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Katharina Grabrucker, Michael Grimm

Universität Passau, RWI Research Network, IZA

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Thailand Vietnam Socio Economic Panel (TVSEP)
TVSEP Database Centre
Leibniz Universität Hannover
Königsworther Platz 1
30167 Hannover, Germany

Contact: lippe@ifgb.uni-hannover.de

Is there a rainbow after the rain? How do agricultural shocks affect non-farm enterprises?

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Katharina Grabrucker[a] and Michael Grimm[a,b,c †]

[a]University of Passau, [b]RWI Research Network, [c]IZA

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Abstract

Increasing weather volatility poses a significant threat to the livelihood of rural households in developing countries. While how rainfall shocks affect agricultural households has been well documented, there is not much evidence on the indirect effects on non-agricultural households. Combining household panel data with grid-level precipitation data, we analyze how rainfall shocks affect non-farm enterprises in rural Thailand. We examine the effects of rainfall shocks on labor supply for independent, non-farm activities as well as the indirect effects of rainfall shocks on non-farm enterprises through forward linkages, backward linkages and the consumption levels of farm households. We find that farm households increase their labor participation in non-farm self-employment in response to rainfall shocks. We also observe that rainfall shocks lead to increased input costs by non-farm enterprises in the food processing industry, to higher input costs by farms, to higher sales by agriculture-related non-farm enterprises and to lower expenditure by farm households on food and other consumption items. These effects are significant for surplus rainfall shocks (i.e., more rainfall than usual) but less robust for deficit rainfall shocks (i.e., less rainfall than usual), yet both surplus and deficit rainfall shocks lower agricultural production compared to normal rainfall conditions.

Keywords: Rainfall shocks, Non-farm enterprises, Farm/Non-farm linkages, Thailand.

JEL Codes: D22**,** J22, J46, Q12, R11

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[†] Katharina Grabrucker, e-mail: katharinagrabrucker@gmail.com; Michael Grimm (corresponding author), e-mail: michael.grimm@uni-passau.de, phone: +49 (0)851 5093310, University of Passau, Chair of Development Economics, Innstrasse 29, 94032 Passau, Germany.

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In times of changing climate and increasing weather volatility, rural households in the developing world face a significant threat to their livelihood (e.g., S. Pandey, Bhandari, and Hardy 2007). Rainfall shocks, for instance, have a direct impact on farm households, which rely to a large extent on rain-fed agriculture. However, these shocks might also indirectly affect the rural non-farm sector through farm/non-farm linkages (see e.g., Janvry and Sadoulet 1995; Haggblade, Hazell, and Brown 1989). Farm households might, as a consequence of rainfall shocks, adjust their labor supply to the non-farm sector (see e.g., Barrett, Reardon, and Webb 2001; Janvry and Sadoulet 2001). Moreover, the non-farm sector might also be affected by changes in the income levels of farm households, as well as changes in the price and supply of agricultural products as a result of potentially worsened agricultural performance.[1]

The literature that focuses on rainfall shocks has largely concentrated on rural households. Many studies analyze how rainfall shocks affect the income and consumption of rural households (e.g., Dercon 2004; Asiimwe and Mpuga 2007; Porter 2008; Phung Duc and Waibel 2009; Völker, Tongruksawattana, and Schmidt 2013; Noy and Patel 2014). Other studies focus on the effects on the health (e.g., Rose 1999; Alderman, Yamano, and Christiaensen 2005; Bengtsson 2010) and education (e.g., Maccini and Yang 2009; Björkman-Nyqvist 2013; Shah and Steinberg 2017) of household members. Again others examine the coping strategies of rural households, for instance the impact of rainfall shocks on the households' labor supply (e.g., Kochar 1999; Rose 2001; Cameron and Worswick 2003; Ito and Kurosaki 2009; Phung Duc and Waibel 2009; Völker, Tongruksawattana, and Schmidt 2013; Amare and Waibel 2014). Another strand of research analyses the interdependencies between the rural farm and the non-farm sector by studying farm/non-farm linkages (e.g., Hirschman 1958; Mellor 1976; Haggblade, Hazell, and Brown 1989; Davis et al. 2002a; A. Pandey 2015). Yet little research has been done combining these two strands, i.e., analyzing the effects of rainfall shocks while focusing on the indirect effects on non-farm enterprises that are triggered through farm/non-farm linkages. A notable exception is a study by Rijkers and Söderbom (2013), which examines the impact of agricultural

[1] Rainfall shocks stand for a strong negative or positive deviation from the average rainfall (i.e., less or more rainfall than average, respectively) in a particular time period. When we refer to 'farm households', we mean households that generate the major part of their income through their own farm. Farm/Non-farm linkages explain the interdependencies of the agricultural (farm) and the non-farm sector. We hereby distinguish between production linkages and consumption linkages. For a detailed definition and description of rainfall shocks, the different types of households and economic units, as well farm/non-farm linkages, the reader can refer to section 2.

shocks and risk on non-farm enterprises in Ethiopia. They found that improved agricultural performance (e.g., due to positive agricultural shocks) increases the households' propensity to run a non-farm enterprise. It also positively affects the profits of these enterprises. Their analysis also suggests a negative relationship between exposure to adverse rainfall shocks and investment in non-farm enterprises.

We add to these two strands of the literature by investigating the indirect effects of rainfall shocks on non-farm enterprises in rural Thailand. We not only consider the effects on labor supply to non-farm enterprises, but also focus on the indirect effects on the performance of non-farm enterprises through farm/non-farm linkages. We distinguish effects due to forward linkages (i.e., supply of inputs to non-farm enterprises by farms), effects due to backward linkages (supply of inputs to farms by non-farm enterprises), and effects due to consumption by farm households.

Thailand is an interesting case for the analysis of these interdependencies. While the country experienced strong economic growth (on average 7.5% in the 1980s and 1990s) and has successfully reduced poverty in the last decades (from 67% in 1986 down to 7% in 2015), rural-urban inequality is still an important challenge in Thailand (World Bank 2017). On the one hand, urban areas – in particular Bangkok but also cities such as Chiang Mai – prosper due to a sustained economic dynamism and experienced a structural change from agriculture, through industry to the service sector. On the other hand, rural areas, especially the relatively poor Northeastern provinces, are to a large extent underdeveloped with the majority of the inhabitants engaged in agricultural activities. The large share of its agricultural sector - by the end of 2017 still 32% of Thailand's population worked in the agricultural sector - makes Thailand particularly vulnerable to weather shocks and climate change (Mahathanaseth and Pensupar 2014). Policies and economic reforms by the Thai government therefore often focus on the agricultural sector but tend to neglect the needs of the rural non-farm sector.

In this article, we analyze how the rural non-farm sector is affected by rainfall shocks using a panel data set of more than 2,000 households from three Northeastern provinces in Thailand observed over five years. To this dataset we link monthly grid-level precipitation data. The virtue of our data is the great level of detail with which both agricultural and non-agricultural activities are documented. To the best of our knowledge, we are among the first to study the effects of rainfall shocks on the non-farm sector in such detail, i.e., not only analyze how these shocks influence the households' labor supply, but also consider the effects through backward and forward linkages as well as the impact on consumption.

We find that too much rain increases labor supply in non-farm enterprises. Our results also show that surplus rainfall shocks lead to increasing input costs (forward linkages) and to higher sales by non-farm enterprises (backward linkages). Surplus rainfall shocks, moreover, seem to positively affect farm spending on machinery of non-farm enterprises (such as tractors, threshing machines, knapsack sprayers) while they lead to a lower spending on hired labor, pesticide and irrigation. Lastly, surplus rainfall shocks appear to have a slightly negative effect on total and food consumption by farm households. The examined effects of deficit rainfall shocks are comparable, though in many cases not statistically significant.

The remainder of the article is structured as follows: In section 2, we describe the main terminology, conceptual framework and related literature, and derive our hypotheses. In section 3, we present the data, descriptive statistics and the context of our study. In section 4, we introduce our empirical strategy and discuss the results of our analysis. We conclude in section 5.

Conceptual framework, literature review and hypotheses

In this section, we introduce the conceptual framework of our analysis and derive our hypotheses. We first define the key terminology used in this article. Thereafter, we discuss the direct effects of rainfall shocks on farm households, before giving an overview of the research on farm/non-farm linkages. Based on this theoretical and empirical background, we then derive our hypotheses on how rainfall shocks indirectly affect non-farm enterprises.

Key terminology

In the literature, rainfall shocks typically refer to a deviation in the amount of rainfall in a certain period from the medium or long-term average. For instance, Ito and Kurosaki (2009) define a rainfall shock as the deviation from the level of rainfall in a particular year from the fifteen-year average, while Rose (2001) relates the rainfall in one year to the average over the previous 22 years. Some studies consider the rainfall in the rainy season only (e.g., Kochar 1999; Amare and Waibel 2014), while others take the whole year into account (e.g., Iyer and Topalova 2014). Rainfall deviation can be positive (i.e., more rainfall than on average) or negative (i.e., less rainfall than on average). The terms ‘positive’ and ‘negative’, thus, do not indicate the direction of the impact of the shock, but rather the deviation of the rainfall from the average. To avoid any misunderstanding, in this article we will call shocks with a positive deviation from the average ‘surplus rainfall shocks’ and shocks with a negative deviation ‘deficit rainfall shocks’.

When analyzing rural households and the rural economy, it is, moreover, important to distinguish between the different types of households, economic units, and labor activities. We define a household as farm household if agricultural work on the own farm constitutes the first occupation and the main source of income for the household members. The term ‘farm’ is, therefore, a classification of a household with respect to its main source of income. The same applies accordingly to ‘non-farm’ households. In contrast to this, there are the economic units, ‘farms’ and ‘non-farm enterprises’, to which household members supply their labor. A farm household earns the dominant share of its income from ‘agricultural activities’ in their farm, but the household may also own a non-farm enterprise or supply parts of their labor to the non-farm sector, i.e., additionally engage in ‘non-agricultural activities’.

Effects of rainfall shocks on farm households

Rainfall shocks directly affect the welfare of rural farm households. In the first place, there is the immediate impact of a rainfall shock on agricultural production. Both types of rainfall shocks (surplus and deficit) might result – depending on the type of crop that is cultivated and on access to irrigation – in a worse harvest and, thus, in an overall lower production output by a farm (see e.g., S. Pandey, Bhandari, and Hardy 2007; Felkner, Tazhibayeva, and Townsend 2009). Assuming that farm households can, if at all, only marginally influence sales prices, the rainfall shock will lead to a reduction in revenue from agricultural activities and – everything else remaining constant – to a lower overall income level of the farm household. This again may have direct effects on the welfare of this household through coping strategies such as the lowering of (food) consumption expenditure, reduced spending on health, or a cut in the expenditure on education. There is an extensive body of research that documents these effects (e.g., Rose 1999; Alderman, Yamano, and Christiaensen 2005; Maccini and Yang 2009; Bengtsson 2010; Skoufias, Rabassa, and Oliveri 2011; Björkman-Nyqvist 2013; Shah and Steinberg 2017). The farm household, however, could also try to mitigate these potential negative consequences by substituting the lost agricultural income with additional income from other labor market activities. This could be achieved by a shift in the household's labor supply toward non-farm employment and self-employment (see e.g., Janvry, Fafchamps, and Sadoulet 1991; Reardon et al. 1998; Barrett, Reardon, and Webb 2001; Janvry and Sadoulet 2001; Dimova et al. 2015). This diversification and reorientation of labor supply is of particular interest for our analysis, as it has a substantial impact on non-farm enterprises. The majority of the empirical papers that analyzed this effect observed a positive relationship between rainfall shocks and labor supply to the non-farm sector, in particular non-farm self-employment. For instance, Ito and Kurosaki (2009) examined how weather risk (defined as the coefficient of variation of rainfall) effects the labor supply of Indian farm households to off-farm activities. They found a positive relationship between weather risk and the labor supply to off-farm activities. In an earlier study, Kochar (1999) analyzed the effect of shocks in income from crops on the labor supply to non-farm activities and the consumption levels of Indian farm households and their members. She found that when facing shocks in income from crops, Indian farm households smooth their consumption by increasing the hours worked in the off-farm labor market. Studying the impact of crop failure on labor supply and consumption in Indonesia, Cameron and Worswick (2003) showed that more than 40% of the households affected by a crop loss shifted their labor supply from farm-related to other activities in order to maintain their consumption level. Rose (2001) explored also the labor supply response of Indian agricultural households to weather risks and observed an increase in labor market participation before and after rainfall shocks. Some research also analyzed these effects for the case of Thailand. For example, Völker, Tongruksawattana, and Schmidt (2013) showed that the price shock in farm inputs in 2008 in Thailand led to a diversification of households out of farming into non-farm employment and self-employment. Also Amare and Waibel (2014) explored the effects of rainfall shocks on non-farm employment in Thailand. Using the same household level dataset as we do (i.e., TVSEP), they observed that, in the event of rainfall shocks, rural households increase their labor supply to non-farm employment and self-employment, while agricultural (e.g., crop pest) and demographic shocks (e.g., death of a household member) trigger a shift of labor to agricultural employment.

