Food Security Risk and Structural Transformation†

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Abstract

Food security risk is an important topic that has long been discussed by development economists and policy makers across countries, while quantitative studies of this issue are rare in the recent macro-development literature. In this paper, we provide a theoretical and quantitative framework to examine the role of food security risk in structural transformation and policies for mitigating food security risk. We provide evidence that poor countries indeed face higher food price volatility and therefore food security risk could be an important impediment to structural transformation of these economies. Quantitatively, a non-trivial portion of the observed agricultural productivity gap may be due to optimal insurance arrangements between urban and rural areas to dampen uncertainties related to volatile agricultural prices. While such arrangements are welfare improving, they will lower real GDP.

Keywords: Food price volatility; structural transformation; agricultural productivity gap; insurance; China

JEL Classification: E13, F43, O11, O13, O41

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1 Introduction

It is well documented that labor productivity within a country is generally higher in non-agriculture than in agriculture. This is the so called agricultural productivity gap (APG) in the macro-development literature, see e.g., Restuccia et al. (2008) and Gollin et al. (2014). The APG averages around 2:1 in developed countries, but 6:1 in developing countries. Despite the large productivity gap, developing countries have a large portion of their labor force working in agriculture. This apparent misallocation of labor is a main reason for the low aggregate productivity and income per capita in these countries.

In this paper, we study food security risk as a potential explanation for the slow structural transformation in poor countries and their observed APG. This is distinct from the literature focused on market distortions and inefficiencies. In particular, we show that a non-trivial portion of the APG may be due to optimal insurance arrangements between urban and rural areas to dampen uncertainties related to volatile agricultural prices. While such arrangements will, as we show, lower aggregate real GDP, they are nevertheless welfare improving.

We build a two-sector open-economy model of structural transformation. Specifically, a rural household chooses the allocation of labor between the agricultural sector and the non-agricultural sector before the realization of food price and hence agricultural wage shocks. An urban household, instead, only allocates its labor in non-agriculture. The risk exposure hence differs between the rural and the urban households. For the urban household, food price volatility generates expenditure risk and they could be better off if the rural household allocates more labor in agriculture to dampen the food price volatility. For the rural household, however, allocating labor to the agricultural sector is subject to income risk associated with food price volatility, and they could be better off by allocating more labor to the non-agricultural sector. Such differences in risk exposure implies gains from trade (or insurance) between the two types of households, and hence the competitive equilibrium is inefficient.

We then study the optimal insurance contract between the two types of households after calibrating our model to data moments. We find that, regardless of which household obtains the social surplus, the optimal insurance implies a substantial over-employment in agriculture, with a transfer from the urban household to the rural household. Such arrangement dampens food price volatility and hence improves welfare for both types of households. The observed agricultural productivity and GDP, however, reduce. This analysis suggests that some of the observed APG may be socially efficient despite the misallocation of labor.

Food self-sufficiency has long been a stated national policy in many developing countries, and food security risk is often used as a justification for the policy. Many economists, however, argue that the food self-sufficiency policy often led to lower productivity in agriculture and worsening food security in the long run, and trade should alleviate rather than exacerbate the food security problem. See, for example, Clapp (2015) for a historical overview of this debate. Food security and food self-sufficiency have historically been an important issue in policy debates going back to at least early 19th century discussions in England about the Corn Law, and featured prominently in the Doha round of WTO negotiations. However, serious quantitative analysis is rare in this literature. Our paper attempts to fill the gap by providing a theoretical and quantitative framework for rigorously examining the issue.

Our paper is related to two strands of literature. First, it is related to a large macro-development literature on understanding the agricultural productivity gap (APG) in developing countries. See, e.g., Restuccia et al. (2008), Vollrath (2009), Lagakos and Waugh (2013), Gollin et al. (2014), Tombe (2015), Herrendorf and Schoellman (2015), Alvarez (2020), Hamory et al. (2021), and Gai et al. (2021). We examine food security risk as a new potential source of the APG. Donovan (2020) is a closely related paper. He studies how risk may reduce farmers' incentive of using intermediate inputs in agriculture and lower the agricultural productivity, but he studies closed economy and does not consider trade nor examine the food security risk faced by urban households. Second, our research is related to a recent literature on trade under uncertainty. See, e.g., Pierce and Schott (2016), Handley and Limao (2017), Alessandria et al. (2019), Steinberg (2019), Caselli et al. (2019), and Allen and Atkin (2022). Different from these studies, we examine the implication of agricultural risk and policy on sectoral labor allocation and the APG. A recent research that is complementary to ours is Adamopoulos and Leibovici (2024), who study how international trade risks affect food security and the pattern of production and trade. We instead investigate how food security affects internal migration and allocation decisions.

2 Data and Evidence

There is substantial heterogeneity in food price volatility across countries. This volatility is also systematically related to a country's level of development. Lower-income countries have materially higher volatility in food prices relative to other consumer goods and services.

To show this, data on food and non-food consumer prices is required. The former is readily available. To infer the latter, we combine data on food expenditure shares and food and general consumer price indices to back out the implied non-food average price. Expenditure shares are from the World Bank Global Consumption Database (GDC; version 2014), supplemented where with data from the U.S. Department of Agriculture's International Consumer and Food Industry Trends. Food and general price indices are from the UN Food and Agriculture Organization's Food Price Index database. We then infer relative food prices in country i from

$$\frac{P_i^a}{P_i^n} = \frac{P_i^a}{(P_i - P_i^a s_i^a)/(1 - s_i^a)}, \tag{1}$$

where s_i^a are food expenditure shares, P_i is the general consumer price index, and P_i^a is the food price index. The available data allows this measure to be constructed for 138 countries for which we also have real GDP per capita data available. We measure the volatility in relative food prices between 2000 and 2022 in two ways, and plot the results against each country's real GDP per capita in Figure 1. First, we report the standard deviation in log relative food prices. Second, we report the average absolute value of monthly changes in relative food prices.[1]

