Agricultural Risk, Intermediate Inputs and Cross-Country Productivity Differences*

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Abstract

Agricultural labor productivity is key for understanding aggregate cross-country income differences. One important proximate cause of low agricultural productivity is the low use of intermediate inputs, such as fertilizers, in developing countries. This paper argues that farmers in poor countries rationally choose to use fewer intermediate inputs because it limits their exposure to large uninsurable risks. I formalize the idea in a dynamic general equilibrium model with incomplete markets, subsistence requirements and idiosyncratic productivity shocks. Quantitatively, the model accounts for two thirds of the difference in intermediate input shares between the richest and poorest countries. This has important implications for cross-country productivity. Relative to an identical model with no productivity shocks, the addition of agricultural shocks amplifies per capita GDP differences between the richest and poorest countries by nearly eighty percent.

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1 Introduction

Differences in agricultural output per worker between the richest and poorest countries are significantly larger than differences in aggregate output per worker (Caselli, 2005; Restuccia, Yang, and Zhu, 2008). In spite of this, over eighty percent of people are employed in agriculture in the poorest countries. Since developing countries employ a large fraction of the population in a particularly unproductive sector, basic accounting suggests that understanding agricultural productivity differences are key in understanding aggregate differences.

One possible cause of these agricultural productivity differences is that farmers in developing countries use fewer intermediate inputs, such fertilizers, pesticides, and specialized seeds. While intermediate inputs have been recognized as the major embodiment of modern scientific farming since at least Schultz (1964), they are still severely underutilized in developing countries. Empirically, the intermediate input share in agriculture ranges from a low of 0.04 in Uganda to 0.40 in the United States, and is positively correlated with per capita income. Moreover, I document in Section 2 that this positive cross-country correlation does not exist in other sectors, suggesting that it may be an important margin for understanding why agriculture exhibits significantly lower productivity than nonagriculture in developing countries. The goal of this paper is to provide a theory to understand the correlation between intermediate input shares in agriculture and income levels across countries, and in turn, assess its role for productivity differences across countries.

The basic idea put forth in this paper is that farmers in developing countries rationally choose to utilize fewer intermediate inputs because it limits their exposure to productivity shocks in the agricultural sector. Because intermediate inputs must be chosen before the realization of the shock, farmers must consider the implications from the possibility of receiving a low shock. While these low shocks are bad for farmers in all countries, they are particularly disastrous for the extremely poor, as consumption moves very close to subsistence. To limit their exposure to the negative consequences of low realizations, farmers in developing countries decrease their ex-ante intermediate input choice. This lowers the intermediate input share in developing countries. Because developing countries use fewer intermediate inputs, output per worker decreases.

I formalize this idea in a dynamic general equilibrium model in which farm input decisions are made jointly with consumption choices. This implies that farmers do not take profit as given when choosing consumption, consistent with a large empirical literature reviewed by Morduch (1995). I further assume that farmers face idiosyncratic productivity shocks, incomplete markets, and subsistence requirements. These features imply that each possible shock realization is weighted by the probability of the shock *and* the farmer's realized marginal utility. As TFP decreases in poor countries, a farmer's income net of subsistence requirements moves closer to zero. This increases marginal utility at low shock realizations relative to farmers in rich countries, implying that poor farmers put more weight on bad potential outcomes. Since poor farmers are putting more weight on low realizations, they decrease their ex-ante intermediate input choices. This generates a "wedge" between the profit maximizing marginal value and price of intermediates. When aggregated, this implies a positive correlation between per capita income and the intermediate input share even though the underlying farm technologies are Cobb-Douglas. This in turn generates lower labor productivity in agriculture.

Quantifying the implications of the model requires taking a stand on two key features of the economy. The first is the distribution of productivity shocks in agriculture. Because the distribution of shocks controls the probability of getting a low realization, it naturally plays an important role. To pin this down, I utilize plot level data from ten Indian villages from the International Crops Research Institute for the Semi-Arid Tropics Village Level Surveys to discipline the distribution of productivity shocks. This data set has the benefit of recording a variety of inputs and outputs of individual farms that can be used to construct a distribution of shocks. I find that the variance is quite large. Second, motivated by the empirical results of Fafchamps, Udry, and Czukas (1998) and Reardon, Matlon, and Delgado (1988), I assume that savings is limited to storage of agricultural output. I discipline this storage technology by using a new set of storage depreciation rates from Africa, constructed by the African Postharvest Loss Information System (APHLIS), which is a set of estimates developed by their network of agricultural scientists. I find that depreciation rates are in the range of fifteen to thirty percent. These data imply that, while in principle farmers can save their way away from this risk, in practice it is extremely costly.

The main quantitative exercise then compares the stationary equilibrium of two economies, a rich and a poor economy, which are meant to capture the relevant differences between the richest and poorest countries in the world. The rich country is calibrated to match key sectoral features of the United States, including the intermediate input share and employment share in agriculture. The poor country differs along three dimensions. It has lower economy-wide TFP, intermediate inputs are more costly, and the depreciation of agricultural storage is higher. Naturally, these exogenous differences generate a lower labor productivity in the poor economy. To isolate the impact of agricultural productivity shocks, I ask how much *larger* productivity differences are in the model with shocks, relative to the identical model with no productivity shocks in the agricultural sector.

The main quantitative results are as follows. The model predicts that the poor economy has an intermediate input share of 0.20, compared to the U.S. intermediate share of 0.40. This is roughly two thirds of the difference found in the data, in which the poorest countries have intermediate input shares that average 0.09. By virtue of Cobb-Douglas production technologies, this difference is due entirely to the addition of agricultural productivity shocks. Differences in intermediate input shares then amplify output per worker differences in the model. Relative to an identical model without productivity shocks, the addition of shocks in the agricultural sector amplifies agricultural output per worker differences by fifty percent and GDP per worker differences by nearly eighty percent. Taken together, the quantitative results imply agricultural productivity shocks are key for understanding both intermediate input choices and labor productivity differences across countries.

Given the important quantitative role played by agricultural productivity shocks, a natural question is the extent to which agriculture-specific distortions (e.g. higher intermediate input prices in developing countries) drive the result. These have been emphasized recently by Buera and Kaboski (2009) and Restuccia, Yang, and Zhu (2008) in models without production risk. While not required to theoretically generate a correlation between income level and intermediate input share, they are key for the quantitative results. Decreasing the price of intermediate inputs to the U.S. level increases the intermediate input share in the poor country by over fifty percent. The model developed in this paper therefore provides another margin through which sector-specific distortions can impact cross-country productivity, when considered in conjunction with agricultural productivity shocks.

This is not the first paper to investigate the role of agriculture in understanding aggregate income differences. In addition to the work on price distortions discussed above, other explanations for cross-country agricultural productivity differences include occupational selection (Lagakos and Waugh, 2011), distortions limiting farm size (Adamopoulos and Restuccia, 2011), barriers that limit specialization through trade (Tombe, 2011), and the possibility of mismeasurement due to home production (Gollin, Parente, and Rogerson, 2004) or underestimation of value added (Herrendorf and Schoellman, 2011). This paper is most similar to previously mentioned work by Restuccia, Yang, and Zhu, who consider the role of price distortions in accounting for intermediate input usage across countries in a static two-sector growth model. The model developed here presents a new margin through which these distortions can impact productivity. Since high prices decrease expected income, farmers limit their exposure to risk by reducing intermediate input usage. This amplification shows up as a lower intermediate input share in poor countries, a result that cannot be generated by price distortions alone.

This paper also builds on a growing and largely distinct literature on household intermediate input decisions in developing countries. Evidence that households under-invest in intermediate inputs has been provided through both experiments (Duflo, Kremer, and Robinson, 2008) and household survey results (Zerfu and Larson, 2010). The latter finds an important role for savings in overcoming the risk inherent in using intermediate inputs, as I do here. Empirically, Rosenzweig and Binswanger (1993) find that production risk plays an important role in understanding intermediate input choices in India. Supported by experimental evidence, Duflo, Kremer, and Robinson (2011) argue that farmers are stochastically present-biased and do not fully understand their bias. I start from the assumption of full rationality, and find that the model can capture two thirds of intermediate input share differences between the richest and poorest countries. Dercon and Christiaensen (2011) test the implications of a model a with fixed cost of purchasing intermediate inputs and productivity shocks using household evidence from Ethiopia. They find that the empirical evidence supports the prediction that productivity shocks generate differences in fertilizer decisions. I investigate the aggregate cross-country implications of agricultural shocks in a two sector general equilibrium model, while remaining consistent with the aforementioned empirical results.

The rest of the paper proceeds as follows. Section 2 presents some motivating evidence of differences in intermediate input shares. In a cross section of countries, there is a strong positive correlation between income level and intermediate input shares in agriculture. This correlation does not exist in the manufacturing or service sectors. The model is described in Section 3. Section 4 provides some theoretical results to show how differences in TFP generate the cross-country correlation between the intermediate input share in agriculture and income level in a world with idiosyncratic shocks, incomplete markets, and subsistence requirements. Turning to quantitative results, Section 5 details the calibration and Section 6 presents the quantitative results of the model. Finally, Section 7 concludes.

2 Motivating Evidence

In this section, I document the statistics that motivate this paper. First, the intermediate input share in agriculture is positively correlated with per capita income in a cross section of countries. Of course, if nonagricultural sectors exhibit the same cross-country relationship, it seems unlikely that it can be a driving force for why agriculture is much *less* productive than nonagriculture in developing countries. In Section 2.2, I show that this positive correlation is limited to the agricultural sector. The manufacturing and service sectors show no such relationship between intermediate input shares and income, supporting the hypothesis that differences in intermediate input shares can help explain why agriculture is particularly unproductive in developing countries.

2.1 Intermediate Input Shares Across Countries

The intermediate input share in agriculture of country j is

$$\widehat{X}^j := \frac{p_x^j X^j}{p_a^j Y_a^j} \tag{2.1}$$

where X is the quantity of nonagricultural intermediate inputs, such as fertilizer, and Y_a is the quantity of agricultural output. The prices faced by the farmer are denoted p_x^j and p_a^j, and are denominated in local currency units. The price p_x^j takes into account any sector-specific distortions that increase the intermediate input price, such as transportation costs. Since I am interested in the decisions of farmers, these are the relevant prices. Note that because $\widehat{X}^j$ is unitless, it is directly comparable across countries. To construct this share, I utilize data from Prasada Rao (1993) for 84 countries in the year 1985, constructed from Food and Agricultural Organization (FAO) statistics.[1] Figure 1 plots the intermediate input share in agriculture with log PPP GDP per capita on the horizontal axis. This is take from the Penn World Tables version 7.0 (Heston, Summers, and Aten, 2011).

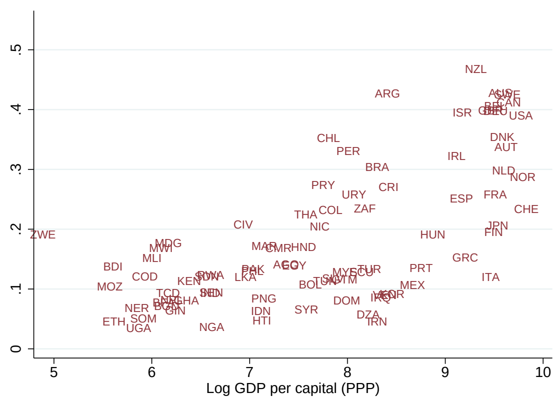


Figure 1: Intermediate Share in Agriculture. Sources are Prasada Rao and PWT.