Farm/Non-farm linkages

With the growing importance of the non-farm sector for rural households, both theoretical and empirical research on rural farm/non-farm linkages has increased over the last decades (e.g., Haggblade and Hazell 1989; Reardon 1997; Reardon et al. 1998). This literature distinguishes between two main types of linkages: production linkages, which can be divided into backward and forward linkages, and expenditure linkages, which can be divided into consumption and investment linkages (see e.g., Hirschman 1958; Mellor 1976; Harriss 1987; Haggblade, Hazell, and Brown 1989; Davis et al. 2002b). Forward linkages refer to sales of agricultural inputs by farms to non-farm enterprises. Consequently, forward linkages implies that the farms' agricultural output (i.e., supply) affects non-farm enterprises such as (food) processing companies and restaurants that use agricultural inputs. Backward linkages, in contrast, refers to sales of non-agricultural inputs by non-farm enterprises to farms. This means that the farms' demand for inputs influences non-farm enterprises that supply products and services to farms, e.g., enterprises that produce and/or sell fertilizer and pesticides, seeds, or farm machinery. Expenditure linkages refers to the interdependencies between farm households and non-farm enterprises as well as non-farm households and farms, due to the spending of one group on the goods and services of the other group (consumption), or through investment expenditure. Hence, the consumption behavior of farm households affects the sales of non-farm enterprises that offer consumer products and services, e.g., grocery shops and other retailers, barbers and street kitchens. The other way around, non-farm households' consumption of agricultural products – such as rice, vegetables, and tea – also affects farms. Turning to investment linkages, farm households might influence non-farm activities when financing and investing in these; the same holds true for non-farm households and farm activities. Several theoretical and empirical papers studied these linkages, ascribing varying degrees of importance to the different types of linkages. For instance, Haggblade, Hazell, and Brown (1989) reviewed the farm/non-farm linkages in rural Africa and gave recommendations to policy makers on how to use these linkages to promote rural development. Taking into account cross-section data from several surveys, data from reports and other statistics from several African countries, Haggblade, Hazell, and Brown (1989) identified consumption by farm households as one of the key drivers for the development of the rural non-farm sector. In another study – modeling the effect of technological advancement in agriculture on the growth of the rural non-farm sector – Haggblade and Hazell (1989) also found a strong impact of the agricultural sector on the non-agricultural sector in several countries, mainly due to consumption linkages. These findings follow the argument by Mellor (1976), who emphasized the importance of farms for non-farm sector growth. They contradict the view of Hirschman (1958), who was among the first to analyze farm/non-farm linkages and who highlighted non-farm enterprises as the central source of growth for the agricultural sector. Studying farm/non-farm linkages in rural Uttar Pradesh in India, A. Pandey (2015) found strong forward and consumption linkages. However, he observed relatively small backward linkages, as farms do not necessarily receive their inputs from local non-farm enterprises. In a case study on rural households in Northern Ethiopia, Woldehanna (2002) observed only limited production linkages between farms and non-farms. He found that farm inputs (e.g., fertilizer and pesticides) are relatively limited and that farm outputs are dominantly consumed by the farm household itself and rarely sold. Woldehanna (2002), however, found that consumption linkages are relatively strong. The dominant share of farm income is spent on food items, while the share of expenditure on non-food items rises when the farm household's income increases.

Indirect effects of rainfall shocks on non-farm enterprises

Drawing on the theoretical and empirical literature, we derive several hypotheses on how rainfall shocks might indirectly affect non-farm enterprises through their impact on farms. Underlying these hypotheses are the assumptions that rainfall shocks have a negative effect on agricultural production output and that these shocks, in consequence, lead to a change in the behavior of farm households. These coping strategies then indirectly affect non-farm enterprises through farm/non-farm linkages. We analyze the following four hypotheses:

1. We expect rainfall shocks to lead to lower agricultural production and hence agricultural income and, thus, induce farm households to diversify their income sources and shift their labor supply (partly) to the non-farm sector. Therefore, we test whether rainfall shocks lead to an increase in the labor supply to non-farm self-employment. In this case we should find an increasing number of individuals indicating that self-employment is their main occupation (H1A) and a higher share of a household's labor force being dedicated to activities related to non-farm self-employment (H1B).
2. Lower agricultural production and hence lower sales are expected to lead, through forward linkages, to changes in the price and the available quantity of inputs for non-farm enterprises. Hence, following a rainfall shock the costs of agricultural inputs by non-farm enterprises should increase (H2).
3. In the event of a rainfall shock, farms might, on the one hand, intensify the use of machinery and production-enhancing measures such as fertilizer in the same season or as preparation for the next season. For instance, when facing a deficit rainfall shock in the

rainy season (June to October), farm households might cope by instantly increasing their spending on irrigation to improve the harvest in the current season or they might increase their spending on irrigation in preparation for the upcoming rainy season. This would show up in a positive impact of deficit rainfall shocks on irrigation spending. On the other hand, farms might not be able to increase input use given their lower agricultural income as a consequence of the rainfall shock. In that case we would observe constant or lower input spending as a consequence of rainfall shocks. However, we believe that the former effect outweighs the latter, i.e., we expect farms to rather increase their demand for inputs. These changes in the demand for inputs might affect, due to backward linkages, non-farm enterprises. Hence, we explore whether rainfall shocks have a positive effect on sales by non-farm enterprises (which focus on sales to farms) (H3A) and on farms' expenses for agricultural inputs per unit of agricultural area (H3B).

4. We anticipate that the reduction of agricultural production will reduce the income of farm households, even though a shift in the labor supply is likely to counteract this effect to a certain degree. Consequently, we evaluate whether rainfall shocks decrease the consumption expenditure of farm households (H4). Unfortunately, our data does not allow us to analyze this potential effect from the perspective of the non-farm enterprise as we cannot distinguish between customers of different types.

Context and data

In this section, we provide details on the context of our study and describe the data we use to test the above hypotheses.

Context and background

From 2003 to 2013, Thailand's GDP per capita grew from 99,766 Thai Baht (THB) to 193,394 THB. Translated into constant 2011 International Dollars using Purchasing Power Parities (USD 2011 PPP), this equals a GDP per capita growth of 40% – from USD 10,753 in 2003 to USD 15,072 in 2013. At the same time, the poverty headcount ratio (based on the national poverty line) was reduced from 32% in 2004 to 11% in 2013 (National Statistical Office of Thailand 2014; World Bank 2018). Nevertheless, the disparities between regions and provinces as well as urban and rural areas are still substantial for a country that is considered an upper middle income country. For instance, while in 2013 Bangkok had a GDP per capita of USD 29,339, it was USD 18,633 in the Central region, USD 9,607 in the Southern region and USD 5,809 in the Northeastern region (National Statistical Office of Thailand 2014; World Bank 2018). The poverty headcount ratio mirrors these economic differences as well. In 2013 in urban areas 8% of the population lived below the national poverty line, while this share was 14% in rural areas. This share is, at 1%, the lowest in Bangkok and, at 18%, the highest in the rural Northeastern region (Wuttisorn 2014). These indicators mirror well the disparities: a high level of economic development with a focus on the manufacturing and service sectors in Bangkok and the central regions and a relatively high level of poverty and vulnerability with a focus on agricultural activities in rural areas, particularly in the Northern and Northeastern regions.

We use data from three provinces in the Northeastern region: Nakhon Phanom, Ubon Ratchathani, and Buri Ram. In 2013, Nakhon Phanom had a GDP per capita of USD 5,695, Ubon Ratchathani of USD 5,103, and Buri Ram of USD 4,979 (in 2011 PPP). These provinces therefore rank among the poorest provinces in Thailand, and are slightly poorer than the Northeastern region's average. In these provinces agriculture still plays a very important role.

At the national level, employment in the agricultural sector has declined over the last decades, but still accounts for approximately 32% of total employment. The sector's output contributes to approximately 25% of total exports (National Statistical Office of Thailand 2018). Worldwide, Thailand is among the largest exporters of rice. Rice exports increased from four million tons in 1990 to almost eleven million tons in 2011. Yet the rice pledging scheme, which was introduced in 2011 and under which the government purchased rice from farmers at prices more than 40% above the market price, led to a temporary decrease in rice exports to less than seven million tons in 2012 and 2013. Exports reached eleven million tons again in 2014 after the rice pledging scheme was terminated. Next to rice, rubber, cassava, sugar cane and palm oil also play a major role in Thailand's agricultural exports (Office of Agricultural Economics 2017).

The output value of the agricultural sector, however, accounted for less than 10% of Thailand's GDP. This relatively low share of value-added compared to the relatively high share of employment indicates a central problem of the country's agricultural sector: the low level of agricultural productivity. For instance, in 2016 the average rice yield in Thailand was 2.9 tons per hectare of land, while it was 3.4 in Cambodia, 3.8 in Myanmar and the Philippines, and 4.2 in Laos. Thailand's main competitors in the global rice trade had a rice yield which was double or even more than double: Indonesia had an average output of 5.4, Vietnam of 5.5 and China of 6.9 tons per hectare of land. Thailand’s low agricultural productivity in rice production is, among other things, due to the large share of subsistence farmers with little access to technology and consequently a relatively low level of agricultural income (Isvilanonda 2010; OECD 2014; FAO 2018).

Socioeconomic data

We use the socioeconomic data from the so-called Thailand Vietnam Socio Economic Panel (TVSEP) which is an ongoing panel household survey that focuses on rural households in Thailand and Vietnam. The survey is implemented by a collaborative research project of the Universities of Hanover and Göttingen with funding from the German Research Foundation (DFG). To date, the survey has been conducted in seven waves (2007, 2008, 2010, 2011, 2013, 2016 and 2017) in three provinces in Northeastern Thailand (Buriram, Nakhon Phanom and Ubon Ratchathani; see appendix Figure A1) and in three provinces from the Northern Central Coast and in the Western Highlands in Vietnam (Ha Tinh, Thua Thien Hue and Dac Lac). In each wave around 4,400 households with approximately 22,000 individuals were surveyed, except in 2011 when only one province per country was covered. The panel data contains rich information on the socio-demographic and socioeconomic characteristics of the households and their members. Moreover, the data provides information on asset ownership, off-farm employment, self-employment, income, expenditure, consumption, borrowing, lending and saving, as well as on livestock and agriculture. Additionally, the survey collects information on perceived risks and experienced shocks as well as households’ related coping strategies. For more information on the survey refer to, for instance, Hardeweg & Waibel (2009) or the project’s homepage (i.e., https://www.tvsep.de/overview-tvsep.html).

In this article, we only consider the data for Thailand from the first five waves (2007, 2008, 2010, 2011 and 2013). In Table 1 we present the descriptive statistics at the individual level and in Table 2 at the household level. We focus on key individual and household characteristics such as labor supply, self-employment, income and expenditure, and rice production. More details on the socioeconomic variables that we use in the analysis are provided in the next section and in the appendix (Table A1).

With respect to gender, education and the main occupation, the TVSEP data (Table 1) provides consistent information across the five waves. Half of the surveyed individuals are male and approximately 90% of them can read. In all five years, around 33% of the sample indicate that farming is their main occupation, whereas 20% report that off-farm employment is their main activity and 6% report that self-employment is their main activity. The remaining share of individuals is either unemployed or unable to work or not part of the labor force (e.g., under 16 years old and attending school). The average age of the individuals slightly increases from 33 years in 2007 to 36 years in 2013, reflecting the aging of our sample over time. Taking into account individuals that are self-employed only (second part of Table 1), we can observe that about 50% of the enterprise owners are male. Enterprise owners are on average 45 years old and have already been running their enterprise for more than nine years. One third of these has an enterprise in the retail sector. The number of family and non-family employees is relatively small and volatile, e.g., on average 0.41 family employees in 2007, 0.55 in 2013, 0.76 non-family employees in 2007 and 0.98 in 2013.

