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# Value Chains, Technology Transfer, Food Security, and Agricultural Development

Dissertation presented to obtain the degree of Doctor in Economics by

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Voor Ank en Gus

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*"Nobody ever figures out what life is all about, and it doesn't matter. Explore the world. Nearly everything is really interesting if you go into it deeply enough."*
— Richard P. Feynman.

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# Chapter 1. Introduction

*"Most of the people in the world are poor, so if we knew the economics of being poor,*
*we would know much of the economics that really matters.*
*Most of the world's poor people earn their living from agriculture,*
*so if we knew the economics of agriculture*
*we would know much of the economics of being poor"*
—T.W. Schultz (Nobel prize lecture, 1979)

Increasing agricultural productivity in developing countries is of key importance for poverty reduction.[1] Productivity gains can directly benefit the many poor people who are dependent on agriculture, either as farmers or as wage laborers. There are more than 570 million farms worldwide, most of them (an estimated 96%) located in developing or emerging economies (Lowder et al. 2016). These farms employ more than 2 billion people, many of whom live in poverty.[2] More importantly, however, are considered the indirect linkages through which the poor can benefit from higher agricultural productivity, such as via a negative effect on food prices or via a positive effect on the demand for locally produced goods and services (Christiaensen and Vandercasteelen 2019). Higher agricultural productivity, through these indirect linkages, allows farmers and farm workers to leave agriculture and find employment in manufacturing or in services. Such "structural transformation" of the economy is widely regarded as one of the most powerful and sustainable pathways out of poverty (Barrett 2010; Barrett et al. 2017; Timmer 2009).

The fact that agricultural productivity is low in most poor countries should thus not surprise us. While, for example, the average yield for the main cereals in the high-growth regions of East Asia and South America grew to a current level of about six tons per hectare (t/ha) and about 5 t/ha, for the relatively poorer regions of South Asia and Africa the current average yields are quite a bit lower, at about 3 t/ha and 1.6 t/ha, respectively.[3]

[1] In fact, empirical research shows that growth in agriculture, on average, has a bigger poverty-reducing effect than growth in other economic sectors particularly for the very-poorest in society (Ligon and Sadoulet 2018; Ivanic and Martin 2018; Dorosh and Turlow 2018).

[2] International Labour Organization, ILOSTAT database. Data retrieved in September 2019.

[3] FAOstat: http://faostat.fao.org, accessed 07-DEC-2019.

Two recent World Bank studies, by Fuglie et al. (2019) and Christiaensen and Vandercasteelen (2019), extensively reviewed the literature to identify the general causes of low agricultural productivity. Both came to the same conclusions. Besides stagnant or falling investment in agricultural research and development in regions where agricultural growth is most needed, the primary reason for low productivity is low adoption by farmers of modern farm inputs that are already available (i.e., improved varieties, farm agro-chemicals, and equipment for mechanization and irrigation) and a lack of knowledge on how to combine these inputs optimally. The underlying—fundamental—explanations for low technology adoption in agriculture are, however, manifold, complex, and closely entangled. Important factors identified by Christiaensen and Vandercasteelen (2019) include the heterogeneous profitability of technology adoption as a result of differences in soil fertility and other physical conditions, lack of timely available and high quality inputs, poorly functioning agricultural extension systems, high transaction costs and oligopolistic market power on markets for farm inputs, credit market constraints, and high investment risks in rain-fed agriculture. Both World Bank reports recognize that many agricultural development programs in the past were not effective due to a singular focus and now call for a more integrated (holistic) approach to agricultural development that can address the multiple binding constraints on agricultural productivity simultaneously.[4]

One holistic approach, that is adopted by this dissertation, involves taking a value chain perspective.[5] A value chain describes the full range of activities which are required to bring a product forward through the different phases of production to final consumers (Kaplinsky and Morris 2001). A typical agri-food value chain involves (farm) input and service companies, farmers, traders, processors, retailers, and final consumers. These actors and the way they interact influence the economic and institutional context in which farmers operates, and thus their decisions on technology use. Traders, processors, and retailers, for example, can directly influence the incentives for technology adoption through the quality requirements they impose on the farmer's products and the prices they pay for products meeting their standards.

[4] Both World Bank studies are wary, however, of returning to the integrated rural development programs that were popular in 1970s to 1990s. These were considered ineffective due to poor adaptation to local context, too little local ownership, low administrative capacity, and a lack of coordination between the various agencies involved.

[5] Other potential holistic approaches include so-called territorial development (or landscape approaches) that intend to offer an integrated solution (e.g., regarding the management of natural resources) for a clearly defined region and integrated cash-asset transfer programs targeted at specific poor persons or households. Both these integrated approaches have recently received increased attention.

Taking a value chain perspective also allows us to see that the failure to adopt modern agricultural technologies not only affects the farmer but may also affect all other actors in the chain. Farm input companies may have lower profits since they cannot sell their technology; processors may not get the raw material they need for producing consumer products that meet their standards; and consumers may not get the products they desire. These actors may thus have an incentive to make the farm adopt the technology.

The first two chapters of this dissertation are based on this insight as these chapters study how a value chain can actually be re-organized by the companies involved to enable and incentivize farmers to adopt new technologies. Specifically, Chapter 2 investigates under which conditions buyers of farm produce (traders, processors, or retailers) have an incentive and are able to transfer technology to farmers. The theoretical model developed in this chapter suggests that technology transfer can be a profitable way for buyers to source (high quality) produce in an environment characterized by imperfect credit and technology markets, but that the feasibility of the transfer depends on the surplus generated by the technology, agents' opportunity costs, different forms of holdups, and the type of technology that is being transferred. Imperfect contract enforcement and the holdup opportunities in the chain negatively affect the feasibility of the transfer, but redistribution of surplus under self-enforcing contracts may allow contracting and technology transfer to be feasible. Whether a self-enforcing contract can be designed depends, among other things, on the type of technology, including the dynamic distribution of the value that it creates and the specificity of the technology to the buyer-farmer transaction. The model also suggests that the self-enforcing nature of the contracts can have major implications for the distribution of surplus generated by the technology transfer and thus the welfare effects of technology adoption.

While Chapter 2 focusses on a specific and common type of value chain organization— interlinked contracting between a buyer and farmer (i.e. contract farming with resource provision)—Chapter 3, based on a literature review, argues that this is just one of the many possible ways in which a value chain can be re-organized to stimulate technology adoption by farmers. Besides buyers, input companies are also identified as common initiators of innovative ways to re-organize the value chain (e.g., by offering credit schemes or leasing arrangements to farmers). As argued earlier, they too lose if farmers, due to market constraints, cannot adopt their products. For bigger or more long term technological investments more complex contracts involving multiple value chain actors are observed. This includes triangular structures and special purpose vehicles. Bringing additional agents to the table allows for sharing the cost of setting up the arrangement, spreading the risk, and enhancing the enforcement capacity through lower information asymmetry and higher reputation costs. Finally, an extreme institutional solution to overcome farmer technology constraints is vertical integration. Vertical integration removes the problems of contract enforcement in technology transfer and provides the company full control over technology implementation at the farm. The empirical cases that are studied in this chapter suggest that the economic effects of these value chain innovations can be substantial as they can move the entire value chain towards a higher equilibrium, with impacts for all agents.

The most straightforward policy implication from the first two chapters therefore relates to recognizing the importance of value chains as an engine for technology adoption, and to the need for allowing this engine to work its best. A key policy to stimulate value chain innovations and technology adoption is thus to improve the business environment. Investments in value chain innovations are less risky and more rewarding if, for example, contract enforcement is easier, if there is more macro-economic stability, and if complementary infrastructure is in place (e.g., roads, electricity, cold chains). If improvements in the general business environment are slow or stagnating, selective public investments in specific value chains (i.e., public-led value chain development) can be considered. This is what is discussed in Chapter 4.

In fact, Chapter 4 explores what public-led value chain development (VCD) entails and discusses in what context it can be a relevant policy instrument. It defines VCD as an intervention that intends to increase the effectiveness or efficiency of a specific value chain by reducing the transaction costs between different stages and by supporting specific value chain actors. Value chain effectiveness in this context is understood as the ability of the value chain to comply with public or private requirements, such as regarding product quality, food safety, or ethical and environmental standards. Value chain efficiency, in turn, is understood as the costs incurred in the chain to bring forward the final product that meets these requirements.

It argues that in a context characterized by imperfect markets, VCD can be a relevant intervention to be initiated not only by private actors but also by (semi-) public actors, such as governments, international organizations, and non-governmental organizations (NGOs). Poorly functioning agri-food value chains can have negative consequences for economic growth, for the welfare of farmers and laborers in these value chains, for the environment, and for the quality and safety of consumer products. The combination of market failure and high social costs can justify public interventions in specific value chains.

As an illustration of an integrated approach to public VCD, the paper then describes the project "SAFAL", which directly intervenes in the aquaculture, horticulture, and dairy value chains in South-West Bangladesh. By reducing the transaction costs between farmers on the one hand and buyers and providers of farm inputs on the other and by supporting key value chain actors, the project had the intention to improve the welfare and food security of about 58,000 smallholders. Central to the project was a push-and-pull strategy whereby value chain actors are both enabled and incentivized to invest and change their practices. Using a matched difference-in-difference methodology, it is estimated that SAFAL substantially increased the income and food security of participating farm households

Chapter 4, as well as Chapter 5, stem from the evaluation of the Dutch food security policy by the Policy and Operations Evaluation Department of the Ministry of Foreign Affairs of the Netherlands (IOB 2018).[6] In fact, as part of this evaluation, five projects with a value chain development component were evaluated using a similar rigorous methodology (difference-in-difference). To put things into perspective, out of these five projects, the program that is used as case study in Chapter 4, SAFAL, was judged to be the most effective (IOB 2018). The identified success factors included a valid theory of change, an intensive yet flexible implementation, and a conducive context. It is for these reasons that this program was chosen over the other four as a case study in Chapter 4: it presents evidence that, under the right conditions, value chain development can be an effective policy instrument.

Finally, Chapter 5 was initiated as part of the same policy evaluation. It intended to provide evidence on the implicit assumption underlying the Dutch Food Security Policy that value chain development programs and other policy instruments that stimulate farmer commercialization, through a positive effect on farmer income, will also lead to better nutritional outcomes. It uses the data from three of the five impact evaluations conducted (one in Rwanda and two in Bangladesh) to investigate whether commercialization by farmers has indeed a positive effect on the nutrient adequacy and diversity of their household's diet.

By estimating a panel fixed-effects model, we find that the average effect of agricultural commercialization on the quality of diets is limited. We find a modest positive effect of commercialization on both dietary diversity and nutrient adequacy in Rwanda, but we do not find evidence for a positive effect in Bangladesh. Moreover, the results from both countries suggest that the relationship between commercialization and dietary quality is best characterized as concave. This would imply that commercialization does contribute to better diets for farm households that sell yet a small share of their production but that the effect on dietary quality diminishes with higher rates of commercialization and

[6] The author of this dissertation was, among others, closely involved in the implementation of this evaluation.

can become negative for households that are already sell a large share of the food they produce. These results suggest that agricultural development programs cannot expect that agricultural commercialization, in itself, leads to an improvement in diets in any transformational sense, but that it can, to a limited extent, help those farm households that sell yet a small share of their production.

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# Chapter 2. Value Chains and Technology Transfer to Agriculture in Developing and Emerging Economies*

## 2.1 Introduction

The adoption of modern technologies in agriculture is widely believed to be important for improving the productivity and welfare of poor farmers in developing countries and a key ingredient for achieving poverty reduction, food security, rural development, and structural transformation. However, the adoption of modern technology, including improved seeds and chemical fertilizer, has been disappointing, particularly in Africa (Evenson and Gollin 2003; Feder, Just, and Zilberman 1985; Sheahan and Barrett 2014).

There is a vast literature on technology adoption focusing on farm size, profitability and risk aversion (Duflo, Kremer, and Robinson 2011; Just and Zilberman 1983; Suri 2011), credit constraints (Croppenstedt, Demeke, and Meschi 2003), human capital and learning (Foster and Rozenzweig, 1995; Lambrecht et al. 2014; Rahm and Huffman, 1984), and quality of technological inputs (Bold et al. 2015). In this chapter we take a value chain perspective and study how traders, processors, and retailers may affect technology adoption by farmers upstream in their value chain.

In the past decades, agrifood value chains have transformed dramatically (Reardon and Timmer 2007). Privatization and liberalization in the 1980s and 1990s induced important transitions in the institutional organization of value chains (Swinnen and Maertens 2007). Around the same time, urbanization, new food safety regulations, and a global increase in average consumer purchasing power resulted in an increased demand for high value and differentiated food products. In combination, this led to a major influx of domestic, as well as foreign direct investment in wholesaling, processing and retailing, and an increase in trade of high value agricultural products (Reardon et al. 2009).

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This had an important impact on modern technology adoption downstream from the farm. There is widespread evidence that food processors, traders, and retail companies in developing and emerging countries upgraded and modernized their production processes using new technology—often as the result of FDI and its horizontal spillover effects (Gow and Swinnen 1998; Reardon and Timmer 2014).

Our focus in this chapter is on vertical spillover effects and farm-level adoption of new technology. Value chains played an important role in this technology adoption. Processors and retailers modernized their procurement systems to be able to source high quality raw material necessary to meet new demands. One important aspect of the modernization process was the introduction of private standards (with corresponding traceability, auditing and certification systems) to overcome information asymmetry, reduce transaction costs and as a marketing tool to further increase product differentiation (Swinnen 2007).

These new demands on farmers' products often required farm-level investments in new technologies, be it to get higher yields for minimum output or to obtain higher quality, or to satisfy other types of standards.[7] With imperfect (or non-existing) technology markets, a key mechanism for farms to access and adopt these new technologies was through vertical coordination in value chains. This took many forms, including smallholder contracting with interlinked technology transfer, triangular structures with technology suppliers or financial institutions, or vertically integrated production (Swinnen and Kuijpers 2016).

This chapter addresses the question how these value chain developments impact technology transfer to—and adoption by—farmers in developing and emerging countries. To answer this question we review the emerging literature on value chains and technology transfer. Building on previous work by Swinnen and Vandeplas (2011), we then develop a model of vertical coordination between "buyers" (processors, traders, etc.) and farms that helps us understand under which conditions technology transfer within value chains takes place. In line with empirical evidence, we find that technology transfer from buyers to farms can occur in an environment with imperfect credit and technology markets but depends on the surplus generated by the technology, the holdup opportunities in the value chain, and the type of technology. We also analyze how

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[7] Standards often prohibit the use of less costly technology (Swinnen et al. 2015). Examples of cheap but often prohibited inputs are child labor, chemical inputs (in organic farming standards), or battery cages in poultry. Some standards require the use of more expensive technologies, such as milk cooling equipment for dairy farmers and traceability systems for farmers supplying supermarket channels. Standards can also require certain additional practices. For example, GlobalGap certification requires clean water for pre-harvest hand washing and certain packaging practices for transportation (Subervie and Vagneron 2013).

holdup opportunities influence the division of the surplus created by the technology, and discuss how the nature of the technology may affect the governance of the value chain.

This chapter contributes to several fields in the literature. First, as discussed above, the extensive literature on technology adoption in agriculture is largely ignoring the role of value chains. Conversely, the emerging value chain literature is predominantly focused on the determinants of farmer participation in modern value chains and the welfare implications for small farmers (e.g. Andersson et al. 2015; Beghin, Maertens, and Swinnen 2015; Bellemare 2012; Maertens and Swinnen 2009; Michelson 2013;) and—with some exceptions—either ignores the role of technology or does not consider it explicitly. Exceptions include some studies on how the transition process in Eastern Europe and the former Soviet Union transformed value chains and induced new technology adoption in agriculture (Dries and Swinnen 2004, 2010; Dries et al. 2009; Gow, Streeter, and Swinnen 2000; Noev, Dries, and Swinnen 2009), and some recent studies on high value chains in developing countries (Asfaw, Mithöfer, and Waibel 2009; Farole and Winkler 2014; González-Flores et al. 2014; Rao, Brümmer, and Qaim 2012). This chapter connects these two bodies of work and argues that (1) understanding the value chain in which a farmer is operating is key for understanding farmer technology adoption, and (2) understanding the role of technology is key in understanding the welfare effects of modern value chains.

Second, to our knowledge this is the first article to model the conditions under which value chains can contribute to technology transfer to agriculture in developing and emerging countries. The extent to which buyers affect the production technology of their suppliers is a major topic within the international technology diffusion literature (Keller 2004). This literature primarily focusses on the vertical spillover effects of multinational firms in the manufacturing sector on their suppliers in developing and emerging countries, either domestically, through FDI (e.g. Javorcik 2004; Blalock and Gertler 2008; Newman, Talbot, and Tarp 2015), or across borders, via trade (e.g. Bustos 2011; Lileeva and Trefler 2010; Van Biesebroeck 2005). The consensus is that supplying to foreign owned companies can improve the productivity of locally owned firms in developing countries (Havranek and Irsova 2011; Martins and Yang 2009). It is however also established that these effects can vary substantially depending on country, sector, and firm characteristics. Farole and Winkler (2014) argue that the specific dynamics of the value chain in which a farmer is operating is key for understanding these effects.

Moreover, the existing theoretical literature on vertical spillovers through backward linkages (i.e. from buyers to suppliers) is focused on manufacturing.

Most notable references include Rodriguez-Clare (1996) and Markusen and Venables (1999). However, these and other studies tend to focus on spillovers in the form of externalities (i.e. non-intentional)[8]; through economies of scale, increased competition, demonstration effects, access to intermediate inputs (with foreign technology embedded in them), or worker mobility, while we model *intentional* technology transfer. One exception is Pack and Saggi (2001) who also look at intentional technology transfer from downstream to upstream companies, taking into account the potential for leakage of the new technology to similar companies supplying to the buyer's competitors. In addition, we explicitly account for imperfect contract enforcement, taking into account the possibility of farmer and buyer holdup. We do this by applying insights from transaction cost theory (Klein, Crawford, and Alchian 1978; Williamson 1979) to a setting of vertical coordination and technology transfer. This makes our model more realistic for the agricultural sector in developing and emerging countries, where contract enforcement is often costly or absent and where problems of contractual holdup are persisting (e.g. Cungu et al. 2008; Barrett et al. 2012).

## 2.2 A Basic Model of Technology Adoption in Value Chains

Consider a farmer with a fixed allocation of labor and land who uses "basic technology" to produce a quantity $q_L$ of a low quality product that can be sold in the local market for a price $p_L$. The farmer's alternative is to sell to a trader, processor, or retailer (who we refer to as "the buyer"). They sell the product (possibly after processing) to urban consumers for a price $p_H$ as summarized in Figure 1. To keep the model simple, we assume processing or marketing costs are zero.

The buyer requires specific standards or minimum amounts of supply from the farm. To comply with the standard or to increase his productivity, the farm therefore needs to apply a more advanced technology. To start, we keep the definition of "technology" general. Later we will consider different types of technologies. The farmer can buy the technology from a "technology providing company" (e.g. fertilizer company or agro-dealer) for a price $\tau^f$.

[8] Technology transfers can also have significant spillover effects beyond the contracted products. For example, Minten, Randrianarison, and Swinnen (2009) and Negash and Swinnen (2013) find that value chain participation by African farmers strongly increased the yield of their non-contracted food crops as a result of increased access to fertilizer and technical assistance.

We assume this technology allows the farmer to comply with the buyer's private standard and/or that it increases the farmer's productivity, reflected in a higher quantity produced $q_H$ (with $q_H \geq q_L$) and/or a higher consumer price ($p_H \geq p_L$), given fixed land and labor inputs.[9] The total value generated by applying the advanced technology is defined as $V = p_H q_H$. Defining $l = p_L q_L$ as the farmer's opportunity cost, the net surplus created by adopting the technology is $S = V - l - \tau^f$. This is the total surplus in the value chain from technology adoption. The farmer's net surplus is $S^f = V^f - l - \tau^f$ with $V^f = \theta p_H q_H = \theta V$ and $\theta$ representing the farmer's share of the consumer price for the high value product. The farmer will decide to adopt the technology if his net surplus $S^f$ is positive, i.e. if:

$$V \geq \frac{(\tau^f + l)}{\theta} \quad (1)$$

This result is illustrated in panel (a) of Figure 2.

This general condition captures both the quantity and quality effects of technology adoption. All else equal, technology adoption is more likely if its quantity effect on productivity ($q_H - q_L$) is larger, if the quality effect ($p_H - p_L$) is stronger, if the farmer's share of the consumer price $\theta$ is larger, if the price of technology $\tau^f$ is lower, and if the opportunity costs of the farmer $l$ are lower.