There is a clear positive relationship between income level and the intermediate share in agriculture, with a correlation of 0.65. To give some idea of the difference between rich and poor countries, the intermediate share in Uganda is ten times lower than that of the United States. The tenth percentile country, as ranked by GDP per capita, has an intermediate share that is four times lower than the United States. The goal of this paper is the understand the importance of this positive correlation for aggregate productivity differences.[2]

[1] Prasada Rao actually reports intermediate input shares at international prices. He also reports purchasing power parities (PPP) of agricultural output and intermediate inputs, which can be translated into measures of relative prices. These two series are used to construct the intermediate input share used here. See Appendix A for further details.

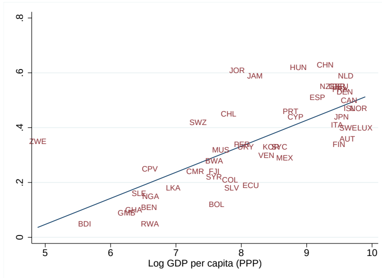
[2] If rich countries are producing different crops than developing countries, one might suspect that the result is driven by different production techniques for these different types of output. While I cannot directly test this, I do group countries by latitude to control for the type of agricultural production, and compare within-group variation. The same correlation holds within groups. These results are available upon request.

2.2 Comparison to Manufacturing and Services

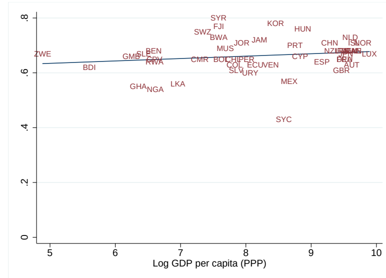
One key feature of agriculture is that production occurs during only the few harvesting seasons per year. Not constrained by these natural limitations, manufacturing and service sector firms are free to produce output throughout the year. This gives these firms two advantages in dealing with risk. First, if a "yearly" shock is realized, nonagricultural firms can adjust their input bundles throughout the year to respond to the shock realization. Because of the limited harvesting opportunities, this is not possible in agriculture. Second, if each production run brings with it an i.i.d. productivity shock, then the law of large numbers implies that simply increasing the number of production runs acts as a kind of insurance. Again, this is not possible in agriculture, because harvesting is limited to the optimal harvesting seasons. These natural production limitations put agricultural firms at a unique disadvantage to cope with production risk.

Evidence of this can be found by examining intermediate input shares in other sectors of the economy. Using domestically priced output and intermediate consumption statistics from the United Nations *System of National Accounts* (SNA), I first confirm the results presented in the last section- agricultural intermediate input shares are positively correlated with GDP per capita in a cross section of countries. This is not the case in manufacturing or services. Figure 2 plots domestically priced intermediate input shares for three sectors: (a) "Agriculture, hunting, forestry; fishing," (b) "Manufacturing," and (c) "Education; health and social work; other community, social and personal services," which is the closest measure of services in the SNA. The plot includes 49 countries with data available for all sectors, and are listed in Appendix A.

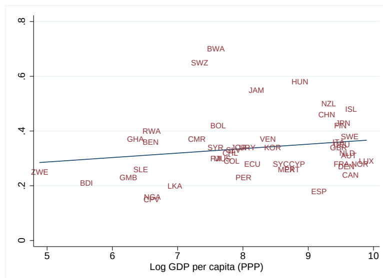
The difference between agriculture and the other two sectors is stark. The intermediate share in agriculture is positively correlated with income, as was also the case using statistics derived from the FAO data. The intermediate shares in manufacturing and services, however, do not exhibit this correlation. To summarize, Table 1 presents the results of a simple linear regression of the sectoral intermediate share on log PPP GDP per capita. In the linear regression, only agriculture has a slope significantly different from zero. The positive relationship between the intermediate input share and per capita income is therefore unique to the agricultural sector. The rest of this paper is devoted to developing a model to



(a) Agriculture, hunting, forestry; fishing



(b) Manufacturing



(c) Education; health and social work; other community, social and personal services

Figure 2: Intermediate Shares in Three Sectors for 1985. Source is UN SNA for intermediate input shares and PWT 7.0 for GDP per capita.

Table 1: Relationship between Intermediate Input Share and Log GDP per Capita (PPP), by Sector

	Agriculture	Manufacturing	Services
Constant	−0.43***	0.59***	0.21*
	(0.11)	(0.06)	(0.11)
Log GDP per capita (PPP)	0.10***	0.01	0.02
	(0.01)	(0.01)	(0.01)
R^2	0.52	0.03	0.03

Table notes: Standard errors are in parentheses. Significance at 0.01, 0.05, 0.1 levels denoted by ***, **, and *

understand the cause of this correlation in agriculture and assess its impact on cross-country productivity differences.

3 Model

As shown above, intermediate input shares are positively correlated with income level. In this section, I develop a multi-sector dynamic general equilibrium model in the spirit of Aiyagari (1994) to investigate the role of productivity shocks in accounting for this correlation. It includes incomplete markets, idiosyncratic productivity shocks, and subsistence requirements.

The model period is a year, and time is discrete and runs $t = 0, 1, 2, \ldots$. There are two sectors, sector a for agriculture and sector m for manufacturing, which includes all nonagriculture. The manufacturing good is the numeraire, so its price is normalized to $p_{mt} = 1$ for all t. Within an economy, there is a continuum of villages with measure one and each village contains a measure one of infinitely lived members, which allows for the possibility of self-insurance against risk. As discussed in Townsend (1994), for example, individuals are relatively well insured against purely idiosyncratic risk. Covariate risk, such as weather, is more difficult to insure against. Therefore, I assume all decisions are made at the village level.

3.1 Technology

Manufacturing The manufacturing output good can be used as either consumption or as intermediate inputs in agricultural production. Production is characterized by a stand-in firm which uses only labor services N_{mt} to produce output according to the constant returns to scale production function

$$Y_{mt} = AN_{mt}$$

where A is a sector neutral TFP parameter. The parameter A is country-specific, and is a measure of the overall productivity of the economy. The firm maximizes profit at each date t, so that N_{mt} is the solution to

$$\max_{N_{mt} \geq 0} \; AN_{mt} - w_t N_{mt} \tag{3.1}$$

where w_t is the wage paid per unit of N_{mt}. In a competitive equilibrium $w_t = A$ for all t.

Agriculture Each village is endowed with one farm that requires intermediate inputs x and labor n_a. Intermediate inputs are purchased from the manufacturing sector. Production occurs according to the decreasing returns to scale production function

$$y_{at} = z_t A x_t^{\psi} n_{at}^{\eta}$$

where $\psi + \eta < 1$ and A is, again, sector neutral TFP. A fraction $1 - \psi - \eta$ of output is devoted to the fixed factor of land, which is normalized to one. The shock z_t is a village-specific productivity shock drawn from a time-invariant distribution with cumulative distribution function $Q(z)$ and support on $[\underline{z}, \overline{z}]$.[3] The realization of z_t is i.i.d. with respect to both villages and time, and $\mathbb{E}(z_t) = 1$. I assume the law of large numbers holds, so that the distribution of shocks across villages is certain.

3.2 Village

A village values consumption from both sectors a and m, and maximizes total expected village utility given by

$$\mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_{at}, c_{mt}) \right]$$

with discount factor $\beta < 1$. The period t utility flow takes the form

$$u(c_{at}, c_{mt}) = \alpha \log(c_{at} - \bar{a}) + (1 - \alpha) \log(c_{mt})$$

where c_{jt} is consumption from sector $j \in \{a, m\}$ and $\bar{a} > 0$ is subsistence requirement of the agricultural good. This utility function is a simplified version of that proposed in Kongsamut, Rebelo, and Xie (2001), and is commonly utilized in models with an agricultural sector. However, the assumption of subsistence plays an important role in this analysis, and is therefore discussed further after detailing the decision problem.

[3] Without the lower bound on z, an equilibrium may not exist because villages cannot satisfy subsistence requirements at realizations close to zero. This turns out not to be an issue when the model is calibrated.

3.2.1 Decision Timing

At time $t-1$, the village chooses to save b_t units of the agricultural good. A fraction δ depreciates, and the village enters time t with $(1-\delta)b_t$ units of savings. This δ is allowed to vary across economies to capture differences in savings technologies across countries. The period t decision problem of a village is broken down into two stages denoted *planting* and *harvesting*, which are separated by the realization of the idiosyncratic shock z.

In the planting stage, each village chooses intermediates x_t to use in their farm. A unit of x can be purchased for a price $p_x \geq 1$. This price is allowed to differ across countries but not time, with the implicit assumption being that there exists a technology that turns one unit of manufacturing output into $1/p_x$ units of intermediate input. Because $1/p_x$ defines the productivity of this technology relative to manufacturing output production, this is a simple way to capture the fact that intermediate inputs are more expensive in developing countries (Restuccia, Yang, and Zhu, 2008). While these price differences are not key theoretically, I will show that they plays a very important quantitative role.

Then, z_t is realized. Recall that this shock is i.i.d. across villages and time. In Bewley models such as this, the ability to self insure decreases as the persistence of the shock increases. In this sense, I am giving the village the best possible chance to self insure by assuming z_t is i.i.d..

In the harvesting stage a village decides how to allocate labor between the agricultural sector, where they can work on the village farm, and in the manufacturing sector, where they can work for wage w_t, which is taxed at rate $\tau \geq 0$. This distortion is designed to capture the fact that the marginal value of labor is lower in agriculture than in manufacturing (Gollin, Lagakos, and Waugh, 2011). I assume that tax revenue is rebated as a lump-sum transfer $T(b, z)$, as to not affect the total income of the village.[4] Just as with intermediate input prices, this distortion is not required to theoretically generate any results, but has a major quantitative impact. Agricultural production occurs, and is sold at the equilibrium price p_a. Profits are made, and consumption and savings choices $(c_{at}, c_{mt}, b_{t+1})$ take place.

[4]If tax revenue is used to purchase goods that are thrown into the ocean, the intermediate good share would be changing both because of the lower manufacturing wage *and* the lower total income in the village. I want to focus only on the former. Moreover it turns out that there are quantitatively important differences depending on which sector goods are purchased from, due to changes in the relative price. Since I am only concerned with lowering the marginal value of labor in agriculture, I have no need to take a stand on this, and therefore rebate tax revenue.

I assume that labor is chosen after the shock realization to capture the fact that off-farm labor is an important form of insurance for farmers (Kochar, 1999).[5]

3.3 Recursive Problem

The timing described above implies that the village state variable is savings b_t, and the aggregate state is the distribution of savings across all villages, denoted $\mu_t(b)$. Since I will be studying the stationary equilibrium, I suppress the dependence of the decision problem on the aggregate state $\mu_t(b)$.