[Table 1 about here]

Turning to the descriptive statistics at the household level (Table 2), we observe an average household size of four members across all five waves. More than 80% have savings as well as health insurance. Even though the share of households that indicate that they had high income fluctuations decreases over the years (from 19% in 2007 to 13% in 2010 and 9% in 2013), the share of households that said they were better off in the previous year increases (from 30% in 2007 to 53% in 2013). The increasing number of households that mainly cook with gas (in contrast to cooking with wood or charcoal) might be an indication of a general improvement in living standards in the surveyed regions. The share of households that engage in crop production remains relatively stable at around 85% across all years. On average, 60% of a household's labor force is occupied in farm activities, 30% in non-farm employment and 10% in non-farm self-employment. Both income from various sources and expenditure on food and non-food items show a high volatility over time, even when inflation is netted out and all values are expressed in constant USD 2005 PPP. Focusing on households that engage in rice production alone, we note that these households have on average approximately three hectares of land that they use for rice production and generate an annual output of between 4,000 and 5,000 kg of rice. Production expenditure, i.e., expenditure on machinery, hired labor, seeds, fertilizer, etc., amount to around USD 400 per year (in USD 2005 PPP).

[Table 2 about here]

Rainfall data

Besides the socioeconomic data from the TVSEP, we use gridded precipitation data from Willmott and Matsuura from the University of Delaware. The data provides measurements of monthly rainfall on a 0.5 degree longitude x 0.5 degree latitude grid point level for the years 1900 to 2014. The estimates are based on data from mainly public, but partly also private weather stations. For more information on how the data was compiled and the estimates calculated, the reader can refer to Matsuura and National Center for Atmospheric Research Staff (2017). As our identification strategy will make use of the variation of rainfall at the sub-district level, we need to interpolate the monthly rainfall for each sub-district.[2] We do so by applying the so-called inverse distance weighting method (see e.g., Shephard 1968). First, we determine the coordinates of a sub-district by querying the Google Maps API with the sub-district name as input. We then identify the four nearest grid points (disregarding country borders, i.e., potentially also cross-border) and calculate for each grid point the direct distance to the sub-district. Lastly, we interpolate the precipitation for the sub-district by taking the average of the rainfall from the four grid points and using the direct distances to the sub-district as inverse weights (i.e., the closer the grid point to the sub-district, the higher the weight). In our analysis, we consider the aggregated rainfall during the rainy season (i.e., from June until the end of October), as the rainfall in these months is decisive for agricultural output. For a given year, we code a rainfall shock if rainfall is 15% lower ('deficit rainfall shock') or 15% higher ('surplus rainfall shock') than the usual rainfall during these months (i.e., the average rainfall in the rainy season over the previous 15 years). In our econometric analysis, we do not use dummy variables for having experienced a deficit or surplus

[2] There are four main administrative levels in Thailand: province ('changwat'), district ('amphoe'), sub-district ('tambon'), and village ('mu ban'). In 2015, Thailand consisted of 76 provinces (including the metropolitan city of Bangkok), 928 districts, 7,425 sub-districts and 57,081 villages. The TVSEP data includes locational information down to the village level. Geographic coordinates, however, are only available down to the level of sub-districts. We therefore determine rainfall shocks at the sub-district and not the village level.

rainfall shock, but instead use the absolute percentage deviation from the long term average. For example, a surplus of 20% above the average is coded 0.2, a surplus of 100% is coded 1, a deficit of 20% is coded 0.2 and so on. If rainfall was within the range of plus or minus 15% of the average, both variables, i.e., rainfall deficit and rainfall surplus, take the value zero. In doing so, we emphasize the shock characteristic of rainfall that is significantly above or below the rainfall experienced in the previous years. Moreover, we consider the magnitude of the shock, by not only using a dummy shock variable, but also by taking into account the extent of the deviation from the average.[3]

As each of the considered waves of the TVSEP surveys were carried out in April of the respective year and refer to the previous 12 months, we combine the TVSEP data of one year with the rainfall data of the previous year. For instance, in the TVSEP survey from (April) 2008, information on the period May 2007 to April 2008 was collected. Thus, we merge the TVSEP data with the rainfall data from the rainy season from June to October 2007. Figure 1 shows the deviation of the rainfall in the rainy season from the 15 years average for each survey year (2007, 2008, 2010, 2011, and 2013) and all sub-districts. It is notable that a high share of sub-districts in the 2007 and the 2008 waves experienced a surplus rainfall shock in the previous rainy season, while in 2010 and 2011 only a small number of sub-districts experienced a surplus rainfall shock in the previous year. Deficit rainfall shocks became more frequent from 2009 onwards; with the highest share of sub-districts experiencing a deficit rainfall shock in the rainy season ahead of 2013.

[Figure 1 about here]

Results

This section tests the hypotheses devised in section 2. For each hypothesis we explain first how we test this hypothesis and then discuss the results.

[3] We also test other definitions of rainfall shocks and their effects on our dependent variables, e.g., one standard deviation or 25% deviation from the average as threshold for a rainfall shock. The results are – with respect to the effect size, sign and significance level – comparable to our results with 15% deviation as threshold. We believe that our definition of a rainfall shock (15% deviation and absolute percentage deviation instead of a dummy) is a good proxy as it depicts a sufficiently large deviation from the average rainfall while still guaranteeing a sufficiently large number of observations being affected by a shock in each of the survey years.

Agricultural production output

Before we can turn to our main analysis, we need to show that rainfall shocks do indeed directly affect agricultural production, which is the underlying assumption of our analysis. We use the following linear model with sub-district and time fixed effects to test whether this assumption holds:

$$Yield_{hklt} = \alpha + \beta RainShock_{lt} + \gamma X_{hklt} + \mu Z_{klt} + \delta_l + \theta_t + \varepsilon_{hklt}, \quad (1)$$

where h denotes the household/farm, k the village, l the sub-district, and t the year.

We focus on rice production and use rice yields, $Yield_{hklt}$, measured in kilogram per hectare of cultivated land, as proxy for our dependent variable of agricultural production. The variable $RainShock_{lt}$ stands for our two explanatory rainfall shock variables, i.e., 'surplus rainfall shock' or 'deficit rainfall shock'. X_{hklt} is a vector of controls relating to the household's agricultural production (i.e., a dummy for whether the household's land is rain-fed or irrigated, expenditure on irrigation, machinery, fertilizer, pesticides, and hired labor, as well as the size of total agricultural land) and other household characteristics (i.e., wealth proxies such as health insurance and size of dwelling, number of working household members, and the labor supply to farm activities). To control for the level of development of a village and village-specific shocks, we include a vector of controls, Z_{klt}, for the farm labor intensity (i.e., the share of household members in a village from the total labor force in this village that supply their labor to farm activities) as well as the average dwelling size in the village. The variables δ_l and θ_t depict sub-district and year fixed effects, respectively. In an alternative specification, we include household instead of sub-district fixed effects. The results of the analysis are shown in Table 3. The results from the OLS regression are shown in column (1), fixed effects regressions in columns (2) to (5). The OLS regression results indicate a negative impact of rainfall shocks on rice yields, which is significant for a deficit rainfall shock, but not significant for a surplus rainfall shock. When estimating a fixed effects model with sub-district fixed effects (column 2) and including year effects (column 3) and village level controls (column 4), the coefficient for a deficit rainfall shock decreases and for a surplus rainfall shock increases (in absolute magnitude). The coefficients are significant for both types of shocks. When we use household fixed instead of sub-district fixed effects, the coefficient associated with a deficit rainfall shock becomes again smaller and the coefficient associated with a surplus rainfall shock becomes larger in absolute magnitude. The results with household fixed effects suggest that a shortfall of rainfall by 20% relative to the average decreases yields per hectare by 276 kg (1378 kg × 0.2). A 20% surplus seems to lower yields by 94 kg per hectare.

Specifications (4) and (5) are here and in what follows our preferred specifications and hence the discussion of the findings will largely focus on these.

The signs of the coefficients associated with the control variables are largely as expected. For instance, the results suggest that rice yields increase with expenditure on inputs (i.e., irrigation, machinery, fertilizer, pesticides, and labor), and labor supplied to farm activities. Yields decline with land size, a result that is often found when analyzing the productivity of small holders. Since this is not the focus of this study, we do not explore this further; interested readers may refer to, e.g., Sen (1966), Feder (1985), Barrett (1996) and, for a recent debate, Helfand and Taylor (2017).

[Table 3 about here]

These results confirm our hypothesis that rainfall shocks have a direct negative effect on agricultural production output. This effect is larger for deficit than for surplus rainfall shocks. Next, we analyze in how much these rainfall shocks affect rural non-farm enterprises through reduced agricultural output.

Labor supply

Given the negative effect of rainfall shocks on agricultural production, we expect individuals and households to change their labor supply to cope with them, i.e., to decrease their level of agricultural activities and increase their level of activities related to non-farm wage work and non-farm self-employment. In this section, we analyze the effect of rainfall shocks on the labor supply to non-farm self-employment, both at the individual and the household level. To estimate this effect, we apply a logit model with time and sub-district fixed effects. The first regression tests whether rainfall shocks increase the probability that non-farm self-employment ($SelfMain_{ihklt}$) is the main occupation of an individual (Hypothesis: H1A):

$$SelfMain_{ihklt} = \alpha + \beta RainShock_{lt} + \partial W_{ihklt} + \gamma X_{hklt} + \mu Z_{klt} + \delta_l + \theta_t + \varepsilon_{ihklt} \quad (2)$$

where i denotes the individual, h the household, k the village, l the sub-district, and t the year.

As before, we include surplus and deficit rainfall shocks, $RainShock_{lt}$, as explanatory variables. W_{ihklt} is a vector of controls for the socioeconomic characteristics of the individual (i.e., gender, age, education level, health, and marital status), while vector X_{hklt} contains variables relating to the household the individual belongs to (i.e., experienced income fluctuation, crop production, days needed to raise 5,000 THB, savings, and wealth proxies such as health insurance, size of dwelling, and cooking with gas). As before, we also control in two of the five specifications for village characteristics, Z_{klt} (i.e., farm labor intensity and average dwelling size in the village) and, additionally, include sub-district fixed effects (or, alternatively, household fixed effects), δ_l, and year effects, θ_t.

Second, at the household level, we estimate how rainfall shocks affect the share of a household's labor supply that is allocated to non-farm self-employment ($SelfShare_{hklt}$). Our expectation is that this share will increase following a rainfall shock (Hypothesis: H1B):

$$SelfShare_{hklt} = \alpha + \beta RainShock_{lt} + \gamma X_{hklt} + \mu Z_{klt} + \delta_l + \theta_t + \varepsilon_{hklt} \qquad (3)$$

where h denotes the household, k the village, l the sub-district, and t the year.

We calculate the share of the household's labor supply to non-farm self-employment as the number of household members that engage in non-farm self-employment divided by the total number of household members that have worked in the previous twelve months (farm or non-farm, employment, self-employment, or casual work). We thereby restrict the sample to working age individuals between 15 and 64 years. The variables on the right-hand side are the same as in Equation (2), except that this time there are no individual characteristics as controls.

Table 4 shows the results estimated at the individual level (Equation (2)). In all five specifications we observe a positive effect of rainfall shocks on the probability that an individual's main occupation is self-employment. This effect is significant at the 1% level for surplus rainfall shocks, but not significant for deficit rainfall shocks. For instance, in specification (4) the coefficient for surplus rainfall shock is 1.259. This means that a deviation of the rainfall from the 15 years average by 1 (i.e., 100 percentage points), leads to an increase of the probability of being self-employed by 126 percentage points. In other words, if rainfall increases by 0.1 (i.e., 10 percentage points) compared to the average (e.g., from 30% to 40% above average), the probability of being self-employed increases by 13 percentage points (1.259/10).

[Table 4 about here]

Turning to the effect of rainfall shocks on a household's labor supply to self-employment, we observe similar results (Table 5). Both types of shocks have a positive effect on engagement in non-farm self-employment, but the effect is statistically significant only in the case of surplus rainfall shocks. For example, specification (4) indicates that the labor supply of a household to self-employment increases by 12 percentage points if the surplus of rainfall relative to the average increases by 10 percentage points. This is exactly the same order of magnitude as the estimations at the individual level (table 4). Using household instead of sub-district fixed effects even suggests an effect of 22 percentage points.

[Table 5 about here]

To summarize, we observe an increase in self-employment at both the individual and household levels in response to both deficit and surplus rainfall shocks, although this effect is statistically significant only in the latter case.