The empirical literature finds that the adoption of technological inputs in "traditional markets" is positively associated with output market prices and negatively with prices of technology. Alene et al. (2008), showed for Kenyan maize farmers that a 1% increase in maize price increases the probability of fertilizer use by 5% and the amount of fertilizer used by 1.04%. Winter-Nelson and Temu (2005) found for Tanzanian coffee growers that a 1% increase in coffee price, increases the expenditure on chemical inputs (such as fertilizer and pesticides) by 1.25%. Zerfu and Larson (2010) find that the adoption of fertilizer is negatively associated with the price of fertilizer relative to output prices in Ethiopia.

In "modern value chains", prices generally tend to be higher, which might positively affect the incentive to adopt yield technology. Wollni and Zeller (2007) find that Costa Rican farmers who produce specialty coffee (gourmet coffee, organic, shade-grown, or fair trade) receive an average price that is 0.09US$/lb higher than the price on conventional markets. Asfaw, Mithöfer,

[9] We ignore the possibility that there is a trade-off between quantity and quality. Such trade off may well exist for given technologies and for some technological innovations. However, many of the technologies that are relevant in our analysis increase both quantity and quality, or at least one without reducing the other.

and Waibel (2009) show that Kenyan vegetable producers who are exporting and GlobalGap certified receive a price 25% higher than non-certified exporters and 150% higher than producers who sell domestically. Subervie and Vagneron (2013) found that GlobalGAP certified lychee farmers in Madagascar receive a 15% higher average price than non-certified farmers. Finally, Hansen and Trifkovic (2014) show that Vietnamese Pangasius farmers who comply with GlobalGAP or BAP standards receive a substantially higher average price than other farmers.

High value chains (i.e., value chains that comply with high standards and thus generate high value) not always pay higher prices but may offer other benefits. Michelson, Reardon, and Perez (2012) report that prices paid by Walmart in the Nicaraguan vegetable sector are significantly lower than prices in the traditional market or prices paid by domestic supermarkets. Farmers accept a lower price because Walmart covers the transportation costs and risks of sourcing the crop in the field and the Walmart price offered is less volatile than the price on the traditional market. Handschuch, Wollni, and Villalobos (2013) found similar results in Chile: although ChileGAP or USGap certified raspberry farmers obtain lower prices, they also face less price variation. Similarly, farmers in Hungary and Slovakia preferred certain value chains and the required technology because these value chains guaranteed market access (World Bank 2005). Hence, stable prices and assured market access, even if average prices are not higher, might induce farmers to invest in production technology.

## 2.3 Technology Transfer Through Vertical Coordination in Value Chains

### *2.3.1 Technology Market Imperfections and Contracting*

Many farmers in developing and emerging countries face technology and credit market imperfections, making it difficult and expensive for them to buy the technology (Croppenstedt, Demeke, and Meschi 2003; Feder, Just, and Zilberman 1985; Morris 2007; Rozelle and Swinnen 2004). The buyer may have better access to the modern technology than the farmer when the buyer has less credit and liquidity constraints; or lower transaction costs due to economies of scale; or lower information asymmetries if the buyer has better knowledge of consumer preferences. The buyer can then offer the farmer a contract, which includes the transfer of technology and conditions for purchasing the product (time, amount and price). We refer to the buyer's opportunity cost of the technology transfer as $\tau < \tau^f$. This opportunity cost will depend on the cost of transfer, as well as on the buyer's potential return to alternative investments (including alternative sourcing contracts). This means that in the absence of a contract, the buyer's "disagreement payoff" is equal to $\tau$. For simplicity, we assume the farmer's "disagreement payoff" is equal to $l = p_L q_L$. [10] The buyer's and farmer's participation constraints are then defined as $\Pi^B \geq \tau$ and $\Pi^f \geq l$, with $\Pi^B$ and $\Pi^f$ denoting the buyer's and farmer's contract payoff, respectively. The total (net) surplus created by the technology transfer and the contract is $S = V - l - \tau$.

The division of the contract surplus can be modeled as a Nash bargaining problem, where each party receives his or her disagreement payoff and a share of the contract surplus (see Swinnen and Vandeplas (2011) for more details). We denote the share that accrues to the farmer as $\beta$, with $0 \leq \beta \leq 1$. To start, we assume that this sharing rule $\beta$ is determined through ex-ante bargaining.[11] Later we explain how the division of surplus depends on contract enforcement and holdup opportunities.

Consider first, as a benchmark, the case that contracts are always perfectly enforced. In this case, given the disagreement payoffs of both parties, the contract payoffs are

$$\Pi^{f^*} = l + \beta S = l + \beta(V - l - \tau) \tag{2}$$

$$\Pi^{B^*} = \tau + (1 - \beta)S = \tau + (1 - \beta)(V - l - \tau) \tag{3}$$

where superscript $^*$ denotes the payoffs with perfect enforcement. Under these assumptions, the technology transfer will take place if the net surplus is positive, i.e. if

$$V \geq \tau + l \tag{4}$$

The value created ($V$) should be larger than the opportunity costs of labor ($l$) and of transferring the technology ($\tau$). This result is illustrated in panel (b) of Figure 2. Technology transfer is more likely if the effect on the value of the farmer's product ($p_H - p_L$) or on the production efficiency ($q_H - q_L$) is higher, if the buyer's opportunity cost of transferring the technology $\tau$ is lower, and if the opportunity costs of labor $l$ are lower.

[10] Implying that technology adoption against a price of technology $\tau^f$ is not profitable and the farmer keeps using the "basic technology" when not involved in the contract. This applies to the domain where $V < (\tau^f + l)/\theta$ in Figure 2.

[11] Note that there is an obvious positive relationship between $\theta$, the share of the consumer price received by the farmer, and $\beta$, the share of the contract surplus that accrues to the farmer.

The provision of finance and inputs by traders is extensively discussed in the interlinked contract literature, focusing mostly on traditional markets (e.g. Hoff and Stiglitz 1990; Smith, Stockbridge, and Lohano 1999). However, also in the context of modern value chains there is substantial evidence of processors and traders providing finance and technology to farmers (e.g. Gulati et al 2007; Sadler 2006). Bellemare (2012) finds that processing companies in Madagascar (e.g. in cotton, vegetables, rice and barley) provide farmers with improved seeds, pesticides, and fertilizer. Dries et al. (2009) document how East European dairy processors develop programs to stimulate farm-level technology investments by offering credit programs, investment loans, and bank loan guarantees to their suppliers, stimulating dairy-specific investments such as improved livestock and cooling equipment.

In addition to the provision of technological inputs and finance, studies document that buyers stimulate adoption of new technologies by farmers in less tangible ways, for instance through training (e.g. World Bank 2005; Negash and Swinnen 2013; Minten, Randrianarison, and Swinnen 2009). Recent studies indicate the potential for vertical coordination to stimulate technology adoption indirectly through e.g. agricultural insurance. Casaburi and Willis (2015) using a randomized control trial among Kenyan dairy farmers, show that the take up of agricultural insurance as part of an interlinked contract (whereby the insurance premium is deducted from the payment at product delivery) is significantly higher than the take up of a stand-alone insurance which requires an upfront payment of the premium. A broad survey from Ghana, Mozambique, Kenya and Vietnam by Farole and Winkler (2014) shows that all interviewed foreign-owned agricultural investors provide some type of technologies to local farmers (including assistance around quality and health, safety and environmental issues).

Studies find that technology transfer is higher in high standard value chains. Schipmann and Qaim (2011) find that technology provision by traders in the Thai sweet pepper sector is more common for farmers participating in the modern retail sector, than for farmers selling on the traditional market. Rao, Brümmer, and Qaim (2012) show that Kenyan vegetable farmers supplying to the supermarket channel tend to use more fertilizer, seeds and manure per acre.

### *2.3.2 Contract Enforcement and Technology Transfer*

The transfer of the technology through contract farming is conditional on the enforcement of the contract. In developing and emerging countries, contracts such as the one described here may be formal or informal. In either case, contract enforcement is nontrivial. With imperfect contract enforcement, contracting and technology transfer might not occur.

Contract breach can take many forms. In the setting considered here, we can distinguish three potential types of holdup that might occur in case of imperfect contract enforcement. First, the farmer could decide to divert the technology provided by the buyer by selling it or using it for different purposes. Secondly, the farmer could default on the contract by selling the product to an alternative buyer, after applying the transferred technology. Such "side-selling" can be profitable as the alternative buyer does not have to account for the cost of the provided technology. Finally, the buyer could hold up the farmer by renegotiating the contract upon delivery if the product produced with the advanced technology is worth more to him than to any other buyer. Instead of paying the agreed contract price, the buyer can pay the farmer the value of his best alternative at that point.

*Farmer Holdup*

Here we focus on farmer holdup through technology diversion and buyer holdup through contract renegotiation, ignoring the possibility of side-selling, to simplify the analysis.[12] If the farmer diverts the technology, we assume the benefit equals the cost of the technology for the buyer $\tau$.[13] In addition, the farmer can still realize his opportunity cost of labor $l$. By violating his contract, the farmer suffers a reputation cost $\phi \geq 0$. These reputation costs can include, for example, the loss of future trading opportunities. Hence, with technology diversion, the farmer's payoff is $\Pi_d^f = l + \tau - \phi$ and the buyer's payoff is $\Pi_d^B = 0$.[14]

In case there is no external contract enforcement (beyond what is captured in the reputation costs) the partners can try to design the contract to be "self-enforcing" to avoid holdups and make the technology transfer work. For the contract to be self-enforcing, the farmer's contract payoff must at least equal his holdup payoff $\Pi_d^f$, while the buyer's payoff must at least equal his disagreement payoff $\tau$. In other words, the technology transfer contract should satisfy the farmer's incentive compatibility constraint ($\Pi^f \geq \Pi_d^f = l + \tau - \phi$) and the buyer's participation constraint ($\Pi^B \geq \tau$). Combining these, the value generated by the transfer should satisfy the following condition for the contract to be feasible:

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[12] Although side-selling by farmers potentially affects the occurrence of technology transfer in a slightly different way than technology diversion, it is conceptually similar. We have not included this to reduce the complexity of the analysis. The extended analysis for side-selling can be obtained from the authors.

[13] We relax this assumption in the section where we look at different types of technologies.

[14] Note that in our model $\tau$ and $l$ are "sunk" costs, which is why they do not directly show up in the buyer and farmer's payoffs. These costs will be reflected in the buyer and farmer's participation constraints.

$$V \geq l + 2\tau - \phi \tag{5}$$

in addition to the condition $V \geq l + \tau$, determined earlier (Equation 4). This implies that technology transfer in value chains is possible when

$$V \geq V^{min} = \max\{l + \tau;\ l + 2\tau - \phi\} \tag{6}$$

If $V$ is sufficiently high, it is possible to adjust the contract terms to satisfy the farmer's incentive compatibility constraint without violating the buyer's participation constraint, making the contract, in principle, feasible. A low $V$, however, might be insufficient to pay the farmer at least his holdup payoff and prevent contract breach. In this case, a self-enforcing contract will not be possible. Obviously, holdup is only profitable for the farmer if the benefit of diverting the technology is bigger than his reputation cost, i.e. if $\tau > \phi$. If $\tau \leq \phi$, the farmer has no incentive to hold up the buyer and the "efficiency" condition (Equation 4) remains binding. These results are illustrated in panel (c) of Figure 2.

*Buyer Holdup*

The buyer may refuse to pay the farmer the agreed share of the value at product delivery and, instead, offer to pay only as much as the farmer's best alternative at that moment $V_s$ (e.g. the value of the produce when sold on the local market). Doing this will result in a reputation cost $\omega \geq 0$ for the buyer. In this case, the contract payoffs become $\Pi_r^B = V - V_s - \omega$ for the buyer and $\Pi_r^f = V_s$ for the farmer. For a self-enforcing contract to be feasible, it should satisfy both the farmer's participation constraint ($\Pi^f \geq l$) and the buyer's incentive compatibility constraint ($\Pi^B \geq \Pi_r^B = V - V_s - \omega$). Combining these implies the following condition for which technology transfer remains feasible under the threat of buyer holdup:

$$l \leq V_s + \omega \tag{7}$$

in addition to the condition $V \geq l + \tau$, determined earlier. This result implies that the effect of buyer holdup on the feasibility of the transfer does not necessarily depend on the value generated by the technology $V$. It does depend on the reputation costs of the buyer ($\omega$) and the alternatives for the farmer ($V_s$). The latter may be a function of the value $V$ or not, depending on the high value market structure and local demand (see the section on types of technology).

Since the buyer's reputation cost $\omega$ is non-negative, $V_s \geq l$ is a sufficient condition for the farmer to agree with this contract. This is the case when the farmer is able to sell the "high-tech" product for at least the value of the "low-tech" equivalent to others than the buyer (e.g. on the local spot-market). In summary, technology transfer through value chain contracting is more likely when the value generated by the technology ($V$), the farmer's best alternative to the buyer's offer ($V_S$), and reputation costs ($\phi$ and $\omega$) are higher, and when the farmer's and buyer's opportunity costs ($l$ and $\tau$) are lower.

Imperfect contract enforcement and holdup problems are widespread in agrifood value chains in developing and emerging countries (e.g. Cungu et al. 2008; Barrett et al. 2012; Saenger, Torero, and Qaim 2014). Studies on the transition processes in the 1990s document extensive value chain breakdown following holdup problems in agrifood chains, as contract enforcement was difficult in these circumstances (Gow and Swinnen 1998; 2001; Swinnen and Rozelle 2006). There is also a substantial literature on the difficulties of enforcement of outgrower schemes in developing countries (see Swinnen and Maertens 2007; Swinnen, Vandeplas, and Maertens 2010 for reviews).

An indicator of the serious problems caused by farmer holdup are the measures taken by buyers to prevent it. Minten, Randrianarison, and Swinnen (2009), for example, document extensive investments in monitoring systems to counter opportunistic behavior of farmers who received technological inputs and technical assistance. Schipmann and Qaim (2011) report that 23% of the farm contracts in their case study in Thailand include agreements about side-selling.

## 2.4 Distribution of the Benefits of Technology Adoption with Imperfect Contract Enforcement

So far we have referred to $\beta$ as the sharing rule, which identifies the distribution of the surplus created by technology adoption between buyer and farmer, and which we assumed is the outcome of a (not modeled) bargaining game between buyer and farmer. However, $\beta$ is only a correct indicator of how the surplus created by the technology transfer will be distributed between the buyer and the farmer under perfect contract enforcement. Under imperfect enforcement, each party can gain "bargaining power" (i.e. claim a larger part of the surplus), if it can make a legitimate threat to hold up the other party. Under imperfect contract enforcement, we define $\hat{\beta}$ as the "imperfect enforcement sharing rule" where

$$\hat{\beta} = \frac{\pi^f - l}{S} \tag{8}$$

with $\pi^f$ the effective contract pay-off for the farmer and $l$ his opportunity costs.

Figure 3 illustrates how the distribution of the technology adoption surplus changes with the value of the technology and the holdup opportunities when farmer holdup occurs at relatively low values of the transferred technology $V$ and when buyer holdup occurs at relatively high values of $V$ (a situation which is consistent with the analysis in the previous section). The upper panel of Figure 3 shows the actual distribution of the surplus with $S$ the total surplus, $\beta S$ the farmer's surplus under perfect contract enforcement, and $\hat{\beta}S$ the farmer's surplus under imperfect enforcement. The buyer's surplus is the vertical distance between the lines representing the total surplus and the farmer's surplus. The lower panel illustrates how $\beta$ is constant for all levels of $V$, while $\hat{\beta}$ changes with $V$.

If we move from left to right in the graph, increasing the value $V$, we pass through several "value regions". In domain A, the value of the technology is too low to overcome the buyer and farmer's combined opportunity costs and it is thus socially not efficient to adopt. In domain B, the value $V$ is large enough for technology transfer to be socially efficient but is insufficient to make the contract self-enforcing and avoid farmer holdup. As demonstrated in the previous section, technology transfer is infeasible if $V < l + 2\tau - \phi$. Beyond this level of $V$ (domain C), the efficiency gain of transferring the technology is large enough to make the contract self-enforcing. In this case, the buyer is willing to offer — what Swinnen and Vandeplas (2011) have termed — an "efficiency premium" to the farmer on top of the perfect enforcement payoff to avoid technology diversion.

At the point where $V = l + 2\tau - \phi$ the entire surplus $S$ is needed to compensate the farmer not to divert the technology. Hence, at this point the entire surplus goes to the farmer ($\pi^f - l = S$) to make the contract self-enforcing. The holdup possibility of the farmer increases his effective bargaining power to the maximum level ($\hat{\beta} = 1$). This theoretical result can explain sometimes significant benefits for smallholder farmers from participating in these value chains despite strong concentration at the buyer level.

As $V$ increases beyond that point, more surplus is created and more surplus is left for the buyer. The farmer's surplus ($\hat{\beta}S$) remains constant since it is determined by the (fixed) level of holdup opportunities. Hence, $\hat{\beta}$ declines with increasing $V$ but $\hat{\beta} > \beta$. More specifically, in domain C farmer holdup remains binding, with $\hat{\beta} = \frac{\tau-\varphi}{V-l-\tau} > \beta$. In domain D neither farmer nor buyer holdup is opportune, such that the perfect enforcement outcome prevails and $\hat{\beta} = \beta$.

In domain E, the value of technology adoption is highest and there will be buyer holdup unless the contract compensates the buyer sufficiently. With buyer holdup binding, $\hat{\beta} = \frac{V_s+\omega-l}{V-l-\tau} < \beta$. The benefits of technology adoption for the farmer, $\hat{\beta}S$, do not further increase with increasing $V$ in domain E, as is illustrated in Figure 3. Buyer holdup potentials impose a maximum surplus for the farmer.

Figure 4 further illustrates when buyer holdup becomes binding for the case that $V_s = l$. Combining the definitions of $S$ and $\Pi_r^B$, it follows that the net benefits of the holdup for the buyer are

$$\Pi_r^B - \tau = S - \omega \quad (9)$$

A value $V_r$ is the net benefits of buyer holdup (represented by the $S - \omega$ line) equal the buyer's share of the surplus $(1-\beta)S$. This occurs at the surplus level $S_r$ for which $S_r - \omega = (1-\beta)S$, which implies that $S_r = \frac{\omega}{\beta}$ and $V_r = l + \tau + \frac{\omega}{\beta}$. It also implies that the maximum net surplus for the farmer $\hat{\beta}S$ equals $\omega$ (and $\hat{\beta} = \frac{\omega}{S}$) over domain E. Hence, the buyer's reputation costs not only affect when holdup will occur, but also the benefits for the farmer from a self-enforcing technology contract.

Finally, an important implication of this analysis is that a simple look at the market structure may give a biased indication of the potential distribution of the benefits of technology transfer through value chains. Our results imply that in a context of imperfect contract enforcement, if the farmer has little market power (represented by a low $\beta$), he or she might still be able to capture a significant share of the surplus of the technology transfer if the farmer's holdup opportunities create incentives for the buyer to pay him an efficiency premium as part of the contract (represented by $\hat{\beta} > \beta$ in domain C).

## 2.5 Types of Technology and Value Chain Governance

### *2.5.1 Types of Technology and Contract Enforcement*

So far we have not been very specific in our use of the term "technology". Technology can capture a variety of factors which affect quality or productivity, including (improved) seeds, fertilizer, knowledge, or specific investments, such as cooling equipment in dairy or irrigation in vegetable production. While all these "technologies" have some common features which makes that they can be modeled like we did so far, they also differ in important aspects.

One aspect is the time dimension of the technology transfer. Some technologies need to be provided every production period, such as seeds, fertilizer, pesticides, and packaging. They are recurring every year and their benefits are realized in the contract year. Other technologies affect the production process beyond the current period, such as knowledge or training, equipment, or investments in traceability systems. These technologies provide long term effects, beyond what is realized in one production cycle. These differences will affect the time dynamics of value that is created and possibly contract enforcement and feasibility. It is likely that the transfer of technologies with short term value effects is easier than that of technologies that have longer term benefits, because the benefits are more likely to be captured in the contract period.[15]

Another important aspect relates to how specific the technology is for the transaction between buyer and farmer.[16] "Technology specificity" has two components in our value chain and contracting framework. One component is what the (ex-ante) value of technology is when the farmer diverts the technology. So far we have assumed this value is $\tau$. However this value will depend on the specificity of the technology and the local technology market imperfections. Define $\tau^d$ as the value that the farmer receives when diverting the technology. Then $\alpha = \frac{\tau^d}{\tau}$ is an indicator of the ex-ante specificity of technology, with $\alpha = 0$ for fully specific technology without a value when diverted.[17] Examples of highly specific technologies ($\alpha$ low) are product packaging and traceability systems that are customized to the specific needs of the buyer. An example of a generic (non-specific) technology is general-purpose fertilizer, which is valuable to other farmers (when diverted).

