\zeta_{i,a}\}_{j=1,\dots,N;l,k\in\mathcal{K}}$, I recover fundamental productivities $(A_{i,l})$ by solving the following system of equations for each country i and sector k:

$$\delta_{i,k}/\theta = \sum_{l\in\mathcal{K}} \chi_{i,lk} \ln A_{i,l} - \alpha_{i,a}\zeta_{i,a}\chi_{i,ak} \ln\left(\frac{L_{i,a}}{Z_{i,a}}\right)$$

D.1 Special Cases

The linear and intermediate-input specifications can be obtained as restrictions of the general framework presented above.

First, when no fixed factor is present, i.e. $\zeta_{i,k} = 1$, the land term vanishes from the unit cost function. In this case, I run the same regression using $\ln \tilde{x}_{ij,k}$ defined in Equation (18) and recover fundamental productivities from the mapping

$$A_{i,s} = \prod_{k\in\mathcal{K}} \exp\left(\frac{\delta_{i,k}}{\varepsilon}\right)^{\left(1_{\{k=s\}}-\alpha_{i,ks}\right)}.$$

Second, when intermediate input linkages are also absent, i.e. $\alpha_{i,sk} = 0$ for all k, s, the expression simplifies further. The unit cost in country i and sector k is now $p_{i,k} = w_i/A_{i,k}$. In this case, I run the same regression as before, but with the corrected dependent variable defined as

$$\ln \tilde{x}_{ij,k} \equiv \ln X_{ij,k} - \ln\left(\lambda_{ii,k}\right).$$

From this regression, fundamental productivities can then be directly recovered as

$$\delta_{i,k}/\theta \equiv \ln A_{i,k} \qquad \forall i, k, \tag{41}$$

which is the same specification used by Costinot et al. (2012).

Finally, considering only a fixed factor used only in the agricultural production results

$$\delta_{i,k}/\theta = \ln A_{i,k} - \zeta_{i,a} \ln\left(\frac{L_{i,a}}{Z_{i,a}}\right), \qquad \forall i, k$$

and for all $k \notin \mathcal{K}^A$ still use 41.

E Trade Costs Measurement

Trade costs are a key determinant of cross-country income differences, especially in agriculture (Waugh, 2010). They extend beyond tariffs to include transport costs, border delays, administrative procedures, and regulatory restrictions (Anderson and Van Wincoop, 2004; Novy, 2013). These trade frictions are systematically asymmetric: poorer countries face disproportionately higher export costs than richer ones (Waugh, 2010). For these economies, such barriers not only reduce trade volumes but also constrain agricultural imports (Adamopoulos, 2011; Tombe, 2015). Quantifying these costs is essential for assessing how openness interacts with agricultural specialization in low-income economies.

To measure trade costs, I use the model's gravity structure following Novy (2013), who generalizes (Head and Ries, 2001). Based on the bilateral trade share defined in Equation (8), the iceberg trade costs from exporter i to importer j in sector k can be written as

$$\tau_{ij,k} = (\lambda_{ij,k})^{-1/\varepsilon_k} \left(\frac{P_{j,k}}{p_{ii,k}} \right).$$

Multiplying the bilateral trade costs in both directions gives

$$\tau_{ij,k}\tau_{ji,k} = (\lambda_{ij,k})^{-1/\varepsilon_k} \left(\frac{P_{j,k}}{p_{ii,k}} \right) (\lambda_{ji,k})^{-1/\varepsilon_k} \left(\frac{P_{i,k}}{p_{jj,k}} \right),$$

and then using the model's gravity relationship $P_{j,k} = p_{jj,k} (\lambda_{jj,k})^{1/\varepsilon_k}$, I obtain

$$\tau_{ij,k}\tau_{ji,k} = \left(\frac{\lambda_{ij,k}\lambda_{ji,k}}{\lambda_{jj,k}\lambda_{ii,k}} \right)^{-1/\varepsilon_k}.$$

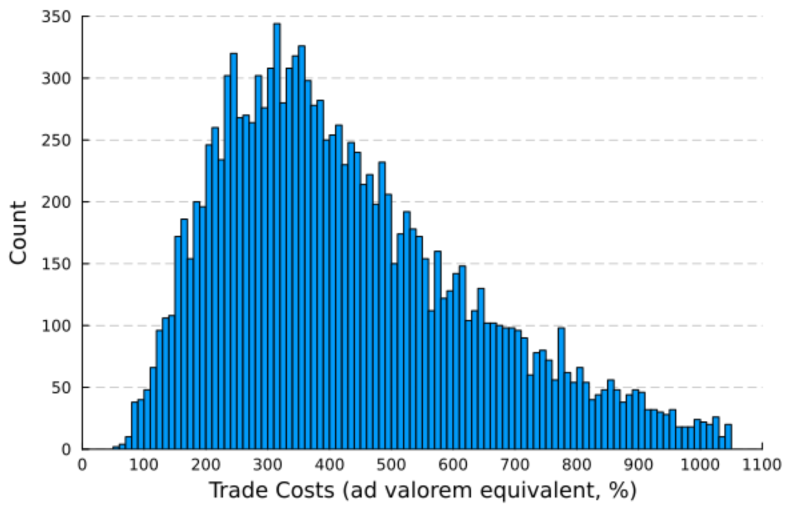
Finally, taking the square root yields the bilateral trade barrier for sector k

$$\bar{\tau}_{ij,k} = \sqrt{\tau_{ij,k}\tau_{ji,k}} = \left(\frac{\lambda_{ij,k}\lambda_{ji,k}}{\lambda_{jj,k}\lambda_{ii,k}} \right)^{-1/2\varepsilon_k}, \tag{42}$$

This measure requires values for $\lambda_{ij,k}$, the share of country j's expenditure on goods from i in sector k, and ε_k, the sector-specific trade elasticity. I assume $\varepsilon = 5$ as the trade elasticity (same for all sectors k), consistent with standard values in the trade literature (Anderson and Van Wincoop, 2004; Costinot and Rodríguez-Clare, 2014; Head and Mayer, 2014).

Equation (42) yields a broad measure of bilateral trade barriers: higher domestic trade shares, $\lambda_{jj,k}$, imply larger inferred barriers, so $\bar{\tau}_{ij,k}$ can be interpreted as the *ad-valorem* tariff-equivalent trade costs between i and j in both directions. Note that it is symmetric by construction.