Forward linkages

In a next step, we turn to the indirect effects of rainfall shocks on non-farm enterprises through forward linkages. Such effects can be analyzed from two perspectives: from the point of view of the non-farm enterprise in the form of changes to input costs, and from the point of view of the farm in the form of changes to the sale of agricultural products to non-farm enterprises. We take the first perspective, i.e. we analyze the effect of rainfall shocks on the input costs of non-farm enterprises. We thereby focus on non-farm enterprises in the food processing industry as these firms mainly use agricultural products as input. Our expectation is that these costs increase following a rainfall shock (Hypothesis: H2). For our estimation we use the following linear model and the (albeit small) sub-sample of food-processing firms:

$$FwInput_{ihklt} = \alpha + \beta RainShock_{lt} + \partial W_{ihklt} + \gamma X_{hklt} + \mu Z_{klt} + \delta_l + \theta_t + \varepsilon_{ihklt} \quad (4)$$

where i denotes the individual (firm owner), h the household, k the village, l the sub-district, and t the year.

The dependent variable, $FwInput_{ihklt}$, is measured as the log of the input costs of an enterprise active in the food processing industry. Next to the explanatory variables $RainShock_{lt}$ (surplus and deficit rainfall shocks), we include characteristics of the firm owner and the firm, W_{ihklt}. Additionally, household characteristics, X_{hklt} as well as village characteristics, Z_{klt} are considered as control variables. We also include sub-district or household fixed effects, δ_l, and year fixed effects, θ_t.

The results are shown in Table 6. They indicate a positive and significant impact of surplus rainfall shocks on input costs, while deficit rainfall shocks seem to have a negative effect on input costs, although the latter effect is not very robust. In the specification with sub-district and time fixed effects as well as village level controls (column 4), the coefficient associated with a surplus rainfall shock has a size of 8.08 and is significant at the 1% level. This means that an increase in the rainfall deviation by 10 percentage points relative to the 15 year average is associated with an increase in input costs by food processing enterprises by about 8.1%. As a placebo test, we also ran the regression for all other enterprises except food processing enterprises and obtained, as expected, a very small coefficient of 0.78, i.e., 0.8% (this is shown in the appendix Table A2). These results imply that, as one would expect, the effect of positive rainfall shocks on input costs is only relevant for enterprises in the food processing industry and not for enterprises in other industries. We take this as supportive evidence for our hypothesis that shocks in the agricultural sector are transmitted via increased input costs to non-farm enterprises in the food-processing sector. We cannot, however, confirm this channel for deficit rainfall shocks.

[Table 6 about here]

Backward linkages

The effect of rainfall shocks on non-farm enterprises through backward linkages (i.e., the supply of inputs by non-farm enterprises to farms) might be twofold. On the one hand, farms may spend less on inputs as their income declines. On the other hand, farms may try to counter their worsening production output by increasing the input intensity and finance this through increased off-farm income.

In a first step, we analyze these effects from the perspective of agriculture-related non-farm enterprises, i.e., the effect on sales by enterprises offering agricultural inputs and services. We expect sales to go up following a rainfall shock (Hypothesis: H3A). We apply a linear model with sub-district and time fixed effects, which takes the following form:

$$BwSales_{ihklt} = \alpha + \beta RainShock_{lt} + \partial W_{ihklt} + \gamma X_{hklt} + \mu Z_{klt} + \delta_l + \theta_t + \varepsilon_{ihklt} \quad (5)$$

where i denotes the individual (firm owner), h the household, k the village, l the sub-district, and t the year.

We measure the dependent variable $BwSales_{ihklt}$ as the log of sales by enterprises that offer agriculture-related inputs and services. As in Equation (4), we include the explanatory variables $RainShock_{lt}$ (surplus and deficit rainfall shocks), individual and enterprise characteristics, W_{ihklt}, household characteristics, X_{hklt}, and village characteristics, Z_{klt} as controls. As above, sub-district or household fixed effects, δ_l, and year fixed effects, θ_t, are included in the regressions as well.

In a second step, we take the perspective of the farm and estimate the effect of rainfall shocks on the farm's input costs (Hypothesis: H3B). We again apply a linear model with sub-district and time fixed effects:

$$BwInput_{hklt} = \alpha + \beta RainShock_{lt} + \gamma X_{hklt} + \mu Z_{klt} + \delta_l + \theta_t + \varepsilon_{hklt} \quad (6)$$

where h denotes the household/farm, k the village, l the sub-district, and t the year.

We use the farm's expenditure on various input categories, i.e., irrigation, machinery, fertilizer, pesticides, and hired labor (all in USD 2005 PPP per hectare of agricultural land) as proxy for the farm's input costs, $BwInput_{hklt}$. As before, both surplus and deficit rainfall shocks enter the regression as explanatory variables. We additionally include a vector of household and farm level controls, X_{hklt}, with variables for total agricultural land and rice production output, wealth proxies such as health insurance and dwelling size, as well as the household size and labor supply to farm activities.

Table 7 shows the results for the effect of rainfall shocks on the log of sales by firms that have forward linkages to the agricultural sector. The results suggest that these firms experience higher sales following surplus rainfall shocks. Deficit rainfall shocks seem to have no significant impact on sales. Compared to enterprises in other industries, the effect of surplus rainfall shocks is significantly higher. For instance, in column (4), the coefficient of surplus rainfall shocks is 6.25 (significant at 1%) for agriculture-related enterprises and 0.94 (significant at 5%) for enterprises in other industries (for details see appendix Table A3). Expressed in USD 2005 PPP, this means that an increase in the rainfall deviation from the long term average by 10 percentage points leads to an increase in sales by 62.5% for agriculture-related firms and only by 9.4% for other firms. The coefficients are slightly higher if household instead of sub-district fixed effects are used. These results indicate relatively strong effects of surplus rainfall shocks on the sales of firms that have forward linkages to the agricultural sector. We do not, however, find significant effects for deficit rainfall shocks.

[Table 7 about here]

Turning to the effect of rainfall shocks on farms' input costs, we observe a diverse picture regarding the direction and significance of the effects (Table 8). The costs for irrigation are as expected: surplus rainfall shocks lead to a decrease and deficit rainfall shocks to an increase in irrigation costs per hectare of land. Moreover, surplus rainfall shocks seem to have a positive and significant impact on the monthly input costs for machinery per hectare of land. When accounting for household and time fixed effects as well as village-level controls, the coefficient of surplus rainfall shocks for machinery input costs amounts to 60.82 and is significant at the 1% level. This means that an increase in the rainfall deviation from the long run average by 10 percentage points leads to an increase in expenditure on machinery by USD 6.1 (here and in the following in USD 2005 PPP) per hectare of land. In contrast, the coefficient associated with deficit rainfall shocks is negative across four of the five specifications and not significant, i.e., deficit rainfall shocks do not seem to have an impact on costs for machinery. Expenditure on fertilizer increases strongly in the case of deficit rainfall shocks. For instance, in column (5), the coefficient for a deficit rainfall shock is 297.99 (significant at 1%). This implies that an increase in the negative rainfall deviation from the average by 10 percentage points leads to an increase of expenditure on fertilizer and pesticides of USD 29.8 per hectare. This compares to a coefficient of -2.58 or USD 0.3 for irrigation costs. With respect to surplus rainfall shocks, spending on fertilizer appears not to be as affected. The coefficient in column (4) is, at 52.7 per hectare (1% significance level), relatively small. Costs for pesticides appear to be affected by surplus rainfall shocks only – in column (5) we observe a coefficient of -6.42 that is significant at 5%. We also find strong negative and significant effects of surplus rainfall shocks on costs for hired labor (e.g., a coefficient of -56.06

per hectare, see column 5). This again suggests that, in the case of surplus rainfall shocks, labor supply to non-farm employment and self-employment increases, while it decreases for agricultural activities.

[Table 8 about here]

Overall, the results indicate that the effect of rainfall shocks through backward linkages from farms to non-farm enterprises are slightly positive. Both sales by agriculture-related enterprises as well as spending on machinery and fertilizer increase with surplus rainfall shocks. The effect of surplus rainfall shocks on input costs for irrigation and hired labor is, as expected, negative. Deficit rainfall shocks, however, do not appear to significantly affect non-farm enterprises through backward linkages, except for sales related to irrigation and fertilizer.

Consumption linkages

Lastly, we investigate the impact of rainfall shocks on non-agricultural firms through consumption linkages. The effect through consumption can again be analyzed from two perspectives: from the perspective of non-agricultural firms that offer consumption goods and services and hence might be affected by reduced sales, and from the perspective of farm households which may lower their consumption expenditure. We analyze the effect from the latter perspective, i.e., the effect of rainfall shocks on the consumption expenditure of farm households. We expect consumption expenditure to decrease in response to a rainfall shock (Hypothesis: H4).

Our linear model with sub-district and year fixed effects takes the following form:

$$ConsExp_{hklt} = \alpha + \beta RainShock_{lt} + \gamma X_{hklt} + \mu Z_{klt} + \delta_l + \theta_t + \varepsilon_{hklt} \; , \qquad (7)$$

where h denotes the household, k the village, l the sub-district, and t the year.

We use the log of total household consumption expenditure in the past 12 months and, alternatively, the log of food or non-food consumption expenditure in the same period (in USD 2005 PPP) as dependent variables, $ConsExp_{hklt}$. Consumption expenditure only includes cash expenditure and does not take into account auto-consumption, i.e., the consumption of food that was produced by the household itself. We include the two rainfall shock variables, $RainShock_{lt}$, as explanatory variables, and household characteristics and wealth proxies, X_{hklt}, as controls. In two of the five specifications village characteristics, Z_{klt}, also enter the regression. We control for sub-district, δ_l, and year fixed effects, θ_t. As we want to understand how rainfall shocks affect the consumption of households that engage in agricultural activities, we discard from the sample all households that are not involved in crop production.

The regression results are presented in Table 9. They indicate that both surplus and deficit rainfall shocks lead to a reduction in the farm household's total consumption expenditure (first part of the table). The level of significance for surplus rainfall shocks is low; including time and sub-district or household fixed effects, the results are significant at 1% for deficit rainfall shocks only. For instance, in specification (4), the coefficients indicate that a decrease/increase of the rainfall deviation from the long run average by 10 percentage points leads to a reduction of total household expenditure by 4.9% (deficit rainfall shock) and 0.08% (surplus rainfall shock), respectively. For food consumption (second part of the table), the coefficients of both types of rainfall shocks are negative and significant in most of the specifications. For instance, when including sub-district and year fixed effects as well as controls for village characteristics (column 4), the coefficient for surplus rainfall shocks is -0.18 (significant at the 10 % level) and the coefficient for deficit rainfall shocks is -0.77 (significant at the 1% level). They imply that an increase of the rainfall deviation from the long run average by 10 percentage points reduces food consumption expenditure by 1.8%, and for a deficit rainfall shock by 7.7%. Turning to consumption expenditure on non-food items and services, the results are mixed (third part of the table). When not controlling for time effects (columns (1) and (2)), we obtain a positive effect for surplus rainfall shocks and a negative effect for deficit rainfall shocks on non-food consumption expenditure (at the 1% significance level). However, when including time effects and controls for village-level characteristics (columns (3) to (5)), the coefficients of both types of rainfall shocks are smaller and are not significant.

[Table 9 about here]

Overall, the results show mixed effects of rainfall shocks on consumption expenditure. The slightly negative effects of rainfall shocks on total consumption might indicate that farm households reduce their expenditure on consumption as they have less income from agricultural activities (though this decline might be partly offset through increased income from non-farm activities as shown above). This reduction in consumption is even more visible when looking at expenditure on food alone: Farm households seem to reduce their expenditure on food. They may of course increase their consumption of own production, yet in times of shocks, this might not be possible. Contrary to our expectations, we observe a slight positive effect of rainfall shocks on non-food consumption expenditure. Considering our preferred specifications (4) and (5), this effect, however, is only significant at the 10% level for surplus rainfall shocks in specification (4).

Summary

Table 10 summarizes again all direct and indirect effects of rainfall shocks on farm and non-farm activities from the previous tables. (FE (1) and FE (2) thus refer to the effects of our preferred specifications in columns (4) and (5)).

[Table 10 about here]

To ease the interpretation of the results, we express the estimated effects in percentages of the standard deviation in Figure 2. We use the results of the specification that includes household fixed effects (i.e., column 5). Figure 2 shows by what percentage of the standard deviation a variable increases or decreases if the deficit or surplus of rainfall increases by 10 percentage points relative to the average. For instance, if the deficit of rainfall relative to the average increases by 10 percentage points, a household's labor supply to self-employment increases by 61% of the standard deviation, while the input costs of a food processing enterprise decrease by 7% of the standard deviation. Analogously, an increase in the surplus of rainfall relative to the average by 10 percentage points leads to an increase of sales by agricultural-related enterprises by 47% of the standard deviation, while food expenditure decreases by 2% of the standard deviation. The figure shows that surplus and deficit rainfall shocks particularly affect labor supply and forward linkages as well as sales by agricultural-related enterprises, while the effect on farms' input costs and consumption is relatively small. Overall, surplus rainfall shocks lead to larger (and more significant) effects than deficit rainfall shocks.