The second component relates to the alternative value of the product after production with the technology has taken place, which is represented by $V_S$. Define then the level of ex-post "technology specificity" as $\gamma = \frac{V_S}{V}$. This definition implies that the transferred technology is fully specific to the transaction ($\gamma = 0$) if it has no value to others ($V_S = 0$). An example of low $V_S$ and low $\gamma$ is when the technology is used to produce a product for which little local demand

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[8] More formally, using parameter $\sigma$ to represent the share of the gross surplus that is obtained in the contract period, the net surplus of technology adoption is $S = \sigma(V - l) - \tau + \frac{\mu(1-\sigma)}{1+\delta}(V - l)$ where $\mu$ represents the probability that the remaining gross surplus from the technology transfer is realized in the future (with $0 \leq \mu \leq 1$), and $\delta$ represents the discount rate. It follows that the surplus requires a larger value to be positive and grows slower with increasing value.

[9] Our concept of "technology specificity" is obviously related to "asset specificity" in the transaction cost literature (e.g. Williamson 1985). See also next section.

[10] The benefit of technology diversion $\tau^d$ may be higher than $\tau$, depending on the nature of the market imperfections (or cost advantage of the buyer) in the technology market. If the difference between $\tau$ and $\tau^f$ (the price that a farmer has to pay for the technology) is due to lower interest rates and potential buyers of the technology (e.g. other farmers) are also credit constrained, then the benefit will be $\tau$ (since other farmers also have to borrow at high interest rates to buy the technology). If the difference is due to e.g. lower transport costs, then the benefit will be $\tau^f$ (since other farmers in the village can now buy it locally).

exists. This can be the case when the "high-tech" crop is exotic or for processing purposes only. For example, Glover and Kusterer (1990) explain that when broccoli and cauliflower were introduced in Guatemala as export crops, no local variety was produced, traded or consumed. Even if the "high tech" crop has a local variant, it still might have certain features not in line with local preferences, which might result in a low local value. Note that technology specificity not only depends on local demand but also on competition in the high value product market. For example, if the buyer has a monopoly, $V_s$ and $\gamma$ are likely lower, while if there are other companies who want to purchase the high value product, $V_s$ and $\gamma$ are higher.

The (total) technology specificity is therefore captured by ($\alpha$, $\gamma$). The two specificity indicators $\alpha$ and $\gamma$ are obviously correlated in some cases but not always. For example, general purpose fertilizer is not very specific ex-ante ($\alpha$ high) but may be very specific ex-post ($\gamma$ low) when there is no alternative buyer of the product produced with the fertilizer.

The specificity of the technology affects the holdup opportunities of both the farmer and the buyer, and therefore the feasibility of a self-enforcing contract with technology transfer. First consider farmer holdup. The farmer's benefit of diverting the technology is $\alpha\tau$. The payoffs in case of technology diversion are therefore $\Pi_d^f = l + \alpha\tau - \phi$, for the farmer and $\Pi_d^B = 0$, for the buyer. As before, for the contract to be self-enforcing under the threat of farmer holdup, it must satisfy the farmer's incentive compatibility constraint ($\Pi^f \geq \Pi_d^f$) and the buyer's participation constraint ($\Pi^B \geq \tau$). Combining these, the condition for which technology transfer is feasible under the threat of farmer holdup becomes $V \geq \Pi_d^f + \tau$, or

$$V \geq l + (1+\alpha)\tau - \phi \qquad (10)$$

Hence, contracting is easier with higher ex-ante specificity of the technology ($\alpha$ lower) as it reduces the benefit of technology diversion for the farmer.

Now consider buyer holdup. If the buyer renegotiates the contract at product delivery he has to pay the farmer as much as his best alternative at that moment $V_s$. With buyer holdup, the farmer's payoff is $\Pi_r^f = \gamma V$ and buyer's payoff $\Pi_r^B = V - \gamma V - \omega = (1-\gamma)V - \omega$. For a self-enforcing contract, the condition for which technology transfer remains feasible under the threat of buyer holdup is

$$l \leq \omega + \gamma V \qquad (11)$$

Contract feasibility is decreasing in the ex-post specificity of the technology ($\gamma$ lower), because it reduces the alternative options of the farmer and therefore increases the buyer's incentive to renegotiate the contract at product delivery.

In summary, the ex-ante technology specificity will increase contract feasibility through reducing farmer holdup, while ex-post specificity decreases contract feasibility through increasing buyer holdup. In the transaction cost literature it is typically argued that increasing asset specificity leads to greater holdup opportunities and lower contracting feasibility (Williamson 1985). Our results show that in the case of interlinked contracting with technology transfer this relationship is more complex. This is because the transfer implies that, instead of the farmer being required to invest in relationship-specific technology, it is the buyer who (pre-) finances the transferred technology. This allows the farmer to hold up the buyer. However, as the specificity of the technology increases, the farmer's benefit of diverting the technology decreases, making contracting more viable. At the same time, higher ex post specificity makes holdup by the buyer more likely.

The technology type thus influences the extent to which technologies can be transferred through value chains. Some technologies (longer term investments, low ex-ante specificity, high ex-post specificity) are more difficult to transfer through value chains than others (short term, high ex-ante specificity, low ex-post specificity). That said, empirical studies show that in some cases technologies which are harder to transfer (such as cooling equipment in dairy, greenhouses and irrigation in horticulture and cotton) have been transferred through value chains (see below). It appears that this required specific value chain governance structures to make it work – making the governance of the value chain endogenous to the type of technology and the nature of the contract enforcement problems.

### *2.5.2 Value Chain Governance*

Understanding what determines the type of governance of economic exchange and value chains has been the subject of a large literature going back to the original writings of Coase (1937) and including e.g. Gereffi, Humphrey, and Sturgeon (2005), Klein, Crawford, and Alchian (1978) and Williamson (1979; 1991). A review of this literature is beyond the scope of this chapter, but it is well known that specificity of technology and assets influences the choice of governance systems (Williamson 1985).

Contracting, as an institutional solution for technology transfer in value chains in the presence of imperfect technology markets, is typically categorized as a "hybrid" form of governance on a spectrum between spot markets and vertical integration (Williamson 1991). However, within the hybrid governance form, there can be much variation. The specific design of the contract can help to avoid holdup and align incentives by re-distributing the contract surplus, depending on the extent of external enforcement and the type of technology. Sophisticated institutional designs may be required to make contracts feasible and transfer technology. Swinnen and Kuijpers (2016) discuss a variety of (hybrid) institutional innovations that have been observed in agri-food value chains to enable technology transfers. These include triangular structures and special purpose vehicles involving processing companies (buyers), financial institutions, technology providers, etc. Including other companies that also benefit from the technology transfer in the contract can enhance contract feasibility by spreading the risk and costs of contract breach, and by enhancing the enforcement capacity through lower information asymmetries and higher reputation costs.

However, it may be that in the absence of external enforcement, for some of the technologies, especially those with long term effects and high ex post specificity, self-enforcing contracts will not work and technology transfer may require vertical integration, whereby two successive stages within the value chain (e.g. agricultural production and processing) are brought together under common ownership and management. Technology transfer within a vertically integrated company avoids holdup problems but may lead to other types of inefficiencies (Klein, Crawford, and Alchian 1978, Williamson, 1985).

Empirical studies show that technology requirements in modern high value chains (as well as the need to economize on transaction costs) has resulted in a remarkable heterogeneity in value chain governance, including a significant amount of vertically integrated production systems, but also various forms of smallholder contracting (see e.g. Beghin, Maertens, and Swinnen 2015; Maertens and Swinnen 2009, 2014; Reardon et al. 2009). The designs of the contracts vary considerably, going from (short run) provision of fertilizer and technical advice to complex (longer run) schemes that provide interlinked bank loan guarantees and investment loans for significant on-farm investments involving processors, financial institutions and technology companies (e.g. Dries et al 2009; Swinnen and Kuijpers 2016). Others show how greenhouses and irrigation infrastructure investments have resulted from vertically integrated value chains (e.g. Maertens, Colen, and Swinnen 2011). The most extreme versions of technology transfer through vertical integration are probably the emergence of huge agro-holdings in countries such as Russia and Kazakhstan (Serova, 2007). While many studies provide case study evidence, there is room for better comparative research to try to understand the interactions between the nature of the technology, the economic environment, the macro-institutional conditions (influencing contract enforcement) and technology transfer and adoption through value chains.

## 2.6 Conclusions

In this chapter we analyze the role that value chains can play in technological change and technology adoption in agriculture. Technology transfer through value chains might be a profitable way for buyers to source (high quality) produce in an environment characterized by imperfect credit and technology markets. The feasibility of the transfer depends on a range of factors, including the surplus generated by the technology, agents' opportunity costs, different forms of holdups and contract enforcement institutions. Imperfect contract enforcement and the holdup opportunities in the chain negatively affect the feasibility of the transfer, but redistribution of surplus under self-enforcing contracts may allow contracting and technology transfer to be feasible. Contract feasibility and technology transfer also depend on the type of technology, including the dynamic distribution of the value that it creates and the specificity of the technology to the buyer-farmer transaction. The type of technology and the holdup opportunities may themselves influence the governance structure of the value chain, which is consistent with empirical observations on a wide variety of contract designs — and institutional organizations more general. Those technologies for which contract enforcement is more problematic (such as long term investments with high ex-post and low ex-ante specificity) may only emerge when a minimum level of external enforcement is available or as part of fully vertically integrated (parts of) value chains.

The contract structure to make self-enforcing contracts work can have major implications for the distribution of surplus generated by the technology transfer and thus equity relationships in the value chain. The distribution will be influenced by holdup opportunities of each party. This may explain empirical observations of significant benefits for smallholder farmers despite strong concentration at the buyer level.

Our theoretical results and hypotheses are generally in line with insights from a growing empirical literature on value chains and their effects in developing and emerging countries. Empirical studies indicate that the technology requirements in high value chains has resulted in a remarkable heterogeneity in value chain governance, from vertically integrated production systems to various forms of smallholder contracting. The designs of the contracts vary considerably, going from (short run) provision of fertilizer and technical advice to complex (longer run) schemes that provide interlinked bank loan guarantees and investment loans for significant on-farm investments involving processors, financial institutions and technology companies.

There is room for better comparative research to understand the interactions between the nature of the technology, the economic environment, the macro-institutional conditions (influencing contract enforcement) and technology transfer and adoption through value chains, and for more evidence on the distribution of the surplus generated by such technology transfer. In addition, whereas our model is static, future research could model the relationships in the value chains more dynamically. This would allow for more explicit modelling of variables such as reputation costs, trust, and the time dimension of technology.

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## 2.8 Figures

**Figure 1: Schematic overview of an agrifood value chain and potential flows between actors.**

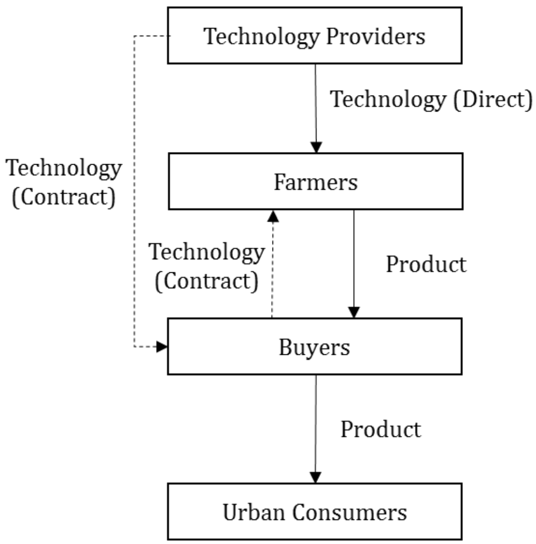


**Figure 2: Technology adoption under three scenarios: (a) direct purchase, (b) technology transfer through value chain contracting and perfect enforcement, and (c) technology transfer through value chain contracting and imperfect enforcement.**

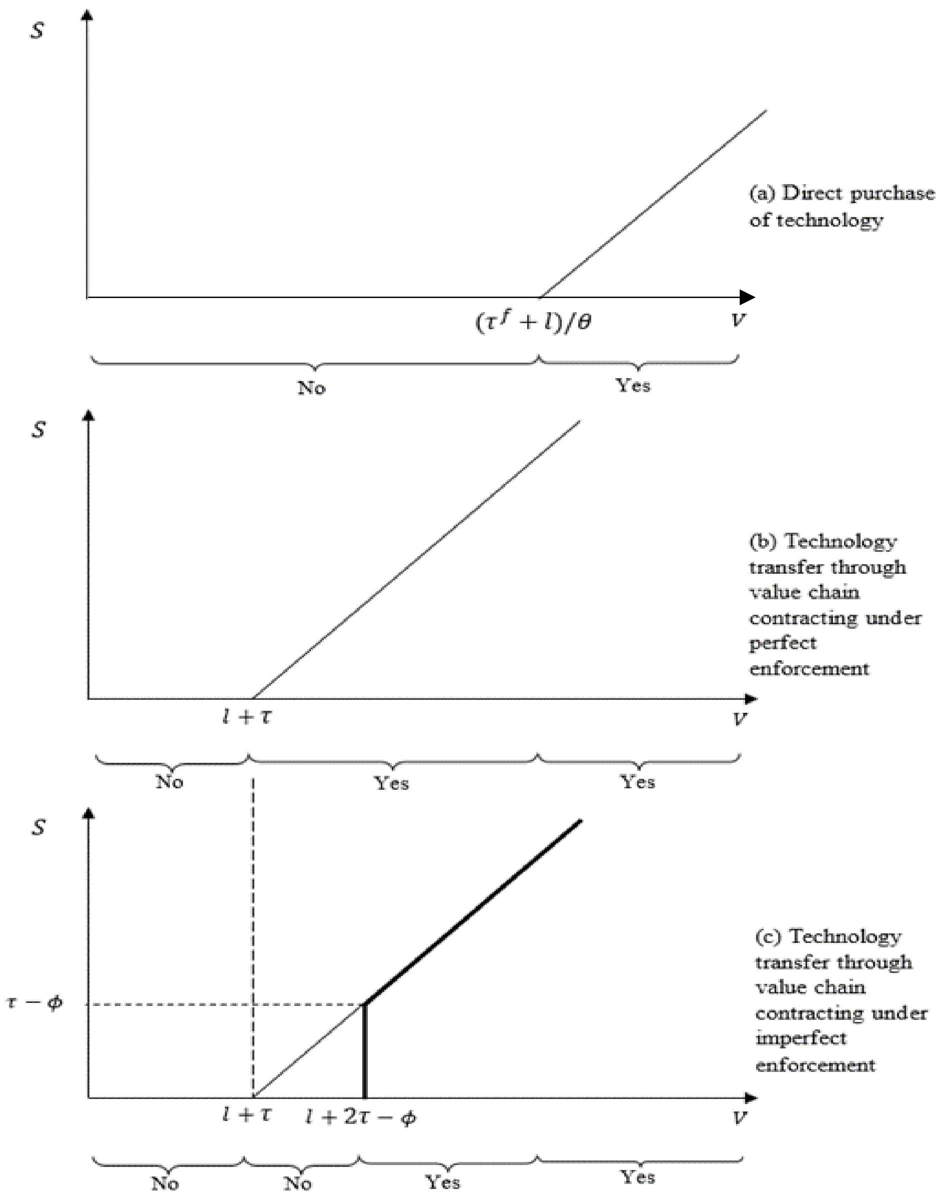


**Figure 3: Distribution of surplus and sharing rules as a function of the value of the technology $V$ and holdup opportunities (with $V_s = l$).**

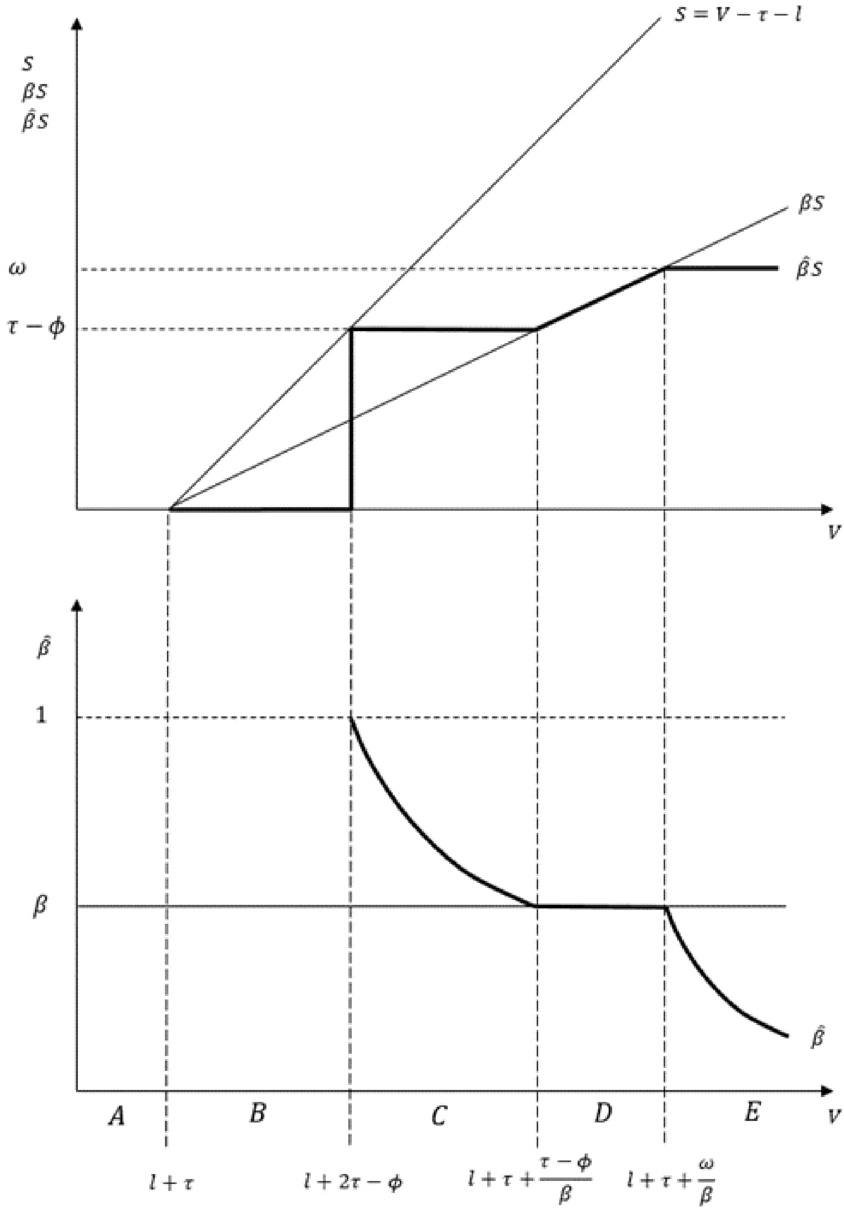
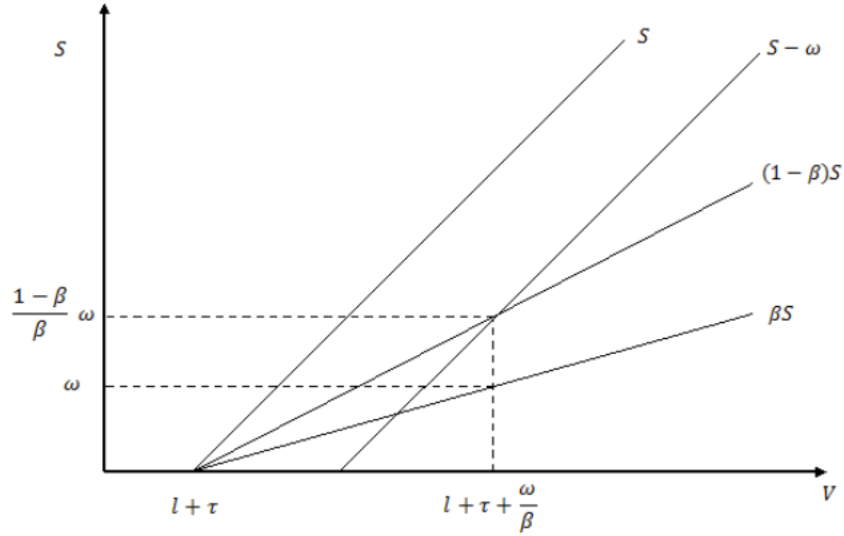


**Figure 4: Buyer holdup and the distribution of surplus (with $V_s$**



# Chapter 3. Value Chain Innovations for Technology Transfer in Developing and Emerging Economies: Conceptual Issues, Typology, and Policy Implications*

## 3.1 Introduction

Increasing the productivity of agriculture in developing and emerging countries requires greater use of modern farm inputs (improved seeds, fertilizer, irrigation, mechanization) and better access to markets by farmers (Barrett et al. 2017). Modern value chains can play an important role in achieving these objectives. Modern value chains, in contrast to traditional value chains, are characterized by more stringent standards (i.e. product and process requirements) and by the use of modern technologies and innovations in the value chain to comply with these standards (Swinnen and Kuijpers 2019).