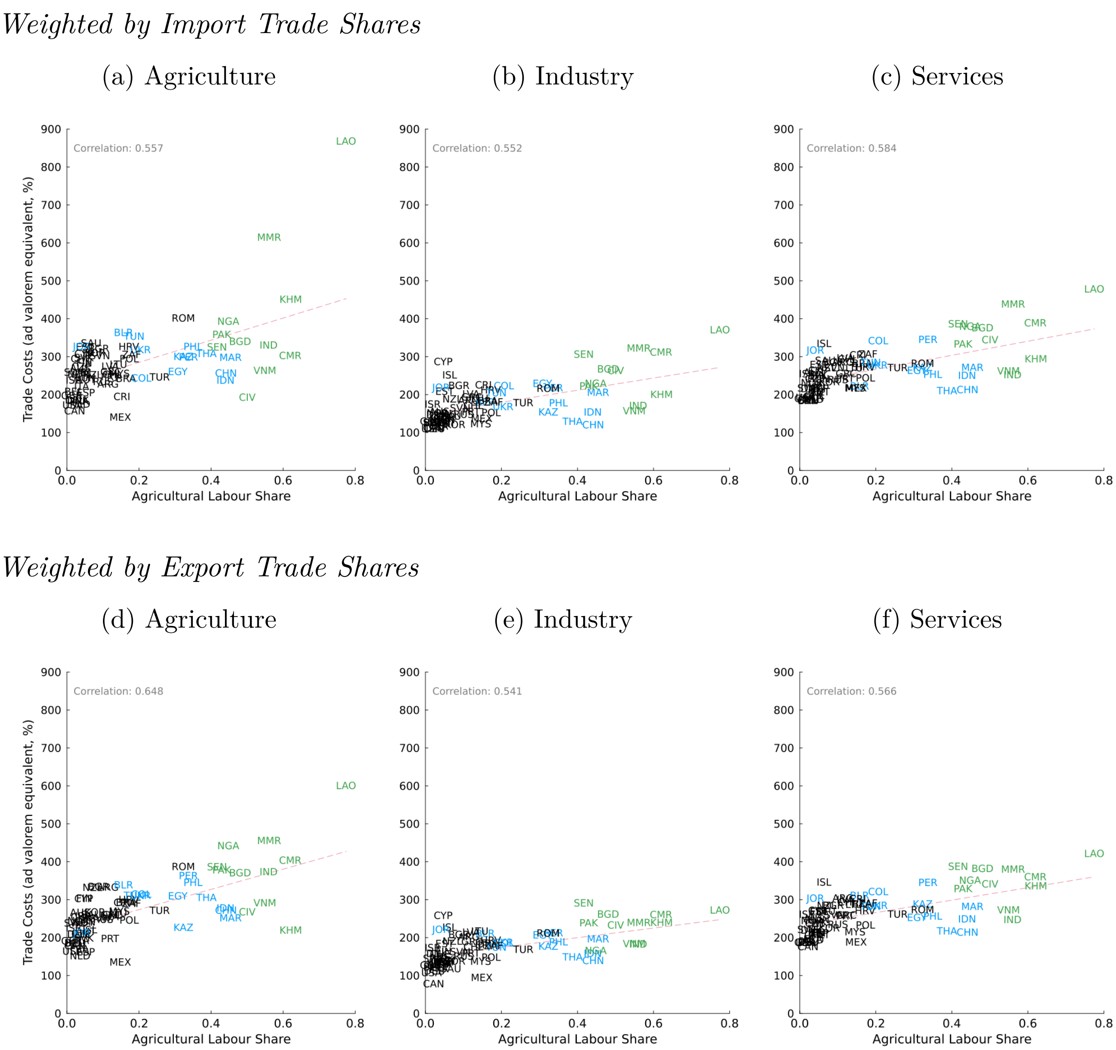
Figure III: Trade Costs Distribution



Notes: Histogram of winsorized trade costs (*ad valorem* equivalent, in percent) across all countries and sectors. Symmetric trade costs are computed following Novy (2013). Outliers are capped using the interquartile range rule with a fixed threshold. Intra-national observations with $\tau_{ii,k} = 1$ are excluded.

Because extreme values of $\tau_{ij,k}$ can be generated by very small $\lambda_{ij,k}$, I winsorize trade costs measures by capping values above the upper bound of the pooled distribution of $\tau_{ij,k}$ across all i, j, k. I use the IQR method defined by up_thr $= Q3 + 1.5 \times IQR$, where $Q3$ is the third quartile and $IQR = Q3 - Q1$. Values above this threshold are capped at up_thr. The procedure preserves the lower bound $\tau_{ij,k} \geq 1$ by construction. The share of capped observations is 5% for symmetric trade cost. Figure III reports histograms of the winsorized distributions, excluding the mechanical mass at $\tau_{ij,k} = 1$ and with 120 equally spaced bins for visual clarity.

Figure IV: Average Trade Costs by Country and Sector



Notes: Each panel plots measured trade costs (*ad valorem* equivalent, in percent) against the agricultural labor share. Trade costs are calculated from bilateral trade shares using Equation (42). The top panels show trade costs weighted by import trade shares, whereas the bottom panels show trade costs weighted by export trade shares. Each column corresponds to a different sector: (a), (d) agriculture; (b), (e) industry; and (c), (f) services. Each point represents a country.

Figure IV shows sectoral trade costs weighted by import and export shares. The top and bottom panels display nearly identical patterns, indicating that trade costs constrain trade in both directions. Across all sectors, countries with larger agricultural labor shares face markedly higher trade costs. The gradient is steepest in agriculture: relative to high-income countries, trade costs for low-income economies are about 1.6 times higher. Within the low-income group, agricultural trade costs exceed those in industry by more than 1.5 times and those in services by roughly 1.1 times.

While the previous section showed that low-income countries are relatively more productive in agriculture, the evidence here indicates that trade frictions are particularly severe in that sector. By limiting access to foreign markets, these barriers constrain the gains from specialization and dampen the benefits of openness for poor countries with a revealed productivity advantage in agriculture.