[Figure 2 about here]

Conclusion

Rural households in particular in the developing world are vulnerable to weather and especially to rainfall shocks. Therefore, a large body of research has studied the impact of these shocks on rural farm households, while only a few have analyzed the potential effects of these shocks on rural non-farm households. We contribute to this literature by considering how rainfall shocks are transmitted from farms to non-agricultural firms through forward and backward linkages. We use a comprehensive panel dataset of approximately 2,200 households covering a period of five years from the Thailand Vietnam Socio Economic Panel and link it with gridded precipitation data.

We find a positive effect of surplus rainfall shocks on labor supply to non-farm self-employment, i.e. rainfall shocks lead to an increasing share of individuals in farm households engaging in non-farm self-employment activities and to a higher probability that an individual from a farm household runs a non-farm enterprise. This finding confirms our hypothesis that households cope with income shortfalls in agricultural activities by shifting their labor supply toward non-farm activities. In the longer run, such shocks might even have a positive effect on the well-being of the rural poor, as they provide an incentive for income diversification and reduce their dependency on weather conditions. Ultimately, they may plant the seeds for structural change toward industrial production and services.

Additionally, we analyze the indirect effects of rainfall shocks on non-farm enterprises through forward and backward linkages and consumption demand. We observe a positive effect (i.e. increasing costs) of surplus rainfall shocks on the input costs of non-farm enterprises that are active in the food processing industry. This shows that rainfall shocks also affect the performance of non-farm enterprises – due to higher prices and, potentially, also a shortage of inputs. As a consequence, non-agricultural firms that use agricultural inputs might be forced to decrease their own output volume, experience lower profits, and may have to search for suppliers in other regions. In contrast, we observe a positive effect of rainfall shocks on non-farm enterprises that have forward linkages to the agricultural sector by offering products and services such as fertilizer, pesticides and seeds. These firms are likely to have higher sales as farms tend to increase their input intensity (i.e., expenditure on inputs per hectare of land) when they experience rainfall shocks. Apparently, farm households try to compensate the reduced production output by increasing their use of inputs. However, as expected, farms reduce their expenditure on irrigation when facing surplus rainfall shocks. Finally, we find that farm households reduce their expenditure on food consumption to cope with rainfall shocks.

Our results show that in the event of rainfall (and potentially other agricultural) shocks, not only the agricultural, but also the non-agricultural sector is significantly affected, mostly negatively. This means that, taken together, the costs of agricultural shocks are much higher than what much of the microeconomic-focused literature has suggested so far. Despite limited market integration in poor rural economies, the spillovers are sizable and are transmitted through various channels. Policies that are implemented to counter the negative effects of shocks should take this into account. Safety nets targeted at farms may need to cover non-farm enterprises too.

In the future, surveys could try to capture even better the particular channels through which rainfall shocks can affect non-farm enterprises. For instance, more details on the customers for agricultural products or the purpose of the purchase (consumption or production input) would help to distinguish even better between the effects on farms and on non-agricultural firms. More information on investments, for instance whether made for farm or non-farm activities, would also add more evidence to these indirect effects on non-farm enterprises.

Figures

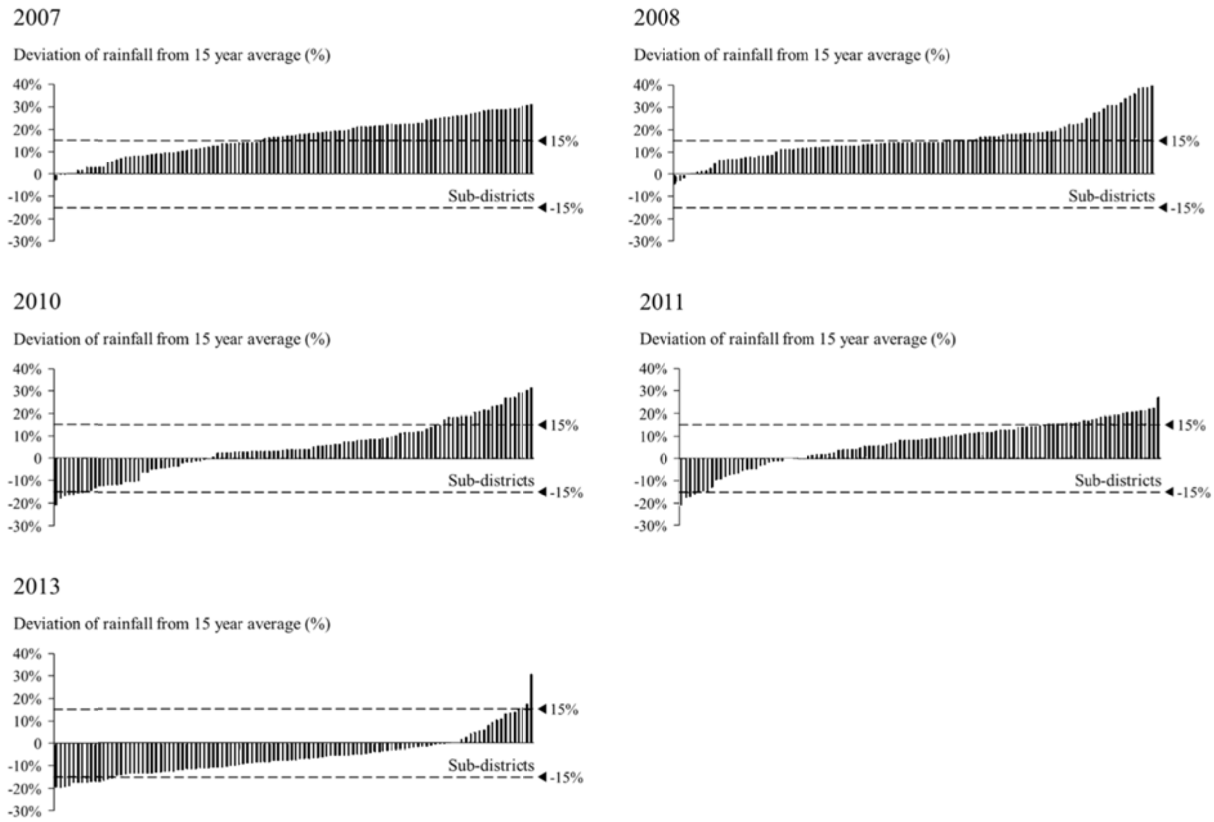

Figure 1. Deviation of sub-district rainfall in the rainy season (June–October) from the 15 year average

Source: Grid-level precipitation data from Willmott and Matsuura from the University of Delaware (Matsuura and National Center for Atmospheric Research Staff 2017)

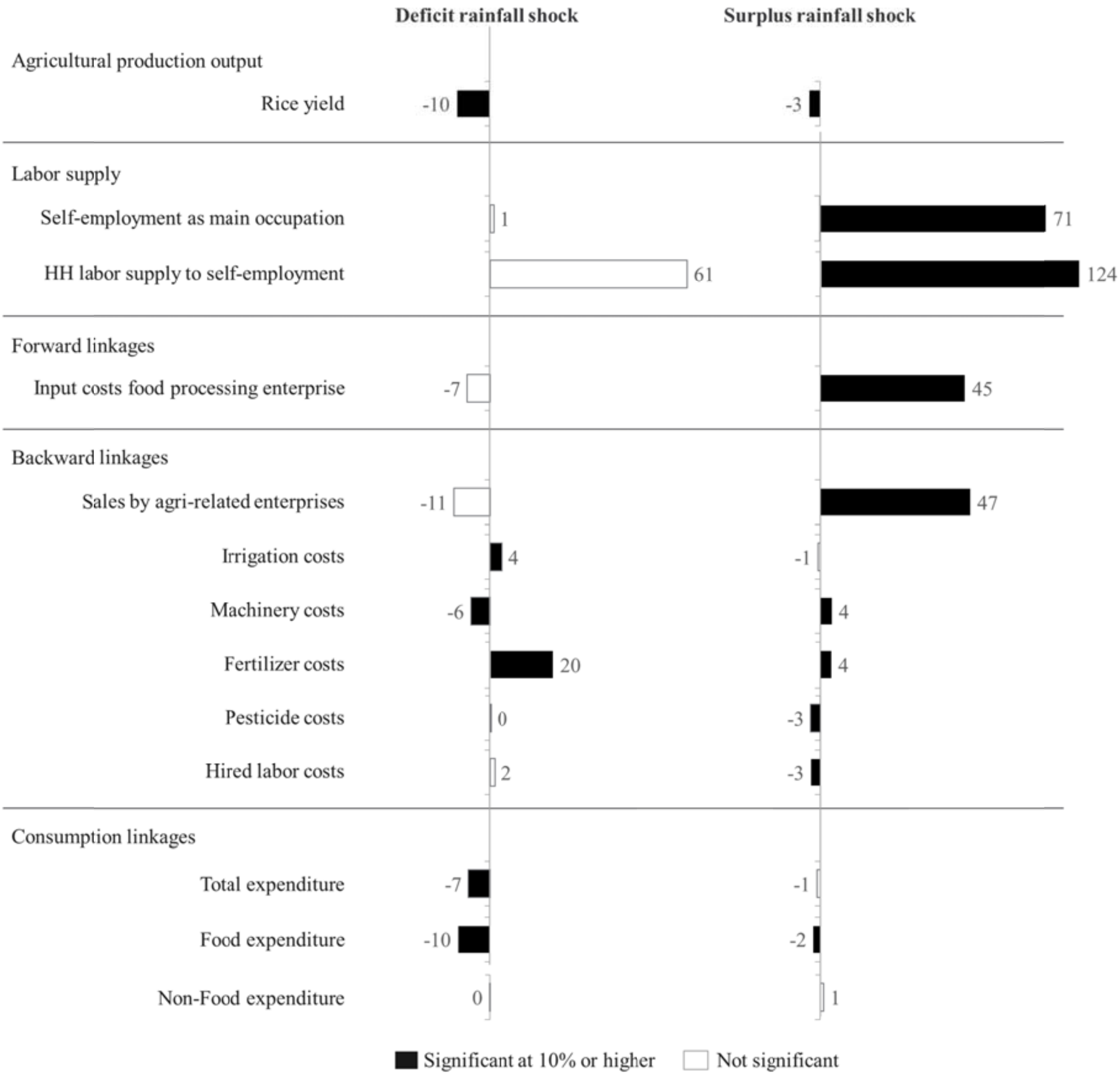

Figure 2. Effect of an increase in the deficit/surplus of rainfall relative to the average by 10 percentage points on the respective variables, expressed in % of one standard deviation