At the harvesting stage, once the choice of x is made and z realized, the value of entering time t with $(1-\delta)b$ savings is

$$V^H(x,b,z) = \max_{c_a,c_m,n_a,b'} \quad \alpha \log(c_a - \bar{a}) + (1-\alpha)\log(c_m) + \beta V^P(b') \tag{3.2}$$

subject to constraint set

$$\begin{aligned} p_a c_a + c_m + p_a b' &= p_a z A x^{\psi} n_a^{\eta} - p_x x + (1-\tau)w(1-n_a) + p_a(1-\delta)b + T(b,z) \\ b' &\geq 0 \\ c_a &\geq \bar{a}, \qquad c_m \geq 0, \qquad n_a \in [0,1] \end{aligned}$$

where V^P is the value of entering the planting stage at $t+1$ with b' units of savings in the stationary equilibrium. The first constraint is the village budget constraint, and the second captures the inability to borrow. The harvesting problem in (3.2) defines decision rules $c_a(x,b,z)$, $c_m(x,b,z)$, $n_a(x,b,z)$ and $b'(x,b,z)$. Working backwards, the planting stage value of entering time t with b savings is

$$V^P(b) = \max_{x\geq 0} \quad \int_z V^H(x,b,z)dQ(z) \tag{3.3}$$

This defines the decision rule for intermediate inputs $x(b)$. For future use, aggregate variables

[5] There is one somewhat peculiar implication of this timing, however. The farmer chooses x in the planting period before sector m production occurs. Technically, the farmer commits to using x intermediates, and then plants x regardless of the realization of z. Since the model period is a year, I do not want to force farmers to purchase intermediate inputs a full year before they are needed. Because fertilizers and seeds can be purchased just days in advance of cropping, I proceed with this abstraction.

will be denoted by capital letters

$$
\begin{aligned}
N_{at} &= \int_b \left[\int_z n_a(b,z) dQ(z) \right] d\mu_t \\
X_t &= \int_b x(b) d\mu_t \\
Y_{at} &= \int_b \left[\int_z zAx(b)^{\psi} n_a(b,z)^{\eta} dQ(z) \right] d\mu_t
\end{aligned}
$$

so that the intermediate input share in agriculture can be written as

$$\widehat{X}_t = \frac{p_x X_t}{p_{at} Y_{at}} \tag{3.4}$$

3.3.1 Discussion and Implications of Modeling Choices

Before defining equilibrium, I briefly discuss two features of the model economy: the form of the utility function and the savings technology.

The Role of Subsistence Requirements The period utility function assumed here is a simplified version of that proposed in Kongsamut, Rebelo, and Xie (2001). Qualitatively, it has two important features. First, it accounts for Engel's law, so that the fraction of total income spent on agricultural output is decreasing in TFP A. Second, it provides an explanation for what Schultz (1953) calls the "food problem." That is, countries with low productivity must employ a large fraction of their population in agriculture to produce sufficient food to feed its citizens. This provides a qualitative answer to why poor countries employ such a large fraction of the population in such an unproductive sector. Quantitatively, Herrendorf, Rogerson, and Valentinyi (2009) show that a general form of this utility function can replicate well the structural transformation process in the United States. In estimating the utility function with the best fit to the data, they find that $\bar{a} > 0$ is necessary to generate a good fit.

Given the empirically consistent predictions of the model, variations on this utility function have become commonplace in modeling the agricultural sector. This paper, however, exploits a feature of this utility function that has yet to be explored in a cross-country framework. Namely, subsistence requirements change the relative risk aversion of a standard constant relative risk aversion (CRRA) utility function to decreasing relative risk aversion (DRRA). However, because villages in this model value two types of consumption, it is not immediately clear how to define relative risk aversion. It turns out, however, that the utility function can be rewritten as a function of only income, which allows for relative risk aversion to be directly defined as a function of income levels. To see this, first define y as the total income at the harvesting stage, given savings b, intermediate choice x, shock z, and the optimal savings decision rule b'

$$y(x, b, z) = p_a z A x^{\psi} n_a^{\eta} - p_x x + (1-\tau) w (1-n_a) + p_a (1-\delta) b + T(b, z) - p_a b'$$

Given this y, a village purchases enough agricultural consumption to satisfy subsistence $\bar{a}$, then splits the rest of their income between the two sectors based on the relative weights assigned by the price p_a and utility parameter α.

$$\begin{aligned} c_a(y) &= \bar{a} + \frac{\alpha}{p_a}(y - p_a \bar{a}) \\ c_m(y) &= (1-\alpha)(y - p_a \bar{a}) \end{aligned}$$

Using these decision rules, the utility flow can be rewritten as a function of total income y,

$$\widetilde{u}(y) := u(c_a(y), c_m(y)) = \Omega - \alpha \log(p_a) + \log(y - p_a \bar{a}) \tag{3.5}$$

where $\Omega = \alpha \log(\alpha) + (1-\alpha)\log(1-\alpha)$. Because utility $\widetilde{u}$ is only a function of income y, relative risk aversion with respect to total income y, given $\bar{a}$ and price p_a, can be defined as

$$R(y|\bar{a}, p_a) = \frac{y}{y - p_a \bar{a}}$$

If $\bar{a} = 0$, this is a standard log CRRA utility function. However if $\bar{a} > 0$, the utility function instead exhibits decreasing relative risk aversion (DRRA), consistent with the household evidence of Ogaki and Zhang (2001) from both India and Pakistan.

With this form of the period utility function, harvesting utility can be written

$$V^H(x, b, z) = \Omega - \alpha \log(p_a) + \log\big(y(x, b, z) - p_a \bar{a}\big) + \beta V^P\big(b'(x, b, z)\big) \tag{3.6}$$

The choice of x is then the solution to

$$V^P(b) = \Omega - \alpha \log(p_a) + \max_{x \geq 0} \quad \int_z \Big[\log\big(y(x,b,z) - p_a \bar{a}\big) + \beta V^P\big(b'(x,b,z)\big)\Big] dQ(z) \tag{3.7}$$

Equations (3.6) and (3.7) illustrate the key tension between expected income and expected utility in the face of subsistence requirements. While profits drive harvest stage utility by increasing y, the planting stage choice of x maximizes expected utility, of which income is only one component. The other is the risk associated with the choice of x. While farm profit increases utility, higher x implies large exposure to risk. To limit this exposure, and thus decrease the variation in harvest utility, the village must decrease the choice of x. Thus, the optimal choice of x balances the need for both high income and low exposure to risk. Since $\bar{a} > 0$ implies DRRA, the inclusion of subsistence requirements can alter the way farmers undertake risky investments for different levels of TFP. After defining equilibrium, I show that this is indeed the case. The inclusion of subsistence requirements interacts with TFP differences and uninsurable risk to generate differences in the domestic intermediate share.

Savings Since subsistence imply DRRA, it is intuitive then that the savings technology can potentially play an important role. Here, I assume that the only savings technology available is costly storage of the agricultural good, and insurance is not available. The lack of properly functioning insurance markets is certainly not controversial in developing countries. However, there are many ways to save around risk, and savings have been shown to be effective in limiting the impact of risk in Bewley models. This section discusses why this model assumes this primitive savings technology.

First, savings banks are generally not utilized. In addition to paying no interest, Dupas and Robinson (2011) find that rural savings banks in Kenya actually charge both a start-up fee and a variable fee for every transaction. In twelve of thirteen developing countries considered, Banerjee and Duflo (2007) find that less than 14% of all people living on under \$1 a day have savings accounts.

Most liquid assets are instead accounted for by livestock and grain storage (Udry, 1995; Swinton, 1988). However, Fafchamps, Udry, and Czukas (1998) show that livestock sales are not be used as a buffer stock in West Africa. This could be due in part to the fact that local markets are poorly integrated, so that local general equilibrium price adjustments make capital goods unable to be used as insurance. Even when they are traded in a way that resembles consumption smoothing, as Rosenzweig and Wolpin (1993) find in India, there is still severe underinvestment in bullocks. Another feature of livestock in developing countries is high depreciation rates. While the mortality rate for cattle are generally around fifteen to twenty percent in Africa, it reaches heights of sixty percent during droughts and disease outbreaks.[6] This positive correlation between low productivity shocks and high cattle depreciation makes it even more difficult to use cattle as a consumption smoothing mechanism. From an aggregate prospective, Lagakos and Waugh (2011) find that capital per worker differences account for similar percentages of output per worker differences in agriculture and non-agriculture. While capital per worker differences are important for understanding aggregate output per worker differences, they are not responsible for the fact that agriculture is significantly *less* productive than non-agriculture.

Instead, agricultural storage seems to be a key consumption smoothing tool. During the same West African drought period considered by Fafchamps, Udry, and Czukas, Reardon, Matlon, and Delgado (1988) find that cereal stocks were almost completely depleted. This suggests that agricultural output storage is the main form of buffer savings in the poorest countries. As one might suspect, storage technologies are heterogeneous between poor and rich countries. In Zimbabwe, for example, almost 30% of maize produced is lost in storage. This is further detailed in the calibration of Section 5.

3.4 Stationary Equilibrium

Turning now to the equilibrium, I will study the stationary competive equilibrium of this economy. This is defined by an invariant distribution $\mu = \mu^*$, a value function V^P, decision rules x, n_a, b', c_a, c_m, labor choice N_m, prices p_a and w, and a transfer function $T(b, z)$ such that

1. The value function V^P solves the villages's problem given by (3.2) and (3.3) with the associated decision rules

2. N_m solves the sector m firm problem (3.1)

[6]See ILCA (1990) for a review of empirical evidence.

3. Markets clear

   (a) Manufacturing labor market:

$$N_m = 1 - \int_z \int_b n_a(b, z) d\mu dQ(z)$$

   (b) Agricultural consumption market:

$$\int_b \int_z c_a(b, z) dQ(z) d\mu(b) = \int_b \int_z zAx(b)^{\psi} n_a(b, z)^{\eta} dQ(z) d\mu$$

   (c) Manufacturing consumption market:

$$\int_b \int_z c_m(b, z) dQ(z) d\mu + p_x \int_b x(b) d\mu = AN_m$$

4. The state contingent transfer balances for all (b, z)

$$T(b, z) = \tau w(1 - n_a(b, z))$$

5. The law of motion for μ, denoted $\mu'(\mu)$, is such that $\mu'(\mu^*) = \mu^*$, and μ^* is consistent with $Q(z)$ and decision rules

4 Analytic Results

This section provides some analytic results to help clarify the mechanics of the model. In particular, I will show that TFP differences generate differences in intermediate input shares if and only if the economy includes incomplete markets, idiosyncratic shocks, and subsistence requirements. This qualitatively replicates the positive correlation between intermediate input shares and income detailed in Section 2. To make these results as sharp as possible, I consider the static version of the model (identically, $\delta = 1$ for all economies). Furthermore, because the two exogenous distortions p_x and τ are not required to theoretically generate a positive correlation between the intermediate input share and TFP, I fix $\tau = 0$ and $p_x = 1$ in all economies. This leaves TFP A as the only difference between any two model economies. All proofs are relegated to Appendix B.

This model relies on the transmission of productivity shocks to consumption risk. To assess the role of productivity shocks and incomplete markets, I compare the model developed above (denoted by superscript I for incomplete markets) with a complete markets version (denoted by superscript C for complete markets). The complete markets version is identical, except that villages are allowed to trade a full set of state contingent assets before the realization of z. How this affects intermediate input choices can be seen by comparing the first order conditions with respect to x in the I and C economies. Because consumption is fully insured against shocks with complete markets, farmers maximize expected profit. If the constraint $n_a \leq 1$ does not bind, then this implies that the first order condition of the planting problem with respect to x would be

$$Ap_a^{1/(1-\eta)}F'(x)\int_Z z^{1/(1-\eta)}dQ(z) = 1 \tag{4.1}$$

where

$$F(x) = x^{\psi/(1-\eta)}\left(\eta^{\eta/(1-\eta)} - \eta^{1/(1-\eta)}\right)$$

and $F'(\cdot)$ is the derivative with respect to x. Without the ability to trade these claims (the I economy), the first order condition with respect to x of the village planting problem yields

$$Ap_a^{1/(1-\eta)}F'(x)\int_Z z^{1/(1-\eta)}\left(\frac{\widetilde{u}'(y(x,z))}{\mathbb{E}_z[\widetilde{u}'(y(x,z))]}\right)dQ(z) = 1 \tag{4.2}$$

where $\widetilde{u}$ is defined as in equation (3.5), and $\widetilde{u}'$ is the derivative with respect to income y. Equation (4.1) shows that the profit maximizing farm considers only the arithmetic mean of $z^{1/(1-\eta)}$. This changes with the addition of incomplete markets. Equation (4.2) shows that the village facing uncertain consumption considers a *weighted* average of $z^{1/(1-\eta)}$, where the weight is given by the marginal utility at the realization of z relative to the mean (the "utility weight" at z). Those realizations of z that imply a higher than average marginal utility are weighted relatively more heavily by a village that faces uninsurable risk. Similarly, those realizations of z that imply a lower than average marginal utility are weighted less heavily. Thus, the inclusion of incomplete markets tilts the weight assigned by every village toward "bad" outcomes. This leads naturally to Proposition 1.