F Estimation of NHCES parameters

F.1 Construction of relative sectoral prices

On the production side, taking logs to Equation (9) results

$$\ln\left(P_{i,s,t}/w_{i,t}\right) = \alpha_{j,a,t}\zeta_{j,a,t}\chi_{j,as,t}\ln\left(L_{i,a,t}/Z_{i,a,t}\right) + \sum_{l\in\mathcal{K}}\frac{\chi_{i,ls,t}}{\varepsilon}\ln\lambda_{ii,l,t} - \sum_{l\in\mathcal{K}}\chi_{i,ls,t}\ln A_{i,l,t}. \tag{43}$$

By the RRP calculation, I have defined

$$A_{i,s,t} = \prod_{k\in\mathcal{K}}\left(\left(L_{i,a,t}/Z_{i,a,t}\right)^{\alpha_{i,a,t}\zeta_{i,a,t}\chi_{i,ak,t}}\exp\left(\delta_{i,k,t}/\varepsilon\right)\right)^{\left(1_{\{k=s\}}-\alpha_{i,ks,t}\right)},$$

which implies

$$\prod_{l\in\mathcal{K}}\left(A_{i,l,t}\right)^{\chi_{i,lk,t}} = \left(L_{i,a,t}/Z_{i,a,t}\right)^{\alpha_{i,a,t}\zeta_{i,a,t}\chi_{i,ak,t}}\exp\left(\delta_{i,k,t}/\varepsilon\right),$$

and taking logs, results

$$-\sum_{l\in\mathcal{K}}\chi_{i,ls,t}\ln A_{i,l,t} = -\,\alpha_{i,a,t}\zeta_{i,a,t}\chi_{i,as,t}\ln\left(L_{i,a,t}/Z_{i,a,t}\right) - \left(\delta_{i,s,t}/\varepsilon\right).$$

Replacing in 43, I can construct prices using

$$\ln\left(\tilde{P}_{i,s,t}/w_{i,t}\right) = \sum_{l\in\mathcal{K}}\frac{\chi_{i,ls,t}}{\varepsilon}\ln\lambda_{ii,l,t} - \left(\delta_{i,s,t}/\varepsilon\right).$$

F.2 NHCES Estimation Equation

On the demand side, taking logs to 2 at time t, I get

$$\ln\omega_{j,k,t} = (\sigma-1)\ln\left(X^{f}_{j,t}/w_{j,t}\right) - (\sigma-1)\ln\left(P_{j,k,t}/w_{j,t}\right) - \nu_{k,t}\left(\sigma-1\right)\ln\left(C_{j,t}\right) + \ln\gamma_{j,k,t}.$$

Since I do not have data on $\ln C_{j,t}$, I assume $\frac{1}{K}\sum_{k\in\mathcal{K}}\nu_k = 1$ and for any variable $a_{j,t}$ I call $\overline{\ln a_{j,t}} = \frac{1}{K}\sum_{k\in\mathcal{K}}\ln a_{j,k,t}$ the log average of variable $a_{j,t}$ across sectors. Applying the within-country log mean across sectors to Equation (21) yields:

$$\overline{\ln \omega_{j,k,t}} = (\sigma-1)\ln X^f_{j,t} - (\sigma-1)\overline{\ln P_{j,t}} - (\sigma-1)\ln C_{j,t} + \overline{\ln \gamma_{j,k,t}}.$$

Substituting this expression back into Equation (21) gives

$$\begin{aligned}\ln \omega_{j,k,t} = (\sigma-1)(1-\nu_k)\left(\ln X^f_{j,t} - \overline{\ln P_{j,t}}\right)\\ - (\sigma-1)\left(\ln P_{j,k,t} - \overline{\ln P_{j,t}}\right) + \nu_k\overline{\ln \omega_{j,t}} + \left(\ln \gamma_{j,k,t} - \nu_k\overline{\ln \gamma_{j,t}}\right).\end{aligned}$$

I estimate ρ and ν_k via GMM using the following specification (Equation 25):

$$\begin{aligned}\ln \omega_{j,k,t} = \phi_{j,k} + (\sigma-1)(1-\nu_k)\left(\ln X^f_{j,t} - \overline{\ln P_{j,t}}\right)\\ - (\sigma-1)\left(\ln \tilde{P}_{j,k,t} - \overline{\ln P_{j,t}}\right) + \nu_k\overline{\ln \omega_{j,t}} + \upsilon_{j,k,t},\end{aligned}$$

where

$$\begin{aligned}\phi_{j,k} \equiv & E\left[\left(\ln \gamma_{j,k,t} - \nu_k\overline{\ln \gamma_{j,t}}\right)\Big|j,k\right] - E\left[\left(\ln \gamma_{j,k,t} - \nu_k\overline{\ln \gamma_{j,t}}\right)\right],\\ \upsilon_{j,k,t} \equiv & \left(\ln \gamma_{j,k,t} - \nu_k\overline{\ln \gamma_{j,t}}\right) - E\left[\left(\ln \gamma_{j,k,t} - \nu_k\overline{\ln \gamma_{j,t}}\right)\Big|j,k\right] + E\left[\left(\ln \gamma_{j,k,t} - \nu_k\overline{\ln \gamma_{j,t}}\right)\right].\end{aligned}$$

I use a IV procedure in which the instruments for $\tilde{P}_{i,s,t}$ are formed using

$$\ln \tilde{A}_{i,k,t} \equiv \sum_{l\in\mathcal{K}} \chi_{i,lk,t}\ln A_{i,l,t},$$

where the additional orthogonality conditions imposed by the IV estimator is

$$E\left[\ln \tilde{A}_{j,k,t}\upsilon_{j,k,t}\Big|j,k,t\right] = 0.$$

That also implies

$$E\left[\overline{\ln \tilde{A}_{j,t}}\upsilon_{j,k,t}\Big|j,k,t\right] = 0.$$

Finally, I assume the following orthogonality condition:

$$E\left[\upsilon_{j,k,t}\Big|\ln X^f_{j,t}, \overline{\ln \omega_{j,t}}\right] = 0.$$

If these conditions are satisfied, a GMM estimator using the IV instrument defined in Equation (24) yields consistent estimates of σ and ν_k.

F.3 Implied Income Elasticities

The income elasticity is defined as

$$\eta_k \equiv \frac{\partial \ln C_{j,k}}{\partial \ln X_j^f}.$$

Starting from Equation (1), utility maximization implies that

$$C_{j,k} = \gamma_{j,k} \left(X_j^f / P_{j,k}\right)^{\sigma} C_j^{\nu_k(1-\sigma)},$$

taking logs:

$$\ln C_{j,k} = \ln \gamma_{j,k} + \sigma \ln \left(X_j^f / P_{j,k}\right) + \nu_k (1-\sigma) \ln C_j. \tag{44}$$

Taking the derivative of Equation (44) with respect to $\ln X_j^f$ yields

$$\frac{\partial \ln C_{j,k}}{\partial \ln X_j^f} = \sigma + \nu_k (1-\sigma) \frac{\partial \ln C_j}{\partial \ln X_j^f}.$$

Furthermore, the derivate of the expenditure share for good k defined in Equation (2) with respect to $\ln X_j^f$ is

$$\frac{\partial \omega_{j,k}}{\partial \ln X_j^f} = \omega_{j,k} \frac{\partial \ln \omega_{j,k}}{\partial \ln X_j^f},$$

where

$$\frac{\partial \ln \omega_{j,k}}{\partial \ln X_j^f} = (\sigma - 1) + \nu_k (1-\sigma) \frac{\partial \ln C_j}{\partial \ln X_j^f},$$

hence

$$\frac{\partial \omega_{j,k}}{\partial \ln X_j^f} = \omega_{j,k} \left[(\sigma - 1) + \nu_k (1-\sigma) \frac{\partial \ln C_j}{\partial \ln X_j^f}\right].$$

