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Takuma Kunieda

(Kwansei Gakuin University)

Keisuke Okada

(Kansai University)

Yasuyuki Sawada

(The University of Tokyo)

Akihisa Shibata

(Osaka University of Economics)

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1-155 Uegahara Ichiban-cho

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Takuma Kunieda*
Kwansei Gakuin University

Keisuke Okada†
Kansai University

Yasuyuki Sawada‡
The University of Tokyo

Akihisa Shibata§
Osaka University of Economics

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Abstract

Building on the two-sector growth model of Matsuyama (1992), this paper explores how the Green Revolution contributed to structural transformation through market-based price adjustments. To address the endogeneity of relative agricultural prices, we employ shift-share (Bartik) instrumental variables drawing on the innovative methodologies and datasets developed by Gollin et al. (2021) and Huang (2024). We further construct a novel projected-TFP instrument to isolate realized agricultural productivity gains attributable to the Green Revolution. Our empirical findings show that the Green Revolution significantly increased agricultural productivity, lowered agricultural prices, and facilitated structural transformation when market mechanisms function effectively. Importantly, institutional quality critically shapes this price-transmission mechanism: weak institutions distort the transmission of agricultural productivity gains into relative prices and thereby impede structural transformation. To quantify these distortions and the associated misallocation, we construct a price-based misallocation (PBM) index that captures institutionally mediated distortions in relative-price adjustment. Overall, our findings show that the benefits of the Green Revolution depend not only on technological progress itself but also on the institutional environment through which productivity gains are transmitted into market prices. These findings highlight the importance of institutional reforms and targeted policies to reduce distortions and maximize the gains from agricultural innovation.

Keywords: Structural transformation; Green Revolution; Misallocation; Economic development; Price-based misallocation (PBM) index

JEL Classification: O11, O13, O43, Q16

*School of Economics, Kwansei Gakuin University, 1-155 Uegahara Ichiban-Cho, Nishinomiya, Hyogo 662-8501, Japan. Email: tkunieda@kwansei.ac.jp

†Faculty of Economics, Kansai University, 3-3-35 Yamate-cho, Suita, Osaka 564-8680, Japan. Email: k_okada@kansai-u.ac.jp

‡Faculty of Economics, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. Phone: +81 3 5841 5572, Fax: +81 3 5841 5523, Email: sawada@e.u-tokyo.ac.jp

§Department of Economics, Osaka University of Economics, 2-2-8 Osumi, Higashiyodogawa-ku, Osaka 533-8533, Japan. Email: a.shibata@osaka-ue.ac.jp

1 Introduction

Over the past half-century, many developing countries have experienced profound structural transformation, marked by declining agricultural output shares and rising incomes. A central force behind this process has been the Green Revolution, which dramatically increased agricultural productivity and helped reduce food scarcity and poverty in low-income economies (Evenson and Gollin, 2003; Gollin et al., 2021; Otsuka, 2024). Yet, despite broadly similar technological advances, the pace and extent of structural transformation have varied markedly across countries (Barrett et al., 2010; Gollin and Kaboski, 2023; Adamopoulos and Restuccia, 2024).[1] In some economies, productivity gains in agriculture translated into lower food prices and rapid reallocation of labor toward non-agricultural sectors, while in others agricultural employment and output shares remained persistently high. A natural explanation for these divergent experiences lies in the behavior of relative prices. As agricultural productivity rises, Engel's law takes effect, depressing the equilibrium relative price of agricultural products and accelerating the process of structural transformation. However, relative prices are equilibrium outcomes shaped not only by technology but also by institutions, policy interventions, and broad market frictions. As a result, productivity improvements do not necessarily generate the same price responses across countries.

This paper examines the impact of the Green Revolution on structural transformation through the lens of relative agricultural prices, and analyzes how this mechanism is moderated by institutional quality. Extending Matsuyama (1992), we develop a general equilibrium framework with non-homothetic preferences and price wedges to show that productivity-driven price declines promote structural transformation only when markets function effectively. We then test these predictions using cross-country panel data for 1962–2010, employing shift-share (Bartik) instrumental variables (IVs) drawing on the innovative methodologies and datasets developed by Gollin et al. (2021) and Huang (2024). In addition, we construct a novel shift-share instrument by projecting observed agricultural TFP onto the Green Revolution index, thereby isolating the component of realized agricultural productivity gains attributable to the Green Revolution. We allow the effects of these instruments on relative agricultural prices to vary systematically with institutional quality. By doing so, our study bridges a critical lacuna in the literature. To the best of our knowledge, relatively little attention has been paid to how institutional and market distortions affect the transmission of agricultural productivity gains into relative prices and, through this price-adjustment mechanism, into structural transformation. This represents a notable omission in the literature, particularly in

[1] According to Barrett et al. (2010), the "getting agriculture moving" stage fits parts of East and Southeast Asia but is "badly off the mark" in much of Africa and Latin America, where policy strategies historically prioritized industrialization and extracted surplus from agriculture, reinforcing urban bias and underinvestment in rural productivity.

light of the highly influential work of Krueger et al. (1988) on policy-induced price distortions that adversely affected agricultural incentives in developing countries (Anderson, 2010). Furthermore, the related studies in the literature, such as David and Otsuka (1994), Hayami and Godo (2005), Larson and Otsuka (2012), Otsuka (2024), and Otsuka et al. (2024), offer critical insights into the impact and future trajectory of the Green Revolution in Asia and Africa, analyzing agricultural productivity growth, relative price dynamics, and structural transformation from a comparative perspective. Our paper seeks to address this gap by examining key aspects of agricultural productivity and structural transformation, with a specific emphasis on the role of price signals. We take the canonical two-sector theoretical model of Matsuyama (1992) very seriously and combine it with new datasets on the Green Revolution compiled by Gollin et al. (2021) and Huang (2024).

To contextualize our study within the literature, research on structural transformation has experienced a major resurgence. This revival is driven by advancements in misallocation modeling, causal inference methods, expanded data availability across diverse contexts, and recent findings that have opened new frontiers in development economics (Restuccia and Rogerson, 2017; Gollin and Kaboski, 2023; Adamopoulos and Restuccia, 2024). A growing body of literature now explores various dimensions of structural transformation, such as rural-to-urban migration, the shift from household to market production, transitions from informal to formal sectors, and the move from self-employment to wage labor (Restuccia and Rogerson, 2017; Teignier, 2018; Itskhoki and Moll, 2019; Restuccia, 2019; Lagakos and Shu, 2023; Aragón et al., 2024).

While rigorous experimental micro-research in development economics has advanced our understanding of misallocation and its sources, it has often neglected broader questions surrounding contemporary structural transformation and the practical challenges of scaling successful local interventions, as noted by Gollin and Kaboski (2023). To provide actionable policy recommendations for fostering effective transformation and development, empirical research must address critical issues such as technological backwardness, market failures, policy distortions, and institutional barriers. In particular, transformative policies of monumental scale, such as the Green Revolution's role in driving structural transformation (Gollin et al., 2021; Huang, 2024), warrant further investigation. There remains an urgent need for empirical research to identify the primary drivers and impediments of structural transformation, particularly industrialization and the transition from agriculture to non-agricultural sectors (Matsuyama, 1992, 2008; Duarte and Restuccia, 2010; Adamopoulos and Restuccia, 2020). Moreover, with the rapid progress in research on misallocation in macro-development economics, it is still crucial to identify the exact sources of misallocation to better understand its role in hindering economic transformation (Hsieh and Klenow, 2009; Restuccia, 2013; Restuccia and Rogerson, 2017; Restuccia, 2019; Adamopoulos et al., 2022; Chen et al., 2023;

Uras and Wang, 2024). More recently, studies have emphasized the importance of specifying the market and institutional frictions underlying observed wedges at the micro level and assessing how these frictions contribute to aggregate misallocation (Ghatak and Mookherjee, 2025; Bergquist et al., 2026). Existing studies on misallocation point to various sources, including regulations and frictions in credit, labor, and land markets. Furthermore, pecuniary and institutional inefficiencies arising from policy distortions, restrictive regulations, weak property rights, and trade barriers are recognized as significant contributors to misallocation. Regarding structural transformation, the literature has predominantly focused on mechanisms driving structural change through income effects via non-homothetic preferences or relative price effects stemming from technological differences across sectors (Adamopoulos and Restuccia, 2024). Notable studies examining the latter aspect include Duarte and Restuccia (2010), Boppart (2014), and Comin et al. (2021). Closely related to our study, Bustos et al. (2016) show that the effect of agricultural productivity growth on structural transformation in an open economy depends critically on the factor bias of technological change. While their analysis emphasizes the resulting reallocation of factors across sectors, our framework complements their perspective by emphasizing how institutional quality shapes the transmission of agricultural productivity improvements through relative agricultural prices into structural transformation.

Our central contribution is to show that agricultural productivity gains translate into structural transformation only when institutions allow relative prices to adjust efficiently, and that distortions in this price-adjustment mechanism constitute a crucial source of misallocation. To preview our findings, the empirical results highlight the Green Revolution's transformative impact on agricultural productivity and structural transformation. More specifically, our instrumental variables estimation using the cross-country panel data on macroeconomic variables as well as information on the Green Revolution confirms that falling agricultural prices, driven by productivity gains, spurred industrial growth. Advanced agricultural technologies significantly increased productivity, reduced agricultural prices, and decreased agriculture's share of economic output, consistent with Engel's law as rising incomes shift consumption away from agricultural goods. In this process, institutional quality played a critical role: the price-reducing effect of the Green Revolution emerges primarily in countries with strong institutions, while weak institutional environments are associated with price distortions and misallocation. Specifically, countries with robust institutions exhibited smaller price distortions and more effective market responses, while weak institutions impeded relative-price adjustment and slowed structural transformation.

To further quantify the role of market distortions, we construct a price-based misallocation (PBM) index that captures distortions in the transmission of agricultural productivity gains into

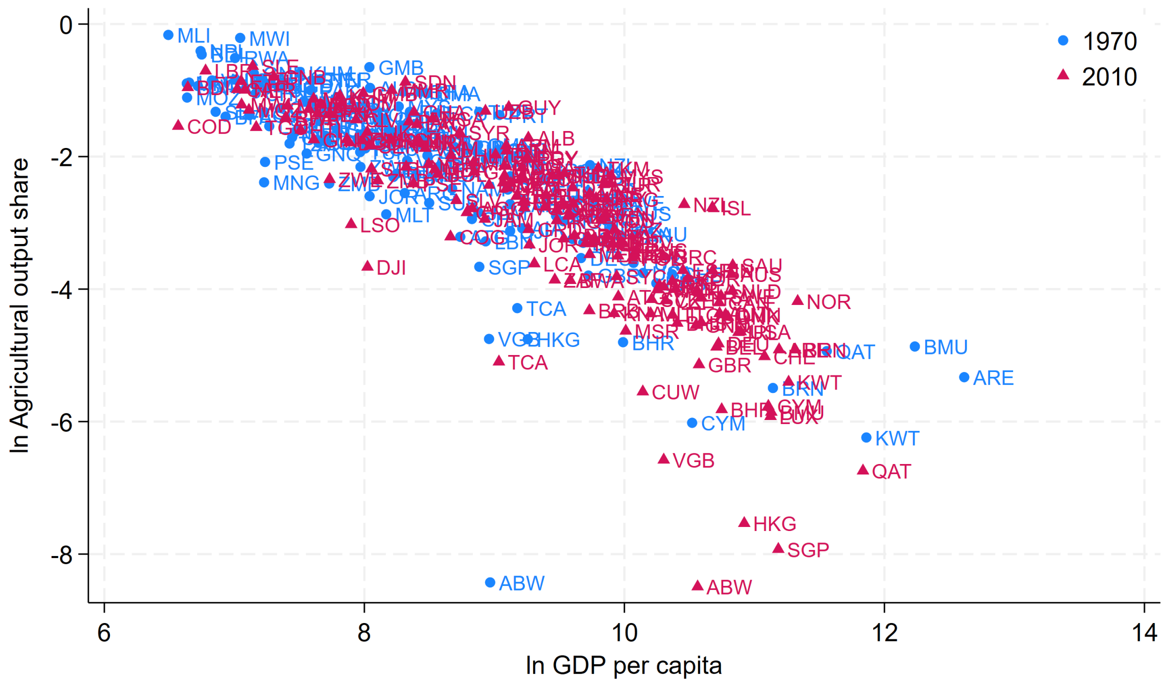

Figure 1: The relationship between the agricultural output share and GDP per capita

Notes: The cross-country relationship between per capita GDP and the agricultural output share, both in logarithms, is presented for 153 countries in 1970 and 180 countries in 2010. The circle and triangle markers denote observations for 1970 and 2010, respectively.

relative agricultural prices. The PBM index provides a simple cross-country measure of price distortions associated with institutional weakness. This index is negatively correlated with income levels across countries and helps explain why similar technological advances can generate very different development outcomes. Together, these findings highlight the central role of institutions in shaping the price-mediated transmission of agricultural productivity gains into structural transformation. Although the Green Revolution has been a powerful driver of agricultural productivity and economic development, its full potential can only be realized in the presence of well-functioning market mechanisms. These findings stress the need for institutional reforms and targeted policies to address underlying market and institutional frictions and maximize the benefits of agricultural innovations.

The remainder of this paper is organized as follows: Section 2 presents stylized facts on structural transformation, followed by Section 3, which introduces a theoretical framework to derive testable implications. Section 4 details the data and econometric analysis framework. Section 5 reports the empirical results, while Section 6 provides an extensive discussion on misallocation and per capita GDP. The final section offers concluding remarks.

2 Stylized Facts on Structural Transformation

Structural transformation has been a critical driver of long-term economic success. Most successful developing economies have followed the trajectory of high-income countries: the share of agriculture in output and employment declines as the industrial sector expands, eventually giving way to "deindustrialization" as the services sector becomes dominant (Asian Development Bank, 2020). For instance, all successful Asian economies invested significantly in transforming agriculture and traditional rural economies. Furthermore, urbanization often progresses in tandem with shifts in industrial structure.

2.1 Shift in Production from Agriculture to Non-Agriculture

Figure 1 presents scatter plots illustrating the cross-country relationship between per capita GDP and the agricultural output share (both in logarithms) for 153 countries in 1970 and 180 countries in 2010. Circles represent the data points for 1970, while triangles represent those for 2010.[2] The figure reveals a strong and remarkably stable negative relationship between per capita GDP and the agricultural output share over the four-decade period. While these data do not allow us to establish direct causality, it is reasonable to expect that per capita GDP growth is associated with a declining share of agricultural output. This process is typically accompanied by a reallocation of production inputs, particularly labor, from agriculture toward higher-productivity non-agricultural sectors. Indeed, numerous theoretical and quantitative studies have analyzed the mechanisms linking economic development, declining agricultural shares, and the reallocation of production inputs toward non-agricultural sectors (Lewis, 1954; Ohkawa, 1961; Ranis and Fei, 1961; Jorgenson, 1961; Harris and Todaro, 1970; Matsuyama, 1992; Temple, 2005; Duarte and Restuccia, 2010; Gollin and Kaboski, 2023; Adamopoulos and Restuccia, 2024).

To strengthen our prediction, Figure 2 presents time-trajectory plots highlighting eight representative countries at different stages of development, selected from Figure 1. These include two now-advanced Asian countries (Japan and Korea), three less-developed Asian countries (China, India, and the Philippines), and three African countries (Malawi, Tanzania, and Uganda). In all Asian countries, per capita GDP growth was accompanied by a declining agricultural output share from 1970 to 2010. Notably, Korea experienced a remarkable leapfrogging compared to the Philippines, which had a similar per capita GDP in 1970.

A striking feature of the Asian countries is the consistency in their time-shift patterns, where per

[2]The data on the agricultural output share of GDP are obtained from United Nations Statistics Division (2024a,b), and the data on GDP per capita are retrieved from the Penn World Table compiled by Feenstra et al. (2015), as described in detail in Section 4.1.