Proposition 1. *In the competitive equilibrium, the intermediate share is lower in the in-*

complete markets economy (I) than the complete markets economy (C) for a given TFP A. That is,

$$\frac{X^I}{p_a^I Y_a^I} < \frac{X^C}{p_a^C Y_a^C} = \psi$$

Graphically, this result can be seen in Figure 3. In the complete markets (C) economy, the utility weight is irrelevant. Put somewhat more formally, it is equal to one at every realization of z, and is shown in Figure 3 as the horizontal dotted line at one. Once consumption risk is tied to production risk, however, this changes. The utility weight at low z realizations increases, causing a decrease in the domestic intermediate share for all TFP levels A, which can be seen in the solid line.

The more interesting issue, however, is how the intermediate input share reacts to changes in A, since the empirical evidence of Section 2 suggests they should be correlated. First, with $\bar{a} = 0$, the interaction of incomplete markets and agricultural productivity shocks is irrelevant in accounting for the fraction of the labor force in agriculture, the intermediate share, or agricultural productivity differences.

Proposition 2. *In the model with uninsurable shocks (I economy) and $\bar{a} = 0$, the following results hold in the competitive equilibrium:*

1. *$n_a(z)$ is independent of A*
2. *The intermediate share $X/(p_a Y_a)$ is independent of A*
3. *For two economies with TFP levels A^1 and A^2, agricultural output per worker differences in the I economy do not increase relative to the C economy. That is,*

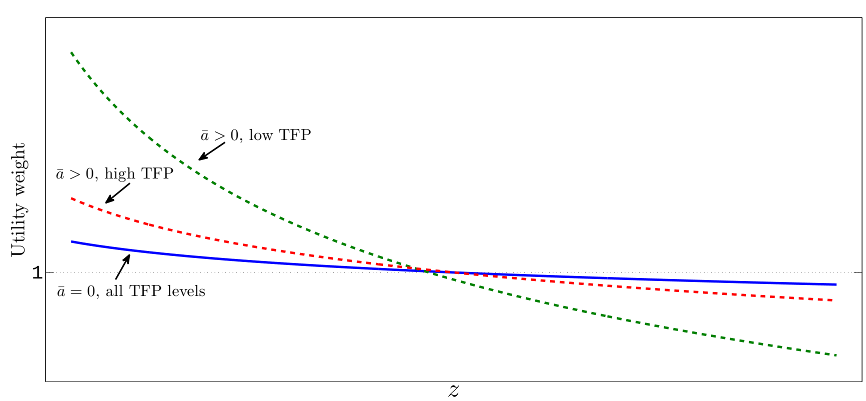
$$\frac{\left(Y_a^{1C}/N_a^{1C}\right)}{\left(Y_a^{2C}/N_a^{2C}\right)} = \frac{\left(Y_a^{1I}/N_a^{1I}\right)}{\left(Y_a^{2I}/N_a^{2I}\right)}$$

While Proposition 1 shows that the equilibrium intermediate input share is lower with risk, Proposition 2 shows that when $\bar{a} = 0$, it does not differ *across* economies. This is due to the fact that $\bar{a} = 0$ implies that the period utility function exhibits CRRA. Therefore, the utility weight in equation (4.2) is independent of TFP. This can be seen in the solid line of Figure 3, which shows that the utility weight for any realization of z is identical for all levels of TFP. Moreover, the third result in Proposition 2 shows that, in the absence of subsistence requirements, the lack of insurance markets plays no role in understanding labor productivity differences across countries. The inclusion of subsistence requirements breaks this result. When $\bar{a} > 0$, the period utility function exhibits DRRA, causing the utility weight to depend on the level of TFP. Proposition 3 shows that the interaction of productivity shocks and subsistence requirements can qualitatively replicate the empirical correlation between the intermediate share and TFP from Section 2.

Proposition 3. *In the competitive equilibrium, the intermediate share is increasing in A if and only if $\bar{a} > 0$.*

In an economy with incomplete markets, idiosyncratic shocks, and subsistence requirements, TFP differences are able to generate differences in the intermediate input share that are qualitatively consistent with the evidence provided in Figure 1. Leaving out any one of these features implies a constant intermediate share. Technically, this result is driven by the interaction of two features implied by subsistence requirements: DRRA utility and an income elasticity that is less than one with respect to the agricultural good. The intuition, however, is as follows. Poor farmers have relatively less income than their rich counterparts for all realizations of z. With subsistence requirements, this difference increases as z decreases. Since farmers weigh each realization of z by their marginal utility at that realization, farmers in poor economies put relatively more weight on low z than their rich counterparts, as can be seen in Figure 3. This causes the intermediate good share to decrease in economies with low A.

Figure 3: Utility Weight for Different Subsistence Levels



Given the theoretical relevance of the interaction between TFP, risk, and subsistence requirements, I now move back to the full dynamic model to investigate the quantitative magnitudes of the results shown here.

5 Quantitative Exercise and Calibration

To assess the quantitative importance of agricultural productivity shocks for cross-country aggregate outcomes, I compare the model's predictions between a rich and poor model economy. The rich country is designed to capture the relevant features of the U.S. economy in 1985, since this is the only year for which I have intermediate input data. I normalize $A = 1$ and calibrate the model with no distortions ($p_x = 1$ and $\tau = 0$) so that the stationary equilibrium matches a number of features of the U.S. economy, including the intermediate input share in agricultural and the sectoral composition of employment. The poor economy differs in its level of TFP A, the depreciation rate of storage δ, the intermediate input price p_x, and the tax rate τ. These are all chosen to match the relevant features of the tenth percentile country as ranked by per capita GDP.[7]

I then proceed to consider two quantitative experiments. The first experiment is to assess the model's ability to generate differences in intermediate input shares and labor productivity. Because the poor economy differs along a number of dimensions, some differences in labor productivity will be exogenously fed into the model. Recall, however, that the model with no productivity shocks generates no differences in intermediate input shares. Therefore, to isolate the impact of intermediate input share differences, I ask how much *larger* productivity differences are in the model with shocks, relative to the identical model with no shocks. The second exercise is to vary p_x and τ in the poor model economy while holding all other parameters fixed. This helps to understand the complementarity between price distortions and productivity shocks.[8] This isolates the direct impact of productivity shocks for different levels of price distortions.

[7]To construct the tenth percentile country, I take the average values from the bottom fifteen to five percent of countries. This averages out some of the variation in intermediate input shares and intermediate input prices. See Appendix A for more details.

[8]The goal of this paper is not to explain these distortions but, given that they exist, to understand their interaction with productivity shocks in the agricultural sector. See Adamopoulos (2011) for the role of the transportation sector in accounting for high intermediate input prices in poor countries and Gollin, Lagakos, and Waugh (2011) for a quantitative exploration on the causes of sectoral differences in marginal value of labor.

Section 5.1 presents the parameters that are the same across economies. Section 5.2 details the differences between the two economies in the baseline calibration, which are TFP A, storage depreciation δ, intermediate input price p_x and labor wedge τ. Table 3 lists all the parameters chosen.

5.1 Common Parameters

In this section, I detail the parameters that are identical to both economies. They include the production technology (except for TFP), the shock distribution, and utility parameters.

Farm Production Parameters The farm production parameters are the shares of intermediates, ψ, and labor, η. These are chosen to match the aggregate intermediate input share and labor share in agriculture in the United States in 1985. The exponent on intermediates is set to $\psi = .40$ which implies that the intermediate share of slightly less than 0.40 in the baseline economy. This is consistent with Valentinyi and Herrendorf (2008) and Restuccia, Yang, and Zhu (2008), who find that this share is about 0.38. Since labor is chosen after the realization of all uncertainty, the parameter η is exactly equal to the payments to labor as a share of gross agricultural output. I choose $\eta = 0.40$, which is consistent with the labor share in Restuccia, Yang, and Zhu (2008). Estimates of this parameter, however, vary widely and Section 6.4 considers the sensitivity of the results to this parameter.

Farm Productivity Shock Distribution There are two possible choices for choosing the shock distribution. The first is to choose two separate shock distributions- one for the U.S. and a second for the poor economy. The second possibility is to assume that the distribution of shocks is the same between the two economies. It turns out that this decision is quantitatively irrelevant. Because the U.S. economy is so far from subsistence, the distribution of shocks is of little quantitative importance. That is, these villages act similar to profit maximizers. When A decreases however, villages become much more sensitive to this distribution because they are (ex-ante) closer to subsistence. Therefore the distribution is chosen to match the poor economy, and I make the innocuous assumption that the distribution is the same in the rich economy, since the mean is always normalized to one.

To estimate this distribution, I turn to the International Crops Research Institute for the Semi-Arid Tropics Village Level Surveys (ICRISAT VLS). These surveys contain plot level inputs and outputs from ten different Indian villages from the years 1975-1976 to 1983 - 1984.[9] I use six of the villages that have data starting in 1975-1976. This data set has a few benefits. First, since I calibrate to the year 1985, it is almost perfectly aligned in terms of year coverage. Second, the villages were chosen to give an overview of the different agro-climatic zones in India. Therefore, I am not estimating risk for a village where, for example, it rains every year.

This section provides an overview of the procedure, while a more detailed explanation is given in Appendix C. First, I choose a fixed set of village specific prices. Since my model does not contain any aggregate risk, I do not include price fluctuations in my measure of risk. I choose to use the prices from 1975, and denote all inputs and outputs in terms of this 1975 price. From there I construct aggregated village level inputs, which include output, agricultural intermediates, nonagricultural intermediates, labor, capital, land, and agricultural output. One issue is that the data measures labor hours, while the model is calibrated to match the fraction of population in agriculture. While not the main driver of productivity differences across countries, Gollin, Lagakos, and Waugh (2011) show that distinction can be important. With that caveat, I treat them as identical here.[10] I subtract agricultural intermediate goods from output. Lastly, I combine capital and the value of land together as the fixed factor in the production function, which is normalized to one in the model.

I now have data equivalents of Y_a (gross output), I (agricultural intermediate inputs), X (nonagricultural intermediate inputs), N_a (agricultural labor), and the fixed factor. Though this is normalized to one in the model, I denote it K here for expositional purposes. This is the combined value of capital and land. From there, I calculate the Solow residual in village v at year t as

$$z^*_{vt} = \frac{Y^{data}_{vt} - I^{data}_{vt}}{(X^{data}_{vt})^{\psi}(N^{data}_{a,vt})^{\eta}(K^{data}_{vt})^{1-\psi-\eta}}$$

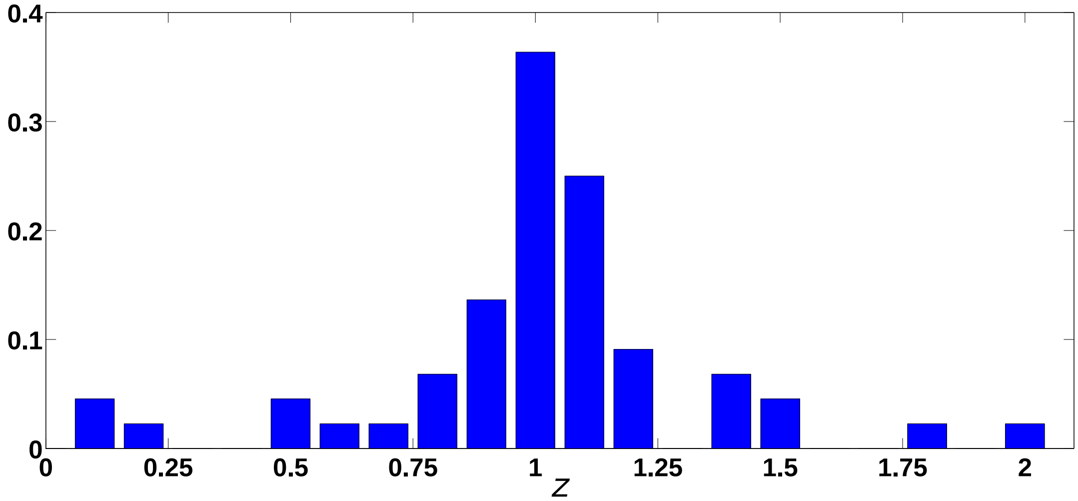
Because TFP in this model remains fixed, I use a Hodrick-Prescott filter with smoothing

[9]The Rabi season runs through the winter and into the following year. I include this season in the year it starts. Thus, each village contains 9 years of data.