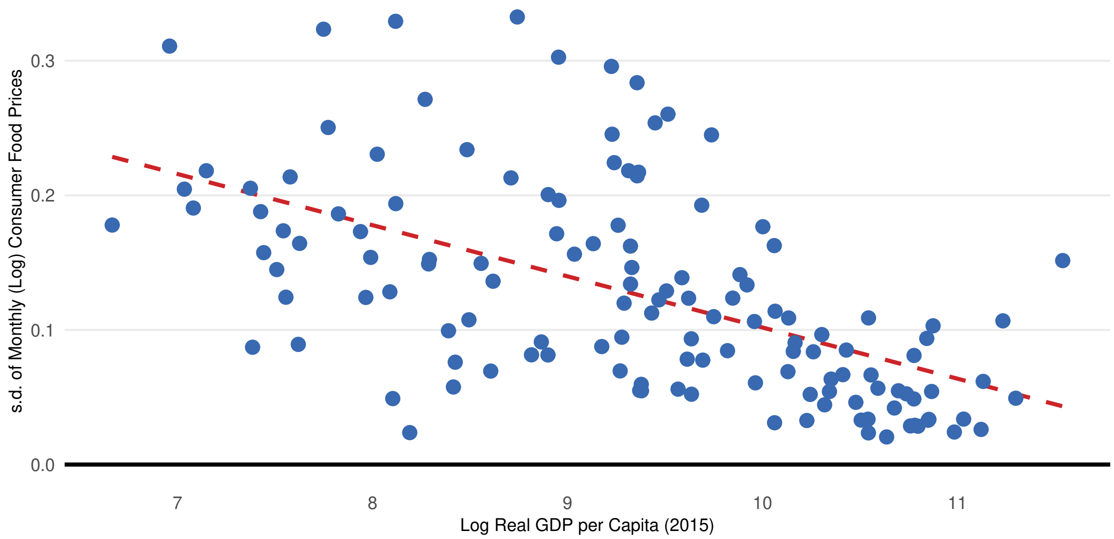
We find a strong negative relationship between a country's level of development and the relative volatility in consumer food prices. On average, a 10 percent increase in a country's real GDP per capita is associated with a 0.038 point decrease in the standard deviation of log relative food prices. Among countries in the top decile of real GDP per capita in our sample, the average standard deviation in relative food prices is 0.059. Countries in the bottom decile have an average volatility that is three times higher, at 0.178. Among the top decile, the average monthly change in relative food prices is just over one percent. That is, relative food prices typically increase or decrease by just over one percent from one month to the next. Among the bottom decile, however, this average monthly change is over 3.7 percent. The dispersion in both measures of relative food price volatility is also higher among lower income countries, whereas higher income countries are much more similar their degree of volatility. This result is not particular to the food expenditure share databases we use to infer relative food prices. Using the shares for a smaller sample of countries from the International Comparisons Program (2017) reveals a similar result.

Food expenditure shares are important for more than just inferring relative food prices. They will be an important component of the model based quantitative analysis to come. In addition, differences in household food expenditures between those in rural agricultural areas compared to those in urban areas will also matter. The World Bank GDC separately reports expenditure patterns in both rural and urban areas for a selection of countries. We display these in Figure 2. While this does not capture the higher income countries in our previous sample, the difference in expenditure shares between rural and urban areas shrinks as a country's level of development increases. Among countries in the bottom decile, the average food expenditure share is 68 percent among rural households and 50 percent among urban households. Countries in the top decile, meanwhile, have average food expenditure shares of 44 percent and 39 percent, respectively. For clarity, this sample of countries includes only

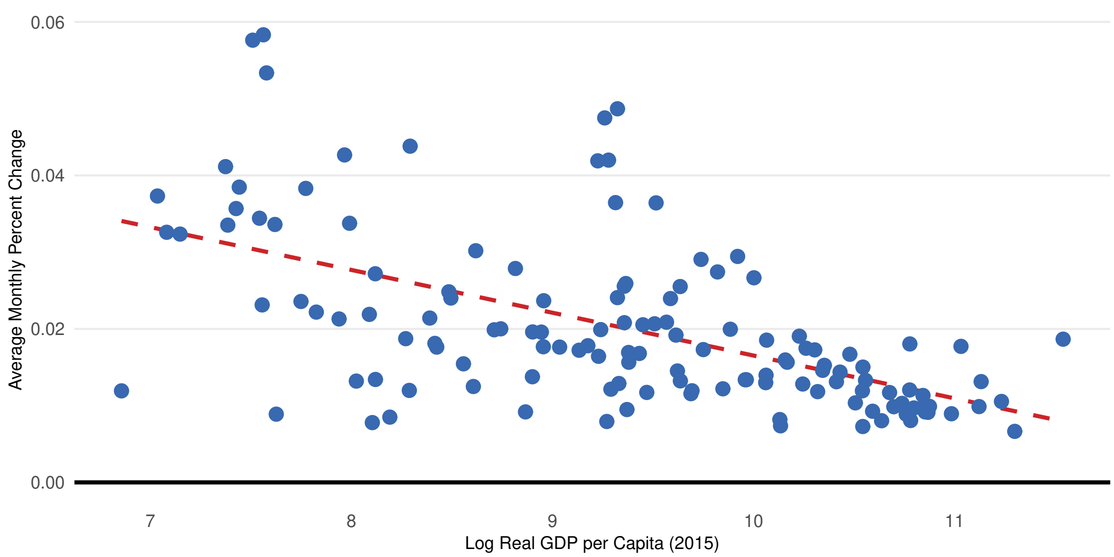
[1] The standard deviation in the absolute value of month-over-month changes also shows a similar pattern, so this is not due to differences in persistent growth rates.