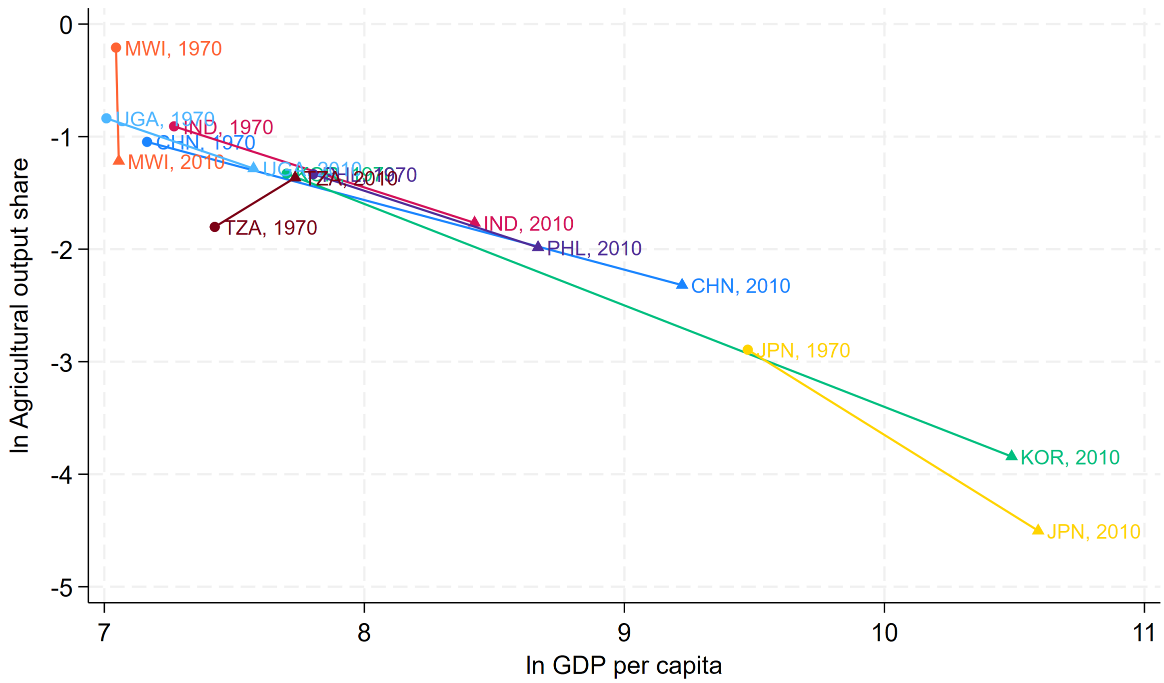

Figure 2: The time-shift plots of eight representative countries

Notes: The time-shift plots of eight representative countries extracted from Figure 1 are presented. The eight countries are at different stages of development and include two advanced Asian economies (Japan and Korea), three developing Asian economies (China, India, and the Philippines), and three African countries (Malawi, Tanzania, and Uganda).

capita GDP and the agricultural output share follow nearly identical trajectories. In contrast, the African countries show deviations from this common path. In Uganda and Malawi, the agricultural share declined with rising per capita GDP, although Malawi's GDP growth was minimal. Tanzania, however, exhibited an unusual pattern, with its agricultural output share expanding alongside an increase in per capita GDP from 1970 to 2010.

2.2 The Role of Market Mechanisms in Driving Transformation

Figures 1 and 2 suggest that economic development is closely associated with structural transformation, typically characterized by a declining agricultural output share. To explore whether market mechanisms operate smoothly—namely, whether a lower relative price of agricultural goods is associated with a smaller agricultural output share—we conduct a semiparametric estimation. Using cross-country panel data for 180 countries over the period 1962–2010, we examine the relationship between the relative agricultural price, $\ln p_{it}$, and the agricultural output share, incorporating year fixed effects as linear components.[3] In this estimation, we measure the relative agricultural price using a country-specific commodity price index constructed by Gruss and Kebhaj (2019). Year fixed effects capture the influence of energy and metals prices, which are largely driven by international commodity markets and commonly affect all countries, thereby helping to isolate variation associated with domestic agricultural goods prices. Detailed descriptions of the data are provided in Section 4.1. The bold line in Figure 3 depicts the resulting semiparametric estimate of the relationship between the relative agricultural price and the agricultural output share (both in logarithms) for 180 countries over the period 1962–2010, with the shaded area indicating the 95% confidence interval. The estimation reveals a positive, albeit weak, relationship between the relative agricultural price and the agricultural output share. In other words, lower relative agricultural prices tend to be associated with lower agricultural output shares.

Despite this positive association identified by the semiparametric estimation, two key issues remain in interpreting this reduced-form relationship. First, the relative agricultural price is endogenously determined, rendering the estimate in Figure 3 potentially subject to endogeneity bias. Although the inclusion of year fixed effects as linear components controls for common time-specific shocks and thereby partially mitigates this concern, it does not account for unobserved time-invariant country-specific heterogeneity. Indeed, when country fixed effects are additionally included, the estimated nonlinear relationship turns negative, a result that we do not report here. Second, the functioning of the price mechanism itself may be distorted by market frictions—most notably weak institutions—that directly affect the determination of agricultural prices. Such frictions are not explicitly captured by the semiparametric approach, as they interact with productivity improvements associated with the Green Revolution in shaping equilibrium prices. The relatively weak positive association between the relative agricultural price and the agricultural output share observed in the semiparametric estimate is therefore suggestive of heterogeneity and market frictions that are not captured by a reduced-form framework. Overall, these considerations underscore the need for an empirical specification grounded in a theoretical framework. Such a framework disciplines the identification strategy, guides the choice of instrumental variables, and provides a coherent basis for robust econometric inference.

2.3 The Role of the Green Revolution

The role of the Green Revolution in driving structural transformation warrants a deeper investigation (Evenson and Gollin, 2003; Gollin et al., 2021). Spanning the 1960s to the 1980s, this transformative era of agricultural innovation significantly boosted crop yields. During this period, farmers adopted

[3] The list of the 180 countries is provided in Table B1 in Appendix B.

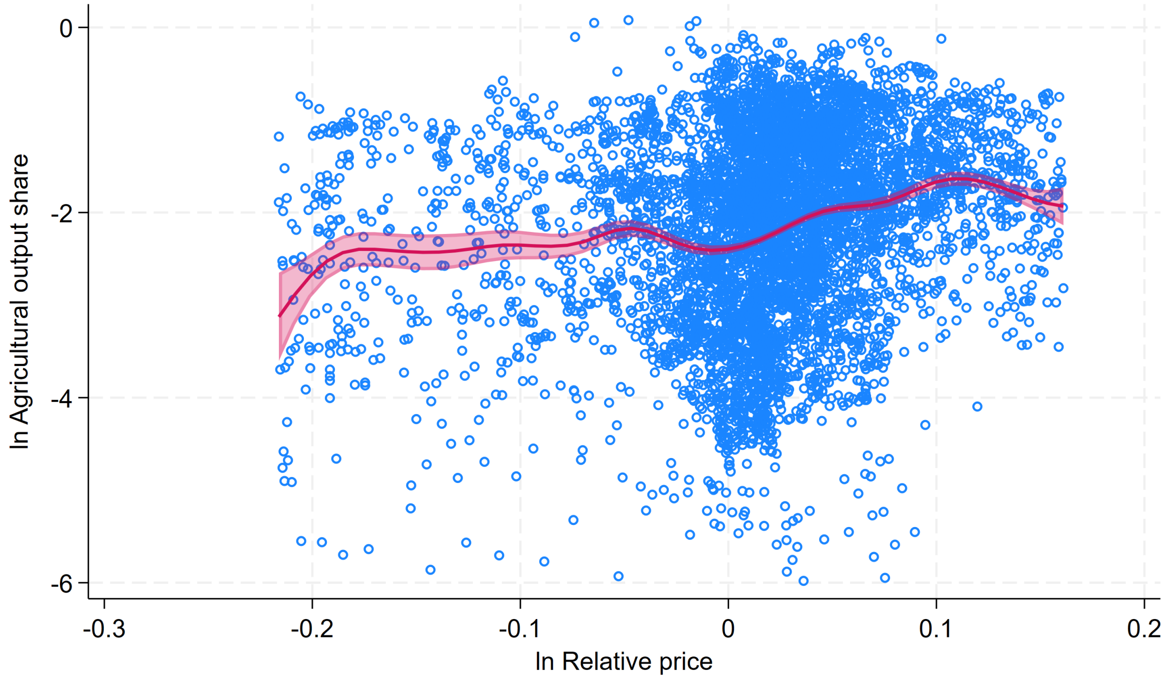

Figure 3: The relative agricultural price versus the agricultural output share

Notes: The bold line depicts Robinson's (1988) semiparametric estimate of the relationship between the relative agricultural price and the agricultural output share (both in logarithms) for 180 countries over the period 1962–2010, with year fixed effects included as linear components. The shaded area indicates the 95% confidence interval. The estimation reveals a generally positive relationship between the relative agricultural price and the agricultural output share. To account for outliers, observations identified as outliers in the relative agricultural price using the procedure of Belotti et al. (2024), with a robust z-score threshold of three, are excluded from the estimation. For ease of visualization, observations with partial residuals (the values plotted on the vertical axis) below -6 are not displayed in the scatter plot; however, these observations are retained in the estimation of the semiparametric relationship and its confidence interval.

advanced technologies, including high-yielding varieties (HYVs) of cereals such as dwarf wheat and rice, together with complementary inputs such as chemical fertilizers (which are crucial for maximizing the potential of these new seeds), pesticides, and controlled irrigation systems.

To measure the impact of the Green Revolution, Gollin et al. (2021) and Huang (2024) construct an index that accounts for factors such as the adoption of high-yielding crop varieties, enhancements in agricultural productivity, and increased use of modern inputs such as fertilizers and irrigation. Specifically, the Green Revolution index is constructed as follows. First, the crop-specific productivity parameter a_{kt} of the crop k at time t can be decomposed as $a_{kt} = a_{kt}^{HYV} \bar{a}_k z_t u_{kt}$, where $a_{kt}^{HYV} = 1$ if no HYVs are available and $a_{kt}^{HYV} > 1$ if HYVs are grown. The magnitude of a_{kt}^{HYV} depends on the degree to which the available varieties improve yields and the uptake of HYVs. The parameter $\bar{a}_k$ is a productivity level specific to the crop and invariant in time, z_t is a productivity trend in the whole country, and u_{kt} is an idiosyncratic productivity shock to the crop k with mean 1. In the empirical implementation, the productivity parameter, $\ln a_{kt}^{HYV}$, is estimated by regressing the yield of each crop k in logarithms on an indicator variable that takes a value of one in years after the release of the first HYV of crop k, interacted with a linear year trend, and on the area harvested using a two-way fixed effects model. Second, letting $t = 0$ denote the period preceding the Green Revolution, the direct contribution of HYVs to aggregate yields, keeping allocations of land and labor constant at their pre-Green Revolution levels, becomes:

$$R_t = \sum_{k=1}^{N} a_{kt}^{HYV} \frac{Y_{Ak0}}{Y_{A0}},$$

where Y_{Ak0}/Y_{A0} is the share of crop k in the aggregate crop production before the Green Revolution. This is the Green Revolution index constructed by Gollin et al. (2021) and Huang (2024). In the empirical analysis, the Green Revolution index is expressed in natural logarithms. Because the Green Revolution index measures the predicted magnitude of Green Revolution-related agricultural productivity improvements, countries that were only weakly affected by the Green Revolution naturally receive low index values regardless of whether they are classified as developed or developing economies. We therefore include both developed and developing countries in the baseline empirical analysis whenever the relevant data are available. Exploiting this broader cross-country variation is particularly useful for examining how agricultural productivity growth translates into structural transformation under different institutional and market environments. At the same time, because the Green Revolution is widely recognized as a transformative force in developing economies, Section 5.3 further examines whether the main findings remain robust when the sample is restricted to developing countries.

In this paper, we focus on how market mechanisms incentivize individuals to respond to price signals, thereby shaping key decisions such as technological adoption, occupational choice, and migration. To explore the role of the Green Revolution in facilitating market-based structural transformation, we conduct semiparametric estimations of the relationship between the Green Revolution index, constructed by Gollin et al. (2021) and extended by Huang (2024), and the relative agricultural price (in logarithms). Figure 4 presents the estimated relationships separately for countries with high and low levels of economic freedom, our proxy for institutional quality, with the shaded area indicating the 95% confidence interval, using data for 121 countries over the period 1962–2010, with year fixed effects included as linear components. Panel (a) reports the estimates for countries whose average Economic Freedom index is above the median, while Panel (b) reports those below the median. A striking contrast emerges across the two groups. In countries

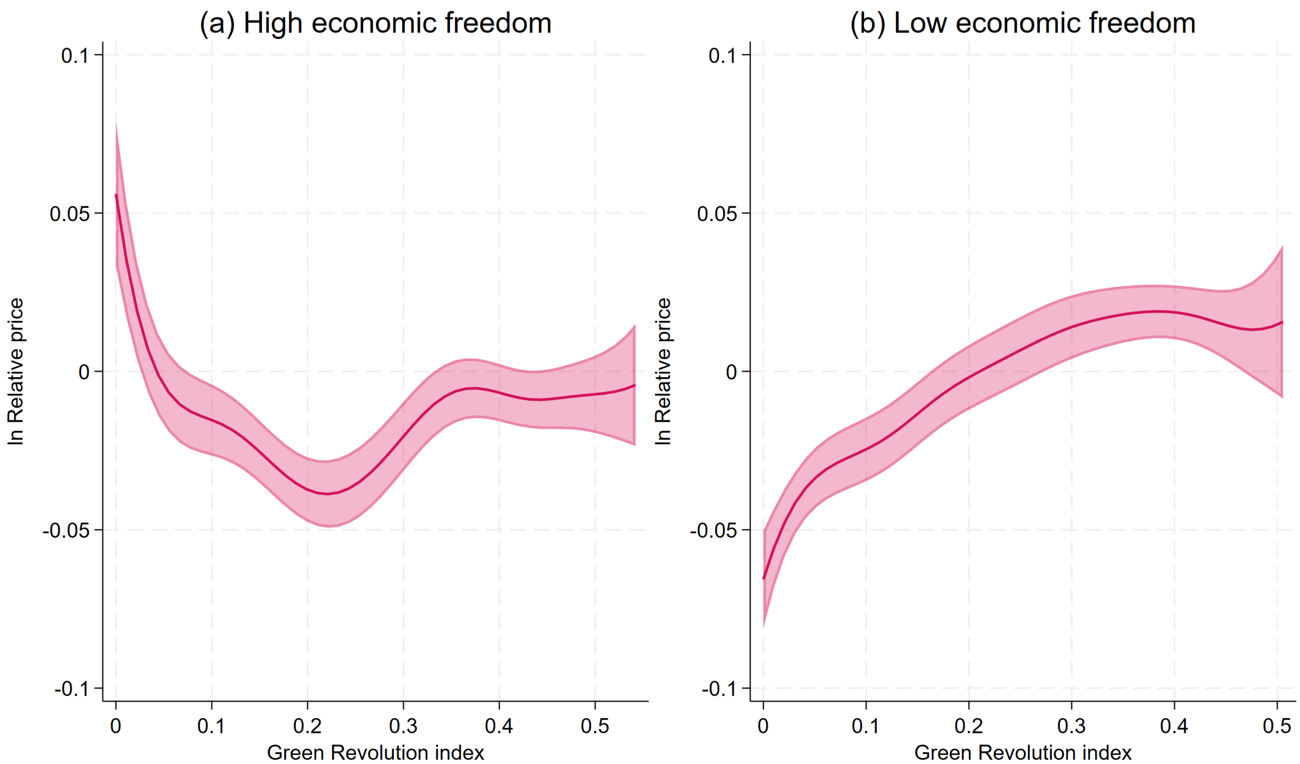

Figure 4: Green Revolution (GR) index versus relative agricultural prices by institutional quality

Notes: The bold lines depict Robinson's (1988) semiparametric estimates of the relationship between the Green Revolution index constructed by Gollin et al. (2021) and extended by Huang (2024), and the relative agricultural price, using data for 121 countries over the period 1962–2010, with year fixed effects included as linear components. The shaded areas indicate the 95% confidence intervals. Panel (a) uses countries whose average Economic Freedom index is above the median, while Panel (b) uses countries below the median.

with high economic freedom, increases in the Green Revolution index are broadly associated with declines in the relative agricultural price, consistent with the theoretical predictions developed in the next section. By contrast, in countries with low economic freedom, the relationship becomes substantially weaker and even positive over part of the support, suggesting that market distortions and institutional frictions hinder the transmission of agricultural productivity gains into lower relative agricultural prices. These semiparametric results suggest that the relationship between the Green Revolution and relative agricultural prices varies systematically with institutional quality. They also underscore the importance of developing a general equilibrium framework that explicitly incorporates market distortions and institutional heterogeneity.

Figures 1–4 collectively suggest that the sustained growth of the global economy has been broadly accompanied by declining agricultural output shares and relative agricultural prices, while the transmission of agricultural productivity improvements into relative-price adjustments varies systematically with institutional quality and market functioning. This trend has made crop products increasingly affordable to consumers and has contributed to large-scale poverty reduction in low-income economies (Hayami and Godo, 2005). Given that real crop prices have exhibited a persistent downward trend over the past 50 years, the preliminary regression result and the semiparametric estimate shown in Figure 3 are consistent with a close association between declining relative agricultural prices, reductions in the agricultural output share, and structural transformation from agricultural to non-agricultural sectors. Moreover, Figure 4 suggests that the relationship between the Green Revolution and relative agricultural prices differs systematically across institutional environments. In countries with high institutional quality, agricultural productivity improvements associated with the Green Revolution tend to translate into lower relative agricultural prices, particularly during the initial phase of implementation, whereas this transmission mechanism appears substantially weaker in countries with low institutional quality. These findings suggest that the Green Revolution did not mechanically generate structural transformation across countries. Rather, its effects depended on whether market mechanisms were able to transmit agricultural productivity gains into relative price adjustments. However, neither the reduced-form regression nor the semiparametric estimations fully elucidate the underlying equilibrium mechanisms through which the Green Revolution, institutional quality, and market distortions interact to shape structural transformation. These mechanisms likely involve shifts in the demand and supply conditions for crops and other agricultural goods, as well as for non-agricultural goods. To address these issues, we develop a theoretical framework that explicitly captures these dynamics, which in turn guides the derivation of the estimation equations used in our empirical analysis.