[10]In the model, hours and people can be used interchangeably. However, the model's calibration and predictions are matched to data on number of people, not hours.

parameter $\lambda = 6.25$, consistent with Ravn and Uhlig (2002), to detrend z^*_{jt} and get values for z_{vt}. Since the shock is assumed to be i.i.d. across time and villages, I can safely assume that each shock realization is drawn from the same distribution. This procedure generates the discrete empirical probability density function displayed in Figure 4.

Figure 4: Empirical Probability Distribution of Shocks



Admittedly, there are a relatively small number of observations from which to draw any absolute conclusions about the nature of agricultural risk. However, even within this small sample, notice that while there are some particularly good years, there are also some particularly bad years. Over five percent of the total probability is below $z = .25$, which seems to be roughly consistent with empirical evidence. Dercon (2002), for example, finds that 78% of households surveyed in the Ethiopian Rural Panel Data Survey had weather related harvest failure in the preceeding twenty years. Haresaw, a village in the Tigray region of Ethiopia, has rainfall levels less than 40% of the median approximately every ten years (Dercon and Christiaensen, 2011), painting a somewhat more dire picture than here. The key in this model is that even though $Pr(z < .25) \approx .05$, farmers in developing countries weight this outcome more heavily than farmers in developed countries. I embed the distribution in Figure 4 into the model.

Utility Parameters Since the model period is a year, I set $\beta = 0.96$. The remaining parameters are the weight on agricultural consumption, α, and subsistence $\bar{a}$. The parameter α controls the share of agricultural output in GDP in the long run as TFP approaches infinity.

I set $\alpha = 0.005$, consistent with the choice of utility weight in Restuccia, Yang, and Zhu (2008) and Lagakos and Waugh (2011). The parameter $\bar{a}$ is chosen so that the rich economy has an equilibrium agricultural employment share of 2.84%, consistent with the U.S. in 1985.

5.2 Economy Specific Parameters

The two economies differ along four dimensions: TFP A, depreciation of stored goods δ, tax rate τ, and intermediate input price p_x. Recall that p_x changes one for one with the relative productivity of the technology that turns manufacturing output into intermediate inputs.

TFP For the U.S. economy, TFP is normalized to $A = 1$. I discipline the TFP in the poor country by manufacturing labor productivity. Since manufacturing labor productivity is equal to A, I set $A = 0.25$ in the poor economy, which is roughly consistent with nonagricultural labor productivity differences between the richest and poorest countries.

Depreciation of Stored Goods To discipline the deprecation rate of agricultural storage, I use estimates of total storage losses in a number of African countries. Before proceeding to estimates of these storage losses, a distinction must be made between weight and quality losses. Since the model contains no notion of quality, the exact empirical counterpart would be depreciation of the *value* of agricultural output. However, quality losses are notoriously difficult to measure, since they can depend on consumers' preferences and cultural customs (de Lucia and Assennato, 1994). Moreover, quality and weight clearly do not change one for one.

With that caveat in mind, I focus specifically on weight losses. Post-harvest losses in developing countries are mostly generated before crops leave the farm (i.e. drying and storing crops), while losses in developed countries are mostly generated outside the farm gate (i.e. table waste by consumers).[11] In developed countries, the advent of cold chain storage systems prolong storage life, making on-farm storage losses nearly irrelevant. In developing countries, crops are still dried by the sun and stored in the open. To put a number to these losses, I turn to the African Post Harvest Loss Information System (APHLIS). APHLIS is a network of local experts that aggregates statistics on weight loss into comparable measures across

[11] See Hodges, Buzby, and Bennett (2011).

African countries and crops. Table 2 presents the estimated weight loss data for a number of crops in a selection of African countries.[12]

Table 2: Post Harvest Weight Loss (%) for Selected Countries and Crops for 2007

	Maize	Wheat	Sorghum	Millet	Rice
Eritrea	17.9	12.9	12.2	10.9	–
Ethiopia	16.4	12.4	12.4	12.1	11.3
Kenya	21.1	12.9	12.7	11.9	13.2
Malawi	19.6	13.4	13.0	12.9	11.6
Mozambique	21.0	–	12.8	12.6	11.4
Rwanda	17.5	14.5	12.5	–	11.3
Sudan	18.0	12.9	12.2	10.7	–
Tanzania	22.0	14.4	12.5	12.3	11.2
Median	19.6	12.9	12.5	12.1	11.4

Table notes: Data from APHLIS

Given these figures, I set $\delta = 0.15$ in the poor economy. It is worth emphasizing that this is a conservative estimate, as quality losses are not included. Increasing δ further would increase the results. I set $\delta = 0.03$ in the rich economy. Since the rich model economy has little need for precautionary savings, changing this value does not influence the results.

Tax Rate Since the US model economy is assumed frictionless, $\tau = 0$. For the poor model economy, I choose $\tau = 0.40$. This is roughly consistent with differences in the marginal value across sectors as found in Vollrath (2009).

Intermediate Input Price The US intermediate price is set to $p_x = 1$. In the poor model economy, the intermediate price is $p_x = 3$. This is consistent with data from Restuccia, Yang, and Zhu (2008), who use FAO data to show that there is a strong correlation between per capita income and intermediate input prices across countries. Table 3 summarizes the parameters.

[12] See Hodges et al. (2010) for a more complete review of APHLIS. Considering more countries only emphasizes the results. The large weight losses presented in Table 2 are present in almost all countries in the data set.

Table 3: Parameter Values for Two Economies

Parameter	US	Poor
Common		
ψ	0.40	0.40
η	0.40	0.40
α	0.005	0.005
$\bar{a}$	0.04	0.04
z, $Q(z)$	*(see text)*	
Specific		
A	1	0.25
τ	0	0.40
p_x	1	3.0
δ	0.03	0.15

6 Quantitative Results

Section 6.1 considers the calibrated model's ability to predict differences in intermediate input shares and labor productivity. I find that the model is consistent with the fact that developing countries have lower intermediate input shares and higher employment in agriculture. This generates significantly lower labor productivity in the agricultural sector. In Section 6.2, I investigate the implications of changing the exogenous distortions p_x, τ, and δ. Interestingly, I find that decreasing (p_x, τ) to U.S. levels has roughly the same impact on the intermediate input share as decreasing δ to the U.S. level. Finally, Section 6.4 considers robustness to the labor share parameter η, as a wide range of estimates exist in the literature.

6.1 Baseline Impact of Agricultural Risk

The baseline model results are presented in Table 4. The first two columns presents the quantitative results when there are no shocks (i.e. $Pr[z = 1] = 1$), but still assuming the differences in (p_x, τ) calibrated above. The second set of columns presents the results of the model when productivity shocks takes the form calibrated in Section 5.1. For comparison, the last columns contain the statistical counterparts from the data. Note that the productivity numbers for the poor economy are normalized to one. Therefore, the reported productivity

Table 4: Baseline Model Results

Economy	*Model: no shocks*		*Model: shocks*		*Data*	
	Rich	Poor	Rich	Poor	Rich	Poor
Output per worker						
Agriculture	24.8	1.0	36.4	1.0	63.7	1.0
Aggregate	6.0	1.0	10.6	1.0	23.1	1.0
Inputs						
Intermediate share	0.40	0.40	0.40	0.20	0.40	0.09
Agricultural labor (%)	2.8	49.0	2.8	74.3	2.8	82.0

of the rich country is its output per worker relative to the poor economy.

Table 4 shows that the addition of agricultural productivity shocks to the model generates significant amplification of labor productivity differences. Agricultural productivity differences are amplified from 24.8 to 36.4, for an increase of 47%. The increase is even larger for the difference in aggregate productivity, which increases from 6.0 to 10.6. This implies that the addition of productivity shocks amplifies aggregate productivity differences by 77%.[13] The model with agricultural productivity shocks gets significantly closer to the data along both productivity dimensions, implying that agricultural productivity shocks are a key component of aggregate income differences across countries.

The reason for this amplification in productivity is due to the role of productivity shocks in changing input choices. By virtue of the Cobb-Douglas production function, the model with no shocks predicts no change in the intermediate input share across countries. Once agricultural shocks are included, the intermediate share prediction for the poor economy decreases from 0.40 to 0.20. This decrease captures 65% of the difference between rich and poor countries, in which the average intermediate share is 0.09. Due to the lack of intermediate inputs used in the poor country, they are instead forced to substitute more labor to reach subsistence consumption. The prediction of the agricultural labor force increases from 49.0 to 74.3 percent of the population, an increase of 52%. Just as with the intermediate input shares, the model with shocks is significantly better aligned with the data along this

[13] Aggregate output per worker is measured as GDP at the U.S. model price, since the total labor force is normalized to one.

Table 5: Decomposition

	Labor Productivity		*Poor Economy Inputs*	
	Agriculture	Aggregate	N_a (%)	$p_x X / p_a Y_a$
Differences in				
δ only	1.0	1.0	2.8	0.40
(p_x, τ) only	2.2	1.0	3.8	0.39
A only	11.6	5.0	19.1	0.35
A, (p_x, τ)	27.9	6.4	46.7	0.30
A, (p_x, τ), δ	36.4	10.6	74.3	0.20

dimension.

6.1.1 Decomposition of Results

The amplification generated by the addition of productivity shocks depends critically on the fact that the poor economy is sufficiently close to subsistence. This is generated by the three distinguishing features of the poor economy: sector-neutral TFP, agriculture-specific distortions, and storage depreciation. A natural question then is the extent to which each of these features matters in delivering the results. Table 5 decomposes the result, and shows that the interaction of all these features are required to generate the results.

The first two columns are agricultural and aggregate output per worker in the rich economy relative to the poor economy. The last two columns are the employment share and intermediate input share in the poor economy. The first three rows change one feature of the poor economy at a time. The first row assumes that the poor economy is identical to the rich in every way except for the calibrated differences in δ. This generates no quantitative differences between the rich and poor economy, implying that differences in the depreciation rate are irrelevant in the absence of other aggregate and sector-specific differences between the two economies. The second row considers only differences in sector-specific distortions (p_x, τ), while row three assumes differences only in TFP A. None of these three features alone is able to generate much difference in intermediate input shares, which maps directly into the amplification due to productivity shocks. However, when differences in A, p_x, and

τ are combined, the model significantly improves along all dimensions. This model is able to capture one third of the difference in intermediate input shares. The addition of storage depreciation differences (row five) greatly amplifies the previous version along all dimensions. Agricultural output per worker differences increase by thirty percent, while aggregate output per worker differences increase by nearly two thirds. This is due to the fact that the intermediate input share in the poor economy decreases by sixty six percent, while the employment share in agriculture increases by sixty percent.