Since $1 = \sum_{k \in \mathcal{K}} \omega_{j,k}$, the derivate of this with respect to $\ln X_j^f$ is $0 = \sum_{k \in \mathcal{K}} \frac{\partial \omega_{j,k}}{\partial \ln X_j^f}$. Replacing the previous expressions yields

$$\frac{\partial \ln C_j}{\partial \ln X_j^f} = \frac{1}{\sum_{k \in \mathcal{K}} \omega_{j,k} \nu_k}.$$

Therefore,

$$\eta_k \equiv \frac{\partial \ln C_{j,k}}{\partial \ln X_j^f} = \sigma + (1-\sigma)\frac{\nu_k}{\sum_{k\in\mathcal{K}} \omega_{j,k}\nu_k}. \tag{45}$$

Using the GMM (IV) estimates of σ and ν_k from Table 1 and the expenditure shares in 2005, I can calculate the implied income elasticities. Table IV reports η_k for agriculture, industry, and services across LICs, LMICs, and HICs. A clear pattern emerges: income elasticities are uniformly higher in LICs and decline monotonically with income. This reflects the fact that lower-income countries allocate a larger share of expenditure to necessity goods and have a stronger marginal propensity to adjust consumption as income rises. Overall, these patterns are consistent with Engel's law, identifying agriculture as a necessity and services as a luxury.

Table IV: Implied Income Elasticities across Income Groups

	LIC	LMIC	HIC
η_{ag}	0.610	0.588	0.571
	(0.019)	(0.007)	(0.006)
η_{ind}	0.944	0.906	0.877
	(0.034)	(0.012)	(0.011)
η_{ser}	1.137	1.089	1.053
	(0.043)	(0.015)	(0.014)

Notes: Income elasticities η_k for the three aggregate sectors (agriculture, industry, services) are computed using the GMM (IV) estimates of σ and ν_k from Table 1 and sectoral expenditure shares in 2005. Reported values are the mean across countries within each income group; values in parentheses denote the standard errors of the cross-country distribution. Results are reported by income group (LICs, LMICs, HICs), as defined in Appendix C.

F.4 Heterogeneity Over Time

To assess the sensitivity of the estimated NHCES parameters to the choice of sample period, I re-estimate $\{\sigma, \nu_k\}$ using the IV specification over alternative windows: 1995--2010, 1995--2015, 2000--2015, and 2000--2020, in addition to the full 1995--2020 sample. The results reported in Table V indicate a degree of stability in the non-homotheticity parameters ν_k. Across all sub-periods, agriculture remains below 1, industry remains close to 1, and services consistently exceed 1, preserving the same income-ranking pattern observed in the baseline estimates.

Table V: NHCES Parameter Estimates by Sample Period

	1995–2020 (1)	1995–2010 (2)	1995–2015 (3)	2000–2015 (4)	2000–2020 (5)
σ	0.136	0.383	0.235	0.264	0.147
	[0.006, 0.389]	[0.132, 0.554]	[0.024, 0.506]	[0.049, 0.479]	[0.012, 0.403]
ν_{ag}	0.638	0.458	0.578	0.708	0.784
	[0.480, 0.808]	[0.157, 0.643]	[0.354, 0.828]	[0.520, 0.883]	[0.640, 0.970]
ν_{ind}	1.042	1.209	1.100	1.035	0.979
	[0.910, 1.171]	[1.057, 1.440]	[0.917, 1.255]	[0.845, 1.217]	[0.844, 1.123]
ν_{ser}	1.332	1.373	1.338	1.265	1.244
	[1.236, 1.473]	[1.114, 1.664]	[1.162, 1.485]	[1.118, 1.413]	[1.150, 1.360]
Country-Sector FE	Y	Y	Y	Y	Y
Observations	1,820	1,120	1,470	1,120	1,470

Notes: Estimates are obtained by two-step GMM using the TFP-based instrument described in Equation (24). Bootstrapped 95% confidence intervals, clustered at the country level, are reported in square brackets (computed from 50 bootstrap samples with replacement). All specifications include country–sector fixed effects. The sample covers up to 70 countries and three aggregate sectors (agriculture, industry, services), using ICIO tables over the relevant period.

The elasticity of substitution σ varies more across sample windows, as expected, given that the degree of price and expenditure variation differs across decades and that the identifying variation for σ is partly driven by changes in relative prices. Periods with more limited or more volatile price movements yield less precise or slightly different substitution elasticities. Nevertheless, σ remains well below one in all windows, indicating that broad sectors continue to behave as gross complements. Overall, the robustness checks confirm that the key patterns of non-homotheticity and substitution are not driven by a particular time period.

F.5 Comparison with Comin et al. (2021)

The orthogonality assumption $E\left[\upsilon_{j,k,t}\middle|\ln X^f_{j,t}, \overline{\ln \omega_{j,t}}\right] = 0$ would be violated if sectoral taste shocks were systematically correlated with total expenditure or average expenditure shares movements. To assess whether such correlations vary systematically with income levels or trade integration, I follow Comin et al. (2021)[15] and estimate the model separately for OECD and non-OECD countries and using trade controls. This split also accounts for the fact that relative prices incorporate domestic trade shares $\lambda_{jj,s}$, which may differ across country groups.

[15] For comparability with Comin et al. (2021, Table III, p. 336), the estimation follows the same structure, including trade controls and separate subsamples for OECD and non-OECD countries.

Table VI: Estimates of NHCES Parameters by Sample

	Full Sample		OECD		Non-OECD	
	(1)	(2)	(3)	(4)	(5)	(6)
σ	0.136	0.181	0.150	0.156	0.149	0.175
	[0.006, 0.389]	[0.011, 0.469]	[0.019, 0.399]	[0.012, 0.455]	[0.019, 0.455]	[0.024, 0.421]
ν_{ag}	0.638	0.572	0.581	0.454	0.717	0.714
	[0.480, 0.808]	[0.348, 0.727]	[0.311, 0.969]	[0.194, 0.842]	[0.390, 0.938]	[0.467, 0.922]
ν_{ind}	1.042	1.056	0.828	0.839	1.141	1.129
	[0.910, 1.171]	[0.899, 1.233]	[0.473, 1.040]	[0.510, 1.072]	[1.029, 1.371]	[0.956, 1.369]
ν_{ser}	1.332	1.383	1.607	1.710	1.154	1.167
	[1.236, 1.473]	[1.230, 1.526]	[1.380, 1.825]	[1.489, 1.999]	[0.972, 1.268]	[1.006, 1.302]
Country-Sector FE	Y	Y	Y	Y	Y	Y
Trade Controls	N	Y	N	Y	N	Y
Observations	1,820	1,820	962	962	858	858

Notes: Estimates are obtained by two-step GMM using the TFP-based instrument described in Equation (24). Bootstrapped 95% confidence intervals, clustered at the country level, are reported in square brackets (computed from 50 bootstrap samples with replacement). All specifications include country–sector fixed effects. The sample covers up to 70 countries and three aggregate sectors (agriculture, industry, services), using ICIO tables over the relevant sample.