In the past decades agri-food value chains have rapidly modernized. Income growth and urbanization increased the demand for higher quality agri-food products. Food safety and quality aspect such as freshness, convenience, diversity, branding, and the sustainability of the production process have become increasingly important. Privatization and economic liberalization have at the same time stimulated domestic and foreign direct investment in wholesaling, processing, and retailing and an increase in trade of high value agricultural products (Reardon et al. 2009). As a result, "rich country standards" are increasingly imposed on "poor country producers" (Henson and Reardon, 2005; Jaffee and Henson, 2004).

Compliance with stringent product or process standards typically requires investments in new technologies by farmers. Many studies have pointed at the challenges for small and poor farmers to satisfy these new requirements and at the risk of further marginalization. In this chapter we argue that these standards

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and required investments may also stimulate innovation, technology transfer, and thus inclusion for these farmers. With imperfect (or non-existing) technology markets, various forms of value chain innovations have been introduced by up- and downstream companies to overcome the technology constraints experienced by farmers. Value chain innovations include various forms of vertical coordination, one of them being smallholder contracting with interlinked technology transfer.

The contribution of our chapter is in the first place empirical by documenting various types of technology transfer through value chain innovations in developing and emerging countries and relating them to conceptual models.[18] To our knowledge this is the first article to systematically document these forms of technology transfer to agriculture and to provide a typology of the different value chain innovations. In addition, in the second part of the chapter we relate these different types of institutional innovations to several factors, such as tightening safety and quality standards, market imperfections, the value in the chain, and the nature of the technology investment (i.e. long versus short term and contract specificity). Finally, in the concluding section we draw on the combined empirical and conceptual insights to draw implications for policy.

This chapter is related to a large theoretical and empirical literature on industrial organization and technology adoption in various fields of economics and management science. This includes seminal contributions on how companies and supply chains are organized to overcome transactions costs and technology constraints (e.g. Economides 1996; Gereffi et al. 2005; Klein et al. 1978; Milgrom and Roberts 1990; Williamson 1985) and to create a competitive advantage (e.g. Barney 1991; Dyer and Singh 1998; Hart and Tirole 1990); on contracting in developing countries (e.g. Bardhan 1989; Bell and Srinavasan 1989); on technology adoption in agriculture (e.g. Feder et al. 1985; Foster and Rosenzweig 2010); on international technology diffusion and vertical productivity spillovers from foreign direct investment and trade (e.g. Havranek and Irsova 2011; Keller 2004; Martins and Yang 2009); on modern food value chains, standards and sourcing (e.g. Reardon et al. 2003; Swinnen and Maertens 2007); and on the optimality of farm structures (e.g. Allen and Leuck 1998; Pollak 1985).

The remainder of this chapter is organized as follows. The next section introduces a conceptual framework that explains under which conditions private-initiated value chain technology transfer is expected to arise. In section 3 a variety of different value chain innovations for technology transfer are discussed

[18] Throughout the chapter we use the concept of "value chain innovations" as institutional designs and models that deviate from the standard value chain structure (as illustrated in Figure 1) that have been introduced to address specific objectives.

and illustrated by empirical examples. Section 4 draws lessons from the empirical review and identifies key factors that played a role in value chain innovation for technology transfer. Section 5 concludes and draws some policy implications based on the theoretical and empirical insights, in particular, it discusses the role of governments in financing technology transfer programs.

## 3.2 Some Conceptual Issues

### *3.2.1 Technology adoption with imperfect markets*

Consider a simple value chain (Figure 1). With perfect markets, decisions to invest in technology are made independently at each stage of the chain.[19] Demand and supply for a product with certain qualities determines the price level and thereby the incentive to invest in necessary technology. For example, a change in consumer demand for higher quality food will translate into a demand for high quality farm output and an incentive to upgrade technology by the farmer—and thus technology investments if profitable.

Notice that parallel to the flow of goods and technology in the value chain there is a flow of finance (in the opposite direction). Access to finance (in the form of own liquidity or loans) at each stage of this chain is crucial as production costs and technology investments are carried in full by the individual actors. Moreover, costs of technology investment are incurred at the start of the production cycle, while payment occurs at the end, making access to capital essential to bridge this gap. This is especially the case in the agricultural sector where the duration of the production process is relatively long.

Note that next to the flow of finance there exists a flow information. Information is important as farmers may need to adjust their production practices and technology when demand, government regulations, or consumer preferences change.

It is not difficult to see why technology adoption in a value chain organized by spot-markets might not be working in the context of imperfect markets.

[19] Foster and Rosenzweig (2010) define technology as "the relationship between inputs and outputs" and the adoption of technology as "the use of new mappings between inputs and outputs, and the corresponding allocations of inputs that exploit the new mappings". In practical terms, technology adoption therefore refers to a transformation of the production process, which might result in enhanced efficiency (requiring less inputs to produce a given output) or in different product attributes (i.e. enhanced quality). This means, in practice, a firm can change its production technology by either combining its current inputs in a different way, or by applying new intermediate inputs (e.g. machinery) in the production process, with a certain technology embedded in it. A farmer for example, may change its production technology by combining his inputs (e.g. labor, land, seeds and water) in a different way, or by using a new intermediate input (e.g. high yielding seeds, chemical fertilizer, or pesticide) produced by an input supplier.

Information transmission may be incomplete, such that farmers are unaware of the requirements for their products or the precise management practices that are required. It is also well known that financial markets are often not working well in developing and emerging countries and that rural credit markets are particularly problematic (Banerjee and Duflo 2014; Bardhan and Udry 1999). Poor farmers may simply not have the financial means to make the investment out of own savings and may not get loans from banks or other lenders. As a result, credit market imperfections and financial constraints will cause technology market imperfections, and the failure to adopt technology by farms.

Another reason for the farmer not to adopt the technology is uncertainty whether the technology investment will be rewarded. This can be due to the possibility of buyer holdup at the time of delivery (Klein et al. 1978; Gow and Swinnen 2001). Examples are late payments, renegotiation of prices at product delivery, or the absence of transparent and reliable quality evaluation procedures, which could lead to inappropriately rejecting produce. There is much empirical evidence that such holdup problems are important and widespread in agri-food value chains in developing and transition countries (e.g. Barrett et al. 2012; Cungu et al. 2008; Saenger et al. 2014).

### *3.2.2 Value chain innovations to overcome technology market imperfections*

The failure to adopt the technology not only affects the farm but also all other agents in the chain. Technology companies have lower profits since they cannot sell their technology; processors do not get the raw material they need for producing consumer products; and consumers do not get the products they desire. All these agents have an incentive to make the farm adopt the technology.

Some of these agents may have better access to finance than the farms because they have more liquidity or have better access to credit, because they can draw on other commercial activities, or because they face lower transaction costs. The latter can be the case when the lead firm provides the technology to multiple suppliers (e.g. as part of an outgrower scheme) and benefits from economies of scale. Other agents in the value chain may also have better information on the required technology because they are closer to the final consumer and therefore might have better knowledge on consumer preferences (or better understanding of government regulations, domestically or abroad) and how different types of technology used by the supplier affect final demand. They may also have a better understanding of the complementarity of technologies along the chain (Milgrom and Roberts, 1990).[20]

These agents can then consider whether it is profitable to set up different types of exchange systems (rather than the spot-market model) to help or induce farms to invest in the required technology such that these agents can benefit from the functioning of the value chain with technology adoption at the farm level. One model is that of "interlinked contracting" between farm and processor. The processor provides the farm access to the technology as part of a supply contract with payment conditions. While such interlinked contracts for input provisions have been analyzed in the traditional development literature (e.g. Bardhan 1989; Bell and Srinivasan 1989)[21], in modern value chains not just basic inputs (such as fertilizer and seed) but much more sophisticated forms of technology transfer occur. Moreover, this is far from the only model. In reality we observe many different forms of value chain innovations with successful technology transfer.

A common element in the different types of value chain innovations is how to enforce technology transfer contracts. Contract enforcement problems not only hamper technological investments by the farmer in a spot market-based value chain, as explained above, but will also hamper the feasibility of technology transfer within the value chain due to potential farmer holdup. Examples of farmer holdup include side-selling of produce after application of the transferred technology, applying the technology to non-contracted products, or selling the transferred technology. Contract enforcement problems have complicated and sometimes prevented technology transfer and adoption.

As we will explain in more detail later in the chapter, the contract enforcement problems are influenced by the macro-institutional environment, the type of technologies, and the value in the chain. This implies that there is no one-size-fits-all value chain innovation for technology transfer, but instead one can expect a wide variety in contractual designs to emerge—which is what we observe. In the next section, we therefore review a series of empirical cases of

[20] Related arguments which affect technology indirectly is how a more efficient information exchange along the value chain can form the basis for a competitive advantage of the entire chain, and how more effective value chain governance can enhance the chain's capacity to respond to changing consumer demand or government regulations (Von Hippel, 1988; Williamson, 1985)

[21] Bell and Srinivasan (1989) define interlinked market transactions as a transaction in which the parties trade in at least two markets on the conditions that the terms of all trade between them are jointly determined. Interlinked market transactions always include an element of credit as they involve exchange of current for future claims. Apart from interlinked credit and output transactions, interlinked transactions also exists in land markets (landlord who provide tenants working capital) and in labor market (employers who give advances to laborers in return for a claim on their labor in peak labor demand periods).

technology transfer through value chain innovations and provide a typology to classify the various empirical cases.

## 3.3 Value Chain Innovations for Technology Transfer: Types and Examples

In this section we provide a typology of institutional innovations for technology transfer in agricultural value chains and give a series of empirical examples from various countries. All examples have in common that they are set in the context of imperfect financial and technology markets and weak contract enforcing institutions. Several of the examples come from technology transfer in the wake of the liberalization process in Eastern European and the former Soviet Union (FSU). There are two reasons for this. First, the liberalization of markets and the privatization of firms in Eastern Europe and FSU in the 1990s and 2000s created a natural experiment where suddenly existing (state-controlled) value chain systems were abandoned. In the pre-liberalization-era, the technology applied at different stages of the value chain was primarily directed by the state. The shift to a market-led economy led to new competitive pressures and created incentives for firms to improve quality and meet new consumer demand. Improving product quality in a context of failing capital and technology markets and imperfect contract enforcement meant that the private sector was forced to come up with innovative contractual solutions to upgrade the technology in the chain. This unique natural experiment provided a series of interesting case studies with rich implications.

The second reason is that the analysis of Eastern European institutional innovations for technology transfer can provide lessons and implications for developing countries. In many other parts of the world, the liberalization process led to a similar break-down of state controlled value chains (Swinnen et al. 2010). However, the Eastern European experience was different in at least two important aspects. First, per capita income at the time of the liberalization was much higher in Eastern Europe and FSU than in other areas that went through a similar liberalization process, such as Sub-Saharan Africa, and South East and East Asia. Second, Eastern Europe received a much greater influx of foreign direct investment (FDI) in the agri-food chains in the years after the economic reforms than Asia and Sub-Saharan Africa. The higher income of residents in Eastern Europe (as well as the proximity to wealthy Western Europe) increased demand for high quality food after the transition and created an incentive to upgrade the technology at farms and elsewhere in the value chain, while the influx of FDI provided the necessary finance to implement technology transfer.

We increasingly observe other—poorer—parts of the world (Sub-Sahara Africa, Asia and Latin America) entering a phase comparable to Eastern Europe and FSU in the 1990s. Increasing urbanization and consumer purchasing power, increasing FDI in agri-food companies, the rise of supermarkets, and an increase in exports of high value crops give rise to high quality and safety standards also in these areas (Henson and Reardon 2005; Reardon and Timmer 2014). Similarly as in Eastern Europe in the 1990s, complying with these standards requires significant upgrading of production, transport, and storage technology in a context of failing markets and weak governance that induces private-sector-led institutional innovations for value chain technology transfer. Hence, the insights from value chain innovations in Eastern Europe and FSU are highly relevant to understand and to inform policy makers in countries that are currently experiencing similar developments.

We organize our discussion by different types of value chain innovations and Table 1 summarizes key characteristics of the models.

*Model 1: Farm - Processor/Retailer Contracting*

Figure 2 illustrates the first model of technology transfer through value chain innovation. This is the case where the company that buys the farm's product (be it a processing, a retailing, or trading company) finances the technology as part of a contract. The contract typically specifies an obligation to comply with buyer standards and includes a transfer of technology or of credit for the technology investment linked to a purchasing agreement. Payment for these financial and technological services is generally accounted for at the time of product delivery. The technology that is provided can be rather simple such as specific seeds, fertilizer, or animal feed. However, much more complex forms of technology transfer are also observed, especially in areas where product quality becomes more important and long term investments are required. More advanced forms of contract-farming can include the provision of technological improvements through extension services, technical and managerial assistance, quality control, and specialized transport and storage services. Sometimes contracts also include loans and assistance for medium-term investments but these are more common in contracts that also involve other companies in the value chain (see Models 3 and 4).

\Studies on horticultural export chains in Africa document the provision of specific inputs (such as seeds and specific fertilizer) as well as elaborate systems of technical advice and extension services to contracted farmers (Henson et al. 2005). For example, Minten et al. (2009) show that access to technology was a major reason why poor farmers decided to sign up for the contracts with horticultural export companies. Bellemare (2012) shows it is common for exporters and processors in African cotton, rice, barley, and tobacco value chains to provide their suppliers with seeds, pesticides and fertilizer.

There are several studies on Eastern Europe and Central Asia that document complex and elaborate value chain contracting systems in the 1990s and 2000s in various sectors including sugar, dairy, barley, and cotton. Cotton gins in Kazakhstan, for example, not only provided seeds and fertilizer, but also water to the cotton farms, with water irrigation systems being a crucial technological input for farms (Sadler 2006). Dries et al (2009) summarize evidence on dairy contracting systems from various countries showing extensive technology transfer. Important components are credit, concentrated animal feed, and technical, veterinary and management advice. Dries and Swinnen (2004; 2010) show, for the case of Poland, that interlinked contracting had a major impact on technology adoption and milk quality, both for small and larger farms.

Van Berkum (2007) documents the case of Danone, the large multinational dairy company, that invested heavily in the Romanian dairy sector. Their main customers were retail chains adhering to European Union standards. Initially, the dairy sector in Romania primarily consisted of small-scale farmers (96% owned one or two cows) who used very basic production technology and produced low milk quality. In response, Danone put in place arrangements to upgrade the quality of their raw milk supply. This included pre-financing farm technological investments. The company financed suppliers purchasing high-tech inputs (including compound feed and detergents for milking equipment) and offered a range of services to their suppliers including field staff visiting suppliers and advising them on hygienic practices, cleaning, and fodder management. Later on they also introduced programs for longer term technological investments (such as field machinery, cooling equipment, and milking installations) as part of the contracts. By 2010, as a result of the program, 90% of the raw milk sourced by Danone complied with European Union standards (Bruszt and Langbein 2014).

Another interesting multi-stage example of technology transfers in value chains is the Eastern European barley-malt-brewing value chains in the 1990s, as documented by Swinnen and Van Herck (2011) and Van Herck et al. (2012). All the major international brewing companies, such as Heineken, Carlsberg, Interbrew (now ABInBev) and SABMiller invested heavily in the privatized

Eastern European malting and brewing industry[22]. All of them faced the problem of sourcing sufficient high quality barley and malt in order to produce high quality beer.[23] Enhancing the malt quality required technological upgrading of the entire value chain. For this purpose the brewing companies developed technology transfer programs, involving malting processors, barley farmers, and seed companies (see Figure 3). Assistance to farms included seed supply and selection schemes, investment assistance, and advice on post-harvest storage and treatment. These programs were successful in both improving quality and productivity. For example, a World Bank (2006) study showed that in Slovakia the yields of barley farmers supplying to Heineken were consistently higher than the average yields of barley producers.

*Model 2: Farm – Technology Company Contracting and Leasing*

Technology companies can also be initiators of technology transfer. Like food processing companies, technology companies also benefit if farms purchase the appropriate technology. To assist farms in purchasing the technology (and ensure payments), technology suppliers have engaged in a variety of contracting schemes. Institutional innovations have focused on reducing financial constraints of farms by introducing credit schemes, by assisting farms in selling their products to improve their cash flow and liquidity, and through leasing arrangements.

One common initiative is finance provision by the technology company (i.e. another form of interlinked contracting), sometimes in combination with output purchasing, as illustrated by Figure 4. Foster (1999) describes how a multinational farm equipment manufacturer partnered with local farm equipment distributors to sell combines and tractors to farms in Ukraine in the 1990s. Farmers could buy equipment from the distributor using a payment scheme. Initially they had to fulfil 25 percent down-payment (in cash or kind). After three additional payments they received full ownership. To overcome financial constraints of the farms and to ensure payment to the technology company, the equipment dealer received the rights to a certain grain area as part of the payment by the farm. In addition, the equipment dealer was given the rights to

[22] Eastern Europe was seen as an attractive destination for its beer drinking culture, relatively high incomes, and geographic as well as cultural proximity to Western Europe. Due to consumer preferences for local brands, the restrictive import tariffs in some of the countries, and the relatively high transport costs of beer, it was more opportune for these large multinationals to enter the European market through FDI, than by exporting their own international brands into the region (Swinnen and Van Herck 2011).

[23] Initially, the foreign multinationals imported malt from their traditional suppliers in Western Europe. However, afterwards they started to invest in the development of a local supply base. Besides logistical and operational reasons, this was also due to high import tariffs and exchange rate uncertainty.

harvest, transport, store, and sell the grain. Hence, while the interlinked contracting by the food processing companies in Model 1 made the food company enter the technology market (vertically coordinating in the upstream part of the value chain), here the technology company entered in buying and selling the farms' products (vertically coordinating in the downstream part of the value chain).

For longer term technology investments, such as machinery, technology companies introduced different types of contracting, such as leasing. Leasing is a specific kind of financial contracting, whereby the lessee (the farm) uses the equipment which is still owned by the lessor (the technology company) by paying a periodical fee. In essence it is an in-kind loan, whereby the equipment forms the collateral (since the lessor keeps ownership). Leasing is often used by suppliers of lumpy technological solutions, such as machinery, to "sell" technology to farms that have no access to credit or cannot come up with the necessary collateral for loans.

Other types of value chain innovations for longer term technology investments included more complex forms of contracting where technology companies were part of an institutional design involving multiple partners. We discuss these as Models 3 and 4.

*Model 3: Contracting with Multiple Agents -- Triangular Structures*

Processors and technology companies are often reluctant to provide loans to farms for significant technology investments. The reasons are obvious: while "simple" technology contracts are risky with contract enforcement problems, the risks are higher with longer term and more expensive technologies. They require substantial amounts of finance and with the increase in the size of the outstanding loans the risk of delayed re-payment or default increases too. In addition, in "simple" technology contracts the time horizon of the technology and the production process coincide (e.g. seeds and fertilizer are linked to one growing season with one harvest). This is no longer the case with longer term investments. Companies have therefore tried to share risk, finance, and monitoring by collaborating with other companies in the value chain in setting up joint programs to provide technology (or investment loans) to farmers.

We refer to institutional designs and collaborations where three agents (including the farm) are involved as triangular structures. The case illustrated by Figure 5 is where a processing company and a financial institution set up a joint program. The processing company typically offers a guarantee to the financial institution if it provides a loan to a farm that has a supplier contract with the processor. The guarantee is basically a promise by the processing company that it will assume the debt obligation of the supplier in case of default. The underwriting is for specific loans for technological upgrading related to the contract and restricted for contracting farms. Another example of a triangular structure is where the technology company participates. In this case the processor can provide a payment guarantee directly to the company that sells the technology. The logic is similar. In general, triangular structures require lower financial commitments and less risk for the company initiating the contracting. The financing (loans) is now (at least partially) covered by other companies. Guarantees to financial institutions may also reduce the interest rate for the farmer, as the guarantee lowers the risk for the financial institution.

Guarantee programs within triangular contracting structures were implemented, for example, by sugar processors in Slovakia (Gow et al. 2000), by retailers in Croatia for fruit and vegetable supplier investments in greenhouses and irrigation (Dries et al. 2004), by pineapple processors in Ghana (Kolavalli et al. 2015), and by dairy processors in several East European countries (Dries et al. 2009). We will briefly discuss two of these examples in greater detail as they have been well document and because their effects were quite dramatic.