Taken together, this decomposition shows that differences in TFP A, sector-specific distortions p_x and τ, and depreciation rate δ all have an important quantitative role when combined. This is in spite of the fact that individually, each seems to be at best a marginal contributor to understanding differences in intermediate input shares across countries.

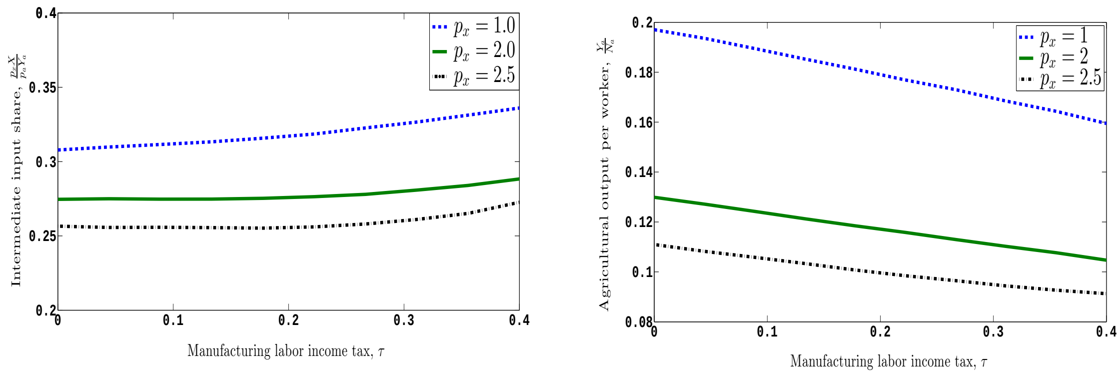
6.2 The Role of Sector-Specific Distortions

Agricultural-specific distortions have been shown to be quantitatively important in understanding agricultural productivity differences. In this section, I also show that they have important implications for understanding intermediate input shares across countries when considered in conjunction with productivity shocks. This implies that policies decreasing these distortions will have the added benefit of decreasing the negative impact of agricultural productivity shocks.

6.2.1 Changes in Price Distortions

In this section, I vary the two exogenous distortions p_x and τ while fixing the rest of the calibration as discussed above. This helps better understand their interaction with agricultural productivity shocks. Figure 5 plots the the intermediate input share (Figure 5a) and agricultural output per worker (Figure 5b) for a number of combinations of (p_x, τ). The horizontal axis on both figures is the tax rate τ. This is reproduced for $p_x \in \{1.0, 2.0, 2.5\}$.

Changes in the Intermediate Input Price Comparing the three curves in Figure 5a at a given level τ, a higher intermediate input price decreases the intermediate input share. This is due to the income effect generated by this distortion. Intuitively, as p_x increases, expected income



(a) Intermediate input share

(b) Agricultural productivity

Figure 5: Model implications for different price distortions

decreases. Villages then limit their exposure to low shock realizations by further reducing intermediate input usage. In the model, this shows up as a decrease in the intermediate input share. As can be seen by comparing the three curves in Figure 5b, this decreases agricultural productivity.

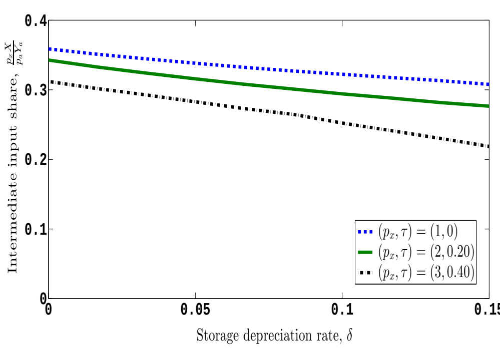
Changes in the Tax Rate The implications of the manufacturing wage tax τ are not the same as for p_x, however. The increasing curves in Figure 5a imply that higher τ generates a higher intermediate input share. This is due to the equilibrium impact of τ being comprised of two opposite effects. First, like any distortion, τ decreases income which drives down the intermediate input choices. The second is that τ also decreases the relative price of agriculture in equilibrium. This decreases the denominator of the intermediate input share, $p_a Y_a$. In the calibrated model, this second effect outweighs the first.[14] Regardless of the implications of τ for the intermediate input share, higher τ unambiguously implies lower agricultural output per worker. This can be seen in the downward sloping curves of Figure 5b, and has been emphasized recently by Restuccia, Yang, and Zhu (2008) and Vollrath (2009).

[14] It is worth emphasizing that this result is due to the fact that tax revenue is rebated to the village. Quantitative experiments in which tax revenue is used to purchase goods (from either sector) show that the intermediate input share would decrease through the same income effect discussed in relation to changes in p_x. In this sense, the model is taking a conservative stance on the impact of agricultural risk in developing countries.

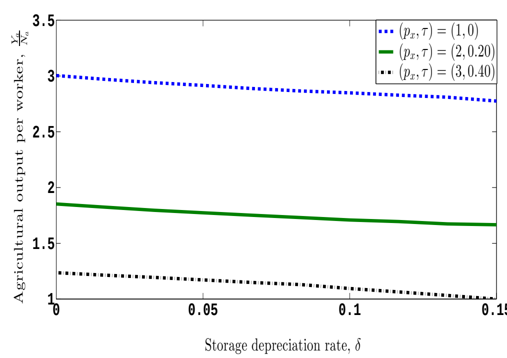
Decreasing Distortions to U.S. Levels A decrease of (p_x, τ) to U.S. levels causes the intermediate input share to increase from 0.20 to 0.31, a fifty-five percent increase. This has important quantitative implications for the amplification of productivity differences due to shocks. Repeating the same exercise as in the baseline case, the addition of agricultural shocks to an otherwise identical model increases agricultural productivity differences from 11.1 to 12.4. This is an increase of twelve percent. Recall that when p_x and τ were calibrated to match their empirical counterparts in developing countries, the addition of shocks amplified agricultural productivity differences by forty seven percent. This implies two things. First, understanding the impact of agricultural shocks on intermediate input choices requires modeling sector-specific distortions in developing countries. Second, eliminating sector-specific distortions has the potential to significantly reduce the impact of production uncertainty in the agricultural sector of developing countries.

6.3 Changes in Savings Technologies

In Table 5, the addition of higher storage depreciation generated important quantitative amplification of productivity differences. In this section, I show that the quantitative impact of storage depreciation depends critically on the level of agriculture-specific distortions in the economy. Figure 6 plots the intermediate input share and agricultural productivity for different levels of p_x and τ.



(a) Intermediate input share



(b) Agricultural productivity

Figure 6: Model implications for different depreciation rates δ

Figure 6a shows that lowering the depreciation rate of storage increases the intermediate input share. This occurs because farmers are able to better save their way out of risk. With the calibrated distortions $(p_x, \tau) = (3, 0.40)$, a decrease of δ from 0.15 to zero implies that the intermediate input share increases from 0.20 to 0.31. This is an increase of approximately fifty five percent, and is nearly identical to the increase from an elimination of price distortions p_x and τ.

The impact of changes in δ depends on the level of sector-specific distortions. When p_x and τ are calibrated to U.S. levels, a decrease in δ from 0.15 to zero implies that the intermediate input share increases from 0.31 to 0.36, for an increase of sixteen percent. This is the top dashed line in Figure 6a. The relatively limited impact of δ in the case with no distortions is due to the fact that villages are relatively wealthier. Therefore, they do not need to rely on savings to make risky input decisions.

Since a lower depreciation rate increase the intermediate input share, it also increases agricultural productivity. This is shown in Figure 6b. In this figure, I normalize the baseline calibrated version of the poor country to one. This is the model with TFP $A = 0.25$, distortions $(p_x, \tau) = (3, 0.4)$ and depreciation $\delta = 0.15$. Holding these distortions fixed at $(p_x, \tau) = (3, 0.40)$, eliminating storage depreciation implies that agricultural productivity increases by about twenty four percent. Again, this increase relies on the level of sector-specific distortions. In the absence of price distortions, eliminating depreciation amounts to only an eight percent increase in agricultural productivity. As discussed above, this is due to the fact that δ has little scope to impact intermediate input choices in the case.

6.4 Robustness to Labor Share Parameter

Estimates of the labor share vary substantially. In this section, I consider the how changes in the agricultural labor share parameter, η, impact the predictions of the model. I hold the rest of the calibration fixed, and vary $\eta \in \{0.2, 0.3, 0.4, 0.5\}$. Table 6 lists the results.

Increasing η causes agricultural productivity differences to decrease, while aggregate productivity differences increase. This is due to two forces that work in opposite directions. First, higher η causes agricultural productivity to decrease in *both* economies. Because the rate of decrease is higher in the rich country, agricultural output per worker differences decrease. At the same time however, higher η causes the employment share in agriculture

Table 6: Model Results for Different η

	$\eta = 0.20$		$\eta = 0.30$		$\eta = 0.40$		$\eta = 0.50$	
Economy	Rich	Poor	Rich	Poor	Rich	Poor	Rich	Poor
Output per worker								
Agriculture	84.8	1.0	50.4	1.0	36.4	1.0	25.3	1.0
Aggregate	5.8	1.0	6.9	1.0	10.6	1.0	13.4	1.0
Inputs								
Intermediate share	0.40	0.27	0.40	0.25	0.40	0.20	0.40	0.18
Agricultural labor (%)	0.5	29.9	1.0	46.1	2.8	74.3	3.1	92.3

to increase. The rate of this increase in higher in the poor economy. Because aggregate productivity is an employment-weighted average of sectoral productivity, aggregate productivity differences tilt towards agricultural productivity differences. This increases aggregate productivity differences as η increases. Higher η also implies that the intermediate input share decreases in the poor economy. Because the parameter on intermediate inputs, ψ, is held fixed, higher η decreases the span of control of the production function, which decreases expected income to villages. To limit exposure to risk, villages decrease investment in intermediate inputs.

Overall, the model's basic predictions stand up to varying the labor share parameter in the production function.

7 Conclusion

This paper quantifies the role of idiosyncratic production risk in accounting for sectoral output per worker differences in a two sector general equilibrium model. In poor countries, farmers use fewer intermediate inputs, driving down agricultural productivity. The model captures about two thirds of the difference in intermediate input shares between the richest and poorest countries, even though underlying farm technologies are Cobb-Douglas. Technically, this result is due to the interaction of uninsurable risk with DRRA preferences generated by subsistence requirements. This has important quantitative implications for productivity across countries. Relative to an identical model with no productivity shocks, agricultural productivity differences are amplified by about 50%, while aggregate productivity differences are amplified by almost 80%.

The model also provides a new channel through which sector-specific distortions can impact productivity. Since distortions decrease income, they feed back into even lower choices of intermediates. Quantitatively, these distortions are key to understanding the complete impact of agricultural risk. Counterfactual experiments show that lowering these distortions facilitates increased self-insurance on the part of farmers, decreasing the impact of agricultural risk on intermediate input shares and productivity.

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Appendices

A Data Sources and Construction

A.1 Productivity and Intermediate Input Share Statistics

I make use of the publicly available data from Restuccia, Yang, and Zhu (2008) for statistics on aggregate productivity, agricultural productivity, labor, and intermediate input prices. This is augmented with purchasing power parities (PPP) for agricultural output and nonagricultural intermediate inputs from Prasada Rao (1993). The resulting dataset contains 84 countries, which are:

Algeria, Angola, Argentina, Australia, Austria, Bangladesh, Belgium, Bolivia, Brazil, Burkina Faso, Burundi, Cameroon, Canada, Chad, Chile, Columbia, Costa Rica,Côte d'Ivoire, Democratic Republic of the Congo, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Germany, Ghana, Greece, Guatemala, Guinea, Haiti, Honduras, Hungary, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Japan, Kenya, Korea, Madagascar, Malawi, Malaysia, Mali, Mexico, Morocco, Mozambique, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Pakistan, Papau New Guinea, Paraguay, Peru, Philippines, Portugal, Rwanda, Senegal, Somalia, South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syria, Thailand, Tunisia, Turkey, U.K., U.S.A., Uganda, Uruguay, Venezuela, and Zimbabwe.