Tables

Table 1. Descriptive Statistics of TVSEP Data – Individual Level

	2007			2008			2010			2011			2013		
Variable	Obs.	Mean	STD	Obs.	Mean	STD	Obs.	Mean	STD	Obs.	Mean	STD	Obs.	Mean	STD
General information															
Male (dummy)	10,822	0.50	0.50	11,349	0.50	0.50	11,797	0.50	0.50	5,301	0.50	0.50	10,427	0.49	0.50
Age (years)	10,806	32.8	20.3	11,344	33.2	20.3	11,797	34.2	20.4	5,302	35.1	20.7	11,811	36.1	20.7
Married (dummy)	10,031	0.56	0.50	9,126	0.66	0.47	11,494	0.55	0.50	4,430	0.66	0.47	8,492	0.66	0.47
Thai (dummy)	10,818	0.93	0.25	11,344	0.94	0.24	11,797	0.94	0.23	5,302	1.00	0.06	10,183	0.94	0.24
Ability to read (dummy)	10,819	0.87	0.34	11,321	0.87	0.34	11,780	0.88	0.33	5,287	0.91	0.29	10,578	0.90	0.30
No education (dummy)	9,546	0.33	0.47	7,795	0.41	0.49	8,440	0.38	0.49	3,901	0.36	0.48	7,675	0.36	0.48
Sick (dummy)	10,801	0.07	0.26	11,334	0.09	0.28	11,167	0.06	0.24	5,077	0.09	0.29	10,197	0.08	0.27
Born in same village (dummy)	10,814	0.75	0.43	11,349	0.75	0.43	11,796	0.75	0.43	5,302	0.73	0.45	10,183	0.75	0.43
Farming main occupation (dummy)	10,808	0.35	0.48	11,318	0.33	0.47	11,558	0.33	0.47	5,138	0.32	0.47	10,180	0.34	0.47
Off-farm employment main occupation (dummy)	10,808	0.18	0.39	11,318	0.20	0.40	11,558	0.20	0.40	5,138	0.21	0.40	10,180	0.20	0.40
Self-employment main occupation (dummy)	10,808	0.05	0.22	11,318	0.06	0.23	11,558	0.06	0.23	5,138	0.07	0.25	10,180	0.05	0.21
Self-employment (self-employed individuals only)															
Male enterprise owner (dummy)	853	0.50	0.50	849	0.52	0.50	921	0.53	0.50	458	0.54	0.50	678	0.51	0.50
Age of enterprise owner (years)	853	45.2	12.5	848	44.8	12.4	921	46.1	13.1	458	45.2	13.2	680	47.4	13.2
Enterprise owner with no education (dummy)	839	0.49	0.50	805	0.46	0.50	895	0.46	0.50	449	0.39	0.49	655	0.40	0.49
Retail business (dummy)	853	0.36	0.48	846	0.33	0.47	918	0.30	0.46	455	0.31	0.46	675	0.33	0.47
Age of enterprise (years)	844	9.34	9.80	844	8.77	9.07	906	9.38	10.21	453	8.95	9.32	680	10.79	10.55
Startup capital (USD)	852	3,194	8,461	824	3,481	9,802	901	4,052	10,230	451	3,860	9,472	679	4,958	11,782
Employees - family members (no.)	841	0.41	0.69	830	0.44	0.73	872	0.54	0.85	452	0.40	0.81	617	0.55	0.94
Employees - non-family members (no.)	839	0.76	3.84	794	0.66	3.11	758	0.78	4.85	425	0.36	1.21	521	0.98	4.40
More than 10 customers total (dummy)	834	0.74	0.44	847	0.75	0.43	906	0.75	0.44	455	0.79	0.41	668	0.79	0.41
Sales (USD)	853	1,688	4,848	811	1,685	4,760	882	2,538	8,190	441	1,939	5,465	659	2,158	5,979
Input costs (USD)	853	961	3,160	818	1,203	4,667	882	1,713	6,898	446	1,234	4,688	640	911	1,815
Profit (USD)	853	602	2,587	820	573	1,402	876	683	1,438	448	733	2,188	672	1,128	3,699

Note: USD measured in USD 2005 PPP.

Table 2. Descriptive Statistics of TVSEP data – Household Level

	2007			2008			2010			2011			2013		
Variable	Obs.	Mean	STD	Obs.	Mean	STD	Obs.	Mean	STD	Obs.	Mean	STD	Obs.	Mean	STD
General information															
Household size (no. of members)	2,186	4.0	1.7	2,136	4.0	1.8	2,105	4.0	1.8	916	4.2	1.9	1,996	3.9	1.7
Last year better off (dummy)	2,180	0.30	0.46	2,134	0.32	0.47	2,100	0.41	0.49	912	0.42	0.49	1,996	0.53	0.50
High income fluctuation (dummy)	2,183	0.19	0.39	2,132	0.25	0.43	2,100	0.13	0.33	912	0.10	0.29	1,994	0.09	0.29
Days needed to raise 5,000 THB	1,898	4.5	14.1	2,087	4.4	15.7	2,031	4.9	19.7	856	8.2	28.7	1,909	6.4	23.4
Savings (dummy)	2,184	0.89	0.31	2,136	0.83	0.38	2,105	0.85	0.36	912	0.83	0.38	1,995	0.78	0.41
Health insurance (dummy)	2,184	0.82	0.38	2,136	0.89	0.31	2,103	0.92	0.27	913	0.85	0.35	1,996	1.00	0.00
Size of dwelling (m^2)	2,186	87.9	57.8	2,118	91.4	57.9	1,754	79.4	40.5	871	92.9	58.4	1,979	98.7	118.9
Cooking with gas (dummy)	2,180	0.26	0.44	2,134	0.21	0.41	2,105	0.28	0.45	916	0.23	0.42	1,996	0.46	0.50
Labor supply and activities															
Engaged in crop production (dummy)	2,174	0.83	0.38	2,136	0.87	0.33	2,104	0.86	0.35	913	0.85	0.36	1,987	0.85	0.36
Labor supply to farm activities (share)	2,175	0.59	0.26	2,121	0.58	0.25	2,083	0.61	0.24	897	0.61	0.25	1,958	0.66	0.25
Labor supply to wage employment (share)	2,177	0.31	0.25	2,127	0.32	0.24	2,104	0.30	0.23	907	0.28	0.23	1,985	0.28	0.24
Labor supply to self-employment (share)	2,183	0.11	0.20	2,129	0.10	0.18	2,084	0.09	0.16	903	0.11	0.18	1,967	0.07	0.15
Income and expenditure (USD)															
Received remittances	2,182	779	2,296	2,136	744	2,173	2,105	949	2,490	916	707	1,923	1,971	803	1,866
Income through crop production	2,184	989	4,406	2,136	1,382	5,998	2,105	1,595	4,466	916	1,911	5,687	1,996	1,724	4,285
Income through wage employment	2,183	2,078	4,434	2,134	1,756	4,847	2,105	2,296	4,628	916	2,953	6,786	1,996	2,835	5,770
Income through self-employment	2,176	1,119	6,652	2,135	1,381	9,630	2,105	2,334	9,356	916	2,850	21,487	1,996	3,283	22,738
Food expenditure	1,994	2,318	1,394	1,995	2,645	1,730	1,995	2,977	1,824	916	3,712	2,463	1,996	1,627	1,446
Non-food expenditure	1,994	2,537	2,307	1,995	3,239	7,114	1,995	2,882	3,308	916	2,345	2,364	1,996	575	684
Rice production (rice-producing households only)															
Agricultural land for rice production (ha)	1,682	2.6	2.0	1,659	3.1	16.3	1,642	2.9	4.3	708	3.0	4.2	1,552	2.7	2.3
Total rice production output (kg)	1,682	4,383	3,938	1,659	4,193	4,471	1,642	4,986	5,091	708	4,509	4,086	1,552	4,909	5,233
Rice yield (kg/ha)	1,682	1,896	1,316	1,658	1,809	1,608	1,642	1,920	1,112	708	1,703	889	1,552	1,939	1,435
Production expenditure (USD/ha)	1,682	407	326	1,658	409	362	1,642	432	299	708	379	252	1,552	434	388

Note: USD measured in USD 2005 PPP.

Table 3. Impact of Rainfall Shocks on Agricultural Production Output – Rice Yield (kg/ha)

Dependent variable	Agricultural production output – Rice yield (kg/ha)				
	OLS	(Linear model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)
Deficit rainfall shock	-1,906.6***	-1,654.2***	-1,602.0***	-1,546.6***	-1,377.9***
	(387.36)	(486.52)	(504.05)	(513.88)	(403.46)
Surplus rainfall shock	-58.367	-204.06	-447.78*	-411.17*	-468.63**
	(148.09)	(173.74)	(229.99)	(216.32)	(202.89)
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Village-level controls	No	No	No	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	6,562	6,562	6,562	6,562	6,562
No. of sub-districts	110	110	110	110	110
No. of households	1,862	1,862	1,862	1,862	1,862
R-squared	0.139	0.126	0.130	0.130	0.125

Note: The variables rain-fed land (dummy), irrigation costs, machinery costs, fertilizer costs, pesticide costs, labor costs (all in USD/ha), agricultural land (ha, log), health insurance (dummy), size of dwelling (m^2), household members in labor force (no.), and labor supply to farm activities (share) are included as control variables in each of the regressions. The variables farm labor intensity of the village (share), and average size of dwellings in the village (m^2) are included as village-level controls in the last two regressions (columns (4) and (5)). USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 4. Impact of Rainfall Shocks on Labor Supply (Individual Level) – Self-Employment as Main Occupation (Dummy)

Dependent variable	Labor supply – Self-employment as main occupation (dummy)				
	OLS	(Logit model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)[a]
Deficit rainfall shock	0.030	0.620	0.473	0.263	0.031
	(0.041)	(0.720)	(0.747)	(0.748)	(0.881)
Surplus rainfall shock	0.152***	1.032***	1.445***	1.259***	1.858***
	(0.016)	(0.243)	(0.315)	(0.319)	(0.382)
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Village-level controls	No	No	No	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	26,442	26,442	26,442	26,442	9,248
No. of sub-districts	110	110	110	110	110
No. of households	2,137	2,137	2,137	2,137	660
(Pseudo) R-squared	0.048	0.058	0.063	0.066	0.045

Note: [a] 1,477 households (i.e., 17,194 observations) have been dropped due to a lack of variation within the particular households over time.

The variables male (dummy), age (years), age squared (years), no education, sick, married, high income fluctuation, engaged in crop production (all dummies), days needed to raise 5,000 THB, savings (dummy), health insurance (dummy), size of dwelling (m^2), and cooking with gas (dummy) are included as control variables in each of the regressions. The variables farm labor intensity of the village (share), and average size of dwellings in the village (m^2) are included as village-level controls in the last two regressions (columns (4) and (5)). Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 5. Impact of Rainfall Shocks on Labor Supply (Household Level) – Household Labor Supply to Self-Employment (Share)

Dependent variable	Labor supply – Household labor supply to self-employment (share)				
	OLS	(Logit model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)[a]
Deficit rainfall shock	0.034	1.520*	1.324	1.042	1.097
	(0.049)	(0.898)	(0.934)	(0.940)	(1.208)
Surplus rainfall shock	0.133***	0.767**	1.398***	1.185***	2.218***
	(0.018)	(0.323)	(0.411)	(0.417)	(0.570)
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Village-level controls	No	No	No	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	8,160	8,160	8,160	8,160	2,354
No. of sub-districts	110	110	110	110	110
No. of households	2,147	2,147	2,147	2,147	577
(Pseudo) R-squared	0.062	0.035	0.043	0.050	0.066

Note: [a] 1,570 households (i.e., 5,806 observations) have been dropped due to a lack of variation within the particular households over time.

The variables high income fluctuation (dummy), engaged in crop production (dummy), days needed to raise 5,000 THB, savings (dummy), health insurance (dummy), size of dwelling (m²), and cooking with gas (dummy) are included as control variables in each of the regressions. The variables farm labor intensity of the village (share), and average size of dwellings in the village (m²) are included as village-level controls in the last two regressions (columns (4) and (5)). USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 6. Impact of Rainfall Shocks through Forward Linkages (Non-Farm Enterprise Perspective) – Input Costs of Food Processing Enterprises (USD, log)

Dependent variable	Forward linkages – Input costs of food processing enterprises (USD, log)				
	OLS	(Linear model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)
Deficit rainfall shock	-1.917	-4.380**	-5.221**	-5.411*	-1.455
	(3.158)	(1.731)	(2.097)	(2.727)	(2.145)
Surplus rainfall shock	-0.422	4.279**	8.012***	8.080***	9.308***
	(0.997)	(1.943)	(2.667)	(2.678)	(2.529)
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Village-level controls	No	No	No	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	130	130	130	130	130
No. of sub-districts	54	54	54	54	54
No. of households	72	72	72	72	72
R-squared	0.458	0.592	0.629	0.640	0.685

Note: The variables male (dummy), age (years), age squared (years), no education, sick, married, self-employment main occupation (all dummies), startup capital (USD), age of enterprise (years), more than 10 customers total (dummy), employees – family members (no.), employees – non-family members (no.), high income fluctuation (dummy), and engaged in crop production (dummy) are included as control variables in each of the regressions. The variables farm labor intensity of the village (share), and average size of dwellings in the village (m^2) are included as village-level controls in the last two regressions (columns (4) and (5)). USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 7. Impact of Rainfall Shocks through Backward Linkages (Non-Farm Enterprise Perspective) – Sales by Agriculture-Related Enterprises (USD, log)

Dependent variable	Backward linkages – Sales by agri-related enterprises (USD, log)				
	OLS	(Linear model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)
Deficit rainfall shock	-3.644	-2.016	5.819	4.683	-1.979
	(3.273)	(3.549)	(5.595)	(5.920)	(7.492)
Surplus rainfall shock	-0.826	2.011	6.503***	6.248***	8.302**
	(1.282)	(1.986)	(2.412)	(2.303)	(3.287)
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Village-level controls	No	No	No	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	145	145	145	145	145
No. of sub-districts	71	71	71	71	71
No. of households	99	99	99	99	99
R-squared	0.394	0.475	0.650	0.659	0.599