Figure 1: Relative Food Price Volatility

(a) Standard Deviation



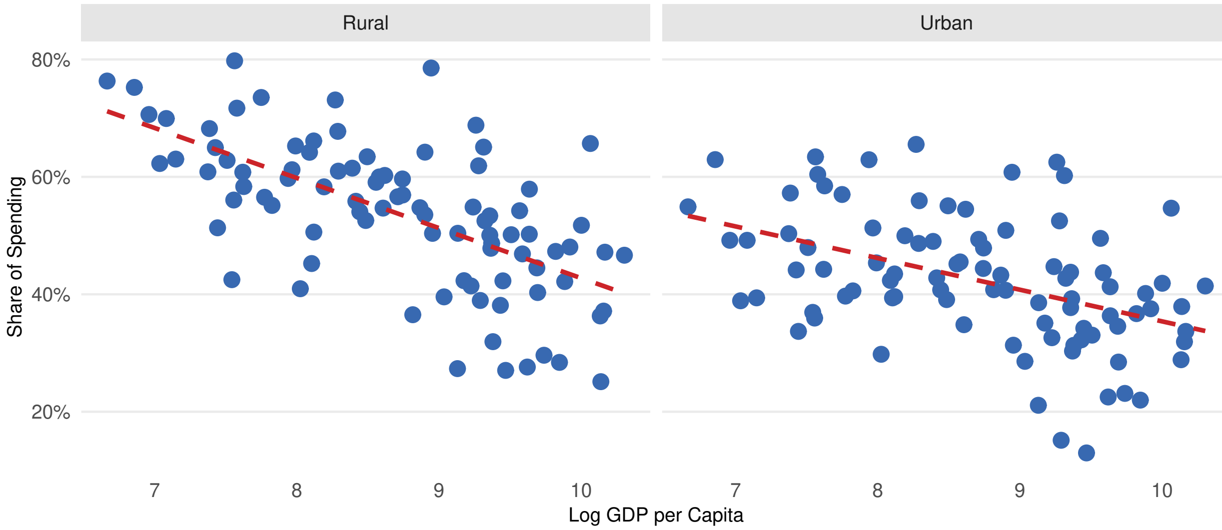
(b) Average Monthly Changes



Note: Panel (a) displays the standard deviation in relative food prices between 2000 and 2022 for each country against its real GDP per capita in 2015. Panel (b) displays the average absolute value of month-over-month percentage changes in relative food prices over the same time period. Of the 138 countries for which we can calculate these data, five outlier (lower income) countries with substantially higher volatility are trimmed from both panels.

Source: Authors' calculations. See text for details.

Figure 2: Household Food Expenditure Shares



Note: Displays the average share of total expenditures allocated to food for both rural and urban households.

Source: Authors' calculations primarily from the World Bank Global Consumption Database. See text for details.

those with real GDP per capita levels in 2015 of less than $30,000 (USD) and therefore is a more restricted sample than displayed in Figure 1.

Volatility in relative food prices may also be associated with a higher share in employment allocated to agricultural activities in lower income countries. As we've seen, lower income countries systematically experience greater degrees of relative food price volatility. But agriculture's share of aggregate employment is also naturally and inversely related to a country's level of development. Regressing agriculture's share of employment (in 2015) for the 133 countries displayed in Figure 1 (a) on their respective (log) real GDP per capita and food price volatility, we find a modestly significant positive coefficient of 27.38 (p-value of 0.051) on price volatility. This implies that higher volatility may be associated with greater agricultural employment shares even controlling for a country's level of development. This is a quantitatively large effect, with a +0.2 increase in the standard deviation in relative food prices (just under the range spanned by lower income countries displayed in Figure 1) would be associated with a nearly 5.5 percentage point increase in agriculture's share of total employment. To be clear, however, while the same association between agriculture's employment share and volatility is positive when using average monthly changes, it is not statistically significant (p-value of 0.224).

3 A Model of Food Security Risk and Labor Allocation

Consider a two-country model where the countries are indexed by $i \in \{1, 2\}$. In each country, there is a representative rural household who supplies labor to an agricultural or non-agricultural sector within the rural area. Rural household members differ in their agricultural and non-agricultural productivities. There is also a representative urban household who supplies labor within the urban area to the non-agricultural sector only. All households consume agricultural and non-agricultural goods, both of which are tradable between countries. We start by describing endowments and preferences within each country, where we abstract the country notation i wherever there is no confusion.

3.1 The Rural Household

Consider a measure N_i of rural households in country i, each of which consists of a continuum of members with heterogeneous abilities. Specifically, each individual is endowed with a pair of agricultural ability z_a and non-agricultural ability z_n. If an individual works in the agricultural (non-agricultural) sector, then the labor income is given by $w_a z_a$ ($w_n z_n$) where w_a and w_n are the wage rates of these sectors per unit of ability. Individuals choose their occupations based on their comparative advantage: An individual chooses to work in agriculture if $z_a/z_n > f$, where f is a cut-off level of abilities depending on the wage rates w_a and w_n. Without uncertainties, $f = w_n/w_a$ as in Lagakos and Waugh (2013).

If the distribution of ability z_a and z_n each follow a Frechet distribution, with dispersion parameter κ, then one can show that the share of household members working in agriculture is $\frac{1}{f^\kappa+1}$. This implies the dispersion parameter κ governs the wage elasticity of employment between agriculture to non-agriculture (Tombe and Zhu, 2019) in the rural area. The average agricultural ability among those who choose to work in agriculture is $(f^{\kappa}+1)^{\frac{1}{\kappa}}\Gamma(1-\frac{1}{\kappa})$, and the non-agricultural ability among those who work in non-agriculture is $(f^{-\kappa}+1)^{\frac{1}{\kappa}}\Gamma(1-\frac{1}{\kappa})$. With all this, one can also show that the total efficiency units of labor inputs in agriculture and non-agriculture are respectively given by

$$H_a(f) = (f^{\kappa}+1)^{\frac{1}{\kappa}-1}\Gamma(1-\frac{1}{\kappa}), \tag{2}$$

$$H_n(f) = (f^{-\kappa}+1)^{\frac{1}{\kappa}-1}\Gamma(1-\frac{1}{\kappa}). \tag{3}$$

Together with wages, the total income of this rural household is then

$$e_i(f_i; w_{ia}, w_{in}) = w_{ia}H_{ia} + w_{in}H_{in}. \tag{4}$$

Rural households' preferences are summarized by the following non-homothetic CES utility as in Yao and Zhu (2021) and Sposi et al. (2021),

$$u(C_i) = \frac{C_i^{1-\sigma}-1}{1-\sigma}, \tag{5}$$

where consumption C_i is implicitly defined as

$$\phi^{\frac{1}{\varepsilon}} C_i^{\frac{(1-\varepsilon)\mu_a}{\varepsilon}} C_{ia}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\phi)^{\frac{1}{\varepsilon}} C_i^{\frac{(1-\varepsilon)\mu_n}{\varepsilon}} C_{in}^{\frac{\varepsilon-1}{\varepsilon}} = 1. \tag{6}$$

The budget constraint is

$$N_i(P_{ia}C_{ia} + P_{in}C_{in}) = e_i. \tag{7}$$

Combining all of the above, one can show that the solution of C_{ia} and C_{in} each satisfy the following:

$$C_{ia} = \frac{\phi P_{ia}^{-\varepsilon} C_i^{(1-\varepsilon)\mu_a}}{\left[\phi P_{ia}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_a} + (1-\phi) P_{in}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_n}\right]^{\frac{\varepsilon}{\varepsilon-1}}}, \tag{8}$$

$$C_{in} = \frac{(1-\phi) P_{in}^{-\varepsilon} C_i^{(1-\varepsilon)\mu_n}}{\left[\phi P_{ia}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_a} + (1-\phi) P_{in}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_n}\right]^{\frac{\varepsilon}{\varepsilon-1}}}. \tag{9}$$