Table VI reports the IV estimates of $\{\sigma, \nu_k\}$ for the full sample, OECD, and non-OECD economies. Columns (1)–(2) show results for the full sample, with and without trade controls. The substitution elasticity remains low, and the estimates of ν_k follow the standard ordering: agriculture below one, industry near unity, and services above one. Including trade controls has little effect on the estimates.

Columns (3)–(4) present results for OECD countries, and Columns (5)–(6) for non-OECD economies. The ranking of ν_k is preserved in both groups, and the estimates remain close to the full-sample values. OECD countries exhibit slightly higher service elasticities and slightly lower industry elasticities, consistent with their higher income levels and larger service shares. Once trade controls are introduced, parameter estimates remain stable across samples. Overall, the similarity of results across country groups indicates that systematic differences in income or openness do not drive the observed patterns of complementarity and non-homotheticity.

G Additional Results

G.1 Autarky Counterfactual

Table VII reports model-implied welfare gains from trade for all countries under alternative model specifications. The "Benchmark" model, which includes non-homothetic preferences, a fixed factor in agricultural production, and input–output linkages, serves as the benchmark. Subsequent columns progressively remove these mechanisms to isolate their contribution to the magnitude and dispersion of gains.

Table VIII and IX show the effects of trade across different specifications for LMICs and HICs.

Table VII: Gains from Trade under Different Specifications

Country	GNI pc (US$)	Benchmark	w.o. NHCES	w.o. FF	w.o. NHCES-FF	w.o. Linkages	w.o. Linkages-NHCES	w.o. Linkages-FF	w.o. Linkages-NHCES-FF
MMR	230	5.20	5.40	5.10	5.40	3.30	3.30	3.20	3.20
LAO	380	7.60	8.30	7.50	8.20	4.90	5.40	4.80	5.30
KHM	430	17.50	19.50	17.20	19.00	10.10	11.20	9.80	10.80
BGD	490	3.60	4.20	3.60	4.20	2.20	2.50	2.20	2.50
VNM	550	12.90	14.70	12.90	14.70	5.90	6.40	5.80	6.40
IND	610	3.60	4.30	3.60	4.30	1.60	1.80	1.60	1.80
CIV	710	8.90	10.70	8.00	9.50	5.20	6.20	4.30	5.10
PAK	740	3.30	3.70	3.30	3.70	1.80	2.00	1.80	2.00
SEN	850	4.60	5.30	4.60	5.30	2.70	3.10	2.70	3.10
NGA	875	2.90	3.40	2.90	3.40	1.80	2.00	1.80	2.00
CMR	1,030	4.20	4.90	4.20	4.90	2.80	3.20	2.70	3.20
IDN	1,060	5.70	6.80	5.70	6.80	3.00	3.60	3.00	3.60
EGY	1,120	6.10	7.10	6.10	7.10	4.00	4.60	4.00	4.60
UKR	1,250	6.10	7.10	6.10	7.10	2.60	3.00	2.60	3.00
PHL	1,260	6.60	8.00	6.60	8.00	3.60	4.10	3.60	4.10
CHN	1,530	4.90	5.80	4.90	5.80	1.90	2.20	1.90	2.20
JOR	2,050	13.30	15.60	13.30	15.60	5.80	6.80	5.80	6.80
MAR	2,060	6.90	8.10	6.80	8.10	3.90	4.50	3.90	4.50
BLR	2,170	9.90	11.70	9.90	11.70	5.50	6.30	5.50	6.30
KAZ	2,180	8.80	10.60	8.80	10.60	4.50	5.50	4.50	5.50
PER	2,270	4.20	5.10	4.20	5.10	2.40	2.80	2.40	2.80
THA	2,520	13.40	15.70	13.40	15.70	5.70	6.50	5.70	6.50
COL	2,650	3.30	4.00	3.30	4.00	1.80	2.20	1.80	2.20
TUN	2,860	7.70	9.20	7.70	9.20	4.50	5.20	4.50	5.20
ROM	2,960	4.90	5.90	4.90	5.90	2.50	2.90	2.50	2.90
BGR	3,060	10.30	12.30	10.20	12.30	4.20	5.00	4.20	5.00
ARG	3,340	3.90	4.80	3.80	4.70	2.20	2.60	2.10	2.50
BRA	3,370	2.40	3.00	2.40	3.00	1.20	1.50	1.20	1.50
RUS	3,410	4.40	5.40	4.40	5.40	2.60	3.20	2.60	3.20
ZAF	4,040	4.30	5.30	4.30	5.30	2.00	2.40	2.00	2.40
CRI	4,400	8.90	10.80	8.80	10.70	5.00	5.90	4.80	5.70
MYS	4,720	14.40	17.70	14.40	17.60	6.40	7.40	6.40	7.40
TUR	5,150	4.30	5.20	4.30	5.20	2.10	2.50	2.10	2.50
CHL	5,200	6.60	8.10	6.60	8.10	3.60	4.30	3.50	4.20
LVA	5,610	8.90	10.80	8.90	10.80	4.00	4.90	4.00	4.90

Table VII: Gains from Trade under Different Specifications (cont.)