Note: The variables male (dummy), age (years), age squared (years), no education, sick, married, self-employment main occupation (all dummies), startup capital (USD), age of enterprise (years), more than 10 customers total (dummy), employees – family members (no.), employees – non-family members (no.), high income fluctuation (dummy), and engaged in crop production (dummy) are included as control variables in each of the regressions. The variables farm labor intensity of the village (share), and average size of dwellings in the village (m^2) are included as village-level controls in the last two regressions (columns (4) and (5)). USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 8. Impact of Rainfall Shocks through Backward Linkages (Farm Perspective) – Monthly Farm Input Costs for Various Categories (USD/ha)

Dependent variable	Backward linkages – Monthly farm input costs (USD/ha)				
	OLS	(Linear model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)
Irrigation costs (USD/ha)					
Deficit rainfall shock	5.023	7.422	10.866	11.564	15.708*
	(7.444)	(10.154)	(9.866)	(9.941)	(8.767)
Surplus rainfall shock	-5.352*	-5.295*	-3.360	-2.822	-2.580
	(2.852)	(3.078)	(3.105)	(3.085)	(3.340)
R-squared	0.038	0.032	0.041	0.041	0.044
Machinery costs (USD/ha)					
Deficit rainfall shock	71.820	-7.536	-94.884	-93.524	-98.632*
	(48.999)	(76.962)	(71.128)	(67.658)	(57.489)
Surplus rainfall shock	-80.819***	24.045	79.156***	80.818***	60.820***
	(18.770)	(21.643)	(23.746)	(24.214)	(22.826)
R-squared	0.037	0.023	0.039	0.039	0.040
Fertilizer costs (USD/ha)					
Deficit rainfall shock	370.42***	323.42***	321.50***	300.09***	297.99***
	(43.615)	(78.999)	(83.229)	(83.305)	(75.789)
Surplus rainfall shock	-66.998***	30.154	75.378***	61.653**	52.768***
	(16.707)	(22.378)	(27.986)	(28.446)	(19.362)
R-squared	0.102	0.095	0.113	0.115	0.112
Pesticide costs (USD/ha)					
Deficit rainfall shock	7.782	8.416	-0.624	-0.211	0.831
	(6.428)	(6.925)	(6.880)	(6.810)	(5.938)
Surplus rainfall shock	-9.501***	-12.963***	-4.916	-4.691	-6.417**
	(2.462)	(2.787)	(3.386)	(3.335)	(3.070)
R-squared	0.020	0.017	0.020	0.020	0.024
Hired labor costs (USD/ha)					
Deficit rainfall shock	-10.569	27.379	22.379	35.709	31.042
	(58.219)	(39.622)	(45.479)	(46.599)	(61.097)
Surplus rainfall shock	-13.975	-43.295**	-45.281*	-36.577	-56.062**
	(22.302)	(20.931)	(24.895)	(26.068)	(27.213)
R-squared	0.038	0.027	0.028	0.028	0.018
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Village-level controls	No	No	No	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	6,562	6,562	6,562	6,562	6,562
No. of sub-districts	110	110	110	110	110
No. of households	1,862	1,862	1,862	1,862	1,862

Note: The variables rain-fed land (dummy), agricultural land (ha, log), total rice production output (kg), health insurance (dummy), size of dwelling (m^2), household members in labor force (no.), and labor supply to farm activities (share) are included as control variables in each of the regressions. The variables farm labor intensity of the village (share), and average size of dwellings in the village (m^2) are included as village-level controls in the last two regressions (columns (4) and (5)). USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 9. Impact of Rainfall Shocks through Consumption Linkages (Farm Perspective) – Expenditure of Farm Households on Consumption in previous 12 Months (USD, log)

Dependent variable	Consumption linkages – Annual consumption expenditure (USD, log)				
	OLS	(Linear model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)
Total expenditure (USD, log)					
Deficit rainfall shock	-1.842***	-2.155***	-0.518***	-0.492***	-0.538***
	(0.217)	(0.795)	(0.171)	(0.174)	(0.179)
Surplus rainfall shock	0.785***	0.762***	-0.027	-0.008	-0.085
	(0.084)	(0.174)	(0.101)	(0.099)	(0.076)
R-squared	0.080	0.066	0.402	0.402	0.536
Food expenditure (USD, log)					
Deficit rainfall shock	-1.427***	-1.419**	-0.793***	-0.773***	-0.844***
	(0.215)	(0.660)	(0.279)	(0.283)	(0.246)
Surplus rainfall shock	0.122	-0.167	-0.199*	-0.182*	-0.191**
	(0.083)	(0.131)	(0.111)	(0.107)	(0.093)
R-squared	0.037	0.029	0.203	0.203	0.258
Non-food expenditure (USD, log)					
Deficit rainfall shock	-2.605***	-3.482***	-0.049	-0.013	-0.012
	(0.315)	(1.135)	(0.238)	(0.247)	(0.218)
Surplus rainfall shock	1.988***	2.407***	0.246**	0.270**	0.120
	(0.122)	(0.266)	(0.117)	(0.120)	(0.098)
R-squared	0.104	0.107	0.522	0.523	0.673
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Village-level controls	No	No	No	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	6,168	6,168	6,168	6,168	6,168
No. of sub-districts	110	110	110	110	110
No. of households	1,778	1,778	1,778	1,778	1,778

Note: The variables rain-fed land, high income fluctuation (dummy), days needed to raise 5,000 THB, savings (dummy), health insurance (dummy), size of dwelling (m^2), and cooking with gas (dummy) are included as control variables in each of the regressions. The variables farm labor intensity of the village (share), and average size of dwellings in the village (m^2) are included as village-level controls in the last two regressions (columns (4) and (5)). USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 10. Impact of Rainfall Shocks on Farms and Non-Farm Enterprises – Summary

Dependent variable	Deficit rainfall shock		Surplus rainfall shock	
	Sub-district FE (1)	Household FE (2)	Sub-district FE (3)	Household FE (4)
4.1. Agricultural production output (Table 3)				
Rice yield (kg/ha)	-1,546.6***	-1,377.9***	-411.17*	-468.63**
	(513.88)	(403.46)	(216.32)	(202.89)
4.2. Labor supply (Table 4 and Table 5)				
Self-employment as main occupation (dummy)	0.263	0.031	1.259***	1.858***
	(0.748)	(0.881)	(0.319)	(0.382)
HH labor supply to self-employment (dummy)	1.042	1.097	1.185***	2.218***
	(0.940)	(1.208)	(0.417)	(0.570)
4.3. Forward linkages (Table 6)				
Input costs food processing enterprises (USD, log)	-5.411*	-1.455	8.080***	9.308***
	(2.727)	(2.145)	(2.678)	(2.529)
4.4. Backward linkages (Table 7 and Table 8)				
Sales by agri-related enterprises (USD, log)	4.683	-1.979	6.248***	8.302**
	(5.920)	(7.492)	(2.303)	(3.287)
Irrigation costs (USD/ha)	11.564	15.708*	-2.822	-2.580
	(9.941)	(8.767)	(3.085)	(3.340)
Machinery costs (USD/ha)	-93.524	-98.632*	80.818***	60.820***
	(67.658)	(57.489)	(24.214)	(22.826)
Fertilizer costs (USD/ha)	300.09***	297.99***	61.653**	52.768***
	(83.305)	(75.789)	(28.446)	(19.362)
Pesticide costs (USD/ha)	-0.211	0.831	-4.691	-6.417**
	(6.810)	(5.938)	(3.335)	(3.070)
Hired labor costs (USD/ha)	35.709	31.042	-36.577	-56.062**
	(46.599)	(61.097)	(26.068)	(27.213)
4.5. Consumption linkages (Table 9)				
Total expenditure (USD, log)	-0.492***	-0.538***	-0.008	-0.085
	(0.174)	(0.179)	(0.099)	(0.076)
Food expenditure (USD, log)	-0.773***	-0.844***	-0.182*	-0.191**
	(0.283)	(0.246)	(0.107)	(0.093)
Non-food expenditure (USD, log)	-0.013	-0.012	0.270**	0.120
	(0.247)	(0.218)	(0.120)	(0.098)

Note: All regressions include year fixed effects and village-level controls. For details on included controls, no. of observations/sub-districts/households, R-squared, etc. please refer to the respective tables. USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Appendix (A)

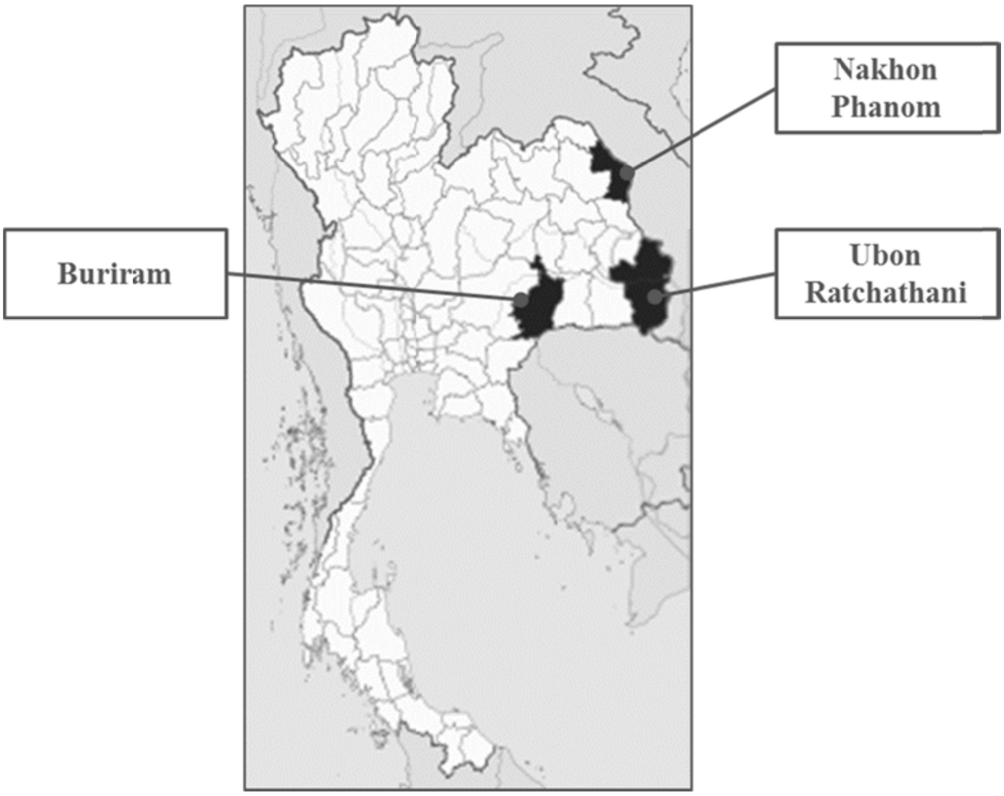

Figure A1. **Location of provinces in Thailand in which the TVSEP surveys were implemented**

Source: Based on SavGIS (http://www.savgis.org/HPAI/thaibound/thbound.html) and Wikimedia (https://commons.wikimedia.org/wiki/File:Thailand_location_map.svg)

Table A1. Overview and Description of Variables Used in this Article

Variable	Description	Observation level	Chapter
Dependent variables			
$\boldsymbol{Yield_{hklt}}$ Rice yield (kg/ha)	Agricultural production output of rice in kilogram per hectare in the last 12 months	Household/ Farm	4.1
$\boldsymbol{SelfMain_{ihklt}}$ Self-employment as first occupation (dummy)	Dummy that equals 1 if the individual indicated that non-farm self-employment is its main occupation, and 0 otherwise	Individual	4.2 (individual)
$\boldsymbol{SelfShare_{hklt}}$ Household labor supply to self-employment (share)	Share of household members that engage in non-farm self-employment compared to total number of household members part of the labor force; variable takes values between 0 and 1	Household	4.2 (household)
$\boldsymbol{FwInput_{ihklt}}$ Input costs of enterprise in food processing industry (USD, log)	Total input costs of enterprises that engage in the food processing industry, i.e., cost for mainly agricultural inputs, in the last 12 months; measured in USD 2005 PPP and as log	Household/ Enterprise	4.3 (enterprise)
$\boldsymbol{BwSales_{ihklt}}$ Sales by agri-related enterprises (USD, log)	Total sales by enterprises that offer agriculture-related products and services in the last 12 months; measured in USD 2005 PPP	Household/ Enterprise	4.4 (enterprise)
$\boldsymbol{BwInput_{hklt}}$ Input costs of farms (USD /ha)	Input costs of farms for irrigation, machinery, fertilizer, pesticide, and hired labor, respectively, in the last 12 months; measured in USD 2005 PPP per hectare	Household/ Farm	4.4 (farm)
$\boldsymbol{ConsExp_{hklt}}$ Consumption expenditure (USD, log)	Expenditure of farm households on total consumption, food consumption and non-food consumption, respectively, in the last 12 months; measured in USD 2005 PPP and as log	Household/ Farm	4.5
(Independent) Explanatory variables			
Deficit rainfall shock	Negative deviation of rainfall of more than 15% below the average rainfall in the rainy season (June to October) in the previous 15 years	Sub-district	All
Surplus rainfall shock	Positive deviation of rainfall of more than 15% above the average rainfall in the rainy season (June to October) in the previous 15 years	Sub-district	All
(Independent) Control variables			
Irrigation costs (USD/ha)	Expenditure on irrigation used in rice production in the last 12 months; measured in USD 2005 PPP	Household/ Farm	4.1
Machinery costs (USD/ha)	Expenditure on machinery used in rice production in the last 12 months; measured in USD 2005 PPP	Household/ Farm	4.1