Substituting these into the budget constraint yields the following that implicitly solves C_i,

$$\phi P_{ia}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_a} + (1-\phi) P_{in}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_n} = (e_i/N_i)^{1-\varepsilon}, \tag{10}$$

or

$$\frac{\phi P_{ia}^{1-\varepsilon} C_i^{1-(1-\varepsilon)\mu_n} + (1-\phi) P_{in}^{1-\varepsilon} C_i^{1-(1-\varepsilon)\mu_a}}{(e_i/N_i)^{1-\varepsilon}} = C_i^{1-(1-\varepsilon)(\mu_a+\mu_n)}.$$

Once we have solved the consumption allocation between agricultural and non-agricultural goods, we can rewrite the rural household's problem as

$$\max_{f_i} \mathbb{E}\left[\frac{C_i^{1-\sigma} - 1}{1-\sigma}\right], \tag{11}$$

subject to

$$\phi P_{ia}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_a} + (1-\phi) P_{in}^{1-\varepsilon} C_i^{(1-\varepsilon)\mu_n} = (e_i/N_i)^{1-\varepsilon}, \tag{12}$$

$$e_i = w_{ia}(f_i^{\kappa} + 1)^{\frac{1}{\kappa}-1}\Gamma(1 - \frac{1}{\kappa}) + w_{in}(f_i^{-\kappa} + 1)^{\frac{1}{\kappa}-1}\Gamma(1 - \frac{1}{\kappa}). \tag{13}$$

Here, the expectation is over the realization of prices $\{P_{ia}, P_{in}\}$ and wages $\{w_{ia}, w_{in}\}$ that we describe later. The rural household chooses f_i to maximize expected utility before the prices and wages are realized.

3.2 The Urban Household

There is a measure N_i^u of urban households, who do not have access to agricultural production. Each urban household consists of a measure one of members whose non-agricultural ability is homogeneous at $\bar{h}_i$. Their income is simply $N_i^u \bar{h}_i w_{in}$, and their utility function is identical to that of the rural household. We denote the urban household's consumption of agricultural and manufactured goods as C_a^u and C_m^u, respectively.

3.3 Production and Trade

Production and trade decisions are static. There is a continuum of goods in the agricultural (a) and non-agricultural (n) sectors. The production function for good $z \in [0, 1]$ in sector $k \in \{a, n\}$ of country i is given by

$$Y_{ik}(z) = A_{ik}(z) L_{ik}(z)^{\beta_k} \left[M_{ika}^{\gamma_{ka}}(z) M_{ikn}^{\gamma_{kn}}(z) \right]^{1-\beta_k}, \tag{14}$$

where $Y_{ik}(z)$, $A_{ik}(z)$, and $L_{ik}(z)$ are output, productivity, and labor input of variety z, respectively, and M_{ika} and M_{ikn} are intermediate inputs used by variety z from final output of sectors a and n, respectively. Here $A_{ik}(z)$ is the realization of a random variable Z_{ik} that follows a Frechet distribution with location parameter T_{ik} and dispersion parameter θ as in Eaton and Kortum (2002). The unit cost of a bundle of input of good k in country i is then given by

$$v_{ik} = w_{ik}^{\beta_k} \left[p_{ia}^{\gamma_{ka}} p_{in}^{\gamma_{kn}} \right]^{1-\beta_k}, \tag{15}$$

which is the same within a sector but not necessarily across sectors.

Both agricultural and non-agricultural goods are tradable but subject to iceberg trade costs. Specifically, if one unit of agricultural or non-agricultural goods shipped from country j to country i, then $1/\tau_{ijk}$ units arrive. We further assume that $\tau_{iik} = 1$. If country j sells one unit of variety z of good k to country i, then the cost is

$$p_{ijk}(z) = \frac{\tau_{ijk} v_{jk}}{A_{jk}}. \tag{16}$$

Country i buys this variety z of good k from the cheapest source, which implies that $p_{ik}(z) = \min\{p_{iik}(z), p_{ijk}(z)\}$. The composite good in each sector k is then an aggregator of varieties $z \in [0, 1]$:

$$Q_{ik} = \int_0^1 \left(q_{ik}(z)^{\frac{\eta-1}{\eta}} dz \right)^{\frac{\eta}{\eta-1}}, \tag{17}$$

where η governs the within-sector elasticity of substitution. The price is then

$$P_{ik} = \Gamma(\Phi_{ik})^{-\frac{1}{\theta}}, \tag{18}$$

where Γ is the Gamma function evaluated at $(1 - (\eta - 1)/\theta)^{\frac{1}{1-\eta}}$ and

$$\Phi_{ik} = T_{1k}(v_{1k}\tau_{i1k})^{-\theta} + T_{2k}(v_{2k}\tau_{i2k})^{-\theta}. \tag{19}$$

Finally, the share of country j's expenditure on sector-k goods from country i, π_{jik}, is given by

$$\pi_{jik} = \frac{T_{ik}(v_{ik}\tau_{jik})^{-\theta}}{\Phi_{jk}}. \tag{20}$$

These components are relatively standard in Eaton and Kortum (2002) frameworks so we omit detailed derivations here.

3.4 Equilibrium

We start by describing the goods market clearing conditions. For each good k, market clearing requires

$$Q_{ik} = \bar{C}_{ik} + (1-\beta_a)\gamma_{ak}\frac{\pi_{1ia}P_{1a}Q_{1a} + \pi_{2ia}P_{2a}Q_{2a}}{P_{ik}} + (1-\beta_n)\gamma_{nk}\frac{\pi_{1in}P_{1n}Q_{1n} + \pi_{2in}P_{2n}Q_{2n}}{P_{ik}}, \tag{21}$$

where the first term on the right-hand side $\bar{C}_{ik}$ is the aggregate domestic consumption given by $N_{ir}C_{ik} + N_{iu}C^u_{ik}$ and the second and the third terms are the quantities of good k used as intermediate inputs for agricultural and non-agricultural sectors, respectively.