Country	GNI pc (US$)	Benchmark	w.o. NHCES	w.o. FF	w.o. NHCES-FF	w.o. Linkages	w.o. Linkages-NHCES	w.o. Linkages-FF	w.o. Linkages-NHCES-FF
LTU	6,020	8.00	9.60	8.00	9.60	4.50	5.30	4.50	5.30
POL	6,290	6.30	7.70	6.30	7.70	3.00	3.60	3.00	3.60
EST	7,500	11.50	14.10	11.50	14.10	5.30	6.40	5.30	6.40
MEX	8,240	4.70	5.70	4.70	5.70	2.80	3.30	2.80	3.30
ROW	8,488	7.70	9.40	7.70	9.40	4.00	4.70	4.00	4.70
HRV	8,570	7.40	8.90	7.40	8.90	3.70	4.50	3.70	4.50
HUN	8,650	12.80	15.40	12.80	15.40	6.20	7.40	6.20	7.30
SVK	9,010	14.60	17.40	14.60	17.40	6.70	7.90	6.70	7.90
CZE	10,280	10.10	12.40	10.10	12.40	4.50	5.50	4.50	5.50
SAU	12,880	7.50	9.30	7.50	9.20	5.30	6.60	5.30	6.50
SVN	15,490	11.40	13.90	11.40	13.90	5.70	6.90	5.70	6.90
PRT	16,190	6.10	7.60	6.10	7.50	2.90	3.60	2.90	3.60
KOR	16,200	5.90	7.40	5.90	7.40	2.90	3.40	2.90	3.40
GRC	19,650	4.90	6.10	4.90	6.10	2.70	3.40	2.70	3.40
CYP	20,260	9.20	11.50	9.10	11.40	4.70	5.80	4.70	5.80
ISR	20,990	6.90	8.70	6.90	8.70	3.80	4.70	3.80	4.70
NZL	21,530	4.90	6.20	4.90	6.20	2.40	3.00	2.40	2.90
ESP	22,140	4.90	6.10	4.90	6.10	2.30	2.90	2.30	2.90
AUS	25,850	3.70	4.70	3.70	4.60	1.80	2.30	1.80	2.30
ITA	28,390	4.30	5.40	4.30	5.30	2.10	2.60	2.10	2.60
CAN	29,530	5.90	7.40	5.90	7.40	3.30	4.10	3.30	4.10
FRA	31,340	4.80	6.00	4.80	6.00	2.50	3.10	2.50	3.10
DEU	32,080	5.20	6.50	5.20	6.40	2.80	3.40	2.80	3.40
BEL	32,910	10.30	12.70	10.30	12.70	4.90	6.10	4.90	6.10
AUT	33,610	7.70	9.60	7.70	9.60	4.10	5.10	4.10	5.10
FIN	35,370	6.50	8.20	6.50	8.20	3.50	4.30	3.50	4.30
NLD	36,790	6.90	8.60	6.80	8.60	3.60	4.50	3.60	4.50
GBR	37,820	4.20	5.40	4.20	5.40	2.30	2.90	2.30	2.90
JPN	39,000	2.20	2.70	2.20	2.70	1.30	1.60	1.30	1.60
SWE	39,690	7.00	8.80	7.00	8.80	3.70	4.60	3.70	4.60
ISL	41,650	6.80	8.60	6.80	8.60	3.60	4.40	3.50	4.40
DNK	42,740	7.50	9.40	7.50	9.40	3.90	4.90	3.90	4.90
USA	43,430	2.10	2.70	2.10	2.70	1.10	1.40	1.10	1.40
NOR	54,290	6.00	7.50	6.00	7.50	3.60	4.50	3.60	4.50
CHE	55,000	6.80	8.50	6.80	8.50	3.50	4.30	3.50	4.30

Notes: The table reports average model-implied welfare gains from trade, measured as $(100 \times (1 - \hat{W}_j))$ in percent, by country. Values in parentheses denote coefficients of variation. The baseline specification assumes Cobb-Douglas preferences and linear production in labor. The rows then incorporate additional features: +NHCES introduces non-homothetic CES preferences; +FF adds a fixed factor (land) in agricultural production; +NHCES+FF includes both. The second block further adds intermediate input linkages to production, combined in turn with NHCES preferences, the fixed factor, or both. Countries are ordered by GNI per capita (Atlas method, current US$).

Table VIII: Effects of Trade across Different Specifications - LMICs

	Benchmark	w.o. NHCES	w.o. FF	w.o. NHCES-FF	w.o. Linkages	w.o. Linkages-NHCES	w.o. Linkages-FF	w.o. Linkages-NHCES-FF
Gains from trade	7.45	8.83	7.45	8.83	3.78	4.41	3.78	4.41
Changes in Expenditure share (p.p.)								
Agriculture	0.09	-0.19	0.05	-0.20	-0.03	-0.22	-0.04	-0.18
Industry	1.72	1.44	1.72	1.44	1.05	0.94	1.05	0.92
Services	-1.80	-1.25	-1.76	-1.24	-1.02	-0.72	-1.01	-0.75
Changes in Labor share (p.p.)								
Agriculture	0.24	0.06	0.28	0.08	0.03	-0.13	0.02	-0.12
Industry	0.61	0.44	0.56	0.41	0.75	0.61	0.74	0.59
Services	-0.85	-0.50	-0.85	-0.49	-0.78	-0.48	-0.76	-0.46
Changes in Labor Productivity (%)								
Agriculture	-4.52	-3.97	-3.79	-3.80	-0.16	0.82	0.00	0.00
Industry	-7.17	-7.11	-7.08	-7.08	0.00	0.00	0.00	0.00
Services	-4.06	-4.04	-4.03	-4.04	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of moving to autarky under the benchmark model described in Section 2. Values show percentage-point (p.p.) or percent changes relative to the baseline open-economy equilibrium. 'Gains from trade' denote the welfare gains from moving out of autarky, expressed as a percentage. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported by income group (LICs, LMICs, HICs), as defined in Appendix C.

Table IX: Effects of Trade across Different Specifications - HICs

	Benchmark	w.o. NHCES	w.o. FF	w.o. NHCES-FF	w.o. Linkages	w.o. Linkages-NHCES	w.o. Linkages-FF	w.o. Linkages-NHCES-FF
Gains from trade	6.87	8.47	6.86	8.45	3.50	4.25	3.48	4.24
Changes in Expenditure share (p.p.)								
Agriculture	0.06	-0.03	0.05	-0.04	-0.05	-0.12	0.00	-0.06
Industry	1.94	1.66	1.94	1.67	1.36	1.22	1.34	1.20
Services	-2.00	-1.63	-1.99	-1.63	-1.31	-1.09	-1.34	-1.13
Changes in Labor share (p.p.)								
Agriculture	0.01	-0.04	0.01	-0.05	-0.16	-0.21	-0.17	-0.23
Industry	1.46	1.32	1.44	1.31	2.02	1.87	2.00	1.86
Services	-1.47	-1.28	-1.45	-1.25	-1.87	-1.66	-1.83	-1.63
Changes in Labor Productivity (%)								
Agriculture	-5.67	-5.37	-5.03	-5.03	0.59	1.36	0.00	0.00
Industry	-7.61	-7.58	-7.59	-7.59	0.00	0.00	0.00	0.00
Services	-3.87	-3.86	-3.87	-3.87	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of moving to autarky under the benchmark model described in Section 2. Values show percentage-point (p.p.) or percent changes relative to the baseline open-economy equilibrium. 'Gains from trade' denote the welfare gains from moving out of autarky, expressed as a percentage. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported by income group (LICs, LMICs, HICs), as defined in Appendix C.