Fertilizer costs (USD/ha)	Expenditure on fertilizer used in rice production in the last 12 months; measured in USD 2005 PPP	Household/ Farm	4.1
Pesticide costs (USD/ha)	Expenditure on pesticide used in rice production in the last 12 months; measured in USD 2005 PPP	Household/ Farm	4.1
Labor costs (USD/ha)	Expenditure on hired labor used in rice production in the last 12 months; measured in USD 2005 PPP	Household/ Farm	4.1
Rain-fed land (dummy)	Dummy that equals 1 if the agricultural land of the household is rain-fed, 0 if it is irrigated	Household/ Farm	4.1, 4.4 (farm), 4.5
Agricultural land (ha, log)	Log of total agricultural land used in rice production in the last 12 months; measured in hectare	Household/ Farm	4.1, 4.4 (farm)
Health insurance (dummy)	Dummy that equals 1 if all household members have a health insurance, 0 if not	Household	4.1, 4.2, 4.4 (farm), 4.5
Size of dwelling (m²)	Size of the household's dwelling/house/flat; measured in m²	Household	4.1, 4.2, 4.4 (farm), 4.5
Household members in labor force (no.)	Number of individuals that live in the household and are part of the labor force	Household	4.1, 4.4 (farm)
Labor supply to farm activities (share)	Share of household members that are part of the labor force supplying their labor to farm activities	Household	4.1, 4.4 (farm)
Male (dummy)	Dummy that equals 1 if the individual is male, and 0 if the individual is female	Individual	4.2 (individual), 4.3 (enterprise), 4.4 (enterprise)
Age (years)	Age of the individual; measured in years	Individual	4.2 (individual), 4.3 (enterprise), 4.4 (enterprise)
Age (years) - squared	Squared age of the individual; measured in years	Individual	4.2 (individual), 4.3 (enterprise), 4.4 (enterprise)
No education (dummy)	Dummy that equals 1 if the individual has between 0 and 4 years of education, and 0 if the individual has more than 4 years	Individual	4.2 (individual), 4.3 (enterprise), 4.4 (enterprise)
Sick (dummy)	Dummy that equals 1 if the individual has been sick in the last 12 months, and 0 otherwise	Individual	4.2 (individual), 4.3 (enterprise), 4.4 (enterprise)
Married (dummy)	Dummy that equals 1 if the individual is married, and 0 otherwise	Individual	4.2 (individual), 4.3 (enterprise), 4.4 (enterprise)
High income fluctuation (dummy)	Dummy that equals 1 if the household indicated that it had a high fluctuation of income in the	Household	4.2, 4.3 (enterprise),

	last 12 months, and 0 otherwise		4.4 (enterprise), 4.5
Engaged in crop production (dummy)	Dummy that equals 1 if the household is engaged in any kind and intensity of crop production, and 0 otherwise	Household	4.2, 4.3 (enterprise), 4.4 (enterprise)
Days needed to raise 5,000 THB	Number of days a household would need to raise 5,000 THB (i.e., approximately USD 150 in 2017)	Household	4.2, 4.5
Savings (dummy)	Dummy that equals 1 if the household did save anything at all in the last 12 months, and 0 otherwise	Household	4.2, 4.5
Cooking with gas (dummy)	Dummy that equals 1 if gas is the main source of energy for cooking, and 0 otherwise (i.e., charcoal, wood)	Household	4.2, 4.5
Self-employment main occupation (dummy)	Dummy that equals 1 if the individual indicated that self-employment is its main occupation, and 0 otherwise	Individual	4.3 (enterprise), 4.4 (enterprise)
Startup capital (USD)	Amount of capital the enterprise owner invested when starting up the enterprise; measured in USD 2005 PPP	Individual/ Enterprise	4.3 (enterprise), 4.4 (enterprise)
Age of enterprise (years)	Age of the enterprise; measured in years	Individual/ Enterprise	4.3 (enterprise), 4.4 (enterprise)
More than 10 customers total (dummy)	Dummy that equals 1 if the enterprise has in total more than 10 customers, and 0 otherwise	Individual/ Enterprise	4.3 (enterprise), 4.4 (enterprise)
Employees – family members (no.)	Number of family-members that work as employees in the enterprise	Individual/ Enterprise	4.3 (enterprise), 4.4 (enterprise)
Employees – non-family members (no.)	Number of non-family employees that are working in the enterprise	Individual/ Enterprise	4.3 (enterprise), 4.4 (enterprise)
Total rice production output (kg)	Total production output of rice in the last 12 months; measured in kg	Household/ Farm	4.4 (farm)
Farm labor intensity of village (dummy)	Average share of household members in a village that are part of the labor force supplying their labor to farm activities	Village	All
Avg. size of dwellings in village (m^2)	Average size of the dwelling/house/flat of the households in the village; measured in m^2	Village	All

Table A2. Impact of Rainfall Shocks through Forward Linkages (Non-Farm Enterprise Perspective) – Input Costs of Enterprises excl. Food Processing Enterprises (USD, log)

Dependent variable	Forward linkages – Input costs of enterprises excl. food processing enterprises (USD, log)				
	OLS	(Linear model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)
Deficit rainfall shock	0.866	1.226	0.393	0.475	1.559
	(0.894)	(0.943)	(0.985)	(0.997)	(1.079)
Surplus rainfall shock	0.371	-0.156	0.747**	0.782**	0.557
	(0.285)	(0.355)	(0.368)	(0.360)	(0.433)
Male (dummy)	0.158**	0.084	0.088	0.088	0.102
	(0.069)	(0.097)	(0.097)	(0.096)	(0.110)
Age (years)	0.070***	0.075***	0.075***	0.075***	0.040*
	(0.016)	(0.020)	(0.020)	(0.020)	(0.023)
Age (years) - squared	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
	(1.62e-4)	(2.04e-4)	(2.02e-4)	(2.01e-4)	(2.23e-4)
No education (dummy)	-0.113	-0.128	-0.106	-0.103	0.079
	(0.088)	(0.113)	(0.114)	(0.114)	(0.172)
Sick (dummy)	0.007	-0.008	-0.013	-0.011	-0.122
	(0.117)	(0.134)	(0.134)	(0.134)	(0.148)
Married (dummy)	0.085	0.021	0.018	0.019	-0.090
	(0.089)	(0.112)	(0.112)	(0.112)	(0.142)
Self-emp. main occupation (dummy)	0.460***	0.475***	0.457***	0.459***	0.282***
	(0.070)	(0.078)	(0.077)	(0.077)	(0.093)
Startup capital (USD)	0.353***	0.342***	0.336***	0.336***	0.247***
	(0.016)	(0.023)	(0.024)	(0.024)	(0.032)
Age of enterprise (years)	-0.007*	-0.005	-0.005	-0.005	-0.008
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
More than 10 customers total (dummy)	0.936***	0.847***	0.852***	0.853***	0.573***
	(0.080)	(0.099)	(0.100)	(0.099)	(0.104)
Employees - family members (no.)	0.428***	0.412***	0.426***	0.426***	0.264***
	(0.048)	(0.048)	(0.048)	(0.048)	(0.050)
Employees - non-family members (no.)	0.041***	0.045***	0.044***	0.044***	0.023***
	(0.009)	(0.0111)	(0.011)	(0.011)	(0.008)
High income fluctuation (dummy)	-0.125	-0.129	-0.095	-0.099	-0.126
	(0.089)	(0.090)	(0.090)	(0.089)	(0.104)
Engaged in crop production (dummy)	-0.094	0.061	0.041	0.041	0.207
	(0.090)	(0.124)	(0.124)	(0.124)	(0.160)
Farm labor intensity of village (share)				0.099	-0.317
				(0.465)	(0.577)
Avg. size of dwellings in village (m^2)				0.001	0.001
				(0.001)	(0.001)
Constant	0.852**	0.817	0.609	0.479	2.380***
	(0.400)	(0.495)	(0.482)	(0.558)	(0.646)

Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	2,690	2,690	2,690	2,690	2,690
No. of sub-districts	110	110	110	110	110
No. of households	981	981	981	981	981
R-squared	0.361	0.329	0.333	0.333	0.152

Note: USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table A3. Impact of Rainfall Shocks through Backward Linkages (Non-Farm Enterprise Perspective) – Sales by Enterprises excl. Agriculture-Related Enterprises (USD, log)

Dependent variable	Backward linkages – Sales by enterprises excl. agri-related enterprises (USD, log)				
	OLS	(Linear model) Fixed effects			
	(1)	(2)	(3)	(4)	(5)
Deficit rainfall shock	-0.471	-1.073	-0.200	-0.432	-1.664*
	(0.766)	(0.755)	(0.780)	(0.781)	(0.860)
Surplus rainfall shock	0.267	-0.109	0.845**	0.944**	0.705*
	(0.241)	(0.341)	(0.360)	(0.360)	(0.399)
Male (dummy)	0.134**	0.107	0.111	0.110	0.048
	(0.058)	(0.077)	(0.077)	(0.076)	(0.092)
Age (years)	0.053***	0.056***	0.056***	0.056***	0.028
	(0.014)	(0.017)	(0.017)	(0.017)	(0.021)
Age (years) - squared	-7.24e-4***	-7.65e-4***	-7.81e-4***	-7.82e-4***	-4.77e-4**
	(1.38e-4)	(1.78e-4)	(1.76e-4)	(1.74e-4)	(2.09e-4)
No education (dummy)	-0.230***	-0.198*	-0.176*	-0.169*	-0.006
	(0.074)	(0.101)	(0.102)	(0.102)	(0.143)
Sick (dummy)	0.006	0.037	0.033	0.037	-0.016
	(0.098)	(0.110)	(0.110)	(0.110)	(0.111)
Married (dummy)	0.165**	0.109	0.106	0.112	0.049
	(0.075)	(0.101)	(0.101)	(0.101)	(0.129)
Self-emp. main occupation (dummy)	0.383***	0.392***	0.368***	0.373***	0.141*
	(0.059)	(0.065)	(0.064)	(0.064)	(0.074)
Startup capital (USD)	0.248***	0.236***	0.230***	0.229***	0.193***
	(0.014)	(0.021)	(0.021)	(0.021)	(0.028)
Age of enterprise (years)	-0.001	-0.000	-0.001	-0.001	-0.002
	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)
More than 10 customers total (dummy)	0.671***	0.621***	0.629***	0.631***	0.496***
	(0.068)	(0.086)	(0.087)	(0.087)	(0.094)

Employees - family members (no.)	0.331***	0.326***	0.341***	0.340***	0.229***
	(0.040)	(0.043)	(0.044)	(0.043)	(0.043)
Employees - non-family members (no.)	0.078***	0.080***	0.080***	0.080***	0.059***
	(0.008)	(0.022)	(0.023)	(0.023)	(0.012)
High income fluctuation (dummy)	-0.164**	-0.188**	-0.161*	-0.169**	-0.177*
	(0.075)	(0.082)	(0.081)	(0.080)	(0.091)
Engaged in crop production (dummy)	-0.104	0.027	-0.000	-0.003	0.127
	(0.076)	(0.105)	(0.104)	(0.104)	(0.122)
Farm labor intensity of village (share)				0.203	-0.198
				(0.439)	(0.475)
Avg. size of dwellings in village (m^2)				0.203	-0.198
				(0.439)	(0.475)
Constant	2.946***	2.961***	2.701***	2.384***	3.652***
	(0.342)	(0.429)	(0.427)	(0.517)	(0.575)
Sub-district FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	Yes
Household FE	No	No	No	No	Yes
No. of observations	2,734	2,734	2,734	2,734	2,734
No. of sub-districts	110	110	110	110	110
No. of households	996	996	996	996	996
R-squared	0.328	0.300	0.308	0.309	0.163

Note: USD measured in USD 2005 PPP. Robust standard errors clustered at sub-district level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

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