The total sales of good k in country i is given by

$$R_{ik} = \pi_{1ik}E_{1k} + \pi_{2ik}E_{2k}, \tag{22}$$

where E_{ik} is country i's expenditure on good k given by

$$E_{ik} = P_{ik}\bar{C}_{ik} + (1-\beta_a)\gamma_{ak}R_{ia} + (1-\beta_n)\gamma_{nk}R_{in}. \tag{23}$$

As we described above, the rural households allocate members between agriculture and non-agriculture, while urban households only work in non-agriculture. As a result, labor markets clear separately for both sectors:

$$w_{ia}H_{ia} = \beta_a R_{ia}, \tag{24}$$

$$w_{in}(H_{in} + N^u_i\bar{h}_i) = \beta_n R_{in}. \tag{25}$$

Country i's import of good k is given by $P_{ik}Q_{ik}\pi_{ijk}$, while the export is $\pi_{jik}P_{jk}Q_{jk}$. Trade balance condition requires

$$P_{ia}Q_{ia}\pi_{ija} + P_{in}Q_{in}\pi_{ijn} = \pi_{jia}P_{ja}Q_{ja} + \pi_{jin}P_{jn}Q_{jn}. \tag{26}$$

A competitive equilibrium consists of a allocations $\{f_i, c_{ia}, c_{in}\}_{i=1,2}$ for the rural household and $\{c^{\text{urban}}_{ia}, c^{\text{urban}}_{in}\}_{i=1,2}$ for the urban household, prices and wages $\{P_{ia}, P_{in}, w_{ia}, w_{in}\}_{i=1,2}$, and trade shares $\{\pi_{ija}, \pi_{ijn}\}_{i,j=1,2}$, such that rural and urban households of each country maximize their utility subject to their budget constraints, and firms in each country maximize their profits.

3.5 Uncertainty and Characterization of the Model

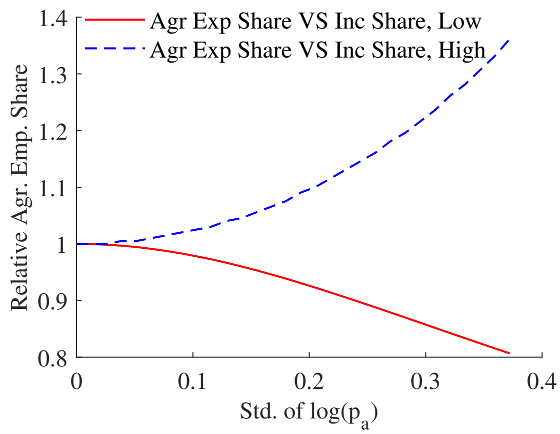
We use a simple example to illustrate how uncertainty in prices and wages affects structural transformation in our model. Consider an economy without trade ($\tau_{ijk} = \infty$) and input-output linkages ($\beta_a = \beta_n = 1$). For country i, the only uncertainty arises from the volatility in agricultural productivity, T_{ia}, that applies to all varieties in agriculture. In this simple case, the agricultural price P_{ia} and wage w_{ia} are volatile, while the non-agricultural price P_{in} and wage w_{in} are constant. The larger the volatility of T_{ia}, the larger the volatility in P_{ia} and w_{ia}.

The risk exposure differs fundamentally between the rural and the urban households. For the urban household, the only uncertainty is the volatility in agricultural price P_{ia}. Hence, volatility in agricultural productivity imposes an expenditure risk to the urban household. The rural household at country i then faces uncertainty in agricultural price P_{ia} and wage w_{ia}, while the urban household only faces uncertainty in agricultural price P_{ia}.

As a result, if the volatility of agricultural productivity is larger, then the urban household would prefer the rural household to allocate more labor to agriculture to dampen the price volatility. For rural household, however, the labor allocation is more complicated. Agricultural income (depending on w_{ia}) changes in the same direction as agricultural expenditure (depending on P_{ia}). If the agricultural expenditure share is high (or the portion of income from agricultural sector is low), then a higher volatility implies that the rural household will allocate more labor to agriculture to minimize the expenditure risk. On the contrary, if the agricultural expenditure share is low (or the portion of income from agricultural sector is high), then a higher volatility implies a *lower* agricultural employment share to minimize the income risk. This is illustrated in Figure 3, where we illustrate the optimal allocation of labor of the rural household. We normalize the agricultural employment to one for the riskless case, and then consider how a mean-preserve spread in agricultural productivity affects the labor allocation.

We further consider the problem of a social planner who maximizes welfare by equating

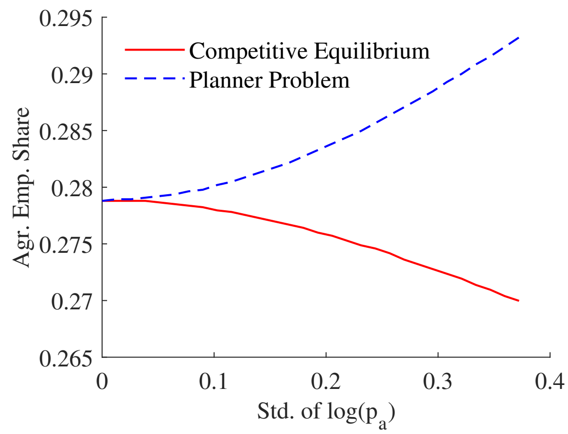
Figure 3: Agricultural Employment Share of Rural Households



Note: This figure illustrates the allocation of labor to the agricultural sector among rural households. We normalize the agricultural employment to one for the riskless case, and then consider how a mean-preserve spread in agricultural productivity affects the labor allocation.

income (and hence consumption) per capita between rural and urban households. Figure 4 contrasts the solution from the competitive equilibrium with the planner's problem. Without any risk, the rural household allocates a portion of labor to agriculture that coincides with the planner's solution. When the volatility increases, however, the rural household will reduce agricultural employment share to minimize income risk associated with p_a. The planner, however, would like the rural household to increase its agricultural employment share to reduce the expenditure risk faced by urban households. The competitive equilibrium is no longer efficient. The key inefficiency in our model is that the urban household only works in non-agriculture, while the rural household can choose their labor allocation between sectors. This asymmetry implies different risk exposure between households and hence there is room for policies to improve social welfare. We will conduct policy analysis in the next section after calibrating our framework.