G.2 The Effects of TFP Improvements

Table X compares the effects of a 10% increase in sectoral TFP across income groups in the benchmark model. Welfare gains from agricultural TFP growth are largest in low-income countries and decline sharply with income, reflecting the diminishing role of agriculture in total output for LMICs and HICs. In all cases, openness slightly amplifies welfare while shifting labor toward agriculture. Labor productivity in agriculture rises strongly in LICs (around 13 percent) but increases more modestly in richer economies. By contrast, a 10% industrial TFP improvement generates larger welfare gains, around 5 percent in LICs and about 4.5 percent in LMICs and HICs, and induces reallocation toward industry under openness, with productivity improvements transmitted through input–output linkages. Overall, the results indicate that agricultural productivity growth primarily benefits poorer economies, whereas improvements in industrial TFP yield broader, economy-wide gains by strengthening inter-sectoral connections.

Table XI and XII show the effects of a 10% increase in TFP across different specifications for LMICs and HICs.

Table X: Effects of a 10% increase in TFP across Income Groups

	LIC		LMIC		HIC	
	Closed	Open	Closed	Open	Closed	Open
TFP improvement in Agriculture						
Welfare changes (%)	2.38	2.58	1.21	1.18	0.53	0.53
Changes in Expenditure share (p.p.)						
Agriculture	-1.37	-1.18	-0.64	-0.51	-0.22	-0.17
Industry	0.14	0.12	-0.03	-0.01	-0.08	-0.05
Services	1.23	1.06	0.67	0.51	0.30	0.22
Changes in Labor share (p.p.)						
Agriculture	-0.88	0.37	-0.33	0.26	-0.10	0.23
Industry	0.07	-0.18	-0.04	0.02	-0.05	0.01
Services	0.80	-0.19	0.38	-0.28	0.15	-0.24
Changes in Labor Productivity (%)						
Agriculture	13.59	11.38	13.25	10.90	12.69	10.09
Industry	2.29	2.02	1.54	1.22	1.05	0.78
Services	0.84	0.80	0.48	0.41	0.26	0.21
TFP improvement in Industry						
Welfare changes (%)	5.39	5.02	6.76	6.56	4.81	4.54
Changes in Expenditure share (p.p.)						
Agriculture	0.20	0.12	0.02	-0.01	-0.02	-0.02
Industry	-2.15	-1.67	-2.56	-1.99	-2.17	-1.63
Services	1.95	1.54	2.54	2.00	2.19	1.65
Changes in Labor share (p.p.)						
Agriculture	-0.02	-0.37	-0.11	-0.06	-0.07	-0.01
Industry	-1.20	3.12	-1.33	4.09	-1.10	3.70
Services	1.23	-2.75	1.44	-4.03	1.17	-3.69
Changes in Labor Productivity (%)						
Agriculture	2.02	2.28	3.99	3.62	4.48	3.60
Industry	16.42	15.62	19.05	17.97	17.86	16.56
Services	3.02	2.74	4.10	3.83	2.82	2.59

Notes: Table reports model-implied effects of a 10 percent increase in sectoral total factor productivity (TFP) under the benchmark model described in Section 2. Separate results are shown for agricultural and industrial TFP improvements, and for both closed- and open-economy environments. Values show percentage-point (p.p.) or percent changes relative to the baseline open-economy equilibrium. 'Welfare Changes (%)' denotes the change in real GDP, expressed in percentage terms. Changes in expenditure shares capture shifts in final demand across sectors; changes in labor shares reflect reallocation of employment; and changes in labor productivity measure the corresponding percentage hat change in value added per worker. Results are reported by income group (LICs, LMICs, HICs), as defined in Appendix C.

Table XI: Effects of a 10% increase in TFP across Different Specifications - LMICs

	Benchmark		w.o. NHCES		w.o. FF		w.o. NHCES-FF		w.o. Linkages		w.o. Linkages-NHCES		w.o. Linkages-FF		w.o. Linkages-NHCES-FF	
	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open
TFP improvement in Agriculture																
Welfare changes (%)	1.21	1.18	1.46	1.43	1.21	1.18	1.46	1.43	0.59	0.60	0.70	0.71	0.60	0.60	0.70	0.70
Changes in Expenditure share (p.p.)																
Agriculture	-0.64	-0.51	-0.60	-0.47	-0.58	-0.54	-0.55	-0.51	-0.74	-0.54	-0.72	-0.51	-0.57	-0.53	-0.55	-0.51
Industry	-0.03	-0.01	0.01	0.04	-0.03	0.00	0.01	0.04	0.30	0.20	0.32	0.22	0.22	0.20	0.24	0.22
Services	0.67	0.51	0.58	0.43	0.61	0.55	0.53	0.47	0.44	0.34	0.40	0.29	0.35	0.33	0.30	0.29
Changes in Labor share (p.p.)																
Agriculture	-0.33	0.26	-0.31	0.28	-0.41	0.42	-0.38	0.45	-0.54	-0.02	-0.52	0.00	-0.57	0.02	-0.55	0.05
Industry	-0.04	0.02	-0.02	0.03	0.00	-0.02	0.02	-0.01	0.21	-0.12	0.23	-0.10	0.22	-0.13	0.24	-0.12
Services	0.38	-0.28	0.33	-0.31	0.41	-0.40	0.36	-0.44	0.33	0.13	0.29	0.10	0.35	0.11	0.30	0.07
Changes in Labor Productivity (%)																
Agriculture	13.25	10.90	13.17	10.83	12.02	11.88	12.02	11.88	13.52	10.02	13.39	9.90	10.00	10.00	10.00	10.00
Industry	1.54	1.22	1.53	1.21	1.41	1.32	1.41	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Services	0.48	0.41	0.48	0.40	0.44	0.44	0.44	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TFP improvement in Industry																
Welfare changes (%)	6.76	6.56	8.22	7.96	6.76	6.56	8.22	7.96	3.27	3.29	3.84	3.85	3.27	3.29	3.84	3.85
Changes in Expenditure share (p.p.)																
Agriculture	0.02	-0.01	0.26	0.22	0.03	0.00	0.26	0.22	0.17	0.06	0.33	0.20	0.13	0.10	0.25	0.22
Industry	-2.56	-1.99	-2.34	-1.78	-2.56	-2.00	-2.34	-1.79	-2.03	-1.62	-1.94	-1.52	-2.01	-1.64	-1.90	-1.53
Services	2.54	2.00	2.08	1.56	2.52	1.99	2.09	1.57	1.86	1.56	1.61	1.32	1.88	1.54	1.66	1.31
Changes in Labor share (p.p.)																
Agriculture	-0.11	-0.06	0.03	0.04	-0.14	-0.09	0.03	0.04	0.13	-0.14	0.24	-0.07	0.13	-0.21	0.25	-0.11
Industry	-1.33	4.09	-1.21	4.17	-1.28	4.00	-1.17	4.07	-2.06	2.33	-1.94	2.43	-2.01	2.32	-1.90	2.40
Services	1.44	-4.03	1.18	-4.21	1.41	-3.91	1.14	-4.11	1.93	-2.18	1.70	-2.36	1.88	-2.11	1.66	-2.29
Changes in Labor Productivity (%)																
Agriculture	3.99	3.62	3.55	3.32	3.63	3.35	3.63	3.35	-0.68	0.87	-1.29	0.45	0.00	0.00	0.00	0.00
Industry	19.05	17.97	18.99	17.93	18.99	17.97	18.99	17.96	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Services	4.10	3.83	4.09	3.81	4.09	3.82	4.09	3.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of a 10 percent increase in sectoral total factor productivity (TFP) under alternative model specifications. Values show percentage-point (p.p.) or percent changes relative to the corresponding open-economy equilibrium under each specification. 'Benchmark' denotes the model described in Section 2; 'w.o. NHCES' assumes $\nu_k = 1$ for all k (homothetic preferences); 'w.o. FF' sets $\zeta_j = 0$ (no fixed factor in agricultural production); 'w.o. NHCES-FF' combines both assumptions; 'w.o. Linkages' removes input-output linkages; 'w.o. Linkages-FF' removes linkages and the fixed factor; 'w.o. Linkages-NHCES' removes linkages and non-homothetic preferences; and 'w.o. Linkages-NHCES-FF' excludes all three features simultaneously. Separate results are shown for agricultural and industrial TFP improvements, and for both closed- and open-economy environments. Results are reported as averages across low-middle-income countries (LMICs), as defined in Appendix C.