3 Theoretical Framework

To motivate the empirical model, we formulate a two-sector dynamic model of structural transformation that incorporates two key mechanisms widely discussed in the literature: (1) income effects driven by non-homothetic preferences, and (2) goods and labor market equilibrium conditions that determine relative price effects stemming from technological differences across sectors. Specifically, we extend the model of Matsuyama (1992) to capture structural transformation through market mechanisms, following the framework of dynamic general equilibrium theory. In this model, the economy consists of two sectors: the agricultural and non-agricultural sectors. While the non-agricultural sector encompasses both manufacturing and services, we do not differentiate between them for simplicity. Time is discrete, indexed by t ($t = 0, 1, 2, \cdots$). The population is assumed to be constant and denoted by L, representing the total labor supply at any given time. Departing from Matsuyama's original model, we abstract from productivity growth in the non-agricultural sector to focus on the impact of agricultural productivity growth. These simplified settings motivate our instrumental variable estimation by allowing us to analyze the impact of the Green Revolution on the relative price of agricultural goods (first-stage IV regression) and the relationship between relative agricultural prices and the agricultural output share (second-stage IV regression).

In the theoretical framework, we introduce a price wedge for two purposes: to investigate misallocation arising from institutional and regulatory deficiencies and to accommodate different degrees of trade openness within a unified framework. For expositional clarity, we first consider a closed economy and then extend the analysis to an open economy, treating them as two polar cases. Importantly, however, the price-wedge formulation is not restricted to these two cases. By allowing the wedge associated with trade openness to vary continuously, the framework can also represent economies lying between the closed- and open-economy extremes. Rather than explicitly modeling all sources of deviations between domestic and world-market conditions, we use this wedge as a reduced-form representation of factors such as the degree of trade openness, non-tradable components, tariffs, transportation costs, and other trade-related frictions that affect the formation of relative agricultural prices. In an open economy, the relative agricultural price is therefore influenced by world market conditions but need not be equalized across countries, since it also depends on the price of non-agricultural goods, trade costs, and other country-specific factors. Thus, while the determination of the relative agricultural price differs across economies with varying degrees of trade openness, what matters for our empirical analysis is whether agricultural productivity improvements are transmitted into structural transformation through relative-price adjustments. This unified perspective motivates our empirical specification, which controls for trade openness to account for differences in relative-price formation while treating the relative agricultural price as the common transmission channel.

3.1 Basic Model

We assume that production technologies in the two sectors are given by

$$Y_t^A = A_t G(L_t), \tag{1}$$

and

$$Y_t^O = F(L - L_t), \tag{2}$$

where Y_t^A and Y_t^O denote outputs in the agricultural and non-agricultural sectors, respectively. The production functions satisfy $G(0) = 0$, $G'' < 0 < G'$, $F(0) = 0$, and $F'' < 0 < F'$. The variable

L_t represents labor employed in the agricultural sector, and A_t denotes agricultural productivity, which is positively affected by the extent of the Green Revolution, R_t. The Green Revolution, which took place from the 1960s to the 1980s, was a transformative period in agriculture that dramatically increased crop yields. During this period, farmers adopted a range of innovative technologies, including HYVs of cereals such as dwarf wheat and rice, together with the widespread use of chemical fertilizers—essential for realizing the yield potential of these new seeds—pesticides, and controlled irrigation systems.

Under the assumption of a perfectly competitive labor market, the equilibrium condition is given by

$$p_t = \frac{F'(L - L_t)}{A_t G'(L_t)}, \tag{3}$$

where p_t denotes the relative price of agricultural goods to non-agricultural goods. Eq. (3) implies that the marginal rate of transformation—the right-hand side of Eq. (3)—equals the relative agricultural price. Geometrically, this condition corresponds to the tangency between the production possibility frontier and the relative price line. Eq. (3) can therefore be interpreted as the supply curve for agricultural goods, since Eq. (1) implies a positive relationship between L_t and Y_t^A given A_t. Note that p_t is an increasing function of L_t in Eq. (3).

The representative consumer maximizes the following lifetime utility function with subjective discount factor ρ:

$$U = \sum_{t=0}^{\infty} \rho^t \left[\beta \log\left(c_t^A - \gamma\right) + \log\left(c_t^O\right)\right], \qquad \beta > 0, \gamma > 0, 0 < \rho < 1, \tag{4}$$

where c_t^A and c_t^O denote consumption of agricultural and non-agricultural goods, respectively, and β represents the utility weight attached to agricultural consumption. In Eq. (4), γ captures the subsistence level of food consumption, thereby incorporating structural change driven by income effects under non-homothetic preferences (Matsuyama, 1992; Adamopoulos and Restuccia, 2024). To rule out economically meaningless outcomes, we assume

$$A_t G(L) > \gamma L, \tag{5}$$

which ensures that the agricultural sector can supply a sufficient amount of output to cover the subsistence consumption needs of all consumers.

From the maximization of Eq. (4) subject to the intertemporal budget constraint, individual consumption choices satisfy the following first-order condition:

$$p_t\left(c_t^A-\gamma\right)=\beta c_t^O. \tag{6}$$

Geometrically, Eq. (6) corresponds to the tangency condition between the instantaneous indifference curve and the static budget constraint, or equivalently, the equality between the instantaneous marginal rate of substitution and the relative price. Accordingly, aggregate consumption demand in the economy satisfies

$$p_t\left(C_t^A-\gamma L\right)=\beta C_t^O, \tag{7}$$

where C_t^A and C_t^O denote aggregate consumption of agricultural and non-agricultural goods, respectively. Using the market-clearing conditions $C_t^A = A_tG(L_t)$ and $C_t^O = F(L - L_t)$, Eq. (7) can be rewritten as

$$p_t=\frac{\beta F(L-L_t)}{A_tG(L_t)-\gamma L}. \tag{8}$$

As in the case of Eq. (3), Eq. (8) can be interpreted as the demand curve for agricultural goods, where p_t is a decreasing function of L_t. As labor input L_t increases, agricultural output rises and the relative price p_t declines, reflecting the standard inverse relationship between the quantity of agricultural goods and their relative price on the demand side.

Figure 5 illustrates the supply and demand curves and shows that the economy features a unique equilibrium (p_t^*, L_t^*), where both p_t^* and L_t^* vary over time due to changes in agricultural productivity A_t. This figure facilitates a comparative statics analysis with respect to A_t.

Proposition 1 *Suppose that agricultural productivity, A_t, increases, for instance, as a result of the Green Revolution. Then, in equilibrium, the relative price p_t^* and the labor employed in the agricultural sector L_t^* both decrease. Formally, it holds that $dp_t^*/dA_t < 0$ and $dL_t^*/dA_t < 0$.*

The first claim of Proposition 1 is straightforward. As A_t increases from A to $\tilde{A}$, both the supply and demand curves shift downward, as illustrated in Figure 5, leading to a decline in the equilibrium price. Hence, we obtain $dp_t^*/dA_t < 0$. To establish the second claim, combining Eqs. (3) and (8) yields

$$p_t^*=\frac{F'(L-L_t^*)G(L_t^*)-\beta F(L-L_t^*)G'(L_t^*)}{\gamma LG'(L_t^*)}, \tag{9}$$

which characterizes the equilibrium relationship between the relative price and labor employed in the agricultural sector. Since the right-hand side of Eq. (9) is increasing in L_t^*, the equilibrium labor allocation L_t^* can be expressed as an increasing function of p_t^*. This implies that $dL_t^*/dp_t^* > 0$. By the chain rule, we have $dL_t^*/dA_t = (dL_t^*/dp_t^*) \cdot (dp_t^*/dA_t) < 0$, which establishes the second claim.

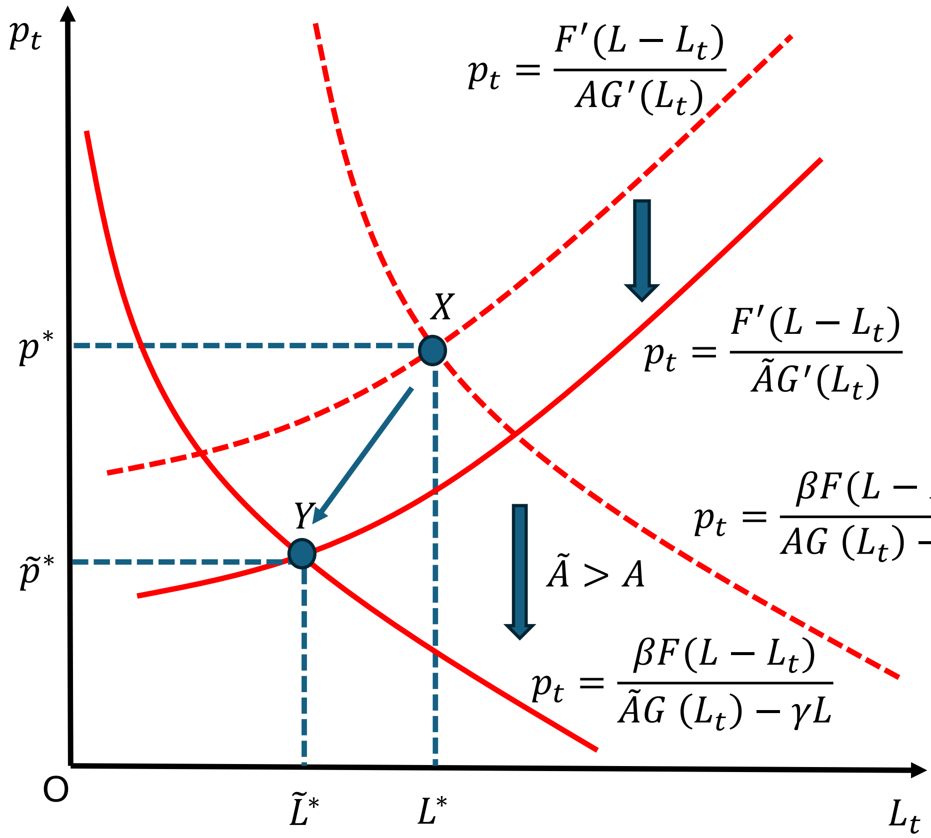

Figure 5: The supply-demand analysis as A_t increases from A to $\tilde{A}$

Notes: Both the supply and demand curves shift downward as agricultural productivity increases. Due to the subsistence food consumption level, γ, Engel's law implies that the downward shift of the demand curve is larger than that of the supply curve. Consequently, the equilibrium moves from X to Y, with both p^* and L^* declining, as characterized by Eq. (9).

The subsistence level γ plays a crucial role in driving this result. Although an increase in agricultural productivity shifts both the supply and demand curves downward, the downward shift of the demand curve is relatively larger than that of the supply curve. This asymmetry arises because the fixed subsistence food requirement becomes relatively smaller compared to agricultural productive capacity as productivity increases. Consequently, labor employed in the agricultural sector declines in equilibrium.

The relative output ratio is defined as $\sigma_t := p_t^* A_t G(L_t^*)/F(L - L_t^*)$. Eq. (8) allows us to rewrite σ_t as $\sigma_t = \beta + \gamma L p_t^*/F(L - L_t^*)$. Furthermore, Eq. (9) implies that L_t^* can be expressed as an increasing function of p_t^*, denoted by $L^* := L^*(p_t^*)$. It then follows that

$$\sigma(p_t^*) = \beta + \gamma L p_t^*/F(L - L^*(p_t^*)) = \lambda(p_t^*)/(1 - \lambda(p_t^*)), \tag{10}$$

where $\lambda(p_t^*)$ denotes the agricultural output share, which has a one-to-one positive relationship with $\sigma(p_t^*)$. We are now ready to present the theoretical implications summarized in Proposition 2, which will guide our empirical analysis.

Proposition 2 *Suppose that agricultural productivity A_t increases. Then, in equilibrium, both the relative price and the agricultural output share, captured by $\lambda(p_t^*)$, decline. More precisely, the relationship between $\lambda(p_t^*)$ and p_t^* satisfies $d\lambda(p_t^*)/dp_t^* > 0$.*

The first claim of Proposition 1 establishes that the relative price decreases in equilibrium when agricultural productivity increases. It follows that $dF(L - L_t^*(p_t^*))/dp_t^* = (dF(L - L_t^*(p_t^*))/dL_t^*) \cdot (dL_t^*/dp_t^*) < 0$. Together with Eq. (10), this implies that $d\lambda(p_t^*)/dp_t^* > 0$. This theoretical result, namely that $d\lambda(p_t^*)/dp_t^* > 0$, is consistent with the empirical pattern observed in Figure 3. To further motivate the empirical analysis in the next section, we clarify the economic mechanism underlying this result. As discussed in Matsuyama (1992), the presence of subsistence food consumption, γ, activates Engel's law. Specifically, an increase in agricultural productivity raises income through the outward expansion of the production possibility frontier. However, due to subsistence food requirements, the share of income spent on agricultural goods declines as income rises. In a closed economy, this shift in consumption demand translates into a lower equilibrium agricultural production share.

In summary, an increase in agricultural productivity leads to a decline in both the relative price of agricultural goods and the agricultural output share. Our empirical analysis tests the hypothesis that the decline in the relative agricultural price induced by the Green Revolution contributes to the reduction in the agricultural output share. Because the relative agricultural price is endogenously determined, we employ an instrumental variable approach. In the first-stage regression, we exploit the prediction that productivity gains from the Green Revolution reduce the relative agricultural price, as established in the first claim of Proposition 1. To do so, we adopt a shift-share IV strategy, echoing Gollin et al. (2021) and Huang (2024). In the second-stage regression, we estimate the effect of the resulting decline in the relative agricultural price on the agricultural output share, as implied by Proposition 2.

3.2 Introducing a Price Wedge

We introduce a price wedge into the model for two main reasons: (i) to analyze misallocation across various factors and (ii) to facilitate the analysis of an open economy within a unified framework. Regarding the first reason, misallocation is a pervasive issue, particularly in developing economies. It may arise from failures in goods, credit, labor, and land markets, as well as from policy-induced distortions, weak property rights, and broader institutional or regulatory deficiencies (Restuccia and Rogerson, 2017). Market mechanisms in such environments are especially vulnerable to institutional weaknesses stemming from government corruption, lobbying pressures of interest groups, or the undue influence of power elites (Martinez-Bravo and Wantchekon, 2023). Moreover, labor market frictions often hinder worker mobility, delay structural transformation, and trap workers in rural or informal sectors, thereby perpetuating poverty and widening wage disparities across sectors. In many developing countries, labor markets have struggled to generate sufficient employment opportunities to support structural transformation and sustained economic growth (Donovan and Schoellman, 2023).

As for the second reason, over the past half century, numerous countries have opened their economies to international trade, resulting in a dramatic surge in global trade volume. Consequently, the Green Revolution in one country could affect other countries through changes in world market conditions and relative agricultural prices, regardless of whether they experienced similar technological progress. To capture both closed- and open-economy environments in a consistent manner, we introduce a price wedge into the model. This allows us to analyze domestic and international interactions under a unified analytical framework.

3.2.1 Misallocation Caused by Market Imperfections Arising from Weak Institutions

The solid lines in Figure 6 depict the supply and demand curves after the Green Revolution. As discussed above, in a closed economy with perfectly functioning markets, the new equilibrium would be located at point Y. However, market imperfections may prevent the economy from moving smoothly from point X to point Y. As illustrated in Figure 6, such imperfections create a price wedge that prevents the demand and supply curves from intersecting at the perfect-market equilibrium, resulting in a relative price of agricultural goods that is higher than the price that would otherwise prevail. Consequently, the efficient allocation of labor becomes unattainable: labor cannot be efficiently reallocated from the agricultural sector to the non-agricultural sector.

To analyze misallocation explicitly, we introduce a wedge parameter, ω_t^m, into the model as follows:

$$\frac{\beta F(L-L_t)}{A_t G(L_t)-\gamma L} = \omega_t^m \frac{F'(L-L_t)}{A_t G'(L_t)} = \omega_t^m p_t, \tag{11}$$

where $\omega_t^m \in (0,\infty)$ represents a price distortion that weakens the adjustment mechanisms in goods and labor markets.