A.1.1 Productivity

I am interested a measure of the ninetieth percentile country relative to the tenth percentile country, similar to that used in Caselli (2005). As a measure of the rich country, I take average of the top ten percent of countries. Listed from largest to smallest income, they are USA, Canada, Switzerland, Australia, Norway, Netherlands, Belgium, and Germany. As a measure of the "tenth" percentile, I take an average of the countries that make up the bottom fifteen to five percent of countries, as ranked by PPP GDP per capita. They are Somalia, Rwanda, Mozambique, Uganda, Malawi, Chad, Zaire and Niger.

The productivity statistics are taken from Restuccia, Yang, and Zhu (2008). They are derived from PWT and FAO data. These averages imply a factor of 63.66 difference in agricultural output per worker and 23.18 difference in aggregate output per worker. On average, 82% of the population in the poor countries work in agriculture.

A.1.2 Intermediate Input Shares

As in the text, the domestic intermediate share in agriculture of country j is

$$\widehat{X}^j := \frac{p_x^j X^j}{p_a^j Y_a^j} \tag{A.1}$$

This measure is not directly reported in Prasada Rao (1993). He does however, report the real intermediate share in agriculture, defined as

$$\widehat{X}^{j*} := \frac{p_x^* X^j}{p_a^* Y_a^j} \tag{A.2}$$

where p_x^* and p_a^* are international prices of intermediate inputs and agricultural output. Combining equations (A.1) and (A.2), it is possible to write the domestic intermediate share as

$$\widehat{X}^j = \widehat{X}^{j*} \left(\frac{p_x^j / p_x^*}{p_a^j / p_a^*} \right) \tag{A.3}$$

The price ratio in equation (A.3) can be calculated from reported purchasing power parities

$$\begin{aligned} PPP_a^j &= \frac{p_a^j}{p_a^*} \\ PPP_x^j &= \frac{p_x^j}{p_x^*} \end{aligned}$$

where p_a^* and p_x^* are international (unreported) prices and (p_a^j, p_x^j) are (unreported) domestic prices for country j. The purchasing power parities are normalized to one in a baseline country, which in Prasada Rao (1993) is the USA. Therefore, $PPP_a^{US} = PPP_x^{US} = 1$, implying $\widehat{X}^{US} = \widehat{X}^{US*}$. Therefore, calculating the domestically priced intermediate share of all other countries reduces to

$$\widehat{X}^j = \widehat{X}^{j*} \left(\frac{PPP_x^j}{PPP_a^j} \right) \tag{A.4}$$

As mentioned, the real intermediate share and the ratio of PPPs are both reported, so this is sufficient to define the domestically priced intermediate input share. The poor group group of countries has, on average, a domestically priced intermediate input share of 0.09 and a real intermediate input share of 0.13. The right hand side of equation (A.4) is the statistic reported in Figure 1. The horizontal axis, GDP per capita, is real GDP per capita for 1985, variable cgdp from the Penn World Tables version 7.0 (PWT).

A.2 Three Sector Comparison: UN System of National Accounts

For the comparison of agriculture to manufacturing and services, I use a set of 49 countries from the UN SNA. The 49 countries with sufficient data for all three sectors Austria, Benin, Bolivia, Botswana, Burundi, Cameroon, Canada, Cape Verde, Chile, Hong Kong, Colombia, Cyprus, Denmark, Ecuador, El Salvador, Fiji, Finland, France, Gambia, Germany, Ghana, Hungary, Iceland, Italy, Jamaica, Japan, Jordan, Republic of Korea, Luxembourg, Mauritius, Mexico, Netherlands, New Zealand, Nigeria, Norway, Peru, Portugal, Rwanda, Seychelles, Sierra Leone, Spain, Sri Lanka, Swaziland, Sweden, Syrian Arab Republic, United Kingdom, Uruguay, Venezuela, and Zimbabwe.

From the UN SNA, I use "Output, at basic prices" and "Intermediate consumption, at purchaser's prices" for the year 1985 for each of the three sectors. Dividing them gives the domestically priced intermediate input share by sector. Figure 2 plots this, along with variable cgdp for 1985 from PWT on the horizontal axis. Note that the intermediate share in agriculture derived from the UN statistics and the FAO statistics may differ. This is due to the fact that the UN statistics includes intermediate inputs produced in the agricultural sector, while the FAO statistics only consider nonagricultural intermediate inputs.

B Proofs

B.1 Proof of Proposition 1

Proof. The profit maximizing first order condition implies that

$$\frac{x^C}{p_a^C Y_a^C} = \psi \tag{B.1}$$

Define x^* to be the optimal choice for the village facing the price p_a^I, but with complete markets. Then the first order condition implies

$$\frac{x^*}{p_a^I Y_a^*} = \psi \tag{B.2}$$

Comparing (B.1) and (B.2), the proposition is equivalent to proving that at the price p_a^I, $x^I < x^*$. Suppose instead that $x^I = x^*$. This implies $n_a^I(z) = n_a^*(z)$. Moreover, the first order conditions imply

$$\int_{\underline{z}}^{\bar{z}} \left(\frac{u'(y(x,z) - p_a\bar{a})(\psi z p_a A x^{\psi-1} n_a(z)^\eta)}{\mathbb{E}_z[u'(y(x,z) - p_a\bar{a})]} \right) dQ(z) = \int_{\underline{z}}^{\bar{z}} (\psi z p_a A x^{\psi-1} n_a(z)^\eta) dQ(z) \tag{B.3}$$

where $u(\cdot) = \log(\cdot)$ and $y(x,z)$ is total income with x intermediate inputs and shock z. This cannot hold, because the concavity of $u(\cdot)$ implies

$$\int_{\underline{z}}^{\bar{z}} \left(\frac{u'(y(x,z) - p_a\bar{a})(\psi z p_a A x^{\psi-1} n_a(z)^\eta)}{\mathbb{E}_z[u'(y(x,z) - p_a\bar{a})]} \right) dQ(z) < \int_{\underline{z}}^{\bar{z}} (\psi z p_a A x^{\psi-1} n_a(z)^\eta) dQ(z) \tag{B.4}$$

By the concavity of the production function, it follows that $x^I < x^*$. ■

B.2 An Additional Lemma for the Proof of Proposition 2

To prove the result, I first characterize the the equilibrium of an I economy with TFP A^2 and $\bar{a} = 0$ in terms of an economy with TFP A^1 and $\bar{a} = 0$. This is done in Lemma 1 below.

Lemma 1. *Consider two I economies characterized by TFP levels A^1 and A^2, both with $\bar{a} = 0$. Denote the equilibrium for economy 1 as $(x^1, n_a^1(z), p_a^1)$. Then the equilibrium for economy 2, $(x^2, n_a^2(z), p_a^2)$ can be characterized as*

$$\begin{aligned} n_a^2(z) &= n_a^1(z) \\ x^2 &= \left(\frac{A^2}{A^1}\right) x^1 \\ p_a^2 &= \left(\frac{A^1}{A^2}\right)^{\psi} p_a^1 \end{aligned}$$

Proof. Two things must be checked for the proposed allocation to be a competitive equilibrium. First, the proposed equilibrium must satisfy the village optimization problem. That is, if $(p_a^1, x^1, n_a^1(z))$ is an equilibrium in economy 1, then $(p_a^2, x^2, n_a^2(z))$ satisfies the farmer's optimization problem in economy 2. Second, markets must clear. These are considered in turn.

Optimization Problem The first thing to check is that the labor choice is identical between the two. Denote $\widehat{z}^1$ as the z for which the constraint $n_a^1(z) \leq 1$ binds. From the first order condition for $n_a(z)$, this is given as

$$\widehat{z}^1 = \frac{1}{\eta p_a^1 x^{1\psi}}$$

First, I show that $\widehat{z}^2 = \widehat{z}^1$. This consists of simply substituting the proposed equilibrium into the equation for $\widehat{z}^2$.

$$\begin{aligned}
\widehat{z}^2 &= \frac{1}{\eta p_a^2 x^{2\psi}} \\
&= \frac{1}{\eta \left(\frac{A^1}{A^2}\right)^{\psi} p_a^1 \left(\frac{A^2}{A^1}\right)^{\psi} x^{1\psi}} \\
&= \frac{1}{\eta p_a^1 x^{1\psi}} \\
&= \widehat{z}^1
\end{aligned}$$

Define $\widehat{z} := \widehat{z}^1 = \widehat{z}^2$. Then for all $z \geq \widehat{z}$, $n_a^1(z) = n_a^2(z) = 1$, so that the optimal labor choice is identical for all $z \geq \widehat{z}$. For all $z < \widehat{z}$, I can check this using the first order conditions for $n_a^1(z)$ and $n_a^2(z)$.

$$\frac{n_a^1(z)}{n_a^2(z)} = \left(\frac{p_a^1 A^1 (x^1)^{\psi}}{p_a^2 A^2 (x^2)^{\psi}}\right)^{1/(1-\eta)}$$

Plugging in (p_a^2, x^2) implies

$$\frac{n_a^1(z)}{n_a^2(z)} = 1$$

This implies that $n_a^1(z) = n_a^2(z)$ for all $z \in [\underline{z}, \bar{z}]$ as required. For simplicity, I drop the superscript on $n_a(z)$, with the understanding that they are identical in both economies.

Next up is to check if x^2 satisfy the required first order conditions, given that x^1 satisfies the first order condition in economy one. Note that when $\bar{a} = 0$, the harvesting utility for a given income y can be written as

$$\begin{aligned} V^H(y) &= \alpha \log(c_a^1) + (1-\alpha)\log(c_m^1) \\ &= \Omega - \alpha \log(p_a^1) + \log(y) \end{aligned} \tag{B.5}$$

where $\Omega = \alpha \log(\alpha) + (1-\alpha)\log(1-\alpha)$. Denote the income of a farmer who chooses intermediates x and gets hit with shock z in economy $j = 1, 2$ as

$$y^j(x, z) = p_a^j A^j z x^\psi n_a(z)^\eta - x + (1 - n_a(z))A^j$$

Plugging in the proposed equilibrium yields the following relationship

$$y^2(x^2, z) = \left(\frac{A^2}{A^1}\right) y^1(x^1, z) \tag{B.6}$$

Equation (B.5) implies that

$$x^j = \arg\max_x \int_Z \log(y^j(x, z))dQ(z)$$

After plugging in the optimal values for $n_a(z)$, the first order condition for this problem can be written as

$$\int_{\underline{z}}^{\bar{z}} \left(\frac{\psi p_a^j z A^j x^{j\psi} n_a(z)^\eta - 1}{y^j(x, z)}\right) = 0$$

Plugging in the proposed equilibrium yields a relationship between economies one and two

$$\int_{\underline{z}}^{\bar{z}} \left(\frac{\psi p_a^2 z A^2 x^{2\psi} n_a(z)^\eta - 1}{y^2(x, z)}\right) = \left(\frac{A^1}{A^2}\right) \int_{\underline{z}}^{\bar{z}} \left(\frac{\psi p_a^1 z A^1 x^{1\psi} n_a(z)^\eta - 1}{y^1(x^j, z)}\right)$$

Since an equilibrium is assumed in economy one, it follows then that

$$\int_{\underline{z}}^{\bar{z}} \left(\frac{\psi p_a^2 z A^2 x^{2\psi} n_a(z)^\eta - 1}{y^2(x, z)}\right) = 0$$

Therefore, the proposed economy two equilibrium satisfies a village's optimization problem.