The first case is Gow et al.'s (2000) analysis of value chain innovations in the sugar sector in Slovakia in the 1990s. They document how foreign investors in Slovakian sugar processors introduced several institutional innovations aimed at stimulating technological upgrading by their sugar beet suppliers. As a result of decades of socialist rule and the disruptions caused by the economic transition, productivity and product quality were low throughout the value chain and falling even further. After upgrading the sugar processing plants, these investors set up a triangular contractual arrangement between themselves, the farms that produced sugar beets, and a select group of companies providing technological inputs, such as seeds, chemicals, and fertilizer. The processing company (Juhocukor) negotiated prices with these input companies and guaranteed payment of the purchases. For longer term technological investments (such as for machinery) they set up a similar triangular structure, but instead of including the technology company, they included a financial institution (Polnobanka) through which the sugar beet farms could get loans to finance these investments. Juhocukor provided Polnobanka with a guarantee for the repayment of the loan and subsidized the interest rate.

Gow et al. (2000) emphasize that the guarantee provided by the processor served two purposes. First, it reduced the risk for the technology companies and the bank to supply technology and credit to the farms. Second, it also signaled to farms that the processor was committed to the contracts and planned to honor them—otherwise it would hurt itself. This second element was important in an environment where contract breach and delayed payment by sugar processors were widespread, causing financial strains on the farms and making them reluctant to contract and invest.[24]

This package of contractual innovations[25] was highly successful. Not only did Juhocukor provide sugar beet suppliers with improved access to advanced technologies, but by investing themselves in the triangular structure with their farms they reduced the farms' risk of investment. The result was (a) a substantial increase in beet yields (tons/hectare), (b) a significant improvement of quality (sugar content) on the farms they contracted with, and (c) a growth of the supply base as other farms wanted to contract with them.

Similar triangular structures were introduced in the dairy sector in Eastern Europe in the 1990s and 2000s. Dries and Swinnen (2004; 2010) show that triangular contracting schemes between processors, farms, and banks in the Polish dairy sector led to a significant increase in the use of improved technology, including (higher quality) dairy cows and on-farm cooling equipment. As a result, milk quality and dairy productivity increased strongly throughout the sector.

Interestingly, these value chain innovations not only induced vertical technology transfer but also horizontal technology spillovers. Gow et al (2000) document how contracting systems that were successful in stimulating farm technology upgrading forced other processing companies to offer similar contractual arrangements to attract farms to supply to them. Interestingly, this contractual convergence and subsequent wave of technological upgrading was not confined to a specific sector (in this case sugar). Other sectors that competed for the same resources (land and farms) started to offer similar contracts. Another interesting institutional spillover worth mentioning is that the financial institution that was involved later standardized and extended the successful contractual model into a range of financial instruments offered to the entire agricultural sector.

*Model 4: Contracting with Multiple Agents -- Special Purpose Vehicles*

An extended form of value chain technology transfer through contracting with multiple agents is the use of so-called "special purpose vehicles" (SPVs). A SPV is a stand-alone company jointly owned by, for example, a processor, a technology provider and a bank (see Figure 6), which will contract with the farms. The contract can include provisions on output, technology, and credit. This structure can bring even more partners into the contracting system and

[24] On the impact of holdups and payment delays on farm investments see Cungu et al. (2008).

[25] In addition Juhocukor launched a media campaign and supported its farms by technical advice and extension services. This included agronomical advice, soil testing, extension services on integrated pest management, and management support (see Gow et al. (2000) for details).

again allows to share risk, technology and monitoring among the partners involved.

A big advantage of institutional solutions such as SPVs is that the partners not only share the cost of transferring the technology (and the accompanying monitoring costs), but also share the risk of potential holdup by the farmer. When a processing company by itself implements technology provision programs, the processor carries the entire risk of contract breach, although both the technology provider and the financial institution benefit. Institutions such as SPVs allow sharing of the risk between various agents, and hence will stimulate investments by companies who otherwise may be deterred by this risk. Moreover, embedding the transaction in a larger network offers the opportunity of reducing the risk of farmer holdup by increasing the reputational costs of violating the contract in the form of lost future trading opportunities with the contract partners.

An example described in the literature is the case of the collaboration between the Russian dairy processor Wimm Bill Dann (WBD) and the Swedish dairy equipment seller De Laval (Top Agrar 2004). The goal of the joint project "Milk Rivers" was to upgrade the technology used by Russian farms. They created a jointly owned "project": a SPV that leased combine harvesters and milking and cooling equipment. The farmers had to cover about 20% to 30% of the costs themselves and received the equipment (provided by De Laval) based on a three to five year leasing basis. The leasing costs were being paid by the farmers by delivering raw milk to WBD. The main condition for suppliers to take part in the program was compliance with WBD quality standards and motivation to improve quality and productivity. Although the project was considered a success, at times the enforcement of the contracts proved difficult, as some of the supported farms started to supply their milk to competitors who offered a higher price. These holdups endangered the feasibility of the scheme (World Bank 2005).

Also in this case horizontal spillover effects have been observed. Serova and Karlova (2010) found that a few years after the WBD-DeLaval project took off, competitors of WBD started copying the scheme to stimulate dairy farm investments. They used a similar construction (also with DeLaval) whereby farms received milking equipment under a leasing contract (as well as technical and veterinary advice and specialized feed and additives) as part of a one- to five-year instalment plan.

*Model 5: Vertical Integration*

In some cases companies have gone as far as taking over the farming activities, i.e. by "vertically integrating" the supply of raw materials in their company.

Vertical integration is an extreme case of the vertically coordinated programs of Models 1-4. Vertical integration removes the problems of contract enforcement in technology transfer and provides the company full control over technology implementation (including e.g. application of pesticides with strict pesticide residue requirements).

However, it also has drawbacks in terms of inefficiencies of labor management in large integrated farms. Large farms face transaction costs because of principal agent problems and monitoring costs in labor contracting, which are typically large in agriculture (Pollak 1985). The importance of these efficiency losses depends on farm specialization and technology, with losses larger for labor intensive activities and where monitoring is more costly (Allen and Lueck 1998).[26]

Moreover, access to land (for new farms created by the downstream company) or take-over of existing farms by companies is non-trivial. It is often difficult to acquire large plots of land due to high farm density in fertile areas or legal constraints (e.g. foreign ownership of land not being allowed). Social pressures (from communities or international civil society) might induce large reputational costs from being associated with "land grabbing". Therefore technology transfer through vertical integration is only observed in specific cases.

One group of technology transfer through vertically integrated systems that have been documented is in export horticulture in Africa. Several studies show how the rise of standards in high value chains and the associated requirement for farmers to invest in modern technology has led towards vertically integrated production systems. For example, Maertens and Swinnen (2009) and Maertens et al. (2011) document how, in the Senegalese horticulture sector the combination of available land (often state or community land) and a tightening of public and private standards (such as HCCP and EurepGAP) induced exporters to

[26] There is an extensive literature on the optimality of farm sizes and structures (Eswaran and Kotwal, 1985; Feder, 1985; Pollak, 1985). The main arguments relate to relative imperfections in the labor markets versus the capital and product markets and explain empirical findings of an inverse U-function between size and efficiency. Efficiency grows with size for the smallest farms, but beyond a certain size, typically coinciding with larger family farms, there is a declining relation between size and efficiency. Family members have higher incentives to provide effort than hired labor. They share in output risk and can be employed with no or less supervision costs. This is the main advantage of family farming over wage-labor based farming. However, these effects, and hence the "optimum size of the farm" depends on the nature of the farm activity (e.g. livestock, staple crops, horticulture), on the available technology, on relative factor abundance, on market imperfections, and on existing regulations and institutions (Swinnen, 2009). Therefore in environments characterized by major market imperfections, "non-traditional" farm structures may have advantages if they are better fitted for the specific environment. For example, in East Germany in the 1990s, "partnerships" (small groups of farmers that pooled their effort in certain production and marketing tasks) outperformed all other forms of farm organization (Mathijs and Swinnen, 2001).

move from smallholder contracting to integrated estate production. Similar shifts to vertical integration have been observed in Ghana (Suzuki et al. 2011), Zimbabwe (Henson et al. 2005) and Kenya (Dolan and Humphrey 2000).[27]

In these cases it concerns farms with significant technology investments (e.g. irrigation and greenhouse infrastructure), high opportunity costs of contract breach (with high technology monitoring costs and stringent product standards), and relatively easy access to land (in Senegal the greenhouses are developed on former state farm land). Interestingly, in Madagascar, similar high-value horticultural export chains are based on extensive smallholder contracting. With smallholders occupying all the available suitable land, there is no room for processor-owned large farms and processors are instead sourcing from smallholders. Minten et al. (2009) explain how the processor provides thousands of smallholders key inputs (such as seed and organic fertilizer) and large extension and training programs as part of a contract, but that pesticide application is done by employees of the processor in order to ensure correct technology application on production aspects that are difficult to monitor and crucial for adherence to stringent standards. In this way, part of the production process and technology adoption is also vertically integrated in these smallholder sourcing systems.

A very different form of vertical integration was observed in the large grain producing areas of the former Soviet Union (Kazakhstan, Russia and Ukraine). Technology transfer in this region is focused on basic inputs (seed and fertilizer) in extensive production systems with limited labor input on vast areas of extensively operated grain production systems. Large agro-holdings, with access to finance from international trading, have taken over severely credit constrained farms, sometimes up to hundreds of thousands of hectares, in the aftermaths of the farm privatization schemes of the 1990s (Gataulina et al. 2006). However, this type of vertical integration, while fully in line with the logic of financial constraints as explained above, appears to be a product of the specific conditions of the transition (including extreme financial constraints and privatization through voucher systems) which are unlikely to occur in other countries (Serova, 2007; Rozelle and Swinnen, 2004).

[27] Note that often the shift towards vertical integration has only been partial, as processing companies maintained a mixture of sourcing channels. There are several motivations for this strategy (Suzuki et al. 2011). An important motivation is to maintain multiple and diverse types of suppliers as part of a risk management strategy (Swinnen, 2007). Suzuki et al. (2011) for example, explain why Ghanaian pineapple exporters combine own-estate production with smallholder-sourcing to anticipate unexpected fluctuations in demand.

## 3.4 Discussion and Lessons from the Empirical Cases and Typology

Several insights can be drawn from the empirical cases and typology.

*Imperfect credit markets and access to finance*

As is clear from the cases, technology transfer programs can be set up by different agents in the value chain, such as traders, processors, technology companies, retailers or financial institutions. We already pointed at the fundamental role played by credit market imperfections as a motivating element for these value chain innovations. Access to finance by the initiator of the technology transfer program is essential. In all of the empirical cases, the firm that initiated the technology transfer innovation either had significant financial sources or received financial input through outside (sometimes foreign) investment. This is because interlinked contracting, pre-financing and guarantees require large upfront investments or sufficient collateral.

*Demand and quality standards*

The empirical cases document that a need for quality upgrading of farm production drives value chain technology transfer programs. This was particularly clear after the economic reforms in Eastern Europe, where due to sudden and strong competitive forces and Western European FDI the demand for high quality products was outpacing supply. Similar market developments are now occurring in Sub-Saharan Africa and other developing parts of the world following the growth in high value exports, urbanization, and a rise in domestic purchasing power. However, it appears that a critical level of quality requirements or growth of demand is needed to trigger technology adoption programs. For example, Janssen et al. (2017) find that urbanization and income growth have caused a very strong growth in demand for milk and dairy products in India over the past 15 years, but no value chain initiatives to stimulate farm level technology adoption.

*Value and contract enforcement*

Contract enforcement not only hampers relationship-specific technological investments by the farmer in a spot market-based value chain, but will also hamper the feasibility of technology transfer by the buyer due to potential supplier holdup (as explained in section 2.2.). In the absence of public enforcement institutions, hybrid forms of value chain governance can try to cope with such opportunistic behavior through "private enforcement mechanisms", i.e. by ensuring enforcement by a third-party or by including safeguards in the contract to make it "self-enforcing". A contract is self-enforcing when the expected net-present value of additional profit resulting from the contract is greater than the hold-up gains for each party (Klein 1980).

Safeguards can be formal, such as a re-alignment of incentives (e.g. by paying a price premium (Swinnen and Vandeplas 2011)), or informal, such as reputation or goodwill trust (Dyer and Singh 1998). Safeguards and third-party enforcement are, however, costly solutions as they involve monitoring of contract compliance and other (coordination) costs.[28] These solutions are therefore more likely to be feasible when sufficient value is created by the transfer, part of which can be used to finance the enforcement mechanisms (Swinnen and Vandeplas 2011). This might not be possible if too little value is created by the technology adoption. Technology transfer is therefore more likely to occur in high value market segments.

*Nature of the technology*

Another important factor affecting the risk of holdup, and therefore the feasibility of a transfer, is the type of technology that is being transferred. It is well known that the *specificity* of the technology with respect to the relationship between the farmer and the firm providing the technology plays an important role in contracting and the institutions that can enforce the contract (Klein et al. 1978; Williamson 1985). If the technology is 100% specific to the transaction (e.g. technology needed to comply with company specific private standards, such as a traceability system), it has no value outside the contract; if it (or its effects) are also valued by others (e.g. in the case of fertilizer) the technology is non-specific. Obviously, the benefits of diverting technology that is non-specific will more be beneficial than diverting technologies that are very specific to the relationship, which makes transferring non-specific technology more risky.

A different dimension of technology is the *time dimension*. As the empirical cases document (and Table 1 summarizes) there is a difference in the value chain innovations between short and longer term technologies. Technology embedded in short-run inputs (e.g. fertilizer, seeds, feed additives, detergent) are typically used up in the production process. Other technologies come in the form of assets and can have a long-term influence on the production process (e.g. transfer of knowledge or machinery). Short-run technologies are typically

[28] Moreover, contracts will to some extent remain incomplete due to drafting costs and asymmetric information (Grossman and Hart 1986). Therefore, as opportunistic behavior cannot be ruled out and ex-post bargaining costs have to be anticipated, it is unavoidable that some "residual holdup risk" will remain.

closer linked to the contracting period. In contrast, long term technology may have effects beyond the contract period. These different time horizons influence the contract enforcement feasibility. This is because supplier holdup rewards for diverting technology are larger for technology with long-term benefits, while reputational costs are expected to be smaller—making contract breach more likely and therefore technology transfers less likely under standard interlinked contracts. Hence, in order to make long term technology transfers work more sophisticated institutional mechanisms might be required which increase the costs of contract breach for the farm and which reduce the risk of contract breach for the contracting company. Alternatively, it may require a more stable macro-economic and institutional environment which contributes to reducing the risk of contract breach.

*Form of VC Model (1&2 versus 3&4)*

A multi-agent institutional organization has probably a higher up-front investment in the form of contracting and negotiation costs than a simpler 2-agent interlinked contracting scheme because there are more parties involved and there are more contracts to be designed.[29] Moreover, partnering with additional agents introduces the possibility of opportunistic behavior by any of those agents.[30] This might either result in a higher residual holdup risk or requires more costly contractual safeguards (Table 2). The advantages of involving multiple value chain agents in technology transfer are (1) that once the governance structure is set-up, the costs of actually transferring the technology (e.g. training of farmers, transporting farm-inputs, installing equipment) and the costs for monitoring the farmer and enforcing compliance with the contract can be shared among multiple agents; (2) that the financial capability of the initiator of the scheme can be lower; and (3) is that the partners can share the residual risk of holdup by the farmer.

What type of VC Model will be preferred is therefore expected to depend on the level of each of these cost categories. Multi-agent solutions become comparatively more attractive if higher up-front set-up costs and the risk of partner hold-up are sufficiently offset by lower technology transfer costs, lower monitoring and enforcement costs, and lower residual risk of farmer holdup.

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[29] Dyer (1997) refers to this upfront investment as "governance set-up costs" which are transaction costs that are incurred before the actual transaction. These include the costs of screening partners, negotiating terms, building trust, and designing the contract. We follow Dyer by arguing that these initial set-up costs subsequently affect the transaction costs incurred after the contract is signed.

[30] For example, in both the triangular structure and the SPV it is the technology company and financial institution that have to make the first (relationship-specific) investment. The processor is therefore in the position to hold up both these partners as it can re-negotiate contract terms once the investment is made.

This is likely to be the case with longer term and more capital-intensive investments (such as medium and long term investments as described in Models 3 and 4 in Section 3).

*Form of VC Model (1-4 versus 5 (Vertical integration))*

Williamson (1991) argues that "hybrid" forms of value chain organization (e.g. interlinked contracting schemes, triangular structures, or SPVs) compared to vertically integrated companies are better able to respond to price changes in the economy as they preserve autonomous ownership. However, as the dependency among value chain actors becomes larger and coordination becomes more important, vertical integration becomes a comparatively more efficient form of organization.[31] As discussed, this is in line with our empirical cases that show that as a result of more stringent private and public standards and the need to transfer technology, processors became more dependent on farmers and the quality of their produce. In some cases this led to (partial) vertical integration.

However, our empirical review suggests that there are also other factors, beyond a minimization of transaction costs, why vertical integration is (not) chosen. Land, for example, is often not easily accessible due to legal or social constraints. Moreover, small autonomous farms might be preferred over large integrated farms simply because they are more efficient for certain (labor-intensive) products (see Section 3.5). In those cases, hybrid forms of value chain governance might be the more profitable solution to realize the technology transfer.

*Farm Organizations and Value Chains*

Reports by development organizations, such as FAO, the World Bank, and NGOs, invariably point at the important role that farm organizations can play in value chains. Conceptually, several reasons have been put forward why farm organizations (such as cooperatives) could enhance technology adoption through value chains. First, a collective marketing agreement with a processor or trader might secure a market outlet for their products, reducing the risk of relationship specific investments. Second, through collective bargaining cooperatives might be able to obtain higher output prices, increasing the return on

[31] The transaction costs of a hybrid governance form (including the safeguard costs, residual holdup costs, and the cost of the transfer itself) are amplified when suppliers are small and many, monitoring contract-compliance is difficult, and when the capability of the farmer is low, standards and technology are complex, and the required technology is difficult to codify in a set of well-defined practices (Gereffi et al. 2005). Vertical integration avoids these type of transaction costs (and holdup altogether) and thus becomes comparatively more attractive as these costs increase.

investment and obtain discounts on equipment, inputs and services. Lumpy investments (e.g. harvesting machinery) might be collectively purchased and hired out to members for a fee. Third, cooperatives might enhance access to credit. Collectively taking a loan can reduce transaction costs and collectively guaranteeing repayment reduces the risk of default following idiosyncratic shocks. Fourth, cooperatives may reduce transaction costs for retailers and food processing companies in sourcing from (small) farmers by pooling supplies and controlling quality. Fifth, cooperatives may also play a role in joint quality control systems. As prices are typically related to quality in modern supply chains, transparency of quality control is a crucial factor to prevent holdups in contracting and, therefore, to make value chains function effectively. Involvement of farm organizations in quality control may help in this. In summary, there are many reasons why farm organizations could play an important role in value chains and innovations.

However, in reality participation by farmers' organizations in these value chain innovations appears rather limited. A few cases that have been documented include a reference by Gow and Swinnen (2001) to how a sheep farmer organization in Hungary in the 1990s participated as a partner in a SPV structure and increased farmers' bargaining power in the contract design.[32] Van Berkum (2007) and Bruszt and Langbein (2014) describe how a dairy farmers association (ISPA) in Romania became a shareholder in a milk processing company (ProMilch) in the late 1990s.[33] Hence, the discrepancy between the conceptual benefits and the absence of empirical success cases is intriguing and certainly an interesting area for future research.

*Competition*

The cases we presented have not dealt explicitly with competition issues. Although it is well known that competition affects contract enforcement, the impact is not as straightforward as may seem. Swinnen and Vandeplas (2010) develop a formal model and show that the impact is complex because of several mechanisms that are influenced by competition. More competition will induce

[32] A case from a developed country is presented by Jardine et al. (2014) who describe how an Alaskan fishery cooperative took ownership in the processing stage of the value chain and how this addressed market failures and improved product quality.

[33] ISPA supported their members in upgrading their technology in several ways: (a) by investing in milk collection centers; (b) by supplying high-quality inputs (feed, medication), which were financed by deducting milk payments; (c) by offering on-farm technical assistance (on a range of topics); and by providing loans to their members (in collaboration with a financial institution (Rabobank)) to invest in equipment, animals, or (re-)construction of stables. Farmers did not have to provide any collateral, but needed to have a durable relation with ISPA, and continue milk delivery to the cooperative.

more incentives for companies to contract with farmers and will improve contract conditions for farmers ex ante. However, more competition may also lead to more options for contract breach (side-selling) ex post, and thus reduce the expected likelihood of contract enforcement, and, as companies anticipate this, a lower likelihood of value chain innovations being introduced. Inversely, a more concentrated processing or technology sector may lead to worse contract conditions for the farms because of reduced bargaining power and to a greater chance of ex post holdup by the company but at the same time may make contract enforcement more likely. Recently, Mérel and Sexton (2017) argued that there may be an optimal level of competition at which contracts can be beneficial for both parties and where hold-up chances are minimized.