Figure 4: Social Planner's Problem



3.6 Complete Financial Markets with Arrow-Debreu Securities

Consider an environment with complete financial markets (Arrow-Debreu securities) to highlight the role of risk sharing among households. Denote the state space as $s \in \mathbb{S}$ that occurs with probability π_s. We further denote the price of the numeraire at state-s as $\mathcal{P}_s$, and the rural household's income and expenditure at state-s as $\mathcal{I}_s$ and $\mathcal{E}_s$. The rural household's problem is then described as follows:

$$\max \sum_s \pi_s \frac{C_s^{1-\sigma} - 1}{1 - \sigma},$$

where C_s is defined as in Equation (6), subject to

$$N(P_{a,s}C_{a,s} + P_{n,s}C_{n,s}) = \mathcal{E}_s,$$

$$\sum_s \mathcal{E}_s \mathcal{P}_s = \sum_s \mathcal{I}_s \mathcal{P}_s.$$

The Lagrangian can be written as

$$\mathscr{L} = \sum_s \pi_s \frac{C_s^{1-\sigma} - 1}{1 - \sigma} - \lambda \left[\sum_s \mathcal{E}_s \mathcal{P}_s - \sum_s \mathcal{I}_s \mathcal{P}_s \right].$$

Take the first order condition with respect to C_s:

$$\pi_s C_s^{-\sigma} = \lambda \mathcal{P}_s \frac{\partial \mathcal{E}_s}{\partial C_s}.$$

We can solve out

$$C_s = \left(\frac{\lambda \mathcal{P}_s \frac{\partial \mathcal{E}_s}{\partial C_s}}{\pi_s} \right)^{-\frac{1}{\sigma}}.$$

Sum over all possible states to obtain

$$\sum_s \pi_s C_s^{-\sigma} = \lambda \sum_s \mathcal{P}_s \frac{\partial \mathcal{E}_s}{\partial C_s}.$$

We can then write λ as

$$\lambda = \frac{\sum_s \pi_s C_s^{-\sigma}}{\sum_s \mathcal{P}_s \frac{\partial \mathcal{E}_s}{\partial C_s}}.$$

Consumption can then be written as

$$C_s = \left(\frac{\mathcal{P}_s \frac{\partial \mathcal{E}_s}{\partial C_s}}{\sum_s \mathcal{P}_s \frac{\partial \mathcal{E}_s}{\partial C_s}} \right)^{-\frac{1}{\sigma}} \left(\frac{\pi_s}{\sum_s \pi_s C_s^{-\sigma}} \right)^{\frac{1}{\sigma}}.$$

We note that aggregate consumption C_s implies

$$\mathcal{E}_s = N \left(\phi P_{a,s}^{1-\varepsilon} C_s^{(1-\varepsilon)\mu_a} + (1-\phi) P_{n,s}^{1-\varepsilon} C_s^{(1-\varepsilon)\mu_n} \right)^{\frac{1}{1-\varepsilon}}.$$

We then have

$$\frac{\partial \mathcal{E}_s}{\partial C_s} = \frac{N}{1-\varepsilon} \left(\phi P_{a,s}^{1-\varepsilon} C_s^{(1-\varepsilon)\mu_a} + (1-\phi) P_{n,s}^{1-\varepsilon} C_s^{(1-\varepsilon)\mu_n} \right)^{\frac{\varepsilon}{1-\varepsilon}} \left((1-\varepsilon)\mu_a \phi P_{a,s}^{1-\varepsilon} C_s^{(1-\varepsilon)\mu_a - 1} + (1-\varepsilon)\mu_n (1-\phi) P_{n,s}^{1-}\right.$$

4 Quantitative Analysis on Food Security Policy

4.1 Calibration

We need to calibrate our framework before we use it to quantitatively assess the implications of food security policy especially on structural transformation and the APG.

We start by describing how we determine the parameters are common across countries. We have 9 parameters governing production and trade. We set the two trade elasticities (θ_a and θ_n) to 4 following Simonovska and Waugh (2014), and the elasticity of substitution across varieties within each industry (η) to 4 following Uy et al. (2013). We obtain the value of 6 parameters on input elasticities from Uy et al. (2013) as well. Specifically, We set the labor shares to be $\beta_a = 0.456$ and $\beta_n = 0.501$, and the share of intermediate inputs to be $\gamma_{aa} = 0.665$, $\gamma_{an} = 0.335$, $\gamma_{na} = 0.084$, and $\gamma_{nn} = 0.916$.

We have 5 parameters on preferences $\{\phi, \mu_a, \mu_n, \varepsilon, \sigma\}$. We choose $\phi = 0.350$, $\mu_a = 1$, $\mu_n = 3.678$, and $\varepsilon = 0.197$ following Yao and Zhu (2021). We choose the parameter σ governing the risk aversion to 4. We note that the implied relative risk aversion in our calibrated economy is below 4. With non-homothetic preferences, the relative risk aversion is inversely related to real income, as highlighted in Donovan (2020). The relative risk aversion is 4 only if households only consume the agricultural good, while it is around 1.8 if the household consumes mostly the non-agricultural good.[2]

We also need to determine κ which governs the migration elasticity. We note that in Tombe and Zhu (2019), κ is exactly the migration elasticity. In our framework, however, the migration elasticity is lower than the value of κ due to risk. The rural household has incentive to diversify between agricultural and non-agricultural employment to minimize income risk, reducing the migration elasticity. We set $\kappa = 3$ which implies a migration elasticity of around 1.6 in our model, not far from Tombe and Zhu (2019). We also note that we do not allow for labor reallocation after the realization of prices and wages, and hence

[2] One can show that if only agricultural/non-agricultural good is consumed, then the relative risk aversion is $1 - (1-\sigma)/\mu_a$ or $1 - (1-\sigma)/\mu_n$.

Table 1: Country-Specific Parameters

Parameter	Value	Target
(N_1, N_2)	$(0.501, 2.015)$	Rural population share
(N_1^u, N_2^u)	$(0.499, 2.196)$	Urban population share
(T_1, T_2)	$(-1.42, -2.44)$	Agricultural employment share
$(\sigma_{1a}, \sigma_{2a})$	$(0.985, 0.985)$	Price volatility of agricultural good
(τ_{12a}, τ_{21a})	$(3.984, 2.604)$	Trade shares
(τ_{12n}, τ_{21n})	$(1.474, 1.474)$	Trade shares

Notes: This table shows the value of country-specific parameters and targets.

our migration elasticity should be considered as the long-run migration elasticity.

For country-specific parameters, we use data moments of China in 2010 to restrict parameters of country i, and the rest of the world corresponds to country j. We normalize the population of China to be one, and hence N_1 and N_1^u represent the rural and urban population shares, respectively. Similarly, N_2 and N_2^u are the rural and urban populations of the rest of the world relative to China.