The price wedge ω_t^m drives a wedge between the marginal rate of substitution in preferences and the marginal rate of transformation in production. When $\omega_t^m = 1$, the market operates efficiently and the allocation coincides with the perfect-market equilibrium. When $\omega_t^m \in (0,1)$, the market

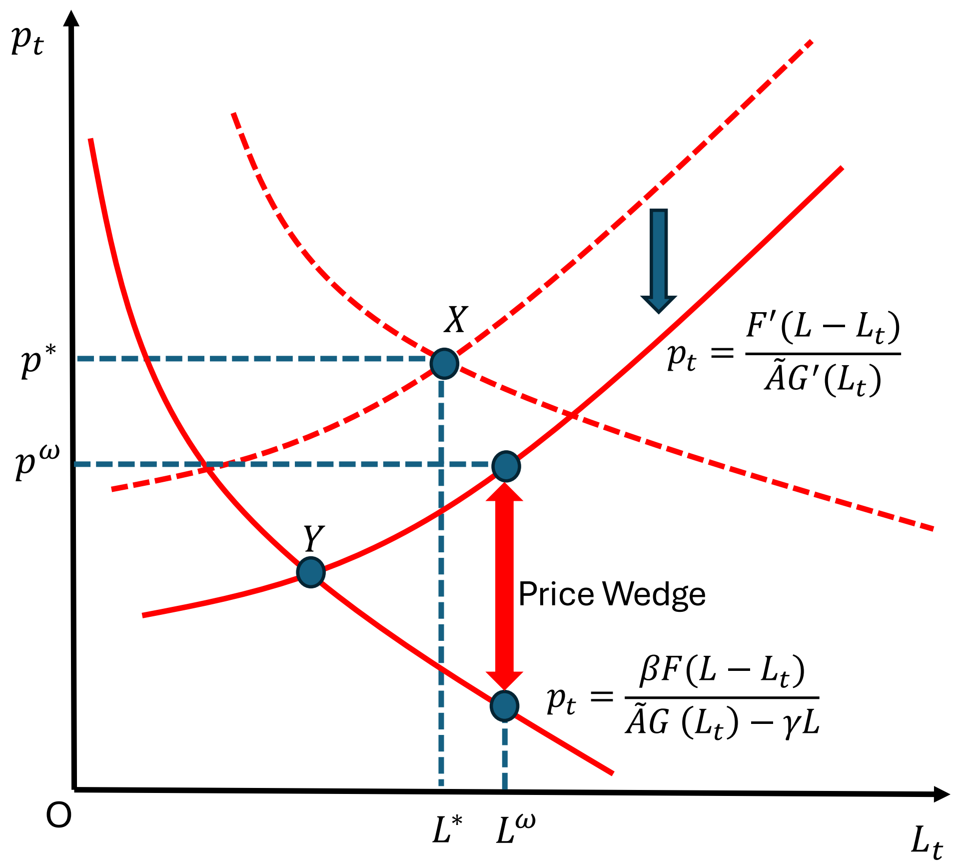

Figure 6: Introducing a price wedge

Notes: We introduce a price wedge into the model for two main reasons: (i) to analyze misallocation across various factors and (ii) to facilitate the analysis of an open economy within a unified framework.

is impaired, and ω_t^m captures institutional barriers or labor market distortions that hinder the frictionless reallocation of labor from the agricultural to the non-agricultural sector (Restuccia et al., 2008; Esteban-Pretel and Sawada, 2014). The case in which $\omega_t^m \in (1, \infty)$ also reflects market distortions. In this case, the direction of misallocation is reversed: the reallocation of labor from the non-agricultural sector to the agricultural sector is impeded, leading to an inefficiently low relative price of agricultural goods.

3.2.2 Analysis of an Open Economy

Generally speaking, trade openness affects structural transformation differently across countries, depending on their comparative advantage in agriculture or industry as well as the degree of trade openness (Matsuyama, 1992; Yanagawa, 1996; Stokey, 2001; Uy et al., 2013; Gollin et al., 2025). Matsuyama (1992) shows that higher agricultural productivity does not necessarily promote industrialization in an open economy; instead, trade dynamics may trap countries in agricultural specialization, thereby slowing structural transformation. Yanagawa (1996) examines economic development within a continuum of countries, in which industrialization in less developed economies emerges endogenously. Extending our baseline closed-economy model to an open-economy setting allows us to examine how the effects of the Green Revolution on structural transformation depend on the relative agricultural price prevailing in an open economy. An open economy is characterized by a relative agricultural price that is influenced by world market conditions. Although the price of tradable agricultural goods may be closely linked to world prices, the relevant relative price in our model is also sensitive to domestic factors, including the price of non-agricultural goods, trade costs, and other country-specific conditions.

In this section, we analyze an open economy in the same spirit as in the misallocation case. This approach allows us to derive a unified estimation equation, regardless of trade openness, by introducing an *equivalent* wedge variable. This unified framework motivates the empirical specification developed in Section 4, where trade openness is controlled for to account for cross-country differences in the determination of relative agricultural prices arising from different degrees of integration into world markets. To this end, we reinterpret the downward-sloping demand curve in Figure 6, which corresponds to the closed-economy case. In an open economy, neither the agricultural nor the non-agricultural goods market necessarily clears domestically. Assuming balanced trade, the demand curve of an open economy can be written as

$$\frac{\beta[F(L-L_t)+p_t^w\epsilon_t^A]}{A_tG(L_t)-\epsilon_t^A-\gamma L}=p_t^w\ (=p_t), \tag{12}$$

where ϵ_t^A denotes exports (imports) of agricultural goods when $\epsilon_t^A>0$ ($\epsilon_t^A<0$), and p_t^w denotes the relative agricultural price prevailing in the open economy. The superscript w indicates the influence of the world market and does not necessarily imply that the domestic relative agricultural price is identical across countries.

Given Eq. (12), the wedge illustrated in Figure 6 corresponds to the case in which $\epsilon_t^A>0$, since

$$p_t^w>\frac{\beta F(L-L_t)}{A_tG(L_t)-\gamma L}.$$

To formalize this situation within the model, we introduce a second *equivalent* wedge parameter, ω_t^s, defined as

$$\frac{\beta F(L-L_t)}{A_tG(L_t)-\gamma L}=\omega_t^s\frac{F'(L-L_t)}{A_tG'(L_t)}=\omega_t^s p_t, \tag{13}$$

where $\omega_t^s\in(0,1]$ when $\epsilon_t^A\geq 0$ and $\omega_t^s\in(1,\infty)$ when $\epsilon_t^A<0$.

When the relative agricultural price p_t^w, as illustrated in Figure 6, is sufficiently high, structural transformation from agriculture to non-agriculture may not occur. Instead, labor employed in the agricultural sector may increase even though the country experiences the Green Revolution ($L^\omega > L^*$ in Figure 6). This outcome arises when the rest of the world has not yet undergone the Green Revolution and the new agricultural technology has not fully diffused internationally, so that world market conditions do not exert sufficient downward pressure on the relative agricultural price prevailing in the open economy.

3.3 Unified Presentation

To present the wedge parameters associated with misallocation and an open economy within a unified framework, we reintroduce a price wedge parameter, ω_t, defined as

$$\frac{\beta F(L - L_t)}{A_t G(L_t) - \gamma L} = \omega_t \frac{F'(L - L_t)}{A_t G'(L_t)} = \omega_t p_t, \tag{14}$$

where $\omega_t = \omega_t^m \omega_t^s$. When analyzing a closed economy, the effect of ω_t^s is neutralized by setting $\omega_t^s = 1$. As ω_t^s decreases (increases), world market conditions place upward (downward) pressure on the relative agricultural price, p_t^w. While we have focused on two polar cases, closed and open economies, real-world economies typically lie between these extremes. Eq. (14) therefore provides a unified representation that can accommodate economies with different degrees of trade openness by allowing ω_t^s to vary continuously, and it serves as the basis for deriving the estimation equation in the empirical analysis.

When examining misallocation arising from market imperfections associated with weak institutions, we allow the wedge parameter ω_t^m to depend on institutional quality. As discussed by Hayami and Godo (2005), weak institutions can act as a barrier to induced innovation. Moreover, weak governance—characterized by corruption, rent-seeking by interest groups, and the dominance of political or economic elites—may facilitate the extraction of innovation rents under insecure property rights. The unified formulation in Eq. (14) enables us to analyze institutional distortions and trade-induced differences in relative price formation within a single, coherent framework.

3.4 Takeaways

Our theoretical analysis yields four key takeaways, which can be stated explicitly as follows:

- In a closed economy, an increase in agricultural productivity induced by the Green Revolution can trigger structural transformation through market mechanisms, depending on the quality of institutions.

- In an open economy, whether a country experiencing the Green Revolution undergoes structural transformation depends critically on the relative price of agricultural goods; structural transformation is promoted when this relative price is sufficiently low.

- If relative agricultural prices remain elevated due to institutional deficiencies or international market conditions in an open economy, a country adopting Green Revolution technologies may fail to achieve structural transformation.

- In an open economy, the relative agricultural price is influenced by global demand and supply conditions for agricultural goods. As Green Revolution technologies spread across countries, the resulting productivity improvements place downward pressure on relative agricultural prices through world markets.

In a multi-country setting, the relative agricultural price is influenced by global demand and supply conditions as well as by the extent to which Green Revolution technologies diffuse across countries. If the Green Revolution occurs in only a limited number of countries and the new agricultural technologies are not widely adopted elsewhere, world market conditions may keep relative agricultural prices sufficiently high to impede structural transformation in countries experiencing the Green Revolution, which may become exporters of agricultural goods. Conversely, countries that do not experience the Green Revolution may become importers of agricultural goods and undergo structural transformation through the resulting changes in relative prices. By contrast, as these technologies become more widespread, productivity improvements place downward pressure on agricultural prices through world markets, thereby facilitating structural transformation across a broader set of economies. Such diffusion may take time. Historically, the first releases of new varieties of rice, wheat, and maize occurred in 1966, 1965, and 1966, respectively, while our empirical analysis covers the period 1963–2010, providing ample time for these technologies to diffuse internationally.

Although these takeaways are stated in terms of the two polar cases of closed and open economies for expositional clarity, the unified price-wedge framework is not restricted to these cases. By allowing the trade-related wedge ω_t^s to vary continuously, the framework accommodates economies with different degrees of integration into world markets, including intermediate cases between the two extremes. What differs across these economies is the determination of the relative agricultural price, whereas its role as the common transmission channel linking agricultural productivity improvements to structural transformation remains unchanged. Thus, the central implication of the unified framework is that the effect of the Green Revolution on structural transformation depends on how productivity improvements are transmitted into relative agricultural prices, rather than on whether an economy is classified as closed or open per se.

4 Empirical Analysis

The theoretical framework developed in the previous section shows that industrial structure evolves smoothly when market mechanisms function effectively. In particular, improvements in agricultural productivity brought about by the Green Revolution lead to a decline in the relative price of agricultural goods, which in turn reduces the agricultural output share. Building on these theoretical predictions, this section empirically examines the role of the Green Revolution in driving structural transformation through market mechanisms.

4.1 Data

The data used in this study are drawn from multiple databases and several previous studies. To ensure comprehensive coverage, we construct an unbalanced panel dataset comprising annual observations for 180 countries over the period 1962–2010, which aligns with the availability of the Green Revolution indices constructed by Gollin et al. (2021) and Huang (2024), while broadly covering the diffusion period of Green Revolution technologies. The list of sample countries and their corresponding descriptive statistics are reported in Tables B1 and B2 in Appendix B, respectively.

The agricultural output share of GDP is obtained from the *National Accounts: Analysis of Main Aggregates* database provided by United Nations Statistics Division (2024a). This database reports sectoral value added based on Revision 3 of the International Standard Industrial Classification of All Economic Activities (ISIC). Under this classification, the "Agricultural output share" is defined as value added from agriculture, hunting, forestry, and fishing divided by GDP. Observations prior to 1969 are supplemented using data from the *National Accounts Statistics: Main Aggregates and Detailed Tables* provided by United Nations Statistics Division (2024b).

Institutional quality is included as an explanatory variable in the baseline empirical specification and is measured using the Economic Freedom (EF) index. This index also serves as an instrumental variable when interacted with the Green Revolution index and projected agricultural TFP, as described in Section 4.3. The EF index is obtained from the *Economic Freedom Dataset* compiled by Lawson and Murphy (2023) and measures the extent to which a country's policies and institutions support economic freedom.[4] Economic freedom is evaluated across five broad dimensions: (i)

[4]The EF index is reported at five-year intervals from 1970 through 2000 and annually from 2001 onward. For 1950, 1955, 1960, and 1965, we use the historical extension, which is constructed using a smaller set of variables than

size of government, (ii) legal system and property rights, (iii) sound money, (iv) freedom to trade internationally, and (v) regulation. In our framework, the EF index is used as an inverse proxy for institutional and market distortions, with higher values indicating stronger institutional environments and fewer impediments to market-based resource allocation.

To measure the relative price of agricultural goods to non-agricultural goods, we employ two alternative price indices. The first is the country-specific commodity price index compiled by Gruss and Kebhaj (2019), which serves as our primary measure. The second is a proxy index constructed as a weighted average of the prices of three major crops—wheat, rice, and maize—sourced from FAOSTAT and provided by the Food and Agriculture Organization of the United Nations (FAO, 2024). This second index is used for robustness checks. Each measure involves trade-offs. The first index captures the relative prices of a broad range of agricultural commodities and thus reflects price movements across the agricultural sector that are comprehensively influenced by the Green Revolution. However, because this index is also affected by global market conditions beyond agriculture, we control for these influences by including year fixed effects in the regression analysis. In contrast, the second index captures the relative price of the three major staple crops within each economy. It represents the real price of these crops, deflated by the consumer price index (CPI). By construction, this measure focuses on a narrower subset of agricultural goods that are directly affected by the Green Revolution, excluding broader segments of the agricultural sector that may be indirectly influenced.

For details of the first index, the commodity price data constitute a comprehensive database that provides country-specific commodity price indices for 182 economies from 1962 onward. This long time span allows us to assess the impact of the Green Revolution, which began in the 1960s. For each country, international price changes for up to 45 individual commodities are weighted using commodity-level trade data. The database includes a commodity terms-of-trade index—commonly used as a proxy for income fluctuations driven by global price changes—as well as other country-specific indicators such as export and import price indices. The database covers four major commodity categories: energy, metals, food and beverages, and agricultural raw materials. First, the energy category includes coal, crude oil, and natural gas, which reflect key global fuel sources. Second, in the metals category, the database tracks prices for aluminum, copper, gold, iron ore, lead, nickel, tin, uranium, and zinc—commodities essential for industrial production, construction, and financial markets. Third, the food and beverages category contains a wide range of agricultural commodities, including bananas, barley, beef, cocoa, coffee, corn, fish, fish meal, groundnuts, lamb, olive oil, oranges, palm oil, poultry, rapeseed oil, rice, shrimp, soybean meal, soybean oil, soybeans,

the main index (Murphy and Lawson, 2018). We linearly interpolate between available observations to construct annual values.

sugar, sunflower seed oil, swine meat, tea, and wheat. These commodities are central to global food supply chains and capture important trends in food security, consumption, and trade. Finally, agricultural raw materials include cotton, hard logs, hard sawnwood, hides, natural rubber, soft logs, soft sawnwood, and wool—inputs critical to industries such as textiles, construction, and manufacturing. By encompassing a broad spectrum of commodities across multiple sectors, this database provides rich information on global price fluctuations, supply-demand dynamics, and longer-term economic trends.

Since our objective is to construct a theory-consistent intersectoral terms-of-trade variable, we focus on measuring the relative price of agricultural to non-agricultural goods. This measure captures the structural price dynamics between sectors that are central to economic development, resource allocation, and structural transformation, and allows for a consistent analysis of long-run intersectoral price movements and their growth implications. Conceptually, Gruss and Kebhaj (2019) construct a country-specific commodity price index using log price differences and time-varying weights based on prior trade flows. For country i in year t, the index is defined as

$$\Delta \ln p_{it} = \sum_{j=1}^{J} e_{ijt} \Delta Q_{jt},$$

where Q_{jt} denotes the log price of commodity j, and e_{ijt} represents the time-varying trade-based weight of commodity j for country i. These log differences are then cumulated to obtain a price-level index in logarithmic form, $\ln p_{it}$. Because the analysis relies on index data, differences in base-year prices across countries remain unaccounted for; however, such base-year heterogeneity is absorbed by the country fixed effects. Our regression procedure filters this price index to obtain a measure of the relative price of agricultural to non-agricultural goods, which serves as our proxy for the intersectoral terms of trade. This filtering strategy operates in two ways. First, in the first-stage regression, projecting the price-level index on agricultural productivity induced by the Green Revolution isolates the component of relative price variation that is systematically related to agricultural productivity, thereby filtering out non-agricultural price movements that are orthogonal to agricultural technology. Second, because energy prices (coal, crude oil, and natural gas) and metals prices are largely driven by global commodity markets, year fixed effects in the first-stage regression absorb common global shocks and worldwide price fluctuations. Together, these two filters help isolate variation in agricultural and food-related relative prices that is relevant for structural transformation.

For details of the second index, each crop price is measured in the standard local currency units using FAOSTAT data (FAO, 2024) and deflated by the consumer price index from International

Monetary Fund (2024). We construct a proxy index of the relative price of agricultural goods as a production-weighted average of the prices of three major crops—wheat, rice, and maize—defined as

$$p_{it} = \sum_{j \in \{w,r,m\}} \left(\frac{\text{Production}_{ijt}}{\sum_{k \in \{w,r,m\}} \text{Production}_{ikt}} \times \text{Relative price}_{ijt} \right), \tag{15}$$

where the index $\{w, r, m\}$ corresponds to wheat, rice, and maize, respectively. By construction, this weighted price index provides a proxy for the relative price of major agricultural goods within each country. Again, because the analysis relies on crop-level index data, differences in base-year prices across countries are not directly accounted for; however, these differences are absorbed by the country fixed effects. Data on gross production values are obtained from FAOSTAT, as reported by FAO (2024).[5]

Additional control variables—GDP per capita, human capital, population, and trade openness—are retrieved from the Penn World Table version 10.01, as detailed by Feenstra et al. (2015). GDP per capita is defined as output-side real GDP at chained PPPs divided by population. Educational attainment is represented by the human capital index, which is based on years of schooling and returns to education. Trade openness is defined as the sum of exports and imports as a share of GDP. All four variables are expressed in natural logarithms in the empirical analysis.