*Institutional environment and macro-economic stability*

The institutional and macro-economic environment obviously play a role since they affect the severity of the capital and technology market imperfections directly as well as indirectly through (expected) problems with contracting and contract enforcement. For example, more sophisticated contracting systems (such as triangular structures) and contracts with programs for longer term technology investments (such as investment loans) did not occur in all transition countries. Studies by Sadler et al. (2006) on the cotton sector in Kazakhstan and by White and Gorton (2006) who interviewed a wide variety of agri-food companies in five FSU countries (Russia, Ukraine, Moldova, Armenia and Georgia) found that many agri-food companies in these countries only provided basic inputs and technology (such as seeds and fertilizer) under contracts as discussed above but did not provide long term investment loans. Neither did they engage in triangular structures. These observations suggest that certain conditions (for example relating to the economic and institutional environment) may need to be fulfilled before more complex value chain innovations may emerge.

*Dealing with changing circumstances*

The technology transfer programs have been set up in environments characterized by strong market imperfections and costly contract enforcement. Successful programs create the right conditions for successful and self-enforcing contracting, and are based on extensive knowledge of the sector and of local conditions. Moreover, these programs need to be flexible enough to adjust the contractual terms to changing circumstances—an often occurring situation in developing and emerging economies. Too large disruptions make contracting infeasible.

*Impacts*

The effects of these programs can be very substantial as they can move the entire value chain towards a higher equilibrium, with impacts for all agents. Spillovers are not restricted to vertical interactions, but can also be horizontal. Competing companies of firms that initiate a technology transfer program may introduce similar contractual arrangements, either to stay in business (as farms will otherwise shift to supplying other companies) or because it is profitable for them to do so once they observe the success of the innovations elsewhere – or both. Such type of contractual convergence may go beyond sectors in which the transfer program was initiated. Other sectors that compete for the same resources (e.g. land) might offer similar contracts as well – or financial institutions may standardize the approach for other farms.

## 3.5 Conclusions and Implications

The adoption of modern technologies is crucial for improving the productivity and welfare of poor farmers in developing countries but technology adoption has been constrained. Many factors have been identified, but the role of value chains has not received much attention so far. In this chapter we have explained why value chains and institutional innovations may play an important role in agricultural technology adoption. With imperfect technology markets, various forms of value chain innovations have been introduced by up- and downstream companies to overcome constraints and enhance farmer access to and adoption of new technologies. We have systematically documented value chain innovations, including smallholder contracting with interlinked technology transfer, triangular guarantee structures with technology suppliers or financial institutions, special purpose vehicles and vertical integration We discussed how the type of VC models and their success is related to various factors, including the nature of the technology requirements in product and process standards, the value created by the technology adoption, the macro-institutional and -economic conditions, the nature of the technology (timing and specificity), the need for finance and risk-sharing among value chain agents, and competition in the value chain.

Important questions relate to the policy implications of our analysis. The most straightforward implication relates to recognizing the importance of value chains as an engine for technology adoption, and to the need for allowing this engine to work its best. A key policy to stimulate technology transfer and adoption in the agricultural sector of developing and emerging countries is therefore to improve the enabling environment for companies to operate in. Enabling environments encompasses various macro-economic and macro-institutional elements.

Macro-economic stability is a key condition for financial markets to function properly. Instability may increase the risk of holdup, as unexpected changes in economic conditions might make it more attractive to default on the contract. Hence, macro-economic stability is not only necessary for the functioning of more traditional finance systems, but also for technology transfer as it reduces the risk of investments.

One of the key findings of our review is that there exists significant variation in private sector technology transfer schemes across countries and sectors. Hence, one should be careful with interventions that may hamper the flexibility of companies to address different circumstances.

Private sector technology transfer might only be feasible for high-value market segments and for certain types of technology. In particular, there is less incentive for transferring long-term oriented technology that is not to some extent relationship-specific, due to a higher risk of supplier hold up (e.g. training on how to increase yields). One could therefore consider public interventions which focus on those firms or farms being excluded from private sector programs, those low-value market segments for which technology transfer is unlikely, and those technologies that are not provided by the private sector.[34] These public programs could learn from the institutional design of the private sector in bringing different partners to the table.

Another option is to leverage the private sector's resources and use value chains for transferring technology to farms. As we showed, access to finance is essential for technology transfer. Therefore, one way to facilitate technology transfer is by offering government finance for private-sector-led technology transfer programs that could otherwise not be financed. This can be achieved through different modalities, such as public-private partnerships involving grants or (concessional) loans.

Alternatively, governments (and NGOs) could directly assist suppliers in upgrading technology (e.g. through training, improving access to essential inputs, and facilitating certification) in anticipation of increasing market demand for high quality produce, or, more actively, in close collaboration with the private sector. Unlike traditional technology adoption programs, these initiatives complement a government initiated productivity push, with a private "market pull". Waddington et al. (2014) review the effectiveness of public agricultural extension services and find effects are particularly large when they are implemented

[34] Note that the same market failures that exist in high-value market segments can exist in low-value segments, such as high transaction costs in credit markets and information asymmetries.

alongside complementary upstream or downstream interventions (access to seeds and other inputs, assistance in marketing produce).

In fact these type of value chain development projects have become increasingly popular among donors active in rural developing areas. A recent example is a joint World Bank – World Food Programme project to set up a staple food sourcing program in East Africa in which it collaborates with private sector input suppliers (seed, fertilizer and pesticides) in an SPV-like institutional organization with smallholder farmers to source staple foods (cereals) from them. Another example is a project by the NGO Solidaridad in the horticulture, aquaculture and dairy sector of South-West Bangladesh (see Chapter 4). They have an intensive 5-year long program in which they are continuously coordinating their farmer assistance to buyer needs and requirements. This farmer assistance includes group formation, training, certification, and creating access to high quality farm inputs and services.

The effectiveness of these programs is, however, only rarely evaluated "rigorously", and most of those studies have appeared in the "gray literature". An exception is Shayonan et al. (2014) who document how a public-private-partnership for technology transfer in Armenia led to a sustainable upgrading of supplier technology. They show how an international aid program (the USDA Marketing Assistance Program) that facilitated linkages between dairy processors and dairy farmers stimulated technology upgrading and investments by these farmers in cows, husbandry facilities and milking equipment, even after the program ended.

However, as all public interventions, also this type of selective government involvement in markets carries a number of risks. For example, the government financing might not be "additional" to private sector initiatives (DCED 2014) or the project may not be sustainable beyond the public funding.

As still little is known about what type of intervention works best in what type of context, further research on this topic, as well as, rigorous monitoring and evaluation of initiated programs is needed. As the impact of the value chain innovations that we have documented here are potentially very significant, these are research areas with a potentially high pay-off.

## 3.6 References

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## 3.7 Figures

**Figure 1: Value Chain and Technology Adoption with Perfect Markets**

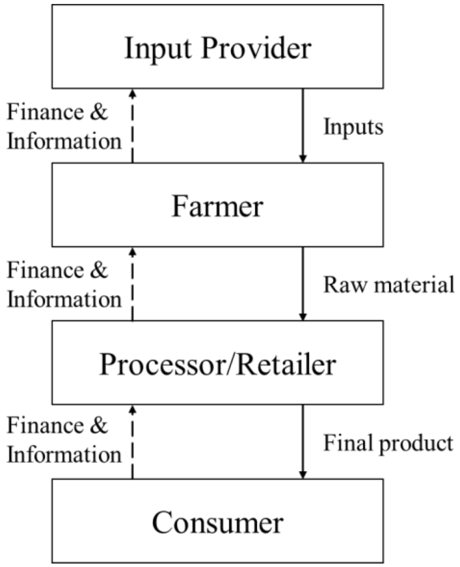



**Figure 2: Farm – Processor Contracting**

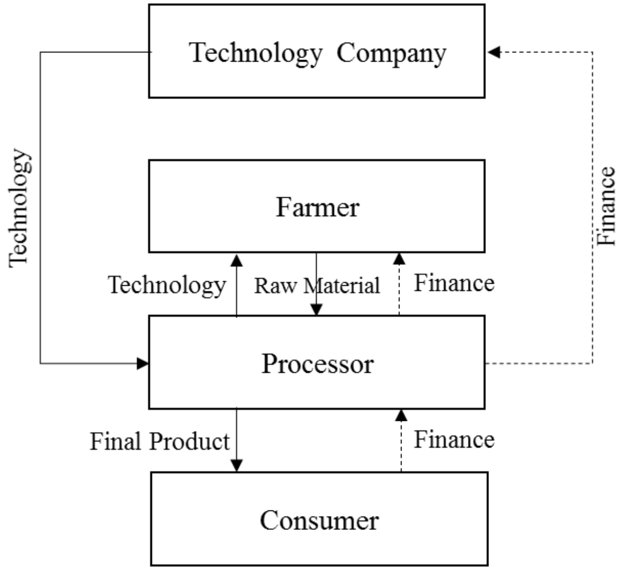


**Figure 3: Multi-stage technology transfer in the brewing sector**

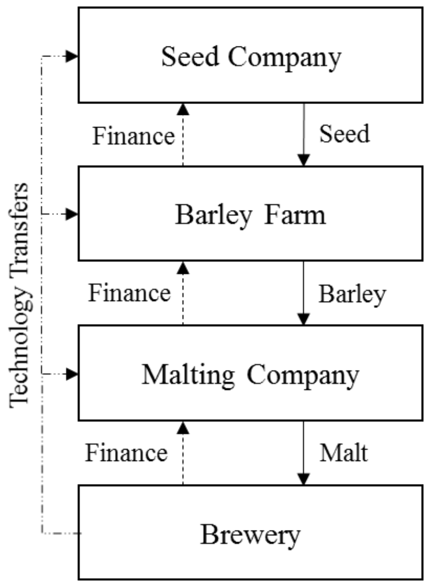



**Figure 4: Farm – Technology Company Contracting**

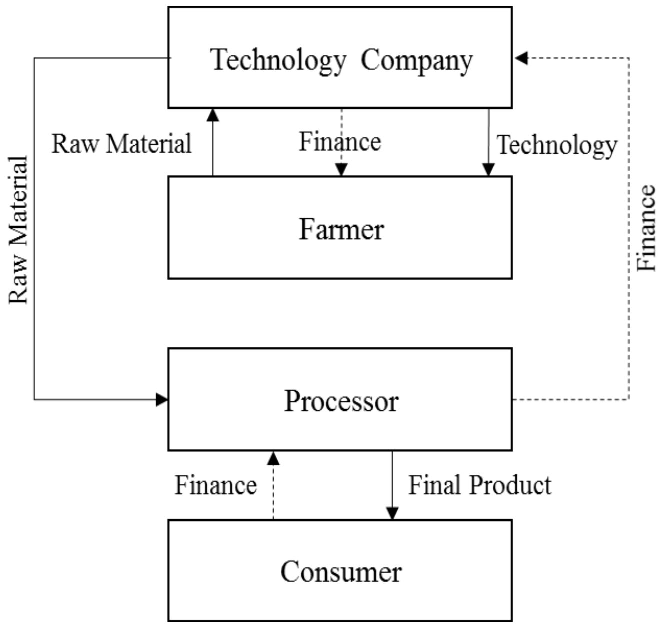


**Figure 5: Triangular Value Chain Structure**

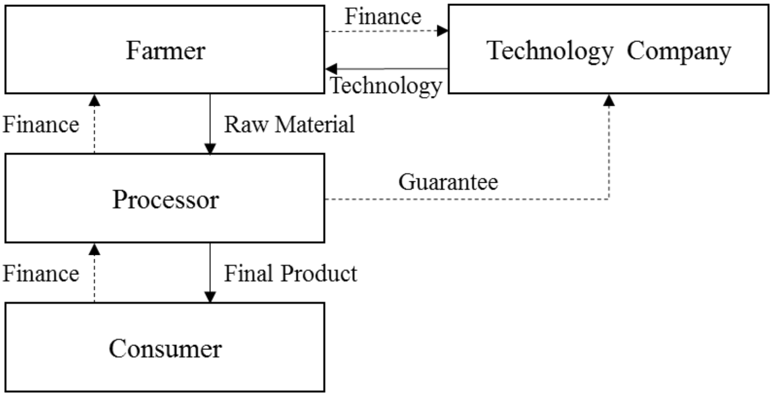
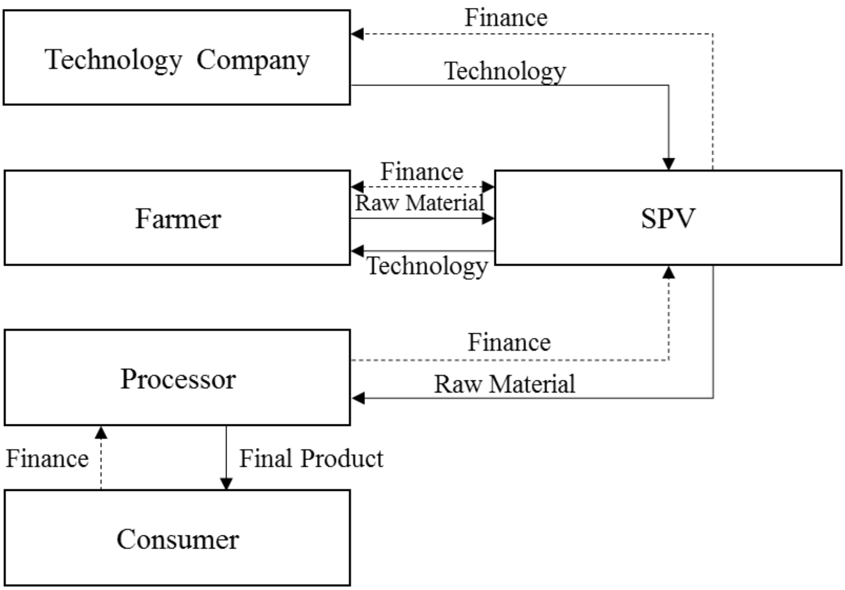



**Figure 6: Special Purpose Vehicles for Technology Transfer**



## 3.8 Tables

**Table 1: Summary of the Value Chain Models**

| **Value Chain Model** | 1. Interlinked Contract | 2. Interlinked Contract | 3. Triangular Structure | 3. Triangular Structure | 4. Special Purpose Vehicle | 4. Special Purpose Vehicle | 5. Vertical Integration |
|---|---|---|---|---|---|---|---|
| **Actors involved** | Processor | TechCo ° | Processor | Processor | Processor | Processor | Processor |
| | Farm | Farm | Bank | TechCo° | TechCo° | TechCo °/ Bank | Farm |
| | | | Farm | Farm | Farm | Farm | |
| **Credit Constraints** | | | | | | | |
| Farm | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Processor | No | Yes | No | No | No | No | No |
| Tech-Company | Yes | No | Yes | No | No | No | Yes |
| Bank | Yes | Yes | No | Yes | Yes | No | Yes |
| **Type of Technology Transferred** | | | | | | | |
| Time Dimension | Short | Short | Long | Long | Long | Long | Long |
| Specificity* | High | High | Low | Low | Low | Low | Low |
| **Land Access** | No | No | No | No | No | No | Yes |

* *Assuming no complementary specific investments are made by the farmer.*

° *TechCo refers to technology compan*

**Table 2: Comparative Transaction Cost Advantages of Simple vs. Complex Institutional Solutions to Realize Technology Transfer**

| | "Simple" Interlinked Contracting (VC Models 1 & 2) | "Complex" Multi-Agent Institutional Innovations (VC Models 3 & 4) |
|---|---|---|
| **Types of Transaction Costs** | | |
| Governance set-up costs | Lower | Higher |
| Costs of Transfer | Higher | Lower |
| Monitoring and enforcement costs | Higher | Lower |
| Residual hold-up risk farmer | Higher | Lower |
| Residual hold-up risk other actors | Lower | Higher |

# Chapter 4. Value Chain Development as Public Policy: Conceptualization and Evidence from the Agrifood Sector in Bangladesh*

## 4.1 Introduction

Market imperfections constrain the welfare and productivity of smallholders in developing countries. Smallholders incur high costs in acquiring improved plant and animal varieties, farm chemicals, equipment, financial services, and information services and face uncertainty regarding the quality of these inputs. (e.g., Bold et al. 2017; Croppenstedt, Demeke, and Meschi 2003; Shiferaw et al. 2015). High input costs and uncertainty result in low adoption and, consequently, low yields and low labor productivity. Smallholders also experience high costs and information asymmetries when selling their products on output markets, particularly if buyers require them to comply with stringent public or private standards regarding quality and food safety (e.g., Maertens, Minten, and Swinnen 2012; Pingali, Khwaja, and Meijer 2005; Reardon et al. 2009; Svensson and Yanagizawa 2009). In addition, these input and output market imperfections can be mutually reinforcing. Low access to output markets reduces the incentive and ability of farmers to adopt modern inputs (Swinnen and Kuijpers 2019b), while low access to inputs reduces access by farmers to output markets by constraining productivity and by hindering compliance with public and private standards (Barrett 2008; Kuijpers and Swinnen 2016).

Value chain development (VCD) is an increasingly popular policy instrument to assist farmers in overcoming these input and output market imperfections. No clear definition of VCD exists, but it is widely understood as a type of intervention that aims to establish or improve linkages between different

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actors in a value chain (Devaux et al. 2018). As such, the term is broadly used to describe initiatives both by the private sector (privateled VCD) and by the public sector (public-led VCD) (Stoian et al. 2012).

While private-led VCD is relatively well studied (see e.g., Bellemare and Bloem 2018; Swinnen and Kuijpers 2019a; Ton et al. 2018 for reviews), there is little research on public-led VCD. In particular, there is little consensus on what public-led VCD entails, in what context it is relevant, and how effective it is (Devaux et al. 2016). Meanwhile, governments, donors, and international organizations invest increasingly larger sums of public funds in VCD initiatives. For example, between 2012 and 2016 the Netherlands alone financed more than fifty public-led agri-food VCD programs in developing countries for a total value of EUR 417 million (IOB 2018).

This chapter explores what "linking value chain actors" or "improving value chain linkages" means and it discusses in what context VCD can be relevant. As an illustration, the chapter describes the public-led VCD project "SAFAL" that directly intervenes in the aquaculture, horticulture, and dairy sector of South-West Bangladesh. Using a matched double-difference methodology, this chapter then estimates the effect of SAFAL on farmer market participation, farm production, farm revenue, net-farm income, and the length of the hungry season experienced by the farmer's household.

To my knowledge, this is one of the first efforts to rigorously estimate the effectiveness of an integrated public VCD project. Others have investigated the effects of partial solutions, such as the use of farmer organizations for collective exchange (e.g., Verhofstadt and Maertens 2014), bringing value chain actors together in platforms (e.g., Cavatassi et al. 2011), and training farmers and certifying them (e.g., Ebata and Huettel 2017; Kersting and Wollni 2012; Ruben 2017; Carter, Tjernström, and Toledo 2019). The project studied in this chapter, however, combines these and other activities into one intervention in an effort to identify and tackle all constraints in the value chain that are binding farmers in accessing technology and output markets.

The estimation of SAFAL's effectiveness is based on information obtained from households participating in the project and from a control group in 2014 and 2016. In an attempt to overcome project placement and self-selection bias, the estimation relies on a difference-in-difference methodology, whereby control farmers are matched with project farmers based on pre-project characteristics to ensure comparability over time.

Using this methodology, it is estimated that the project has, on average, increased the share of output sold by farmers in the market by 13 percentage points, total farm production value by USD 704, and farm revenue by USD 472. However, also farm expenditures increased by about USD 300 as a result of the project, resulting in an estimated increase in net-farm income of USD 404 and in farm profits of USD 172. Finally, it is estimated that the project has reduced the length of the hungry season experienced by participating households by about 12 days.

The remainder of this chapter is organized as follows. Section 4.2 provides a conceptualization of value chain development and discusses in what context it can be relevant. Next, the agrifood context in which SAFAL is implemented is described in Section 4.3 followed by a discussion of the project's intervention logic in Section 4.4. The methodology for estimating the project effects is discussed in Section 4.5, the data is described in Section 4.6., and the estimation results are presented in Section 4.7. Finally, the chapter is summarized in Section 4.8.

## 4.2 Value chain development in theory and practice

### *4.2.1 Agri-food value chains and market imperfections*

A value chain describes how a production process is undertaken by different actors and at what stages the (intermediate) product is exchanged between actors. Products move from "upstream" to "downstream"— from input suppliers and farms to processors, traders, retailers, and, finally, consumers, while in the opposite direction there is a stream of finance and information (Swinnen and Kuijpers 2019a).