We parameterize the sectoral productivity T_{ik} as a product of the economy-wide TFP T_i and a random variable of sectoral productivity shocks T_{ik}^{ε}, the log of which follows a uniform distribution with a mean of zero and a standard deviation of σ_{ik}. To simplify the calibration, we assume that the non-agricultural productivity T_{in} is non-stochastic, and hence all uncertainty arises from the agricultural productivity T_{ia}. We further assume that T_{i1} and T_{i2} are perfectly correlated across countries with the same standard deviation. We then choose $\sigma_{1a} = \sigma_{2a} = 0.985$ to match the standard deviation of relative price (agricultural versus non-agricultural goods) at country i of 0.693. We note that the volatility of prices are sufficient statistics for our analysis of households' labor allocation, and hence the assumption on the source of volatility is less important. We choose the level of TFP (T_i) to match the agricultural employment shares of both countries.

We also need to determine the trade costs τ_{ijk}. We have in total 4 trade costs but only three trade share moments in the data, a well-known problem in the literature (Waugh, 2010). We hence assume the non-agricultural trade costs are symmetric, i.e., $\tau_{12n} = \tau_{21n}$. We choose these trade costs to match three moments: agricultural export accounts for 3.2 percent of total export of China; agricultural import accounts for 3.6 percent of total import of China; total export accounts for 33.8 percent of China's GDP.

4.2 Complete Financial Market with Arrow-Debreu Securities

4.3 Food Security Policy

Given the inefficiency, we now consider the macroeconomic implications of relevant food security policy. We focus on policies in country 1 (China), abstracting from policy interventions in country 2 (rest of the world).

Consider a transfer from urban to rural households within country 1 that subsidizes agricultural employment at a flat rate of τ_1 per unit of labor. The rural household, in turn, commits to give a fraction τ_2 of their total income, which is subject to income volatility arising from w_{ia}, to the urban household. Technically, this transfer is equivalent to an insurance contract between the rural and urban households. This contract is motivated by real-world policies that governments in many countries subsidize agriculture to minimize food security risk. Note that this contract could potentially reduce risk for both households: the rural households reduces their income risk as a portion of volatile income is replaced by a flat rate of subsidy; the urban households reduces their expenditure risk as the revenue received from the rural household is positively correlated with their expenditure on the agricultural good.

This contract is hence characterized by $\{\tau_1, \tau_2\}$. We assume the urban household takes all the social surplus, or in other words, the rural household has no bargaining power in determining this contract. Technically, this implies that, conditional on τ_1, we choose τ_2 such that the rural household is indifferent between participating in this contract or not, or the individual rationality constraint is binding for the rural household. This is consistent with the common assumption in the political economy literature that the government could be urban-biased. The timing is that the urban household proposes this contract $\{\tau_1, \tau_2\}$. The rural household chooses its agricultural employment share. Then the households observe the price, produce, and the contract is enforced. We solve this problem with a backward induction, i.e., given the contract, the rural household chooses its agricultural employment share first. Taking this into account, the urban household determines τ_1 that maximizes the expected utility.

Table 2 contrasts the baseline calibrated economy and the economy with this insurance contract. When we allow for this insurance contract, the optimal subsidy rate τ_1 is large: it is around two thirds of expected agricultural wage rate. This is consistent with prevalent subsidy policies to the agricultural sector in the real world. With this insurance, the rural household allocates more labor to the agricultural sector, and nationwide agricultural employment share increases from 25.8 percent in our baseline calibration to 31.4 percent. This larger agricultural employment share substantially dampens agricultural price volatility, as the standard deviation of the agricultural price reduces by around 12 percent. This is mostly because, with more agricultural employment, agricultural output is further away from the subsistence requirement, and hence agricultural price does not increase as much when the economy faces a low agricultural productivity shock. Consumption volatility of both rural and urban households also declines. As shown in Table 2, the standard deviation of real consumption, C and C^u, reduces both rural and urban households. The decline in consumption volatility is a result of both dampened price volatility and risk sharing between households. For the urban household, we further calculate their net agricultural expenditure, i.e., the expenditure on agricultural good net of the payment received from the rural household (which is zero in the baseline). This net expenditure reduces by around 16 percent, another evidence that the contract reduces expenditure risk faced by the urban household.

We note that no one lose with this contract, and hence the social welfare must be higher. This welfare gain is entirely from risk sharing between households. Despite higher welfare, the real GDP measured with baseline price declines by 1.2 percent, and agricultural labor productivity declines by 12 percent. The nominal APG, measured as differences in value added per worker between sectors, enlarges by 31.5 percent. Our experiment highlights that the increased APG and reduced GDP may not be inefficient in terms of welfare. In fact, a stand-in government could potentially implement a taxation and transfer policy like the insurance contract we specified above to improve social welfare despite enlarging the APG.

Our research yields important policy implications. The APG is widely discussed in the literature, see for instance Restuccia et al. (2008), Lagakos and Waugh (2013), Gollin et al. (2014), Herrendorf and Schoellman (2015), Chen (2020), Lagakos et al. (2020), and Gai et al. (2021). Specifically, the APG is often viewed as a result of frictions, such as migration costs, that impede the optimal allocation of labor between rural and urban area. Our results highlight, however, that the APG could be an efficient outcome arising from the risk-sharing incentives of the urban household, rather than caused by frictions.

In addition, with this insurance contract, agricultural import further reduces to only 1.6 percent of total import, while agricultural export more than doubles. This suggests that the risk consideration indeed acts as an implicit trade barrier of the agricultural good, despite no explicit trade cost changes.

4.4 Urban Bias Versus Rural Bias

We now discuss on our assumption that the urban household takes all the social surplus from the contract. This is consistent with the urban bias in developing countries that has been discussed in the development and political economy literature. Suppose instead that we assume the rural household takes the social surplus. Specifically, conditional on τ_1, we choose τ_2 such that the urban household's individual rationality constraint is binding. The rural household then determines τ_1 that maximizes the expected utility. This corresponds to the case that the government is biased towards the rural household, perhaps due to strong influence of farmers in election politics, as in many developed countries.

The third column of Table 2 shows the results associated with this alternative specification

Table 2: Equilibrium with/without Insurance

	Baseline	Optimal insurance contract	
		Urban bias	Rural bias
Optimal subsidy rate (τ_1/w_a, %)	–	65.3	33.2
Agr. emp. share (%)	25.8	31.4	28.5
Volatility (standard deviation)			
Agricultural price	0.693	0.610	0.654
Rural consumption	0.022	0.013	0.018
Urban consumption	0.133	0.121	0.127
Urban net agr. expenditure	0.129	0.101	0.112
Real GDP (Δ, %)	–	-1.2	-0.4
Real agr. labor productivity (Δ, %)	–	-12.0	-6.0
Nominal APG (Δ, %)	–	$+31.5$	$+14.2$
Agr. import (% of total import)	3.6	1.6	2.4
Agr. export (% of total export)	3.2	7.1	4.9

Notes: This table displays the equilibrium moments for our model with and without the rural-urban insurance. See text for details.