4.2 Estimation Framework

Abstracting from potential endogeneity issues associated with the relative agricultural price, we derive the following estimation equation from Eq. (14):

$$\ln \lambda_{it} = \alpha_1 \ln \lambda_{it-1} + \alpha_2 \ln p_{it} + \alpha_3 \ln q_{it} + \mathbf{X}'_{it}\mathbf{b} + \mu_t + \eta_i + u_{it}, \tag{16}$$

where $\ln \lambda_{it}$ denotes the logarithm of the agricultural output share of country i at time t. The right-hand-side variables include its lagged value, the logarithm of the relative agricultural price $\ln p_{it}$, and the logarithm of institutional quality $\ln q_{it}$. The vector of control variables, $\mathbf{X}_{it}$, includes a constant term and standard covariates such as the logarithm of real GDP per capita, human capital, the logarithm of population, and trade openness. In Eq. (16), μ_t denotes a time-specific effect, η_i a country-specific effect, and u_{it} an error term.

This empirical specification reflects the unified price-wedge framework developed in Section 3.2. In the theory, the determination of the relative agricultural price depends on both institutional

[5] Crop price data are not consistently available for all years in FAOSTAT. When either crop price data or gross production value data are missing, the corresponding crop-year observation is excluded from the construction of the weighted relative price.

distortions and trade-related factors associated with the degree of integration into world markets, which are represented by the components of the price wedge. Empirically, we account for these sources of price variation by explicitly including institutional quality and trade openness in both the first- and second-stage regressions. Institutional quality plays an additional role in the first-stage specification by conditioning the extent to which Green Revolution-induced productivity improvements are transmitted into relative agricultural prices, as discussed in Section 4.3. Country fixed effects further absorb time-invariant country-specific components of the wedge, including persistent differences in institutions, market structure, and trade integration, while year fixed effects absorb common time-varying components, including global market conditions. Admittedly, these controls do not necessarily eliminate all possible sources of price distortions, but they help isolate the relative-price variation relevant to the transmission mechanism emphasized by the theory. In Appendix A, Eq. (A12) provides the micro-foundation for the second-stage regression model, while Eq. (A15) provides its first-stage counterpart; both are derived from Eq. (14).

The controls included in $\mathbf{X}_{it}$ account for key determinants of structural transformation and sectoral composition. Specifically, real GDP per capita and human capital proxy for the stage of economic development, which plays a critical role in shaping production structure and labor allocation. The logarithm of population captures scale effects that influence aggregate demand and agricultural output shares. Trade openness is defined as the ratio of the sum of exports and imports to GDP. As emphasized in the theoretical framework, closed and open economies represent two polar cases, while real-world economies typically exhibit intermediate degrees of integration into world markets. The continuous measure of trade openness allows the empirical specification to accommodate this variation. Importantly, although the determination of the relative agricultural price varies with the degree of trade openness, its role as the transmission channel linking agricultural productivity improvements to structural transformation remains common across these cases. Accordingly, our empirical analysis focuses on whether productivity improvements associated with the Green Revolution are transmitted into the relative agricultural price, rather than on classifying economies as closed or open.

The primary coefficient of interest is α_2, which measures the elasticity of the agricultural output share with respect to the relative price of agricultural goods. However, the relative agricultural price, $\ln p_{it}$, is likely endogenous. To address this concern, we employ an instrumental variable estimation strategy. Relative agricultural prices are inherently endogenous because agricultural output shares and prices are jointly determined in equilibrium, as demonstrated in the theoretical analysis. The direction of the resulting bias is ambiguous. If unobserved supply-side shocks are absorbed into the error term, ordinary least squares (OLS) estimates may be downward biased. Conversely, unobserved political lobbying or rent-seeking behavior—associated with a high agricultural output share—may raise relative agricultural prices, leading to an upward bias in α_2. The IV approach mitigates these potential biases arising from the endogeneity of relative agricultural prices.

The inclusion of the lagged dependent variable, $\ln \lambda_{it-1}$, captures gradual market adjustment. In practice, adjustment toward equilibrium is not instantaneous due to behavioral inertia, market frictions, and gradual adaptation to new technological and institutional environments. Consumers, producers, and markets typically respond to price changes with lags, generating delayed supply and demand responses. To model such dynamics, Nerlove (1958) developed the distributed lag framework to estimate long-run supply and demand elasticities. This framework remains a cornerstone of econometric modeling in environments characterized by slow adjustment (Bessler et al., 2010). Consistent with this tradition, our empirical specification in Eq. (16) can be viewed as a dynamic panel framework that incorporates elements of both continuous-treatment difference-in-differences (DID) and analysis of covariance (ANCOVA) specifications. The DID-type element arises from exploiting differential changes in relative agricultural prices across countries and over time, with the magnitude of these changes serving as a continuous treatment intensity. The ANCOVA-type element arises from conditioning on the lagged agricultural output share, thereby accounting for differences in prior sectoral structure. Because relative agricultural prices are endogenous, we further use Bartik shift-share instruments to isolate the component of relative-price variation induced by the Green Revolution. Country and year fixed effects additionally control for time-invariant country heterogeneity and common time-specific shocks. As shown in Appendix A, the inclusion of the lagged dependent variable is also theoretically motivated by allowing the price wedge associated with market frictions to depend on the lagged agricultural output share.

4.3 Identification Strategy

We exploit theoretical insights on equilibrium price determination to motivate our choice of instrumental variables for addressing the endogeneity of relative agricultural prices. In our empirical implementation, we employ four alternative sets of instrumental variables to ensure robust identification and to isolate exogenous variation in relative agricultural prices. These instruments are designed to enhance the credibility of causal inference. The derivation of the corresponding first-stage estimation equations is provided in Appendix A.

First, agricultural productivity is presumed to increase as a result of the Green Revolution. This fundamental insight motivates the use of the Green Revolution (GR) index as an instrumental variable. Our identification strategy exploits plausibly exogenous variation in the timing of the release of Green Revolution technologies (Gollin et al., 2021). The Green Revolution index employed in this study is constructed by Huang (2024), who extends the original framework of Gollin et al. (2021) to include a broader set of countries, including developed economies. As documented in Evenson and Gollin (2003) and Gollin et al. (2021), the release years of HYVs are plausibly exogenous to country-specific economic conditions and exhibit substantial variation across crops. Following the approach of Gollin et al. (2021), we exploit the staggered timing of HYV releases to estimate the causal impact of the Green Revolution on crop-level yields. These crop-level causal estimates are then aggregated using pre-Green Revolution crop production shares to construct country-level predicted gains in agricultural productivity. We use this predicted Green Revolution measure as an instrumental variable. This variable constitutes a shift-share (Bartik) instrument, which we use to identify exogenous variation in relative agricultural prices at the aggregate level. Unlike conventional shift-share instruments whose shift components may reflect aggregate economic conditions, our instrument grounds the shift component in crop-level productivity gains predicted from plausibly exogenous variation in the timing of HYV releases. Combined with pre-Green Revolution crop production shares, this construction generates cross-country variation in predicted agricultural productivity gains that is plausibly exogenous to contemporaneous country-specific economic conditions. We exploit this variation to identify the component of relative agricultural price movements induced by the Green Revolution.

Second, while the Green Revolution index captures the timing and diffusion of new agricultural technologies, it does not directly measure realized productivity gains. To more closely reflect productivity improvements induced by the Green Revolution, we construct an alternative instrumental variable based on agricultural total factor productivity (TFP). Let $\tau_i := [\ln \tau_{i1}, \ldots, \ln \tau_{it}, \ldots, \ln \tau_{iT}]'$ and $R_i := [R_{i1}, \ldots, R_{it}, \ldots, R_{iT}]'$ denote, respectively, country i's agricultural TFP (in logarithms) and Green Revolution index over the estimation period $t = 1, \ldots, T$. By projecting τ_i onto R_i,

$$\hat{\tau}_i := \frac{\tau_i' R_i}{\|R_i\|^2} R_i,$$

we isolate the component of agricultural TFP that is attributable to the Green Revolution. We then use the projected agricultural TFP, $\hat{\tau}_i$, as an instrumental variable. This projected TFP variable can be interpreted as a linear combination of shift-share (Bartik) instruments, capturing cross-country heterogeneity in the extent to which Green Revolution exposure is associated with realized agricultural productivity gains. Data on agricultural TFP are obtained from the September 2023 release of the International Agricultural Productivity dataset produced by the United States Department of Agriculture, Economic Research Service (USDA-ERS, 2023). This dataset is constructed using a growth accounting framework based on multiple sources, including the FAO and the International Labour Organization (ILO). For robustness checks, we also construct an alternative productivity measure based on agricultural labor productivity, defined as the gross value of agricultural output from crops, livestock, and aquaculture divided by the number of economically active adults (male and female) primarily employed in agriculture. The gross agricultural output and agricultural labor data used to construct this measure are obtained from the same dataset, and we construct a projected agricultural labor productivity measure following the same procedure.

Third, we employ the one-period-lagged weighted relative price as an additional instrumental variable, denoted by $p_i := [\ln p_{i0}, \ldots, \ln p_{iT-1}]'$, paired with the Green Revolution index and the projected agricultural TFP. In real-world market transactions, various frictions may slow the adjustment of prices. To capture such gradual price dynamics, we follow Nerlove (1958) and Bessler et al. (2010) by incorporating lagged price variables into the analysis. Accordingly, we assume that real price rigidity operates through prices alone and does not directly affect structural transformation beyond its impact on current prices. This assumption constitutes the exclusion restriction underlying the use of lagged relative prices as instruments. Based on this strategy, we construct two sets of instrumental variables: $Z^1 = [(R_1' \cdots R_N')' \ \ (p_1' \cdots p_N')']$ and $Z^2 = [(\hat{\tau}_1' \cdots \hat{\tau}_N')' \ \ (p_1' \cdots p_N')']$, where N denotes the number of countries.

Finally, to account for potential misallocation arising from market failures, policy-induced distortions, and broader institutional weaknesses, we extend the instrument set by incorporating institutional quality. Although institutional quality enters the second-stage regression directly as an explanatory variable in Eq. (16), it may also condition the extent to which Green Revolution-induced productivity improvements are transmitted into relative agricultural prices. To capture this heterogeneity, we allow the Economic Freedom index to interact with the Green Revolution index and projected agricultural TFP in the first-stage regression. We construct two additional instrument sets such that $Z^3 = [(R_1' \cdots R_N')' \ \ \mathrm{diag}\,[q_1' \cdots q_N']\,(R_1' \cdots R_N')' \ \ (p_1' \cdots p_N')']$ and $Z^4 = [(\hat{\tau}_1' \cdots \hat{\tau}_N')' \ \ \mathrm{diag}\,[q_1' \cdots q_N']\,(\hat{\tau}_1' \cdots \hat{\tau}_N')' \ \ (p_1' \cdots p_N')']$, where $q_i := [\ln q_{i1}, \ldots, \ln q_{iT}]'$ denotes country i's Economic Freedom index. By introducing the interaction terms $\mathrm{diag}\,[q_1' \cdots q_N']\,(R_1' \cdots R_N')'$ and $\mathrm{diag}\,[q_1' \cdots q_N']\,(\hat{\tau}_1' \cdots \hat{\tau}_N')'$, we allow the marginal effect of Green Revolution-induced productivity improvements on relative agricultural prices to vary with institutional quality.

These four sets of instrumental variables are employed separately to identify exogenous variation in the relative agricultural price. The identifying assumption underlying all instrument sets is that, conditional on country and year fixed effects and the set of control variables included in the second-stage regression, the instruments affect the agricultural output share only through their impact on the relative agricultural price. This exclusion restriction is motivated by the theoretical framework, which emphasizes relative-price adjustment as the primary channel through which

Green Revolution-induced productivity improvements affect structural transformation.[6] While institutional quality is included directly in the second-stage regression, its interaction with the Green Revolution enters the first stage to capture heterogeneity in the transmission of productivity improvements into relative agricultural prices. The derivation of the first-stage estimation equation in Appendix A further clarifies this channel, and the overidentification tests reported in the empirical section provide additional, albeit indirect, support for the validity of the exclusion restrictions.

5 Empirical Results

Before discussing the estimation results, we briefly revisit the theoretical implications characterizing the relationship among agricultural productivity, the agricultural output share, and the relative price of agricultural goods. When the Green Revolution enhances agricultural productivity, the production possibility frontier expands. Owing to the subsistence nature of food consumption, the expenditure share devoted to agricultural goods declines, which in turn reduces the agricultural sector's output share—either in a closed economy or in an open economy when agricultural technology becomes sufficiently widespread globally and the relative price of agricultural goods falls. Overall, the theoretical framework predicts that, when market mechanisms function effectively, an increase in agricultural productivity lowers both the relative price of agricultural goods and the agricultural output share, thereby promoting structural transformation. In the following sections, we present empirical estimation results that are consistent with these theoretical predictions.

5.1 Basic Specifications

In specifications (1)–(3) of Table 1, we use Z^1—which consists of the one-period-lagged relative agricultural price and the Green Revolution index—as instrumental variables for the relative

[6] A potential threat to our identification strategy would arise if the Green Revolution stimulated technological improvements in the non-agricultural sector through channels independent of relative agricultural prices, thereby directly affecting structural transformation. However, the induced innovation hypothesis developed by Binswanger and Ruttan (1978) and Hayami and Ruttan (1985) suggests that what may appear to be a direct technological channel can in fact constitute part of a broader price-mediated response. Under this hypothesis, the direction of technological change responds endogenously to changes in relative prices. As one input becomes more expensive relative to potential substitutes, profit-seeking firms have stronger incentives to develop technologies that economize on the relatively costly input and make greater use of cheaper alternatives. More broadly, induced innovation theory implies that the direction of technological change may be causally driven by changes in relative prices, either through private-sector innovation or through political demand for public research aimed at relaxing increasingly binding constraints (Barrett et al., 2010). Importantly, this mechanism is consistent with our exclusion restriction insofar as any induced technological response in the non-agricultural sector is itself triggered by Green Revolution-induced changes in relative prices. In that case, technological adjustment constitutes part of the broader price-mediated channel through which the Green Revolution affects structural transformation, rather than an independent direct effect of the instrument on the outcome.

Table 1: Instrumental variables estimation of agricultural output share equation, 1963–2010

	(1)	(2)	(3)	(4)	(5)	(6)
Second-stage regression						
Lagged ln agricultural output share	0.935***	0.915***	0.894***	0.924***	0.888***	0.863***
	(0.013)	(0.023)	(0.024)	(0.010)	(0.013)	(0.013)
ln Relative price	0.165***	0.169***	0.182***	0.168***	0.168***	0.181***
	(0.050)	(0.052)	(0.047)	(0.050)	(0.049)	(0.044)
ln Human capital		-0.099**	-0.022		-0.075	0.010
		(0.042)	(0.049)		(0.046)	(0.051)
ln Population		0.120***	0.063**		0.145***	0.084***
		(0.026)	(0.031)		(0.018)	(0.027)
ln Economic freedom		-0.020	0.008		-0.026	0.001
		(0.015)	(0.019)		(0.017)	(0.021)
ln GDP per capita			-0.060***			-0.062***
			(0.012)			(0.013)
ln Trade openness			-0.012*			-0.015**
			(0.006)			(0.007)
First-stage regression						
Lagged ln Relative price	0.837***	0.826***	0.824***	0.839***	0.826***	0.823***
	(0.031)	(0.036)	(0.035)	(0.032)	(0.036)	(0.035)
Green Revolution	0.029	0.025	0.020			
	(0.018)	(0.023)	(0.024)			
Projected ln agricultural TFP				0.004	0.005*	0.005**
				(0.002)	(0.002)	(0.003)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
First-stage F-statistic	436.65	295.10	286.65	348.35	276.02	296.54
Hansen test (p-value)	0.21	0.33	0.15	0.31	0.24	0.10
Countries	137	110	110	126	108	108
Observations	5604	4513	4513	5205	4425	4425

Notes: The dependent variable is the natural logarithm of agricultural output share. Numbers in parentheses are robust standard errors clustered at the country level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

agricultural price. The second-stage results in specification (1) show that the relative agricultural price has a positive and statistically significant effect on the agricultural output share, in line with the theoretical prediction. The lagged agricultural output share also enters positively and significantly, indicating strong persistence in the sectoral structure. Specification (2) augments the baseline model by including additional control variables. The estimated coefficient on the relative agricultural price remains positive and statistically significant, confirming the robustness of the baseline result. In addition, population has a significantly positive effect on the agricultural output share, which is consistent with the theoretical implication derived from Eq. (10): as population increases, aggregate demand for agricultural goods expands. In specification (3), per capita GDP is further added to the set of control variables. Its coefficient is negative and statistically significant, consistent with the descriptive patterns shown in Figures 1 and 2. The coefficient on human capital is negative but statistically insignificant. Overall, the estimated effects of the lagged agricultural output share, the relative agricultural price, and population are stable across specifications (1)–(3).

The F-statistics for the tests of excluded instruments in the first-stage regressions are sufficiently high in specifications (1)–(3), indicating that the problem of weak instruments is unlikely to arise. Furthermore, the Hansen tests of overidentifying restrictions in specifications (1)–(3) do not reject the orthogonality condition, suggesting that the lagged relative price and the Green Revolution index (Z^1) can reasonably be regarded as a valid set of instrumental variables. However, the actual estimates suggest the need to refine our econometric specification to better capture the underlying mechanisms and account for potential distortions affecting the relationship among the Green Revolution, relative agricultural prices, and the agricultural output share. Specifically, while the coefficient of the one-period-lagged relative agricultural price is positive and significant in the first-stage regressions of specifications (1)–(3) in Table 1, as expected, the positive coefficient of the Green Revolution index in specifications (1) and (2) is not necessarily consistent with our theoretical prediction. This apparent inconsistency may reflect two related factors. First, the Green Revolution index captures exposure to new agricultural technologies but does not directly measure realized agricultural productivity gains. Second, institutional and market frictions may distort the transmission of Green Revolution-induced productivity improvements into relative agricultural prices. In sum, the mapping between the Green Revolution and relative prices may have been shaped by misallocation stemming from various factors, including failures in goods, credit, labor, and land markets; regulatory constraints and policy-induced distortions; weak property rights and governance; and broader institutional shortcomings (Restuccia and Rogerson, 2017). These distortions could have weakened—or even reversed—the expected effect of the Green Revolution on relative agricultural prices.