With perfect markets, the coordination in the value chain happens through price changes (Swinnen and Kuijpers 2019a). A change in demand at the consumer level affects prices throughout the value chain, such that the supply in each stage of the value chain is able to meet this demand. A higher consumer demand for safer food, for example, translates into higher prices and increases the demand by retailers for agricultural products that meet better food safety standards. This increases the price farmers can receive for these products and increases, in turn, their demand for knowledge and farm inputs necessary to meet these new standards. This gives farm input companies, service providers, and laborers, in turn, an incentive to provide these inputs.

Spot-markets for agri-food products and farm inputs and services might, however, not function perfectly and involve high transaction costs; possibly to such extent that some actors effectively have no access to these markets (e.g., Alene et al. 2008; De Janvry, Fafchamps, and Sadoulet 1991; Key, Sadoulet, and De Janvry 2000; Winter-Nelson and Temu 2005). Transaction costs can include costs incurred ex-ante, such as searching trade partners and obtaining information on prices, product attributes, and private standards; costs incurred during the transaction, such as transportation and storage costs and tariffs; and costs incurred ex-post, such as monitoring and enforcement costs (Hobbs 1997; North 1990).

These transaction costs are expected to be higher for value chains that adhere to more stringent public or private standards, as these require more detailed and regular information transmission (Pingali, Khwaja, and Meijer 2005) and investments in specific technologies and practices to comply with these standards (Kuijpers and Swinnen 2016). The necessity of relationship-specific investments by the farmer increases the contract enforcement costs as it introduces the risk of holdup by the buyer (Klein, Crawford, and Alchian 1978; Gow and Swinnen 2001). Buyers could, for example, renegotiate prices at product delivery, pay later, or renege in other ways on the contract after the farmer has made the relationship-specific investments. As a result, farmers may refrain from making these investments in the first place.

A market imperfection at one stage can affect the functioning of the entire value chain: the ability of the value chain to comply with public or private requirements, such as regarding product quality, food safety, or ethical and environmental standards (value chain effectiveness) and the costs incurred in the value chain to bring forward the final product (value chain efficiency). As such, it affects all actors involved in the chain. Not only the farmer is affected, for example, if he or she has inadequate access to input and output markets (Swinnen and Kuijpers 2019a). Also input and service companies are affected, because they cannot sell their farm inputs and services; traders, processors, and retailers are affected, because they cannot get the raw material that meets their requirements; and consumers are affected, because they cannot get the products they desire.

### *4.2.2 Value chain development to overcome market imperfections*

Value chain development is a catch-all term for interventions that aim to improve value chain functioning. More specifically, it can be understood as an intervention that aims to increase the effectiveness or efficiency of a specific value chain by reducing the transaction costs between different stages and/or by supporting actors in the chain to enable them to provide intermediate products that meet the requirements of actors downstream. As mentioned in the introduction, value chain development can be initiated and financed by the private sector or by the public sector.

### *4.2.3 Private-led value chain development*

VCD initiated by the private sector entails the introduction of new institutional arrangements, other than spot-markets, to coordinate transactions in the value chain. These include value chain innovations such as interlinked contracting (including contract farming and leasing), farmer cooperatives, triangular structures, special-purpose vehicles, and vertical integration (Swinnen and Kuijpers 2019a). These alternative institutional arrangements can lower transaction costs (Williamson 1979, 1991) and can enable specific value chain actors to adopt the technology necessary to meet the requirements of value chain actors downstream (Swinnen and Kuijpers 2019a). In this way, private-led VCD can improve both the efficiency and effectiveness of the value chain.

A better functioning value chain is potentially in the interest of all value chain actors. It is therefore not surprising that in practice VCD is observed to be initiated by traders, processors, and retailers (typically to secure a supply of raw materials that meet their quality and food safety standards); by farm input companies, such as equipment manufacturers, hatcheries, seed and chemical companies (typically to secure a demand for their intermediate products); and by farmer organizations (typically to secure access to high quality inputs and to remunerative output markets) (Swinnen and Kuijpers 2019a).

A key issue with private-led VCD is that assisting farmers by providing inputs introduces the risk of holdup by these farmers (Swinnen and Vandeplas 2011; Kuijpers and Swinnen 2016). Examples of farmer holdup include side-selling of produce after application of the provided inputs, applying these inputs to non-contracted products, or selling the inputs. In the absence of public enforcement institutions, initiators of private-led VCD can try to cope with potential farmer holdup through private enforcement mechanisms: by ensuring enforcement by a third-party or by including safeguards in the contracts to make them self-enforcing. Safeguards can be formal, such as a re-alignment of incentives, for example, by paying a price premium (Swinnen and Vandeplas, 2011), or informal, such as through reputation or goodwill trust (Dyer and Singh, 1998).*Public* VCD (initiated by governments, international organizations, or NGOs), on the other hand, is typically motivated by specific social or environmental objectives, such as stimulating efficiency and growth in the agri-food sector, improving food safety, improving farmer market access and incomes, reducing the environmental impact of farm practices, or increasing consumer access to more nutritious food. In this respect, interventions mainly aim to improve the effectiveness of value chains in achieving these outcomes.[35]

[35] Voluntary ethical and environmental standards often play a central role in VCD for three reasons. First, standards and certification schemes can define the minimum or maximum ethical and environmental effects or can describe what "good practices" entail. Secondly, they allow for assessing whether value chains adhere to these standards (and enforcement). Finally, standards can improve information transmission to the consumer and thus increases consumer demand for products meeting these standards.

#### *4.2.4 Public-led value chain development*

Public-led VCD, on the other hand, is initiated by (semi-) public actors, such as a government, international organization, or NGO, and typically motivated by specific social or environmental objectives. Common objectives include stimulating efficiency and growth in the agri-food sector, improving food safety, improving farmer market access and incomes, reducing the environmental impact of farm practices, or increasing consumer access to nutritious food. In this respect, interventions mainly aim to improve the effectiveness of value chains in achieving these outcomes.

Broadly speaking, two approaches to public-led VCD are observed in practice: the direct and the indirect approach. The indirect approach entails enabling and incentivizing lead firms to develop the value chain(s) from which they source their produce; i.e., to enable private-led VCD. Private-led VCD requires access to finance by the company initiating the intervention, because setting up contracts and supporting value chain actors requires upfront investments (Dyer 1997; Ruben, Boselie, and Lu 2007). Moreover, VCD investments are risky, because they introduce the possibility of opportunistic behavior, such as side-selling or price re-negotiation at delivery (Swinnen and Vandeplas 2011). To overcome financial and risk constraints, (semi-) public actors can offer concessional loans for private-led VCD investments or engage in public-private partnerships (PPPs) in which both the costs and risks can be shared of a "project" that serves both public and private objectives.

The direct approach to public-led VCD entails direct public support to key stages and linkages in the value chain. This can include financial and technical assistance to value chain actors (e.g., Carter, Tjernström, and Toledo 2019), capacity building of farmer associations (e.g., Donovan, Blare, and Poole 2017; Donovan and Poole 2014), bringing value chain actors together in platforms (e.g., Devaux et al. 2009), or an integrated project that uses a mix of these and other approaches. The logic of these interventions varies greatly, but they all have in common that they aim to improve value chain effectiveness or efficiency by reducing transaction costs and/or by supporting specific value chain actors.

## 4.3 Project context

Agriculture in (South-West) Bangladesh is characterized by large numbers of very small family farms that make intensive use of the scarce cultivable land available. Rice has always been the most dominant crop, covering about 80%

of the cultivated area (Gumma et al. 2012). This means Bangladesh's agricultural sector is one of the least diversified in the world (Headey and Hoddinott 2016).

Bangladesh was at first slow to adopt high-yielding rice varieties, irrigation, and farm-chemicals (the so-called green revolution technologies), but since the 1990s adoption rates picked up (Headey and Hoddinott 2016; Hossain, Bose, and Mustafi 2006) and rice productivity rose from 2.5 tons per hectare in 1995 to more than 4.5 tons per hectare in 2016 (see Figure 1). This period of rapid rice intensification coincided with sustained economic growth, poverty reduction, and urbanization. This, in turn, increased consumer demand (and prices) for non-staple food products, such as fish, vegetables, fruits, dairy, and meat (Sur and Zaman 2008).

Higher rice productivity allowed farmers to reduce the land devoted to rice without compromising the caloric needs of their families, while the increase in demand for non-rice food products gave farmers an incentive to use this land for aquaculture and horticulture production. As such, Bangladesh is now moving away from rice monoculture and towards a more diversified agri-food sector.

### *4.3.1 Aquaculture*

The most spectacular shift has taken place towards aquaculture. Since 1995, aquaculture production increased by sevenfold: from 317,000 tons then to 2.2 million tons in 2016 (see Figure 1). This is explained both by increases in yields and by the expansion of fish pond area. In fact the land devoted to fish ponds in the South-West region has more than doubled between 2004 and 2014 (Hernandez et al. 2018). As a result, aquaculture is now the most important source of fish in Bangladesh, accounting for 56% of total fish production (Shamsuzzaman et al. 2017).

Hernandez et al. (2018) describe a number of trends that are closely interlinked with this growth in production. First, there was a strong increase not only in the land area devoted to aquaculture production but also in the number of aquaculture producers. Second, production systems shifted from a subsistence-orientation to a more commercial orientation with increased use of purchased inputs, such as fingerlings, manufactured feed, and chemicals. Third, the non-farm components of the fish value chain have experienced rapid transformation and growth. In particular, there has been strong growth in the number of hatcheries, nurseries, small- and medium-scaled feed mills, feed dealers, fish traders, and wholesale markets. Finally, these changes in aquaculture production are mirrored by growth in the domestic demand for aquaculture products. Rashid et al. (2018) show that the increase in consumption took place across Bangladesh's population but that it was highest for the poorer households and the households in urban areas.

This growth in the aquaculture sector has important development implications. Rashid et al. (2018), for example, estimate that 10% of the poverty reduction in Bangladesh between 2000 and 2010 can be attributed to the growth in aquaculture. Others have linked the growth in aquaculture to the major improvements in food security and nutrition that Bangladesh has experienced (E-Jahan, Ahmed, and Belton 2010; Belton, van Asseldonk, and Thilsted 2014; Toufique and Belton 2014).

The described changes in the aquaculture sector of Bangladesh also apply to the South West. One way in which the aquaculture sector in the South-West is distinctly different, however, is that it is the main shrimp producing region. Although the region is still dominated by the production of white fish and tilapia in inland ponds like in the rest of the country, it also has a thriving shrimp sector, which needs saline coastal ponds or enclosures (Hernandez et al. 2018; Shamsuzzaman et al. 2017). This distinction is key, because unlike carp and tilapia, shrimp production is mainly targeted at the export market.

### *4.3.2 Horticulture*

Although less rapidly than in aquaculture, there has also been growth in horticulture. In fact, between 1995 and 2016, the production of vegetables and fruits grew from about 2.9 million tons to about 9.8 million tons per year: a growth of 260% (see Figure 1). This is partially explained by a growth in yields, but primarily by an increase in land devoted to horticulture. Despite this rapid development, the diversification towards horticulture has received little attention in the literature. Perhaps this is due to the fact that this is a relatively recent phenomenon. In fact, growth in the horticulture sector took off as recently as 2003.

Although production growth in horticulture has been substantial, it has been unable to meet the growth in domestic demand. As a result, producer prices for important horticultural products have risen sharply in the past 15 years. For example, the annual producer prices (in USD) for onions, tomatoes, and mangoes grew, respectively, by a factor 1.66, 2.25, and 2.38 between 2003 and 2017. In reaction, the imports of fruits and vegetables has become much more important; growing from a mere USD 37 million in 1995 to almost USD 1 billion in 2015.[36]

[36] The data on horticulture prices and import values are obtained from FAOstat.

*4.3.3 Dairy*

Unlike aquaculture and horticulture, the dairy sector in Bangladesh has been completely stagnant in the past two decades. Dairy output between 1995 and 2016 grew by just 6%. Milk yields are extremely low in international comparison and have not improved since 1995. The small growth in output is therefore entirely explained by a small expansion in the number of cattle. Meanwhile, there is a growing domestic demand for milk products and both milk prices and milk imports have risen sharply since 2005.

There is little research on the underlying causes of low productivity in the sector. Some have suggested that an important explanation is the country's high population density, leading to severe land and hence feed constraints, particularly during the dry season (Choudhury and Headey 2018; Khan, Peters, and Uddin 2009). Other factors that have been suggested include low penetration of crossbreeds, high burden of animal disease, poor animal husbandry practices, low availability of vaccines, feed supplements, and artificial insemination services, and a low availability of collection points and processing facilities (Saadullah 2002; World Bank 2018).

## 4.4 Project description and intervention logic[37]

*4.4.1 Project description*

The Sustainable Agriculture, Food Security and Linkages (SAFAL) project directly intervenes in key stages and linkages in the aquaculture, horticulture, and dairy value chain. It is financed by the Netherlands Ministry of Foreign Affairs and implemented by the NGO Solidaridad. The goal of SAFAL is to improve the welfare and food security of about 58,000 smallholders in the districts of Khulna and Jessore in South-West Bangladesh. To achieve this, the project uses a flexible intervention logic to tackle all binding constraints faced by these farmers in accessing markets. In practice, the project activities can, however, be grouped in four components.

First, the project facilitated the formation of 1000 producer groups (500 in aquaculture, 300 in dairy, and 200 in horticulture) with about 45 to 60 members each. Every two producer groups is led by one "lead farmer" elected by the group members. These lead farmers are trained by the project in producer group management and are given intensive sub-sector specific training on production and marketing practices, such that they can act as service providers for

[37] Information in this Section is obtained from official documentation such as project proposals, annual reports, newsletters, and the mid-term review and several interviews with project staff in August 2013, January 2014, and September 2016.

their producer groups (e.g., testing of water quality, de-worming of cattle, advising on the use of organic pesticides etc.). Every lead farmer receives a fixed honorarium from the project of about 25 US dollar per month and are, in essence, an extension of the project staff. In addition, every producer group is governed by an executive committee consisting of seven famers. The committee is responsible for drafting a business plan, organizing member meetings, and engaging with providers of inputs and buyers of produce.

The project uses an inclusive approach by allowing all households in the community that were active in a given sub-sector (either aquaculture, dairy, or horticulture) to participate in a producer group, regardless of their farm size or other characteristics. In addition, women were actively encouraged to participate as members of producer groups, in the executive committees, and as lead farmers.

The second component consists of farmer training and the promotion of new farming practices. The trainings are generally conducted by lead farmers together with field organizers, who are in turn trained by sub-sector experts. Trainings are planned throughout the year, following the production cycle. See Table 1 for a list of training topics by sub-sector. In addition, the project collaborated with farmers in setting up about 600 demonstration plots for displaying the benefits of existing technologies and about 120 pilot plots for the testing and promotion of novel technologies.

Within the third component, the project provides support to small-scale entrepreneurs in providing services to farmers in the community. This includes the lead farmers who provide fee-based services and farm inputs to farmers, agro-input shops, community livestock service providers, mobile agro-input sellers, cooled transport services, feed and organic fertilizer production, and collection centers. These entrepreneurs are supported financially (e.g., shop construction, stocking of products, provision of vans and rickshaws) and technically (i.e. training on the products and services they are providing) and are brought into contact with farm input companies with whom the project negotiated prices (see the fourth component below).

The fourth component consists of the representation of the producer groups and the micro- and small enterprises by the project (described under component 3) in coordination and negotiation activities with farm input companies and potential buyers, such as traders, processors, and retailers (see Table 1). This entails searching these companies, negotiation on contract terms, and engaging in agreements. With retail companies, processors, and traders the project entered into agreements about product and process requirements, payment-schemes, and potential (co-)investments in transport, collection, and packaging. Large scale buyers with whom the project entered agreements include dairy processor BRAC, supermarket AGORA, and shrimp processor and exporter MU SEAFOOD. With input companies the project entered into agreements regarding the distribution of quality inputs, discounts on agri-inputs, and (co-)investments in training and demonstration plots. Large agri-input companies (producing seeds, fertilizer, equipment, feed, and animal health products) with whom the project entered into agreements include R. Rahman Hatchery, Anik Hatchery, Winning Agro, ACI Agribusiness, Ispahani Agro, and Lalteer Seeds Limited.

*4.4.2 Intervention Logic*

See Figure 3 for a schematic overview of the intervention logic of SAFAL. Central to the project is the immediate objective of improving farmer access to technology and to output markets by reducing transaction costs. The project is expected to reduce these transaction costs in at least three ways. First, the formation of producer groups (component 1) reduces the costs for dealing with a large number of farmers individually. In essence, it allows a portion of the transaction costs to be divided over a larger number of farmers. For example, it can reduce the per-farmer costs incurred for searching partners, obtaining information, negotiation, writing up contracts, transport, and contract enforcement. In addition, collective negotiation can lead to discounts on inputs, which essentially makes them better accessible. Secondly, by organizing farmers and by representing them in coordination activities with agribusinesses (component 4), the project incurs part of the one-time transaction costs of entering into agreements that would otherwise fall on the farmers themselves. And finally, by assisting farmer service providers the project reduces the distance farmers have to travel to purchase inputs or services or sell their produce to a certain market outlet (component 3).

Enhanced access to services and farm inputs, in combination with farmer training (component 2), is expected to enhance the ability of farmers to change their production and post-harvest practices. Besides increasing productivity and total production, the project intends to enable farmers such that they can meet buyer requirements (and access output markets). To this end, the project, for example, promoted practices such as the use of sex pheromone traps and organic pesticides, the use of pathogen-free post larvae, grading and sorting of vegetables, and protected and hygienic storage of produce.

Improved access to output markets is expected to be important for farmers to obtain better prices for their farm produce. Supermarket Agora, for example, is willing to pay a price premium for mangoes if farmers meet their requirements. However, not only larger companies are expected to pay better prices for better quality products. Some practices are expected to improve product quality and yield better prices, regardless of market outlet. These include protected storage, washing, and sorting of vegetables, improved cow feeding practices to increase fat-content in milk, and more regular and selective harvesting in aquaculture. In turn, access to out-put markets and the possibility of obtaining higher prices for produce also can provide an incentive to farmers to invest and change practices.

Finally, it is expected that higher prices in combination with higher total production will lead to higher farm revenue. Although it is expected that, as a result of better access to input markets, farm expenditures will increase as well, the net-effect on household income is expected to be positive. Finally, it is expected that higher income contributes to a reduction in food insecurity.

A second aspect that is central to the project is the simultaneous use of a push and pull strategy: value chain actors are both incentivized and enabled to invest and change their practices. This can be illustrated by Safal's activities in the Mango sector. The project first entered into an agreement with the domestic retailer Agora to introduce a high quality pesticide free mango variety on the shelves of the supermarkets of Dhaka. As the demand for pesticide-free mangoes is high and the supply low, Agora was willing to provide farmers with a price premium. The project supported their mango producer groups to meet Agora's requirements by promoting the adoption of organic pesticides, pheromone traps (to capture insects), and post-harvest practices (i.e. hygienic handling of produce, grading, sorting, and packaging). To achieve this, farmers were in need of services (e.g., collection centers and transport services) and farm inputs (e.g., pheromone traps and organic pesticides). This, in turn, provided an incentive for entrepreneurs to invest and provide these inputs. To ensure that they are able to do this the project supported these entrepreneurs financially and technically and negotiated discounts with the farm input companies.

The SAFAL program fits the conceptualization of a direct public-led value chain development program as discussed in Section 2. The program is initiated, financed, and implemented by (semi-) public actors: the Netherlands Ministry of Foreign Affairs and the NGO Solidaridad. It directly intervenes at key stages and linkages of the value chain by assisting farmers and farm input/service providers and by reducing the transaction costs between farmers, input companies, and buyers. Finally, the primary goal of the program is to improve the effectiveness of the value chains in creating better outcomes for farmers in terms of higher income and improved food security.

## 4.5 Identification Strategy

The goal is to estimate the average effect of the project on participating farmers. This effect is defined as the average difference in the observed outcome for farmers participating in the project and the outcome that would have been observed if these farmers would not have participated (i.e. the counterfactual). Using the potential outcome framework (Roy 1951; Rubin 1974; Splawa-Neyman, Dabrowska, and Speed 1990), this can be written more formally as

$$\gamma = E[Y(1)|D = 1] - E[Y(0)|D = 1] \tag{1}$$

with $\gamma$, the average effect on project participants, $D$ the participation status (equal to one if the farmer is a participant and equal to zero otherwise), and $Y(D)$, the potential outcome as a function of participation. Because the counterfactual ($Y(0)|D = 1$) is unobserved (by definition), it must be estimated. This is done by using outcomes observed for farmers that did not participate in the project (a control group).