(rural bias). The results remain qualitatively the same: Even with rural bias, the insurance contract also implies a larger agricultural employment share than the baseline, a lower real GDP, lower agricultural labor productivity, and an enlarged APG. That again highlights that the enlarged APG does not arise from the assumption that the urban household takes all surplus. Instead, the enlarged APG is an outcome of risk sharing incentives among households.

Assuming the rural household takes all surplus does affect our results quantitatively. Specifically, the optimal subsidy rate is now around one third of agricultural wage, much lower than that of the urban-biased setup despite still large in magnitude. The risk sharing between households is substantially less. This suggests that the rural household has different risk sharing requirements than the urban household. The nominal APG increases by 14 percent in this case, a magnitude smaller than that of the urban-biased setup.

The comparison between rural- and urban-biased policy sheds interesting lights on cross-country comparison. It is usually argued that policies in rich countries are often rural-biased or pro farmers, while poor countries often implement policies that are urban-biased or pro urban residents (Hayami and Ruttan, 1971). Our framework implies that the APG should then be higher in poor countries than in rich countries, consistent with findings in Gollin et al. (2014). In addition, our framework suggests that the insurance mechanism generates an APG regardless of the rural- versus urban-bias. This is also consistent with the reality that even in rich countries we still observe an APG in the data (Gollin et al., 2014).

5 Conclusion

Food security risk is an important topic that has long been discussed by development economists and policy makers across countries. However, there has been no quantitative study of the issue in the recent macro-development literature. In this paper, we provide a theoretical and quantitative framework to examine the role of food security risk in structural transformation and policies for mitigating food security risk. We provide evidence that poor countries indeed face higher food price volatility and therefore food security risk could be an important impediment to structural transformation of these economies. We also show that risk sharing arrangements between urban and rural households within a country improves welfare, despite reducing real GDP and the enlarging APG. Such arrangements also manifest themselves as implicit trade barriers to the agricultural good, increase agricultural employment share, and slow down structural transformation. Finally, we show that political factors such as urban bias or rural bias could have a direct impact on the type of risk sharing arrangements, and consequently implicit trade barriers and the APG.

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Appendix

A An Illustrative Model

To begin, we use a highly stylized model to illustrate the core intuition behind the theoretical framework that we will use for examining the role of food security risk in structural transformation.

To highlight the role of food security risk on labor allocation between agriculture and non-agriculture, consider a small open economy with free trade and no labor market frictions. Agents in this economy have identical Stone-Geary utility functions given by

$$u\left(c_a, c_m\right) = \varphi_a \ln\left(c_a - \overline{c}\right) + \varphi_m \ln\left(c_m\right),$$

where c_a and c_m are consumption of internationally tradable agricultural and manufacturing goods, respectively. Let p_a and p_m be the international prices of the two goods. The prices are volatile, but agents choose their consumption after the realization of the prices.

Agent choose consumption to maximize $u\left(c_a, c_m\right)$, subject to their total expenditures $p_a c_a + p_m c_m$ not exceeding their income e. This implies agricultural and manufacturing consumption are respectively

$$c_a = \varphi_a p_a^{-1}\left(e - p_a\overline{c}\right) + \overline{c},$$
$$c_m = \varphi_m p_m^{-1}\left(e - p_a\overline{c}\right),$$

and therefore the agent's indirect utility is

$$v\left(e, p_a, p_m\right) = \ln\left(\frac{p_a}{P}\right) + \ln\left(\frac{e}{p_a} - \overline{c}\right),$$

where

$$P = \left(\frac{p_a}{\varphi_a}\right)^{\varphi_a} \left(\frac{p_m}{\varphi_m}\right)^{\varphi_m}$$

is the ideal price index.

There are two types of agents in the economy: farmers and urban workers. The representative farmer is endowed with an agricultural production technology:

$$y_a = A_a l_a,$$

where A_a is the domestic agricultural productivity and l_a is the time devoted to farming by the representative farmer. The farmer is also endowed with one unit of time, which could be used for farming or work in non-agriculture that pays a wage rate w_m. So, the farmer's income is

$$e = p_a A_a l_a + w_m (1 - l_a).$$

Farmers have to decide their labor allocation before the shocks are realized. So, the farmer's problem becomes

$$\max_{0 \le l_a \le 1} E \left[\ln\left(\frac{p_a}{P}\right) + \ln\left(\frac{e}{p_a} - \bar{c}\right) \right]$$

which is equivalent to

$$\max_{0 \le l_a \le 1} E \left[\ln\left(A_a l_a + \frac{w_m}{p_a} (1 - l_a) - \bar{c} \right) \right].$$

Mathematically, this is equivalent to a portfolio choice problem in finance, with two asset returns being A_a and $\widetilde{A}_m = w_m/p_a$. If $A_a < \widetilde{A}_m$, which is equivalent to $\frac{A_a}{A_m} < \frac{p_m}{p_a}$ or the farmer does not have comparative advantage in agriculture, the optimal choice of l_a is zero and the farmer buys agricultural good from the international market.

With shocks, however, even if $E[A_a] < E\left[\widetilde{A}_m\right]$, the farmer may still choose positive l_a if A_a is less risky than $\widetilde{A}_m$. In a sense, the risk of $\widetilde{A}_m = w_m/p_a$ is the food affordability risk or food security risk. Due to the subsistence constraint $\bar{c}$, farmers with lower income (because of lower A_a and/or lower $\widetilde{A}_m$) are more risk averse. Thus, the effect of food security risk on labor allocation is larger the poor the farmers are. This may partially explain why poorer countries import less food and rely more on domestic agricultural production despite lower productivity in agriculture.

Urban workers, by contrast, do not have access to the agricultural technology. So, an urban worker's income is simply w_m and their expected utility is

$$E\left[\ln\left(\frac{p_a}{P}\right) + \ln\left(\frac{w_m}{p_a} - \bar{c}\right)\right]$$

Without agricultural technology, urban workers cannot diversify their risk by working in domestic agriculture. There is a potential gain of trade, then, between farmers and urban workers. In this context, government purchases of food from domestic farmers that are resold to urban workers is a way to achieve such risk sharing. Some other food self-sufficiency policies may also be interpreted as an effort to help urban workers to diversify food affordability risk or food security risk.