To more directly capture realized productivity gains associated with the Green Revolution, we employ an alternative set of instrumental variables, Z^2, consisting of projected agricultural TFP and the one-period-lagged relative agricultural price. Projected agricultural TFP is constructed as the projection of observed agricultural TFP onto the Green Revolution index. This variable captures the component of realized agricultural productivity that is associated with Green Revolution-induced technological advances. By using this instrument, we aim to isolate the realized productivity component of the Green Revolution from broader variation in agricultural TFP.

Specifications (4)–(6) in Table 1 report the corresponding estimation results. The second-stage estimates are largely consistent with those obtained in specifications (1)–(3). In the first-stage regressions, projected agricultural TFP enters with a positive and statistically significant coefficient in specifications (5)–(6). This finding is *inconsistent* with the theoretical prediction that, in a frictionless market, higher agricultural productivity induced by the Green Revolution should reduce relative agricultural prices. The F-statistics for the excluded instruments in specifications (4)–(6) are sufficiently large, indicating no weak-instrument concerns. In addition, the Hansen tests do not reject the orthogonality condition in specifications (4) and (5), although the null is marginally rejected at the 10% level in specification (6). Overall, the second-stage effect of the relative agricultural price on the agricultural output share, as well as the first-stage effect of the lagged relative agricultural price on the current relative price, are statistically significant and consistent with the theoretical framework. However, when variables capturing the Green Revolution are included in the first-stage regression without accounting for heterogeneity in institutional quality, their effects on contemporaneous relative agricultural prices do not conform to the theoretical prediction.

5.2 Green Revolution and Weak Institutions

Can we disentangle the underlying market frictions while retaining the Green Revolution index as an instrumental variable, thereby resolving the inconsistencies observed in the first-stage regressions of Table 1? As discussed in Section 3 and Appendix A, inefficiencies arising from weak institutional quality may distort the transmission of the Green Revolution into market prices. Building on this insight, we introduce an interaction term between the Green Revolution index and institutional quality in the first-stage regression. The rationale is that stronger institutions—by securing property rights and supporting market mechanisms—can mitigate production misallocation and allow productivity gains to be transmitted more effectively through prices. Overall, institutional quality enters the first-stage specification in two distinct ways. First, its level accounts for the direct effect of institutional differences on the formation of relative agricultural prices. Second, its interaction with the Green Revolution index allows the price response to agricultural productivity improvements to vary systematically with institutional quality.

Accordingly, we employ the instrument set Z^3, which augments Z^1 with the interaction term between the Economic Freedom and Green Revolution indices. The second-stage results reported in specifications (1) and (2) of Table 2 are similar to those in specifications (1)–(3) of Table 1. The F-statistics for the excluded instruments are sufficiently large, and the Hansen tests do not reject the orthogonality condition, supporting the validity of the instrument set. In the first-stage regression, the Green Revolution index enters with a positive and statistically significant coefficient, while its interaction with the Economic Freedom index is negative and statistically significant. These estimates imply that the marginal effect of the Green Revolution on relative agricultural

Table 2: Augmented instrumental variables estimation of agricultural output share equation with nonlinear institutional effects, 1963–2010

	(1)	(2)	(3)	(4)
Second-stage regression				
Lagged ln agricultural output share	0.915***	0.894***	0.888***	0.863***
	(0.023)	(0.024)	(0.013)	(0.013)
ln Relative price	0.171***	0.184***	0.170***	0.183***
	(0.051)	(0.046)	(0.048)	(0.043)
ln Human capital	-0.099**	-0.022	-0.075	0.010
	(0.042)	(0.049)	(0.046)	(0.051)
ln Population	0.120***	0.063**	0.145***	0.084***
	(0.026)	(0.031)	(0.018)	(0.027)
ln Economic freedom	-0.020	0.008	-0.026	0.002
	(0.015)	(0.019)	(0.017)	(0.021)
ln GDP per capita		-0.060***		-0.062***
		(0.012)		(0.013)
ln Trade openness		-0.012*		-0.015**
		(0.006)		(0.007)
First-stage regression				
Lagged ln Relative price	0.824***	0.821***	0.825***	0.821***
	(0.033)	(0.032)	(0.033)	(0.032)
Green Revolution	0.340***	0.361***		
	(0.112)	(0.120)		
Projected ln agricultural TFP			0.021***	0.025***
			(0.007)	(0.008)
Green Revolution × ln Economic freedom	-0.157***	-0.170***		
	(0.051)	(0.056)		
Projected ln agricultural TFP × ln Economic freedom			-0.009***	-0.011***
			(0.003)	(0.004)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
First-stage F-statistic	274.04	286.00	238.84	271.66
Hansen test (p-value)	0.16	0.20	0.13	0.15
Countries	110	110	108	108
Observations	4513	4513	4425	4425

Notes: The dependent variable is the natural logarithm of agricultural output share. Numbers in parentheses are robust standard errors clustered at the country level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

prices depends critically on institutional quality. When institutional quality is low, the Green Revolution raises relative agricultural prices, consistent with distortions in the price-transmission mechanism. As institutional quality improves, this distortion diminishes, and at sufficiently high levels of institutional quality, the Green Revolution exerts its theoretically predicted effect of lowering relative agricultural prices. We further examine this mechanism using the alternative instrument set Z^4, which includes projected agricultural TFP and its interaction with institutional quality. Specifications (3) and (4) in Table 2 yield results that are qualitatively similar to those in specifications (1) and (2). The second-stage estimates closely resemble those reported in specifications (4)–(6) of Table 1. In the first-stage regression, the interaction between projected agricultural TFP and the Economic Freedom index is negative and statistically significant at conventional levels, while projected agricultural TFP itself enters positively and significantly.

Taken together, these results indicate that the negative effect of agricultural productivity on the relative agricultural price emerges only in sufficiently well-functioning markets. The empirical evidence thus highlights the central role of institutional quality in shaping the price transmission of the Green Revolution and, ultimately, in facilitating structural transformation from an agriculture-based economy toward a non-agricultural one.

5.3 Developing Countries

Thus far, we have examined both developed and developing countries jointly, using the Green Revolution index constructed by Huang (2024). However, analyzing the structural transformation induced by the Green Revolution is particularly relevant for developing countries, as emphasized by Gollin et al. (2021), because many of these economies have experienced rapid industrialization over the past five decades.

Table 3 reports the estimation results for the subsample of developing countries.[7] As shown in the table, the signs and statistical significance of the key variables—including the relative agricultural price, agricultural productivity (measured by the Green Revolution index and agricultural TFP), and their interaction with institutional quality (Economic Freedom)—remain consistent with those reported in Table 2. Although the magnitudes of the estimated effects are somewhat smaller, the qualitative patterns are preserved. This finding is consistent with the view that the Green Revolution has contributed to reducing malnutrition and poverty by making food more affordable for the vast majority of people in low-income countries. The regression diagnostics further support the reliability of the estimates. The F-statistics for the excluded instruments are sufficiently large, indicating no weak-instrument concerns, and the Hansen tests do not reject the orthogonality condition in all specifications.

Overall, although the Green Revolution appears to have accelerated structural transformation less strongly in developing countries—as reflected by the smaller coefficient estimates on the relative agricultural price in Table 3 compared with Table 2—the pooled regressions including both developed and developing countries suggest that developed economies may have benefited additionally from the international diffusion of Green Revolution-induced productivity gains through world markets,

[7] Gollin et al. (2021) focus on a sample of 90 developing countries. We consider the same set of countries; however, the sample is slightly smaller due to missing data for some control variables.

Table 3: Augmented instrumental variables estimation of agricultural output share equation with nonlinear institutional effects in developing countries, 1963–2010

	(1)	(2)	(3)	(4)
Second-stage regression				
Lagged ln agricultural output share	0.877***	0.843***	0.877***	0.843***
	(0.016)	(0.015)	(0.016)	(0.015)
ln Relative price	0.101**	0.129***	0.101**	0.128***
	(0.044)	(0.038)	(0.045)	(0.038)
ln Human capital	-0.122***	-0.043	-0.122***	-0.043
	(0.046)	(0.049)	(0.046)	(0.049)
ln Population	0.078**	-0.005	0.078**	-0.005
	(0.033)	(0.039)	(0.033)	(0.039)
ln Economic freedom	-0.043**	-0.013	-0.043**	-0.013
	(0.018)	(0.022)	(0.018)	(0.022)
ln GDP per capita		-0.063***		-0.063***
		(0.012)		(0.012)
ln Trade openness		-0.017*		-0.017*
		(0.009)		(0.009)
First-stage regression				
Lagged ln Relative price	0.893***	0.888***	0.893***	0.886***
	(0.016)	(0.017)	(0.016)	(0.018)
Green Revolution	0.256***	0.268***		
	(0.092)	(0.098)		
Projected ln agricultural TFP			0.016**	0.018**
			(0.007)	(0.008)
Green Revolution × ln Economic freedom	-0.123***	-0.135***		
	(0.045)	(0.049)		
Projected ln agricultural TFP × ln Economic freedom			-0.008***	-0.010***
			(0.003)	(0.004)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
First-stage F-statistic	1565.22	1166.20	1056.52	882.25
Hansen test (p-value)	0.11	0.54	0.45	0.86
Countries	75	75	75	75
Observations	3062	3062	3062	3062

Notes: The dependent variable is the natural logarithm of agricultural output share. Numbers in parentheses are robust standard errors clustered at the country level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

which placed downward pressure on their relative agricultural prices. A further explanation for the smaller estimated effects of the relative agricultural price in developing countries relates to institutional quality, whose influence may persist even after controlling for Economic Freedom in the first-stage regressions. Weak institutions—manifested in insecure property rights, inefficient regulatory environments, and limited market-supporting governance—can hinder the efficient reallocation of resources following improvements in agricultural productivity. When institutional constraints restrict factor mobility and distort market signals, the decline in the agricultural output share induced by falling relative agricultural prices is attenuated. In such environments, productivity gains from the Green Revolution do not fully translate into sectoral reallocation, thereby dampening the responsiveness of the agricultural output share to relative price changes. This mechanism is consistent with the theoretical framework, in which institutional distortions weaken the adjustment toward the new equilibrium.

5.4 Robustness Using an Alternative Relative Agricultural Price

To assess the robustness of the baseline results, we re-estimate the agricultural output share equation using an alternative measure of the relative agricultural price constructed from FAO crop-level data (see Eq. (15)). Table 4 reports the estimation results for the period 1970–2010. In the second-stage regressions, the key qualitative patterns documented in the baseline estimations remain intact across all specifications. In particular, the lagged agricultural output share continues to exhibit a high degree of persistence, and the coefficient on the alternative relative agricultural price remains positive and statistically significant, although its magnitude is smaller than in the baseline results. In the first-stage regressions, we employ the instrument sets Z^3 and Z^4. For Z^4, we consider two alternative constructions based on projected agricultural TFP and projected agricultural labor productivity, each interacted with Economic Freedom. Across all specifications, the first-stage regressions display qualitatively similar patterns to those reported in Table 2, with the exception that the coefficient on projected agricultural productivity is not always statistically significant. These results indicate that even when a crop-based price index constructed from domestic price data is used, lower relative agricultural prices are associated with a reduction in the agricultural output share, consistent with the theoretical mechanism linking productivity improvements and institutional quality to structural transformation.

The regression diagnostics further support the robustness of the findings. Although the F-statistics for the excluded instruments are somewhat smaller than those in the baseline estimations, they remain well above conventional thresholds, suggesting no serious weak-instrument concerns. The Hansen tests provide mixed evidence regarding instrument validity: the orthogonality condition is rejected in specifications (1) and (3), but not in specifications (2) and (4)–(6). Importantly, specifications (2), (4), and (6) include per capita GDP and trade openness as additional control variables, and the inclusion of these controls substantially improves the Hansen test outcomes. This pattern suggests that the additional controls could capture macroeconomic variation that may otherwise be correlated with the instruments, thereby improving the performance of the overidentification tests. Accordingly, while some caution is warranted, the non-rejection of the orthogonality condition in specifications (2), (4), and (6) provides stronger support for the validity

Table 4: Augmented instrumental variables estimation of agricultural output share equation with nonlinear institutional effects, 1970–2010, using FAO crop-level data

	(1)	(2)	(3)	(4)	(5)	(6)
Second-stage regression						
Lagged ln agricultural output share	0.877***	0.852***	0.878***	0.853***	0.878***	0.853***
	(0.021)	(0.020)	(0.021)	(0.020)	(0.021)	(0.020)
ln Relative price (FAO crops)	0.010**	0.010**	0.010**	0.010**	0.010**	0.010**
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
ln Human capital	-0.091	-0.029	-0.091	-0.030	-0.091	-0.030
	(0.071)	(0.082)	(0.071)	(0.082)	(0.071)	(0.082)
ln Population	0.175***	0.124***	0.173***	0.122***	0.173***	0.122***
	(0.030)	(0.034)	(0.030)	(0.033)	(0.030)	(0.033)
ln Economic freedom	-0.036	-0.002	-0.035	-0.001	-0.035	-0.001
	(0.026)	(0.028)	(0.026)	(0.028)	(0.026)	(0.028)
ln GDP per capita		-0.059***		-0.060***		-0.060***
		(0.012)		(0.012)		(0.012)
ln Trade openness		-0.018***		-0.019***		-0.019***
		(0.005)		(0.005)		(0.005)
First-stage regression						
Lagged ln Relative price (FAO crops)	0.696***	0.696***	0.697***	0.698***	0.698***	0.698***
	(0.094)	(0.094)	(0.093)	(0.093)	(0.093)	(0.094)
Green Revolution	4.988***	4.855***				
	(1.818)	(1.854)				
Projected ln agricultural TFP			0.180***	0.158**		
			(0.066)	(0.078)		
Projected ln agricultural labor productivity					0.098*	0.087
					(0.051)	(0.055)
Green Revolution	-2.223***	-2.149**				
× ln Economic freedom	(0.839)	(0.853)				
Projected ln agricultural TFP			-0.111***	-0.101***		
× ln Economic freedom			(0.033)	(0.036)		
Projected ln agricultural labor productivity					-0.052**	-0.047**
× ln Economic freedom					(0.021)	(0.022)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
First-stage F-statistic	49.02	48.26	30.13	27.99	27.56	25.39
Hansen test (p-value)	0.08	0.32	0.08	0.21	0.18	0.36
Countries	99	99	98	98	98	98
Observations	3020	3020	3000	3000	3000	3000

Notes: The dependent variable is the natural logarithm of agricultural output share. Numbers in parentheses are robust standard errors clustered at the country level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

of the instrument sets in the specifications with additional controls.

The first-stage results in Table 4 also reinforce the baseline findings. The Green Revolution index enters positively and significantly, while its interaction with institutional quality enters negatively and significantly, indicating that stronger institutions facilitate the price-decreasing

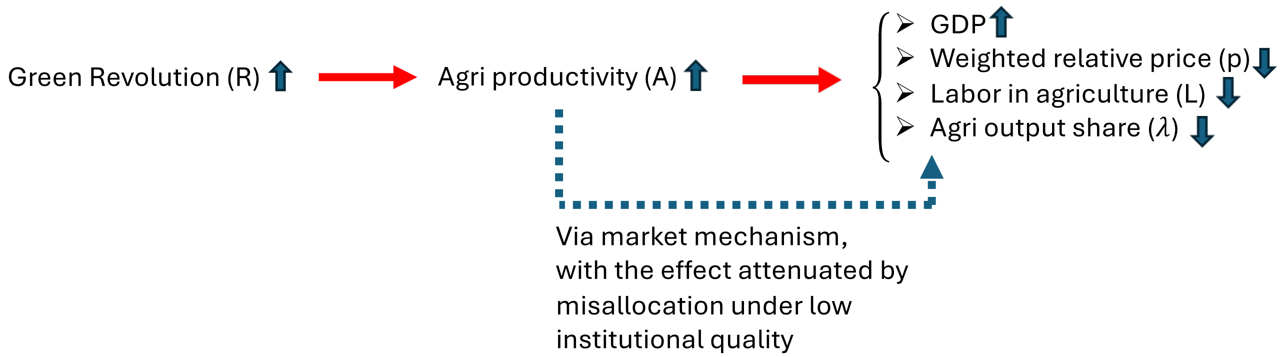

Figure 7: Development and structural transformation via market mechanisms

effect of the Green Revolution. Similarly, projected agricultural TFP and projected agricultural labor productivity exert positive effects on the alternative relative agricultural price, but these effects are dampened—and in some cases reversed—when interacted with the Economic Freedom index. These patterns imply that improvements in agricultural productivity translate into lower relative agricultural prices only in environments characterized by sufficiently high institutional quality, consistent with the theoretical predictions and the baseline results reported in Table 2.