Table XII: Effects of a 10% increase in TFP across Different Specifications - HICs

	Benchmark		w.o. NHCES		w.o. FF		w.o. NHCES-FF		w.o. Linkages		w.o. Linkages-NHCES		w.o. Linkages-FF		w.o. Linkages-NHCES-FF	
	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open
TFP improvement in Agriculture																
Welfare changes (%)	0.53	0.53	0.67	0.67	0.53	0.53	0.67	0.66	0.25	0.27	0.31	0.33	0.26	0.27	0.31	0.33
Changes in Expenditure share (p.p.)																
Agriculture	-0.22	-0.17	-0.21	-0.16	-0.21	-0.19	-0.20	-0.18	-0.34	-0.22	-0.33	-0.21	-0.26	-0.24	-0.25	-0.23
Industry	-0.08	-0.05	-0.06	-0.03	-0.08	-0.06	-0.06	-0.04	0.10	0.05	0.11	0.07	0.08	0.06	0.09	0.07
Services	0.30	0.22	0.27	0.19	0.28	0.25	0.26	0.22	0.23	0.16	0.22	0.15	0.18	0.18	0.17	0.16
Changes in Labor share (p.p.)																
Agriculture	-0.10	0.23	-0.10	0.23	-0.13	0.39	-0.13	0.40	-0.24	0.08	-0.24	0.09	-0.26	0.17	-0.25	0.18
Industry	-0.05	0.01	-0.04	0.02	-0.04	-0.01	-0.03	-0.01	0.07	-0.12	0.08	-0.11	0.08	-0.16	0.09	-0.15
Services	0.15	-0.24	0.14	-0.25	0.17	-0.38	0.16	-0.39	0.17	0.04	0.16	0.02	0.18	-0.01	0.17	-0.02
Changes in Labor Productivity (%)																
Agriculture	12.69	10.09	12.66	10.06	11.89	11.73	11.89	11.73	13.59	8.83	13.54	8.77	10.00	10.00	10.00	10.00
Industry	1.05	0.78	1.04	0.77	0.99	0.91	0.99	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Services	0.26	0.21	0.26	0.21	0.24	0.24	0.24	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TFP improvement in Industry																
Welfare changes (%)	4.81	4.54	6.07	5.72	4.81	4.54	6.07	5.72	2.38	2.35	2.93	2.88	2.38	2.35	2.93	2.88
Changes in Expenditure share (p.p.)																
Agriculture	-0.02	-0.02	0.05	0.04	-0.01	-0.02	0.05	0.04	0.06	0.00	0.12	0.05	0.04	0.03	0.09	0.07
Industry	-2.17	-1.63	-2.01	-1.48	-2.17	-1.64	-2.01	-1.48	-1.78	-1.40	-1.69	-1.31	-1.77	-1.41	-1.68	-1.32
Services	2.19	1.65	1.97	1.44	2.18	1.65	1.96	1.44	1.72	1.40	1.58	1.27	1.73	1.38	1.59	1.25
Changes in Labor share (p.p.)																
Agriculture	-0.07	-0.01	-0.03	0.01	-0.09	-0.02	-0.04	0.01	0.04	-0.10	0.08	-0.08	0.04	-0.17	0.09	-0.13
Industry	-1.10	3.70	-1.02	3.76	-1.08	3.67	-1.00	3.73	-1.79	2.28	-1.70	2.36	-1.77	2.30	-1.68	2.37
Services	1.17	-3.69	1.05	-3.77	1.17	-3.65	1.05	-3.74	1.75	-2.18	1.62	-2.28	1.73	-2.13	1.59	-2.23
Changes in Labor Productivity (%)																
Agriculture	4.48	3.60	4.24	3.45	3.96	3.49	3.96	3.49	-0.50	1.37	-0.98	1.08	0.00	0.00	0.00	0.00
Industry	17.86	16.56	17.84	16.55	17.81	16.57	17.81	16.56	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Services	2.82	2.59	2.82	2.59	2.81	2.59	2.81	2.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: Table reports model-implied effects of a 10 percent increase in sectoral total factor productivity (TFP) under alternative model specifications. Values show percentage-point (p.p.) or percent changes relative to the corresponding open-economy equilibrium under each specification. 'Benchmark' denotes the model described in Section 2; 'w.o. NHCES' assumes $\nu_k = 1$ for all k (homothetic preferences); 'w.o. FF' sets $\zeta_j = 0$ (no fixed factor in agricultural production); 'w.o. NHCES-FF' combines both assumptions; 'w.o. Linkages' removes input-output linkages; 'w.o. Linkages-FF' removes linkages and the fixed factor; 'w.o. Linkages-NHCES' removes linkages and non-homothetic preferences; and 'w.o. Linkages-NHCES-FF' excludes all three features simultaneously. Separate results are shown for agricultural and industrial TFP improvements, and for both closed- and open-economy environments. Results are reported as averages across high-income countries (HICs), as defined in Appendix C.