Market Clearing Aggregate sector a output for economy $j = 1, 2$ is

$$Y_a^j = Ax^{j\psi}\mathbb{E}_z(zn_a(z)^\eta)$$

Thus,

$$\frac{Y_a^1}{Y_a^2} = \left(\frac{A^1}{A^2}\right)\left(\frac{x^1}{x^2}\right)^\psi \tag{B.7}$$

Therefore, at the proposed equilibrium,

$$\frac{Y_a^1}{Y_a^2} = \left(\frac{A^1}{A^2}\right)^{1+\psi} \tag{B.8}$$

For any $\bar{a} \geq 0$, the total demand for sector a consumption is given by

$$D_a^j = (1-\alpha)\bar{a} + \frac{\alpha}{p_a^j}\mathbb{E}_z[y^j(X^j, z)] \tag{B.9}$$

Using equation (B.6),

$$\frac{\mathbb{E}_z[y^1(x^1, z)]}{\mathbb{E}_z[y^2(x^2, z)]} = \frac{A^1}{A^2} \tag{B.10}$$

Since $\bar{a} = 0$, equations (B.9) and (B.10) and the prices p_a^1 and p_a^2 imply that

$$\frac{D_a^1}{D_a^2} = \left(\frac{A^1}{A^2}\right)^{1+\psi} \tag{B.11}$$

Since the proof assumes an equilibrium in economy 1, equations (B.8) and (B.11) imply $Y_a^2 = D_a^2$ so that the agricultural output market clears in economy two. Since the labor market in sector m clears trivially, Walras' Law implies that the sector m output market also clears. ■

B.3 Proof of Proposition 2

Proof. With Lemma 1 in hand, the three claims of the proposition follow quickly.

B.3.1 $n_a(z)$ is independent of A

This follows directly from Lemma 1.

B.3.2 The intermediate input share is independent of A

Denote $\hat{X}^j$ as the intermediate good share in economy $j = 1, 2$, so that $\hat{X}^j$ is defined as

$$\hat{X}^j = \frac{x^j}{p_a^j Y_a^j} \tag{B.12}$$

First, note that total agricultural output in economy j is given as

$$Y_a^j = A^j (x^j)^\psi \mathbb{E}_z(z n_a^j(z)^\eta) \tag{B.13}$$

Using the fact that $n_a^1(z) = n_a^2(z)$ and plugging (B.13) into (B.12) gives

$$\frac{\hat{X}^1}{\hat{X}^2} = \left(\frac{x^1}{x^2}\right)^{1-\psi} \left(\frac{p_a^2}{p_a^1}\right) \left(\frac{A^2}{A^1}\right)$$

Plugging in the equilibrium found in Lemma 1, this gives

$$\begin{aligned} \frac{\hat{X}^1}{\hat{X}^2} &= \left(\frac{A^1}{A^2}\right)^{1-\psi} \left(\frac{A^1}{A^2}\right)^{\psi} \left(\frac{A^2}{A^1}\right) \\ &= 1 \end{aligned}$$

Since A^1 and A^2 are arbitrary, this completes the proof.

B.3.3 No increase in productivity relative to C economy

For any two economies characterized by TFP A^1 and A^2 and complete markets (the C economy), it is easy to show that in equilibrium,

$$\begin{aligned} n_a^1 &= n_a^2 \\ x^2 &= \left(\frac{A^2}{A^1}\right) x^1 \end{aligned}$$

Since this is the same as in the incomplete markets model (the I economy), relative agricultural labor productivity between the two economies is equal in both.

■

B.4 Proof of Proposition 3

Proof. Consider the equilibrium for economy 1 with TFP equal to A^1. Denote this equilibrium $(p_a^1, X^1, N_a^1(z))$. Suppose that the intermediate good share is $\hat{X}^1 < \psi$, where the inequality follows from Proposition 1. Define X^{1C} to be the optimal choice of the farmer who faces p_a^1 and no risk. We know that the intermediate good share is $\hat{X}^{1C} = \psi$. Therefore, the ratio is

$$\frac{\hat{X}^1}{\hat{X}^{1C}} = \frac{\hat{X}^1}{\psi} = \left(\frac{X^1}{X^{1C}}\right)^{(1-\eta-\psi)/(1-\eta)}$$

Thus, we can write $\hat{X}^1$ as

$$\hat{X}^1 = \psi \left(\frac{X^1}{X^{1C}}\right)^{(1-\eta-\psi)/(1-\eta)}$$

Similarly, it follows that in economy 2,

$$\hat{X}^2 = \psi \left(\frac{X^2}{X^{2C}}\right)^{(1-\eta-\psi)/(1-\eta)}$$

These equations show that the intermediate good share is directly related to how "far" the optimal choice of X is from the choice X^C. What's left to show is that when $\bar{a} > 0$ and $A^1 > A^2$,

$$\frac{X^1}{X^{1C}} > \frac{X^2}{X^{2C}}$$

This follows from the fact that, when $\bar{a} > 0$, relative income net of subsistence,

$$\frac{y^1(z) - p_a^1\bar{a}}{y^2(z) - p_a^2\bar{a}}$$

is decreasing in z. ∎

C Calibration of Shocks

The data used was collected by ICRISAT. I use the version that was released by Stefan Dercon, via the Oxford University website. It is publicly available at
http://www.economics.ox.ac.uk/members/stefan.dercon/icrisat/ICRISAT/oldvls.html.

The ICRISAT VLS is an unbalanced panel set covering 10 villages in India. The data covers the time period 1975 - 1984.

The goal is to calculate the value of the following inputs at the village level: capital K, agricultural intermediates I, nonagricultural intermediates X, human labor hours N_a, and land L. Allowing for some abuse of notation, let these letters also denote the set of all inputs of that type, so K is the set of all capital goods in the economy, for example.

C.1 Prices

For concreteness, I explain the prices in terms of the set of nonagricultural intermediate good set X.

I use a constant set of prices so that I do not include price fluctuations in my value of uncertainty. Price construction proceeds as follows. First, all prices are considered at the village level. Therefore, fix a village v. I use 1975 as my base year. Prices are available only by imputing them from the quantity and value of inputs used. Therefore, if input $x \in X$ is used at $t = 1975$, the price I use is

$$p_{v,x} = \frac{TV_{v,x}}{Q_{v,x}}$$

where TV and Q are total value and quantity of input x at the plot level. Notice that this implies that if input x is not used every period, I cannot calculate a $p_{v,x,t}$ at every period. Thus, if x is not used at $t = 1975$, I need to calculate some price $p_{v,x,1975}$. I use the following procedure. First, get all prices $p_{v,x,t}$ for all $x \in X$ and all t in v. Denote the set of inputs that have prices available for all years as $X' \subseteq X$. Construct average change in price over all inputs $x' \in X'$. This gives me an average price change for $1975 - 1976$ (denoted g_{75}^X), another for $1976 - 1977$ (g_{76}^X), etc. Note that this average price change is specific to input set X. That is, I do not require $g_{75}^X = g_{75}^K$, for example.

Now consider an input $x \in X$ that is first used in v at $t^* \neq 1975$. Then the first available price for x is p_{v,x,t^*}. To construct the 1975 price $p_{v,x,1975}$, I deflate the value by the relevant growth rates

$$p_{v,x,1975} = \frac{p_{v,x,t^*}}{\Pi_{t=1975}^{t=t^*-1} \left(1 + g_t^X\right)}$$

Since the prices remain constant over time, I refer to the price of input x in village v as $p_{v,x}$, dropping the time subscript.

C.2 Construction of Inputs

The data includes 5 inputs: Capital, land, human labor, non-agricultural intermediates, and agricultural intermediates.

C.2.1 Capital

I use class code E, farm equipment and implements and class code M, major farm machinery, and class code R, production capital assets. Class code E includes basic farm equipment such as plows and hoes. Class code M includes major machinery such as tractors and electric pumps.

A key capital component in agriculture is productive animals. Therefore, I also include bullock labor hours at the plot level, both owned and rented bullocks. The value of an hour of an owned bullock is imputed from the rental rates of hired bullock hours, so they are valued equally. Thus, the value of bullock hours on plot p owned by family f in village v at time t is given as

$$B_{f,p,v,t} = r_v^b \left(B^o_{f,p,v,t} + B^r_{f,p,v,t} \right)$$

where the rental rate r_v^b is computed using the technique described above.

Combining these two values gives the total capital input for production on plot p owned by family f in village v at time t, denoted $K_{f,p,v,t}$.

$$K_{p,f,v,t} = \left(\sum_{k \in K} p_{k,v} Q_{k,f,p,v,t} \right) + B_{f,p,v,t} \quad \forall \, (p, f, v, t)$$

C.2.2 Human Labor

The Y files give hours of male, female, and child labor in the data. Since I calibrate to match the fraction of the population over 15 years of age, I include only male and female labor. Child labor is a small component with the lowest price (i.e. not as productive as an adult laborer). Including it makes no discernible difference. Similar to bullock labor hours, the Y files include disaggregated data on both family and hired workers. Once again though, the value of family labor is imputed from market value, so they are valued equally.

Letting H^f and H^h denote family and hired hours, the total value of labor on plot

(p, f, v, t) is given by

$$N_{p,f,v,t} = \sum_{j=M,F} w_{v,j} \left(H^f_{p,f,v,t} + H^h_{p,f,v,t} \right)$$

where $w_{v,j}$ is the value per hour of $j \in \{M, F\}$.

C.2.3 Non-agricultural Intermediates

Nonagricultural intermediates include pesticides, which are input codes $1A{-}9A$, and fertilizer (input codes $A - Z$). Therefore, the total non-agricultural intermediate goods on a given plot is

$$X_{p,f,v,t} = \sum_{x \in X} p_{v,x} Q_{x,p,f,v,t}$$

C.2.4 Agricultural Intermediates

Agricultural intermediates can be included by using the Y files. Organic manure in the data are inputs $1 - 7$. Seed is denoted as inputs $CA - ZK$. The quantity and values are in the Y files. As with the other inputs, the total value of agricultural intermediate inputs on plot p owned by farmer f in village v in year t is

$$I_{p,f,v,t} = \sum_{i \in I} p_{v,i} Q_{i,p,f,v,t}$$

C.2.5 Land

A key issue with modeling idiosyncratic risk is things that may look like risk for the economic modeler may actually be unmeasured idiosyncratic differences. Since I do not want to include idiosyncratic differences as risk, I include land quality in my construction of land input. To do so, I use plot value in the PS file. This is the value of the land, given as *Value of Land (Y-11)* in the manual and is 'Rs. 100' per acre. I allow this value to vary over time. Therefore, I do not assume that each plot has the same value in every period. My measure of land L then is

$$L_{p,f,v,t} = TV^L_{p,f,v,t}$$

where $TV^L_{p,f,v,t}$ is the total value of plot p owned by farmer f in village v at time t.

C.3 Output

Total value of output is given by summing over output values in the Y files by plot level. I include both actual production and by-products produced by farming. Since sometimes more than one crop is planted on a plot, I sum over all outputs on the plot. Letting Y denote the possible set of outputs, total output on a given plot is

$$Y^a_{p,f,v,t} = \sum_{y \in Y} p_{y,v} Q_{y,p,f,v,t}$$

C.4 Decomposition of Residuals

As it currently stands, the data are at the (p, f, v, t) level. The next step is to sum over (p, f) to get village v values of inputs and output at year t. This now gives me the input vector $(K, L, N_a, I, X)_{v,t}$. Now, I can calculate the residual

$$z^*_{v,t} = \frac{Y^a_{v,t} - I_{v,t}}{X^{\psi}_{vt} N^{\eta}_{a,vt} (K_{vt} + L_{vt})^{1-\psi-\eta}}$$

where η and ψ are taken from the calibration in the main text. The rest is explained in the main text.