Overall, the robustness checks using the alternative agricultural price index confirm the central conclusion of the analysis: institutional quality plays a pivotal role in shaping the price-mediated transmission of the Green Revolution. Even when using a narrower, crop-based measure of agricultural prices, the interaction between productivity improvements and institutional quality remains essential for understanding how the resulting price adjustments shape structural transformation.

5.5 Remarks on Findings

Figure 7 summarizes the main findings from our empirical analysis. As shown in the first-stage regressions reported in Tables 2–4, the Green Revolution contributes to a decline in the relative price of agricultural goods—primarily through increases in agricultural productivity—when an economy is characterized by strong institutional quality. Through standard market mechanisms, and in line with Engel's law, this decline in the relative agricultural price leads to a reduction in the agricultural output share, as demonstrated in the second-stage regressions.

Institutional quality plays a central role in shaping the extent to which the Green Revolution translates into lower relative agricultural prices. In other words, the effectiveness of the Green Revolution critically depends on the strength of institutions. The estimates in Tables 2–4 support this mechanism: when institutional quality is low, the expansion of the Green Revolution is associated with a stronger positive effect on the relative agricultural price, reflecting market frictions and distortions. As institutional quality improves, this positive effect diminishes and eventually reverses, allowing the theoretically predicted price-decreasing effect of the Green Revolution to emerge.

Overall, while market mechanisms are fundamental to structural transformation from an agriculture-based economy toward a non-agricultural one, their effectiveness is substantially constrained by institutional quality.

The empirical findings are consistent with the implications of our theoretical framework. As summarized in the takeaways in Section 3.4, an increase in agricultural productivity brought about by the Green Revolution can promote structural transformation when institutions allow productivity gains to be transmitted effectively into lower relative agricultural prices. Furthermore, the determination of the relative agricultural price varies with the degree of trade openness: in economies more integrated into world markets, relative agricultural prices are more strongly influenced by global market conditions, including the international diffusion of Green Revolution technologies. Nevertheless, the relative agricultural price remains the common transmission channel linking agricultural productivity improvements to structural transformation across economies with different degrees of trade openness. Our empirical findings are consistent with this unified mechanism and with the view that the international diffusion of Green Revolution technologies was sufficiently widespread over the sample period to influence relative agricultural prices across countries.

An additional finding concerns the role of trade openness, which enters both the first- and second-stage regressions. These two appearances of trade openness may reflect distinct channels. In the first stage, trade openness helps account for cross-country differences in the formation of relative agricultural prices arising from different degrees of integration into world markets. This is the relative-price channel emphasized by our unified theoretical framework: greater exposure to world markets affects the extent to which relative agricultural prices are influenced by global market conditions, together with other trade-related factors represented by the price wedge.[8] In the second stage, by contrast, the coefficient on trade openness is consistently negative across Tables 1–4, even after controlling for the relative agricultural price. This finding suggests an additional association between integration into world markets and structural transformation that

[8]Although not reported in the tables, the estimated coefficient on trade openness in the first-stage regressions is generally negative but statistically insignificant. This pattern is consistent with potentially heterogeneous effects of trade integration on relative agricultural prices across countries. For economies with a comparative disadvantage in agriculture, greater integration into world markets may lower relative agricultural prices through increased exposure to relatively inexpensive agricultural imports, whereas the opposite effect may arise in economies with a comparative advantage in agriculture. The statistically insignificant average effect may therefore reflect, at least in part, such cross-country heterogeneity. Moreover, as emphasized in the theoretical framework, trade openness alone does not fully characterize the trade-related wedge, which may also reflect tariffs, transportation costs, non-tradable components, and other country-specific factors affecting relative-price formation.

operates beyond the relative-price channel explicitly modeled in our theoretical framework. Several mechanisms may underlie this second-stage relationship. Greater trade integration may promote the expansion of non-agricultural sectors independently of the relative-price channel by enlarging access to foreign markets and facilitating imports of capital goods, intermediate inputs, and technologies that enhance non-agricultural productivity. Such expansion reduces the agricultural output share even conditional on the relative agricultural price. Trade integration may also facilitate resource reallocation according to comparative advantage. For countries with a comparative disadvantage in agriculture, this reallocation may favor non-agricultural production, whereas the opposite may occur in countries with a comparative advantage in agriculture. Since these mechanisms are not explicitly distinguished in our theoretical framework or empirical specification, we interpret the negative second-stage coefficient on trade openness as an average conditional relationship rather than as evidence for any single causal channel.

6 Misallocation and Per Capita GDP

As shown in the first-stage estimation results in Tables 2 and 3, low institutional quality is associated with distortions in the transmission of agricultural productivity improvements into the relative price of agricultural goods. Building on these results, we construct a price-based misallocation (PBM) index to quantify distortions in the transmission of agricultural productivity improvements into relative agricultural prices. Such distortions can generate misallocation by impeding the market-based reallocation of resources associated with structural transformation. Specifically, using the estimated coefficients from the first-stage regression in specification (2) of Table 2, we define the misallocation component as

$$\mathrm{PBM}_{it} = M_{it} - \bar{M}_t,$$

where

$$M_{it} = 0.013 \times \ln q_{it} - 0.170 \times R_{it} \times \ln q_{it},$$

and $\bar{M}_t$ denotes the cross-country average of M_{it} in year t. As implied by the first-stage regression, a lower value of M_{it} corresponds to a lower relative agricultural price, indicating a mitigation of inefficiencies in resource allocation. By subtracting the cross-country average in each year, the PBM index captures the relative degree of price-based misallocation across countries while netting out common global trends in the Economic Freedom ($\ln q_{it}$) and Green Revolution (R_{it}) indices. Consequently, the PBM index is comparable across both countries and years and measures how effectively markets transmit agricultural productivity improvements into lower relative agricultural prices. Inefficient transmission reflects distortions and institutional frictions associated with misallocation. The PBM index is not intended to directly quantify allocative inefficiency in the conventional sense (Ghatak and Mookherjee, 2025; Bergquist et al., 2026). Rather, it measures institutionally mediated distortions in the transmission of agricultural productivity gains into relative price adjustments. In our framework, such distortions contribute to misallocation by impeding the market-based reallocation of resources associated with structural transformation. Because the Green Revolution index enters the PBM measure through its interaction with institutional quality, the index reflects not the direct intensity of the Green Revolution itself, but the extent to which productivity improvements are translated into lower relative agricultural prices under different institutional environments.

Figure 8 illustrates the relationship between the PBM index and per capita GDP using semiparametric estimation. Figure 8(a) presents the baseline specification, in which the Green Revolution index and year fixed effects are included as linear components. This specification primarily reflects cross-country variation and reveals a pronounced negative association between price-based misallocation and income levels: countries exhibiting greater distortions in relative agricultural prices tend to have lower per capita GDP. Figure 8(b) additionally controls for country fixed effects, thereby isolating within-country variation over time. While the negative association between the PBM index and per capita GDP remains visible, the slope becomes noticeably flatter. This attenuation suggests that a substantial part of the observed relationship operates through persistent cross-country differences in institutional environments and market functioning. At the same time, the remaining negative association indicates that changes in price-based misallocation within countries are systematically related to income dynamics. Overall, the two panels indicate that price-based misallocation is not only a cross-sectional correlate of development but also a meaningful within-country indicator of economic performance over time. This decomposition is particularly important for our interpretation of institutional quality, as it suggests that price distortions reflect both slow-moving structural characteristics and time-varying policy and market conditions. This interpretation is consistent with the broader literature on institutions and economic outcomes (e.g., North and Thomas, 1973; North, 1981; Acemoglu et al., 2001), as well as with cross-country evidence linking misallocation to lower productivity and income levels (Jones, 2016).[9]

[9] The results above highlight that the PBM index captures important cross-country variation in market distortions associated with structural transformation and economic development. While the main focus of this paper is on the role of the Green Revolution and market-based price adjustments in driving structural transformation, the PBM index may also be informative for broader policy issues. To keep the main discussion focused, we present an exploratory analysis of the relationship between the PBM index and distributional policies in Appendix C.

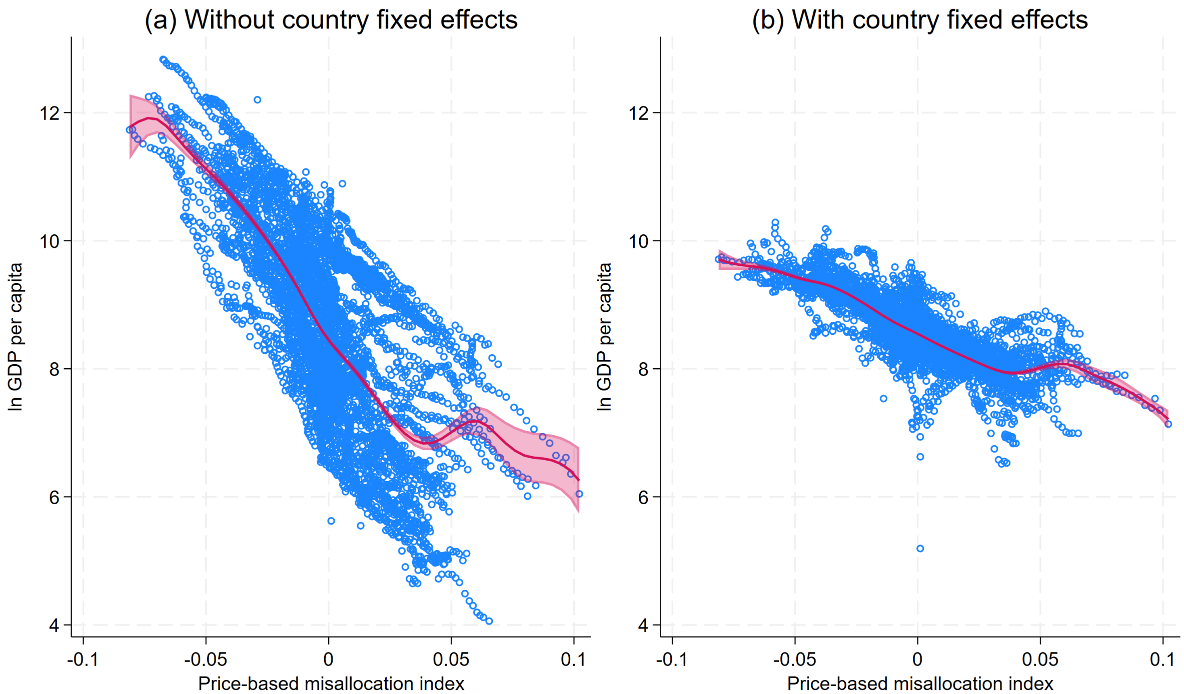

Figure 8: Misallocation versus per capita GDP

Notes: The bold lines in the two panels depict Robinson's (1988) semiparametric estimates of the relationship between the price-based misallocation (PBM) index and per capita GDP for 122 countries over the period 1962–2010. Panel (a) includes the Green Revolution index and year fixed effects as linear components, while Panel (b) additionally controls for country fixed effects. The shaded areas indicate the 95% confidence intervals. Across both specifications, higher values of the PBM index are associated with lower levels of per capita GDP. The negative association remains visible even after controlling for country fixed effects, although the slope becomes noticeably flatter, suggesting that a substantial part of the relationship reflects cross-country differences, while within-country variation in price-based misallocation remains systematically related to income differences.

7 Concluding Remarks

This study highlights the transformative impact of the Green Revolution on agricultural productivity and structural transformation. Guided by theoretical insights grounded in Engel's law—where rising incomes reduce the expenditure share on agricultural goods—we provide empirical evidence showing that the adoption of advanced agricultural technologies significantly increased productivity, reduced relative agricultural prices, and lowered agriculture's share in economic output, particularly in economies with well-functioning markets. Beyond these direct effects, our findings support the view that the Green Revolution contributed to reductions in malnutrition and poverty by making food more affordable and accessible in low-income countries. Theoretical insights on equilibrium price determination also motivated our instrumental variable strategy, allowing us to address endogeneity in relative prices. The IV estimates consistently support the link between declining agricultural prices and structural transformation, illustrating how productivity gains in agriculture facilitated broader industrial development.

Institutional quality emerges as a key determinant of these mechanisms. Countries endowed with strong institutions experienced lower levels of misallocation and more efficient market responses to the Green Revolution, whereas weak institutional environments amplified inefficiencies and impeded structural transformation. In sum, market-based mechanisms through which the Green Revolution promotes structural change are not guaranteed to operate effectively in the presence of market failures, policy-induced distortions, and weak institutional frameworks.

To further examine these institutional distortions, we developed a price-based misallocation (PBM) index that captures distortions in the transmission of agricultural productivity gains into relative agricultural prices and the associated misallocation. The PBM index exhibits a robust negative association with per capita GDP, underscoring the broader importance of reducing misallocation for economic development. This result highlights persistent challenges that prevent some economies from fully realizing the potential gains of the Green Revolution. Institutional weaknesses—including poor governance, corruption, and insecure property rights—continue to distort prices and constrain efficient resource allocation. In some cases, government interventions further delay the reallocation of resources from agriculture to higher-productivity sectors. While agricultural subsidies may be politically appealing, non-distortive forms of support are more conducive to long-run economic performance, as they preserve the price signals necessary for structural transformation.

Our study underscores the need for institutional reforms aimed at strengthening governance, curbing corruption, and securing property rights in order to reduce resource misallocation in agriculture. Greater integration into world markets can facilitate the international diffusion of agricultural technologies, but its effects on structural transformation depend on how global market conditions are transmitted into domestic relative agricultural prices and on the institutional environment. Rather than relying on broad-based subsidies that distort prices, policymakers should adopt targeted interventions to address specific market failures, such as improving farmers' access to technology and credit. Adaptive policy approaches—tailored to institutional and market conditions through investments in agricultural research, farmer training, and improved management practices—are likely to be more effective (Otsuka et al., 2024). Gradual sectoral reforms combined with targeted support may yield better outcomes, particularly in weaker institutional settings. Finally, future research incorporating rigorous counterfactual analyses and crop-specific price dynamics would further refine policy design and deepen our understanding of how institutional reforms and market-based mechanisms jointly shape long-run economic transformation. More broadly, this study contributes to the development and growth literature by clarifying how technological progress in agriculture translates into structural transformation through price mechanisms, and by showing that institutional quality critically mediates this transmission.

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Appendices

Appendix A: Derivation of the Baseline Estimation Equations

From Eq. (14), the supply and demand equations for country i at time t can be written as

$$p_{it} = \frac{F'\left(L - L_{it}\right)}{A_{it} G'\left(L_{it}\right)}, \tag{A1}$$

$$p_{it} = \frac{\beta F\left(L - L_{it}\right)}{\omega_{it}\left(A_{it} G\left(L_{it}\right) - \gamma L\right)}. \tag{A2}$$

Institutional quality affects the economy through two channels: the determination of the relative agricultural price and the evolution of agricultural productivity. We first assume that the price wedge parameter, ω_{it}^{m}, depends on the lagged agricultural output share, λ_{it-1}, and the current institutional index, q_{it}, such that

$$\omega_{it}^m = w_i \lambda_{it-1}^{\theta_1} q_{it}^{\theta_2}, \tag{A3}$$

where $w_i > 0$ and $\lambda_{it-1} = p_{it-1}A_{it-1}G(L_{it-1})/\left(F(L - L_{it-1}) + p_{it-1}A_{it-1}G(L_{it-1})\right)$. We can infer that θ_2 is positive because a higher institutional index mitigates the price wedge. However, the sign of θ_1 is theoretically ambiguous and must be determined empirically. This ambiguity arises because structural transformation may either reduce or exacerbate misallocation. Specifically, two opposing outcomes of the Green Revolution can be considered. In the first case, the Green Revolution alleviates market distortions: a smaller λ_{it-1} (indicating a lower agricultural share in the previous period) increases ω_{it}^m, thereby narrowing the price wedge. In the second case, however, the Green Revolution intensifies misallocation. Although agricultural productivity improves, powerful elites extract a greater share of agricultural surplus. Consequently, both the relative price of agricultural goods and the land allocated to agriculture may rise, amplifying the misallocation problem. Thus, the sign of θ_1 remains indeterminate without empirical estimation.

Additionally, the evolution of agricultural productivity is affected by the extent of the Green Revolution, R_{it}, such that

$$A_{it} = \exp\left[R_{it}(a \ln q_{it} - b)\right] A_{it-1}^{\chi}, \tag{A4}$$

where $\chi \in (0, 1)$ and $a, b > 0$. As noted in Eq. (A4), the Green Revolution promotes agricultural productivity only when institutional quality becomes sufficiently high; otherwise, the Green Revolution negatively affects agricultural productivity.

Consider a reference equilibrium characterized by $(\bar{A}, \bar{p}, \bar{L})$, around which we log-linearize the model. The reference values may be viewed as representative of the sample averages, while satisfying the equilibrium conditions (A1) and (A2). Log-linearizing Eqs. (A1) and (A2) around $L_{it} = \bar{L}$ and $A_{it} = \bar{A}$, we obtain

$$\ln p_{it} = \ln\left(\bar{L}^{-\Lambda}\Phi\right) + \Lambda \ln L_{it} - \ln A_{it}, \tag{A5}$$

$$\ln p_{it} = \ln\left(\bar{L}^{\Omega}\Psi\right) - \Omega \ln L_{it} - \phi \ln A_{it} - \ln \omega_{it}, \tag{A6}$$

where

$$\Phi := \frac{F'(L - \bar{L})}{G'(\bar{L})},$$

$$\Psi := \frac{\beta \bar{A}^{\phi} F(L - \bar{L})}{\left(\bar{A}G(\bar{L}) - \gamma L\right)},$$

$$\Lambda := -\left(\frac{F''(L - \bar{L})\bar{L}}{F'(L - \bar{L})} + \frac{G''(\bar{L})\bar{L}}{G'(\bar{L})}\right),$$

$$\Omega := \frac{F'(L-\bar{L})\bar{L}}{F(L-\bar{L})} + \frac{\bar{A}G'(\bar{L})\bar{L}}{\bar{A}G(\bar{L})-\gamma L},$$

and

$$\phi := \frac{\bar{A}G(\bar{L})}{\bar{A}G(\bar{L})-\gamma L}.$$

From Eqs. (A5) and (A6), we obtain

$$\ln p_{it} = \frac{\Lambda}{\Lambda+\Omega}\ln\Psi + \frac{\Omega}{\Lambda+\Omega}\ln\Phi - \left(\frac{\Lambda\phi+\Omega}{\Lambda+\Omega}\right)\ln A_{it} - \frac{\Lambda}{\Lambda+\Omega}\ln\omega_{it}, \tag{A7}$$

or equivalently,

$$\ln p_{it} + \ln A_{it} = \frac{\Lambda}{\Lambda\phi+\Omega}\ln\Psi + \frac{\Omega}{\Lambda\phi+\Omega}\ln\Phi + \left(\frac{\Lambda(\phi-1)}{\Lambda\phi+\Omega}\right)\ln p_{it} - \frac{\Lambda}{\Lambda\phi+\Omega}\ln\omega_{it}. \tag{A8}$$

Furthermore, Eqs. (A5) and (A8) yield

$$\ln L_{it} - \ln\bar{L} = \frac{1}{\Lambda\phi+\Omega}\ln\Psi - \frac{\phi}{\Lambda\phi+\Omega}\ln\Phi + \left(\frac{\phi-1}{\Lambda\phi+\Omega}\right)\ln p_{it} - \frac{1}{\Lambda\phi+\Omega}\ln\omega_{it}. \tag{A9}$$

Baseline equation in the second-stage regression

Log-linearizing the agricultural output share, λ_{it}, around $A_{it}=\bar{A}$, $p_{it}=\bar{p}$, and $L_{it}=\bar{L}$, we obtain

$$\ln\lambda_{it} = \ln\left((1-\pi)\left(\bar{p}\bar{A}\right)^{-\pi}\right) + \pi\left(\ln p_{it}+\ln A_{it}\right) + \delta\left(\ln L_{it}-\ln\bar{L}\right), \tag{A10}$$

where

$$\pi := \frac{F(L-\bar{L})}{F(L-\bar{L})+\bar{p}\bar{A}G(\bar{L})}$$

and

$$\delta := \frac{G'(\bar{L})\bar{L}}{G(\bar{L})}.$$

Note that the expression for δ uses the equilibrium condition in Eq. (A1). In particular, direct log-linearization yields $\delta = \pi\left[G'(\bar{L})\bar{L}/G(\bar{L}) + F'(L-\bar{L})\bar{L}/F(L-\bar{L})\right]$, which reduces to $G'(\bar{L})\bar{L}/G(\bar{L})$ by Eq. (A1).

Substituting Eqs. (A8) and (A9) into Eq. (A10) yields

$$\begin{aligned}\ln\lambda_{it} = \ln\left((1-\pi)\left(\bar{p}\bar{A}\right)^{-\pi}\right) + \frac{\pi\Lambda+\delta}{\Lambda\phi+\Omega}\ln\Psi + \frac{\pi\Omega-\delta\phi}{\Lambda\phi+\Omega}\ln\Phi \\ + \frac{(\phi-1)(\pi\Lambda+\delta)}{\Lambda\phi+\Omega}\ln p_{it} - \frac{\pi\Lambda+\delta}{\Lambda\phi+\Omega}\ln\omega_{it}.\end{aligned} \tag{A11}$$

From Eq. (A3), (A11) becomes

$$\ln \lambda_{it} = B_0 - B_1\theta_1 \ln \lambda_{it-1} + B_2 \ln p_{it} - B_1\theta_2 \ln q_{it} - B_1 \left(\ln w_i + \ln \omega^s_{it}\right), \tag{A12}$$

where

$$B_0 := \ln\left((1-\pi)\left(\bar{p}\bar{A}\right)^{-\pi}\right) + \frac{\pi\Lambda + \delta}{\Lambda\phi + \Omega} \ln \Psi + \frac{\pi\Omega - \delta\phi}{\Lambda\phi + \Omega} \ln \Phi,$$

$$B_1 := \frac{\pi\Lambda + \delta}{\Lambda\phi + \Omega},$$

and

$$B_2 := \frac{(\phi - 1)(\pi\Lambda + \delta)}{\Lambda\phi + \Omega}.$$

Eq. (A12) is the baseline equation in the second-stage regression for our empirical investigation. In Eq. (A12), we can infer that $B_2 > 0$ (since $\phi > 1$) and $-B_1\theta_2 < 0$, which are consistent with the theory. However, the sign and magnitude of $-B_1\theta_1$ are indeterminate as previously explained. The last two terms associated with $\ln w_i$ and $\ln \omega^s_{it}$ are captured by country-specific effects and the trade-openness control variable in the panel data estimations, respectively.

Baseline equation in the first-stage regression

From Eqs. (A3), (A4), and (A7), it follows that

$$\begin{aligned}\ln p_{it} - \chi \ln p_{it-1} = (1-\chi)C_0 - C_1 \left\{(a \ln q_{it} - b)R_{it}\right\} \\ - C_2 \left\{(1-\chi)\ln w_i + \theta_1(\ln \lambda_{it-1} - \chi \ln \lambda_{it-2})\right. \\ \left. +\theta_2(\ln q_{it} - \chi \ln q_{it-1}) + (\ln \omega^s_{it} - \chi \ln \omega^s_{it-1})\right\},\end{aligned} \tag{A13}$$

where

$$C_0 := \frac{\Lambda}{\Lambda + \Omega} \ln \Psi + \frac{\Omega}{\Lambda + \Omega} \ln \Phi,$$

$$C_1 := \frac{\Lambda\phi + \Omega}{\Lambda + \Omega},$$

and

$$C_2 := \frac{\Lambda}{\Lambda + \Omega}.$$

Furthermore, Eq. (A12) becomes

$$\ln \lambda_{it-1} = B_0 + B_2 \ln p_{it-1} - B_1 \left(\ln w_i + \theta_1 \ln \lambda_{it-2} + \theta_2 \ln q_{it-1} + \ln \omega^s_{it-1}\right),$$

or equivalently,

$$\theta_1 \ln \lambda_{it-2} = \frac{B_0}{B_1} - \ln w_i + (\phi - 1) \ln p_{it-1} - \frac{1}{B_1} \ln \lambda_{it-1} - \theta_2 \ln q_{it-1} - \ln \omega^s_{it-1}. \tag{A14}$$

Substituting Eq. (A14) in Eq. (A13) yields

$$\begin{aligned} \ln p_{it} = {} & (1-\chi)C_0 + \frac{B_0 C_2 \chi}{B_1} + \chi \left(1 + C_2(\phi - 1)\right) \ln p_{it-1} \\ & - C_2 \left(\theta_1 + \frac{\chi}{B_1}\right) \ln \lambda_{it-1} - C_2 \theta_2 \ln q_{it} - C_1 \left(a \ln q_{it} - b\right) R_{it} \\ & - C_2 \left(\ln w_i + \ln \omega^s_{it}\right). \end{aligned} \tag{A15}$$

Eq. (A15) is the baseline equation for the first-stage regression, in which $\ln p_{it-1}$, R_{it}, and $R_{it} \ln q_{it}$ are excluded instrumental variables. Again, the last two terms associated with $\ln w_i$ and $\ln \omega^s_{it}$ are captured by country-specific effects and the trade-openness control variable, respectively.

Appendix B: Country List and Descriptive Statistics

We list the 180 sample countries and their descriptive statistics in Tables B1 and B2, respectively.

Table B1: List of countries

Afghanistan	Comoros	Hungary	Mongolia	Sierra Leone
Albania	Congo, Dem. Rep.	Iceland	Montenegro	Singapore
Algeria	Congo, Rep.	India	Morocco	Slovak Republic
Angola	Costa Rica	Indonesia	Mozambique	Slovenia
Antigua and Barbuda	Croatia	Iran, Islamic Rep.	Myanmar	Solomon Islands
Argentina	Cyprus	Iraq	Namibia	South Africa
Armenia	Czechia	Ireland	Nepal	Spain
Australia	Cote d'Ivoire	Israel	Netherlands	Sri Lanka
Austria	Denmark	Italy	New Zealand	Sudan
Azerbaijan	Djibouti	Jamaica	Nicaragua	Suriname
Bahamas, The	Dominica	Japan	Niger	Sweden
Bahrain	Dominican Republic	Jordan	Nigeria	Switzerland
Bangladesh	Ecuador	Kazakhstan	North Macedonia	Syrian Arab Republic
Barbados	Egypt, Arab Rep.	Kenya	Norway	Tajikistan
Belarus	El Salvador	Kiribati	Oman	Tanzania
Belgium	Eritrea	Korea, Rep.	Pakistan	Thailand
Belize	Estonia	Kuwait	Panama	Timor-Leste
Benin	Eswatini	Kyrgyz Republic	Papua New Guinea	Togo
Bhutan	Ethiopia	Lao PDR	Paraguay	Tonga
Bolivia	Fiji	Latvia	Peru	Trinidad and Tobago
Bosnia and Herzegovina	Finland	Lebanon	Philippines	Tunisia
Botswana	France	Lesotho	Poland	Turkmenistan
Brazil	Gabon	Liberia	Portugal	Tuvalu
Brunei Darussalam	Gambia, The	Libya	Qatar	Turkiye
Bulgaria	Georgia	Lithuania	Romania	Uganda
Burkina Faso	Germany	Luxembourg	Russian Federation	Ukraine
Burundi	Ghana	Madagascar	Rwanda	United Arab Emirates
Cabo Verde	Greece	Malawi	St. Kitts and Nevis	United Kingdom
Cambodia	Grenada	Malaysia	St. Lucia	United States
Cameroon	Guatemala	Maldives	St. Vincent and the Grenadines	Uruguay
Canada	Guinea	Mali	Samoa	Vanuatu
Central African Republic	Guinea-Bissau	Malta	Sao Tome and Principe	Venezuela, RB
Chad	Guyana	Mauritania	Saudi Arabia	Viet Nam
Chile	Haiti	Mauritius	Senegal	Yemen, Rep.
China	Honduras	Mexico	Serbia	Zambia
Colombia	Hong Kong SAR, China	Moldova	Seychelles	Zimbabwe

Table B2: Descriptive statistics

Variable	Obs.	Mean	Std. dev.	Min.	Max.
ln Agricultural output share	7187	-2.305	1.176	-7.927	-0.116
ln Relative price	7712	-0.016	0.190	-2.371	0.670
ln Relative price (FAO crops)	3754	8.806	2.986	-7.138	17.347
ln Human capital	6390	0.647	0.354	0.007	1.309
ln Population	7364	15.536	1.915	10.603	21.037
ln Economic freedom	6299	1.731	0.257	0.626	2.228
ln GDP per capita	7364	8.682	1.176	5.369	12.618
ln Trade openness	7364	-1.181	1.089	-13.556	2.932
Green Revolution	6770	0.130	0.125	0	0.542
Projected ln agricultural TFP	6207	2.780	2.151	0	8.227
Projected ln agricultural labor productivity	6207	5.216	4.180	0	17.491

Notes: These statistics are calculated based on the data from 180 countries listed in Table B1.

Appendix C: Distributional Policy and the PBM Index

In this appendix, we investigate under what conditions a distributional policy in the agricultural sector is associated with the PBM index. To do so, we focus on the Producer Support Estimate (PSE), measured as a percentage of gross farm receipts. We assemble the data on the PSE for all countries for which data are available in 2010, including Organisation for Economic Co-operation and Development (OECD) countries and some non-OECD countries. The PSE, developed by the OECD (2024), provides internationally comparable data on the level of agricultural support. It measures the annual monetary value of gross transfers from consumers and taxpayers to agricultural producers. Since the database reports only an aggregate value for the European Union (EU), the same value is assigned to each EU member state. The PSE consists of several components, among which market price support (MPS) is a major component. MPS captures gross transfers arising from the gap between domestic market prices and border prices of agricultural commodities at the farm-gate level.

Figure C1 indicates a semiparametric estimate controlling for the Green Revolution index. Because the Green Revolution index enters the estimation as a linear control, the fitted relationship reflects variation conditional on Green Revolution intensity rather than raw cross-country differences in the PSE. Consequently, although the same PSE value is assigned to all EU member states, the estimated relationship does not imply identical fitted values across those countries. The figure reveals a clear negative relationship between the PBM index and the PSE—an outcome that may appear somewhat unexpected at first glance. One possible interpretation of this negative association is that it reflects policy responses to declining agricultural prices: in economies with strong institutions and more effective market mechanisms, governments may provide support to agricultural producers as productivity improvements place downward pressure on agricultural prices. In other words, while market forces tend to lower relative agricultural prices as misallocation diminishes, governments may intervene through non-price instruments—less distortionary forms of support, such as decoupled direct payments—to protect agricultural incomes. Such subsidies may become politically necessary when productivity gains translate into declining agricultural prices. Indeed, Figure C1 aligns with the post-1990s global trend toward agricultural *decoupling*, where more market-distorting forms of support have increasingly been replaced by decoupled payments based on historical entitlements to meet the World Trade Organization (WTO) "green box" requirements. This strategy effectively severs the link between government financial aid and current production levels or market prices.

As illustrated in Figure C1, countries with a low PBM index tend to exhibit both substantial declines in agricultural prices and relatively high levels of producer support. These patterns suggest

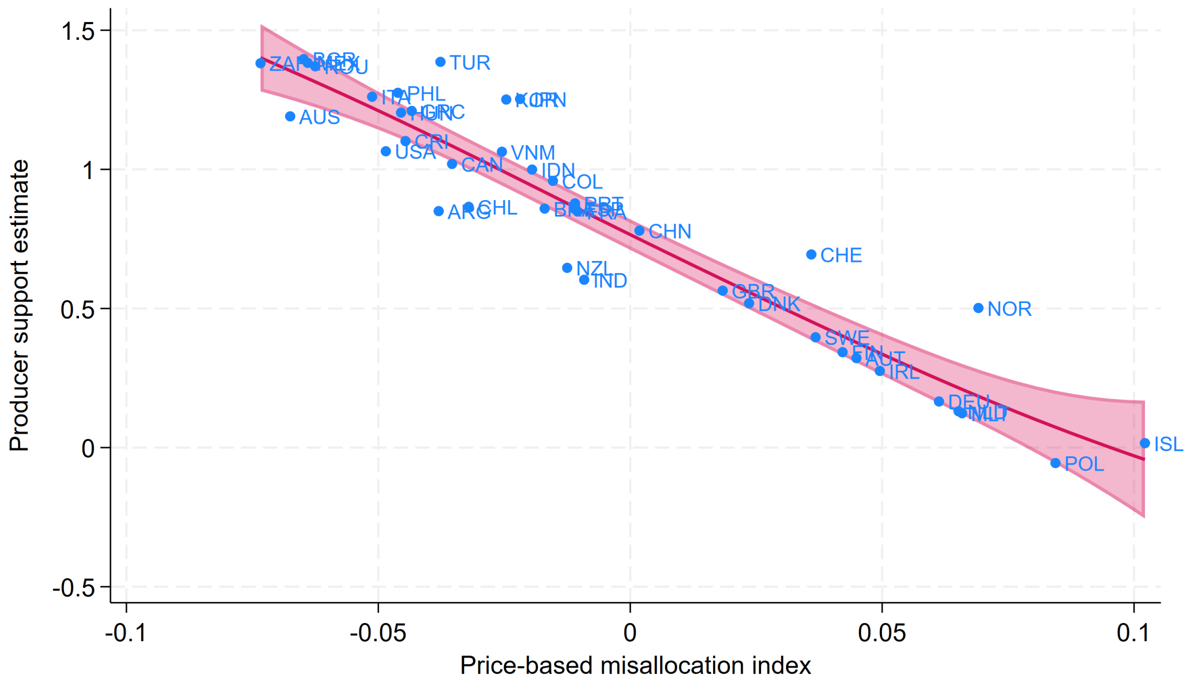

Figure C1: Producer support estimate versus misallocation

Notes: The bold line depicts Robinson's (1988) semiparametric estimate of the relationship between the price-based misallocation (PBM) index and the producer support estimate for 29 OECD countries and 11 non-OECD countries in 2010 with the Green Revolution index included as a linear component. The shaded area indicates the 95% confidence interval. This observed negative relationship may reflect policies enacted for political reasons, in which governments might have implemented subsidy policies when the relative prices of crops decreased due to productivity increases in the agricultural sector.

that governments in countries that have successfully undergone structural transformation are politically responsive, providing income support through non-price mechanisms rather than through price distortions. Consequently, such non-price interventions may partly account for the previously observed negative relationship between the PBM index and per capita GDP.

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