A random selection of control farmers is, however, expected to be different in observable and unobservable ways from project participants, making a simple comparison of outcomes biased. There are two reasons why this is the case. First, the NGO decided in which communities the project is implemented and which farmers are eligible for participation. It does this based on a number of criteria. The community, for example, should contain an adequate number of small farmers in a given sub-sector (aquaculture, dairy, or horticulture) willing to participate in a producer group, it should have sufficient potential for improving production and marketing practices, and it should be relatively food insecure. Farmers are only eligible for participation if they are active in either aquaculture, dairy, or horticulture and willing to form a group. Not taking this into account can lead to so called program placement bias at the village and farmer level. Secondly, as participation is voluntary, farmers "self-select" as participants in the project. It is likely that farmers who decide to participate are different from those farmers that decide not to participate in ways that are observable (e.g., age, land size, or productivity) and unobservable (e.g., entrepreneurial ability, risk preferences, and locus of control). In other words, participation is not random.

To overcome program placement and self-selection bias, this chapter relies on a matched difference-in-differences (MDID) estimator (Heckman et al. 1998). Following Heckman et al. (1997) and Smith and Todd (2005), this estimator is given by:

$$MDID = \frac{1}{n_1} \sum_{p \in N_1} \left\{ \left(Y_{p,t=1} - Y_{p,t=0}\right) - \sum_{c \in N_0} W(p,c) \left(Y_{c,t=1} - Y_{c,t=0}\right) \right\} \quad (2)$$

where $Y$ is the outcome of interest, $p$ is an individual participant in the set of project participants $N_1$ that are included in the estimation, $c$ is an individual control farmer in the set of control farmers $N_0$, $n_1$ is the number of participants in the set $N_1$, and $t$ is the time with $t = 0$, the start of the project and $t = 1$, the end of the project. The weights $W(p, c)$ are obtained through a matching procedure (see below).

Like a normal difference-in-differences estimator (without matching) it compares the difference in outcome before and after the project between a group of participants and a control group. This allows for controlling for unobservable time-invariant farm characteristics that are related to both the participation-decision and the observed outcomes. The key assumption underlying a difference-in-difference estimator is that in absence of the project the average outcomes for the control and treatment group would have moved in parallel direction. This assumption is less likely to be valid if the participants and control farms have different pre-project characteristics, because this might cause different reactions to common trends and shocks, such as to weather shocks, infrastructural development, or the economic-boom in the aquaculture sector (Abadie 2005).

To improve the comparability through time, project participants are matched with control farmers based on observable pre-project characteristics.[38] This is done based on the propensity score $e(X) = Pr(D = 1|X)$: the probability that a farm participates in the project conditional on observable farm characteristics $X$. Rubin and Rosenbaum (1983) showed that if potential outcomes are independent of participation conditional on covariates X, they are also independent of participation conditional on the propensity score $e(X)$.

To calculate the propensity scores I run a probit regression with participation (0 or 1) as dependent variable and a list of covariates (pre-project farm household characteristics) that are expected to influence both participation and the outcomes of interest. The propensity score for each household is then obtained by taking the predicted value of the estimated probit model.

38 Both village and farmer level characteristics are used to match control and treatment farmers. Matching thus helps in reducing bias as a result of village and farmer program placement and self-selection. An additional way in which program placement bias is reduced is by selecting the sampling area for control farmers that match the characteristics of project areas in terms location (i.e. by using neighboring regions), agricultural production structure, and geography. See Section 6 for more details.

The covariates included in the model cannot be affected by participation in the project. To ensure this, they should therefore either be constant over time or measured before the start of the project (Caliendo and Kopeinig 2008). In addition, it should be taken into account that omitting important covariates can increase bias in estimating the effectiveness, while including too many unimportant covariates can increase the variance of the propensity score (see Heckman et al. (1997), Dehejia and Wahba (1999), and Bryson et al. (2002) cited in Caliendo and Kopeinig (2008)). With this in mind, I included the pre-project age, gender, and education of the household head, the size of the household, the distance of the household to the main road, whether the farmer produced any dairy, horticulture, or aquaculture products in the year before participation, the size of the land owned by the household, the length of the hungry season, yearly wage income, yearly income from renting out land, the percentage of production sold, total production value, and farm expenditures.

Kernel matching is used to obtain the weights $W(p,c)$ in Equation (2). This procedure matches each participant with a weighted average of *all* control observations (see Heckman et al. (1997) and Caliendo and Kopeinig (2008) for more details).[39] It gives a higher weight to those control farmers that have a propensity score closer to the propensity score of the participant.

Only those observations are included that are within the common support. This means I drop the observations from the control group that have a propensity score lower than the minimum propensity score in the group of participants and those observations from the group of participants that have propensity score higher than the maximum propensity score in the control group.

Finally, I rely on the following weighted linear regression model to obtain the MDID estimator:

$$Y_{it} = \beta_0 + \beta_1 t + \beta_2 D_i + \beta_3 D_i * t + e_i \tag{3}$$

where $\beta_3$ is the MDID estimate of the project effect, obtained using weights equal to unity for participants and equal to $\sum_{p \in N_1} \sum_{c \in N_0} W(p,c)$ for the control households. Standard errors are obtained by bootstrapping (1000 repetitions). Each repetition includes the re-estimation of propensity scores, kernel

39 More precisely, using an epanechnikov kernel function and a bandwidth of 0.05, the weight of a control household that is matched to one project participant is given by
$W(p,c) = \frac{3}{4}\left(1 - \left(\frac{e(X^p)-e(X^c)}{0.05}\right)^2\right) / \sum_{k \in N_0} \frac{3}{4}\left(1 - \left(\frac{e(X^p)-e(X^k)}{0.05}\right)^2\right)$, with $\left|\frac{e(X^p)-e(X^c)}{0.05}\right| \leq 1$.

matching, dropping of observations outside the common support, and a re-estimation of Equation (3) using the newly obtained weights.[40]

## 4.6 Data

### *4.6.1 Survey*

The data used in this chapter were collected in the project upazilla's (sub-districts) of Manirampur, Abhaynagar, Dumuria, and Paikgacha in April-June 2014 and 2016. These upazilla's were selected because implementation in these upazilla's would start immediately after the baseline survey. The survey was commissioned and financed by the Policy and Operations Evaluation Department of the Netherlands Ministry of Foreign Affairs (as part of a review of the food security policy of the Netherlands) and implemented by a consortium of APE, AIDEnvironment, and BRAC University / Development Research Initiative (DRI).

Within the project upazilla's, ten project unions were selected where SAFAL planned to start implementation immediately after the baseline survey: two in Dumuria, two in Paikgacha, three in Manirampur, and three in Abhaynagar. Then, to reduce the risk of spillovers but to ensure comparability over time, each project union was matched with a nearby control union in the same upazilla with similar characteristics (such as agricultural production structure, nearness to a regional town, and geography). See Figure 3 for a map with the resulting selection of project (green) and control unions (red). Although the control unions in the north are further from the district capital Khulna, they are in no sense more remote as they are close to the district capital of Jessore to the North (not on the map)

Households were selected using clustered random sampling at the village level. First, 27 project and 27 control villages were sampled randomly within the 10 project and control unions, respectively. Secondly, in each project village ten households were sampled randomly from a list of project participants. In the control village, ten households were sampled from a list of all households in the village that were active in either horticulture, aquaculture, or dairy.

### *4.6.2 Operationalization of outcome variables*

Following the intervention logic (see Figure 3), I estimate the effect of the project on several indicators. First, output market participation is used as a proxy for output market access. Output market participation is defined as the gross

[40] The main estimation uses stata package "diff" (Villa 2016).

value of farm sales divided by the gross value of all products produced by the farm (Govereh, Jayne, and Nyoro 1999; Strasberg et al. 1999). Included are the production and sale of products from agriculture, aquaculture, and livestock rearing. Sales and production values are calculated based on product-specific median prices reported in the sample. The use of median prices is necessary to assign a value to products not sold. Median prices are kept constant over time to assure that any variation results from a change in proportion of produce sold.

The value of total production measured against medium prices in the pooled 2014 and 2016 sample is used as a proxy for farm production. Alternative indicators such as production in kilograms or agricultural yield are not viable, because project participants have highly mixed farming systems: they typically produce multiple agricultural crops in combination with multiple types of fish and livestock products.

Farm revenue is measured by the total earnings resulting from the sale of agriculture, aquaculture, and livestock products. In contrast to the value of total production, farm revenue uses the actual prices reported by the farmers (and not the median prices).

Two indicators are used to get some insight in the welfare effects of the project: farm profit and net farm income. Farm profit is defined as farm revenue minus farm expenditures. Net farm income is defined as the value of farm production minus farm expenditures. Farm expenditures include expenses on seed, fertilizer, pesticides, labor, irrigation, fish feed, fingerlings, veterinary products/advice, and livestock feed. The use of farm profit is more common, but this can only give a partial idea of the overall welfare effects in a context where farmers consume a large part of what they produce. In this case, looking at the total value of production minus costs would result in a more comprehensive assessment of the welfare effect.

Finally, the number of months in the past year in which households were worried about not having enough food (the length of the hungry season) is used as a proxy for food security (Bilinsky and Swindale 2010). This indicator measures the number of months in which the household did not have secure access to food

### *4.6.3 Descriptive statistics*

Table 2 presents the 2014 descriptive statistics for the project participants and control group and a balance test. Four project participants and four control households could not be re-interviewed 2016. In addition, fourteen observations are dropped because they contained outliers in terms of farm revenue. As a result, the total sample size used in the analysis contains 253 project participants and 265 control households.

Among the project participants, 175 households participated in a producer group around aquaculture, 54 in a producer group around dairy, and 42 in a producer group around horticulture. These households are spread out over 25 different aquaculture groups, 14 dairy groups, and 5 horticulture groups.

There are large differences between project participants and control households. In general, project participants tend to be better off as they have a higher farm revenue, a higher total production value, are better educated, own more land, and have higher output market participation. In addition, a (much) larger percentage of the project participants is a producer of aquaculture.

These differences in household characteristics are particularly important in light of our identification strategy. To reiterate Section 5, large pre-project differences make it less likely that the parallel trends assumption underlying the difference-in-difference estimation is valid. The fact that there are large difference in our case underlines the importance of matching the project participants with control farmers on pre-project characteristics.

In 2016, all farmers were asked whether they experienced an improvement in market access, access to technology, and prices. Project participants were more likely to report a positive change on all these aspects. About 92% of the project farmers reported to have experienced improvements in market access (vs. 64% in the control group), 66% experienced better access to technologies (vs. 35% in the control group), and 83% experienced better prices (vs. 62% in the control group). Although this subjective reporting is not sufficient to conclude that the project has been successful, it does warrant a further investigation.

## 4.7 Estimation Results

### *4.7.1 Project participation and matching*

Table 3 displays the results of the probit regression of participation in the project on the pre-project farm household characteristics. These results suggest that project participation in our sample is positively associated with the size of land holdings, production value, and being an aquaculture producer, and negatively associated with being a horticulture producer.

Figure 4 shows the distribution of the propensity scores of project participants and the control group. The two distributions are substantially different, with a much larger group of control farmers with low propensity scores. This further confirms the importance of matching prior to calculating the difference-in-difference estimator. Importantly, there is sufficient overlap of the distribution of the control group with the distribution of the project participants. This implies that there are project participants and control households with similar observable characteristics. However, eleven households from the control group (on the low end of the distribution) and eighteen households from the treatment group (on the high end) fall outside the common support area and are thus dropped from the sample. The remaining sample that falls within the common support thus includes 255 control households and 234 project participants.

See Table 4 for the descriptive statistics after the matching procedure. According to a two sample t-test, the two groups have become more similar in characteristics as result of the matching procedure. In fact, after applying the kernel weights, there are no statistically significant pre-project differences in average household characteristics remaining between the control and project group.

*4.7.2 Main estimation*

Using the kernel weights obtained through the matching procedure, Table 5 presents the 2014 and 2016 mean values for the four outcome indicators, the 2014 and 2016 differences between control and project group, and the double-difference estimate of the average project effect on the project participants. Before looking at the double-difference estimates, it is good to observe that the sample was balanced in 2014 in terms of pre-project outcomes: there are no statistical significant differences between the project group and kernel weighted control group in any of the outcome indicators prior to the intervention.

The double-difference estimates (last column of Table 5) suggest that there is a high likelihood that the project has had a positive effect on all our outcome indicators. According to our best estimation, project participation (on average) increased output market participation by 13% ($P$=0.009), the value of farm production by USD 704 ($P$=0.011), and farm revenue by USD 472 ($P$=0.017). In other words, it is estimated that farmers, as a result of project participation, started to produce more (in monetary terms), sold a larger percentage of what they produced, and, as a result, increased their farm revenue.

For a better indication of the net-income effect of the project, changes in farm expenditures must be take into account. According to the results, farm expenditures went up with USD 300 ($P$=0.015), on average, as a result of the project. A higher use of (purchased) farm inputs of higher quality was a project objective, so this was expected. In fact, it might be the case that production went up *because* of higher farm expenditures.

These input expenditures are subtracted from the value of production to estimate the net-income effect and from total farm revenue to estimate farm profits. According to our point estimates, net-farm income went up by USD

404 ($P$=0.037) and farm profits increased by USD 172 ($P$=0.243). The lower coefficient, in combination with a high standard deviation, means that there is quite some uncertainty regarding the estimated effect on farm profits. The statistically significant effect on net-farm income does suggest, however, that the overall welfare effect of the project has been positive.

Finally, it is also estimated that the project led to a reduction in the length of the hungry season by about 0.4 months ($P$=0.023). Assuming 30 days per month, this would imply an average reduction in the time in which households feel food insecure of about 12 days. This is a reduction of about 62% compared to 2014.

### *4.7.3 Robustness*

The robustness of these findings is checked by estimating several alternative specifications (see Table 6 for a summary of the matched difference-in-difference estimates for the different specification and different outcome variables). First, I check whether the results are sensitive to the applied matching function by (a) increasing the kernel bandwidth to 0.1; (b) decreasing the bandwidth to 0.02; (c) applying three-to-one nearest neighbor matching with replacement as an alternative to kernel matching (see Caliendo and Kopeinig 2008); and (d) using weights equal to unity for the participating farmers and equal to e(X)/(1-e(X)) for control farmers as suggested by Hirano and Imbens (2001) and Hirano et al. (2003).

I also check whether the results are sensitive to the choice of matching variables by (e) excluding all outcome variables in the matching procedure following the critique by Chabé-Ferret (2017) and by (f) excluding all time-variant variables following the critique by Daw and Hatfield (2018).

Next, I use an inverse hyperbolic sine (IHS) transformation for farm revenue, production value, input expenditures, wage income, income from land rent, farm profit, and net farm income instead of the absolute values. The IHS transformation can be necessary because these variables have right-skewed distributions that can skew the estimates. In a way, the risk of skewed estimates is already reduced by trimming the data at the 99th percentile of farm revenue, but this might not be sufficient. Like the more conventional log-transformation, the IHS transformation returns a distribution closer to normal without the skewness but allows for retaining observations that have a value of zero (Burbidge, Magee, and Robb 1988). Finally, I also check whether not trimming the data at the 99th percentile of farm revenue changes the results (specification h).

All of the alternative specifications yield results similar to the main estimates presented in Table 5: none of alternative estimates is significantly different from the estimates using the main model. The point estimate for the net farm income effect using specification (e) and (f) is, however, quite a bit lower than the estimates using our main specification (i.e. to such extent that it is not statistically significant any more). One potential explanation is that using the alternative specifications resulted in statistically significant differences in pre-project characteristics between the control and project group after the matching procedure. In particular, the average pre-project farm revenue, production value, farm profit, and net farm income were significantly higher for the project participants than for the matched control group.

## 4.8 Summary and concluding remarks

In this chapter I have defined value chain development as an intervention that intends to increase the effectiveness and/or efficiency of a specific value chain by reducing the transaction costs between different stages and/or by supporting specific value chain actors. Value chain effectiveness in this context is understood as the ability of the value chain to comply with public or private requirements, such as regarding product quality, food safety, or ethical and environmental standards. Value chain efficiency, in turn, is understood as the costs incurred in the value chain to bring forward the final product that meets these requirements.

In a context characterized by imperfect markets, VCD can be a relevant intervention to be initiated not only by private actors but also by (semi-) public actors, such as governments, international organizations, and NGOs. From a public perspective, poorly functioning agri-food value chains can have negative consequences for economic growth, for the welfare of farmers and laborers in these value chains, for the environment, and for the quality and safety of consumer products. The combination of market failure and high social costs can justify public interventions in specific value chains. It is unclear, however, to what extent VCD is an effective policy instrument for improving value chain functioning and achieving better outcomes.

As an illustration of public-led VCD, this chapter described the SAFAL project by the NGO Solidaridad that directly intervened in aquaculture, horticulture, and dairy value chains in South-West Bangladesh. By reducing the transaction costs between farmers on the one hand and buyers and providers of farm inputs on the other and by supporting key value chain actors, the project had the intention to improve the welfare and food security of about 58,000 smallholders. Central to the project was a push-and-pull strategy whereby value chain actors are both enabled and incentivized to invest and change their practices.

Using a matched difference-in-difference methodology, I estimate that SAFAL in-creased output market participation, total production, farm revenue, and net-farm income, and that it reduced the length of the hungry season experienced by farm households.

There are, however, a number of limitations to the applied estimation strategy. First, although the matched difference-in-difference estimator allows for controlling for a large number of household characteristics, it cannot completely exogenize project participation. Secondly, the outcome indicators are mere proxies for the actual project effects. It is yet unclear, for example, whether the project improved prices received by farmers and other aspects of food insecurity. In addition, the study has not captured the longer term effects of the project. It is yet unclear, for example, whether the newly established institutional structure will continue to exist also after the project ends. Lastly, and perhaps most importantly, there might be (unintentional) consequences that are not taken into account here. The project might, for example, have led to substitution of project farmers for non-project farmers in certain high-value value chains. Other stakeholders, which are not accounted for in the assessment include the supported micro-entrepreneurs, laborers in the value chains, and consumers.

This chapter showed that public-led value chain development can be a relevant and potentially effective strategy to stimulate commercialization, increase food production, improve smallholder welfare, and reduce food insecurity. Obviously, this does not imply that value chain development will be effective as a policy instrument in any way it is implemented in any type of context. More research is needed to get a better grasp at what type of value chain intervention works best in what context. In addition, future research could use better identification strategies, such as randomized controlled trials, and could look beyond the immediate effects on farmers, to improve the assessment of its effectiveness.

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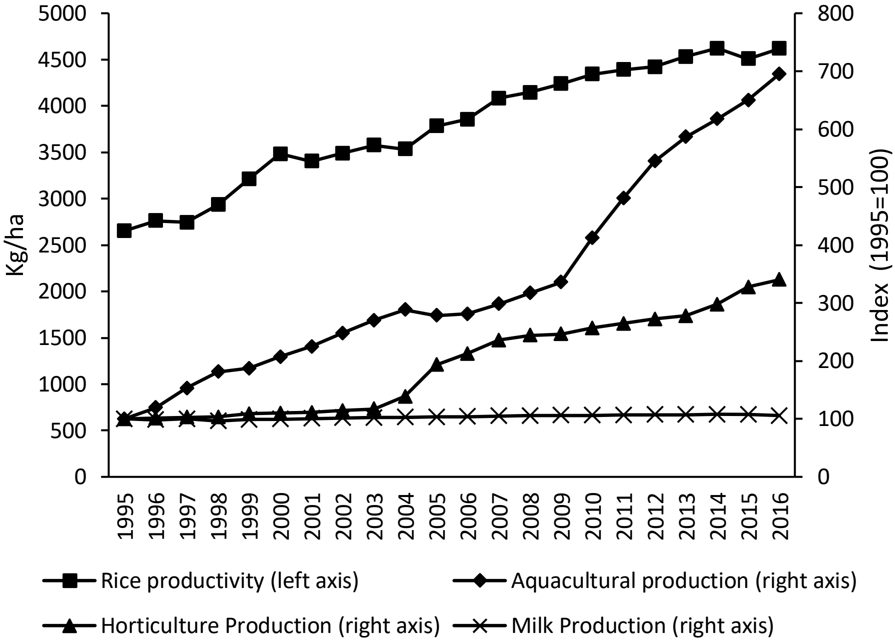
## 4.10 Figures

**Figure 1: Rice productivity and production growth of aquaculture, horticulture, and dairy (tonnes)**




*Source: FAOstat and FAO - Fisheries and Aquaculture Information and Statistics Branch (accessed on 06/04/2018).*

**Figure 2: Simplified intervention logic**

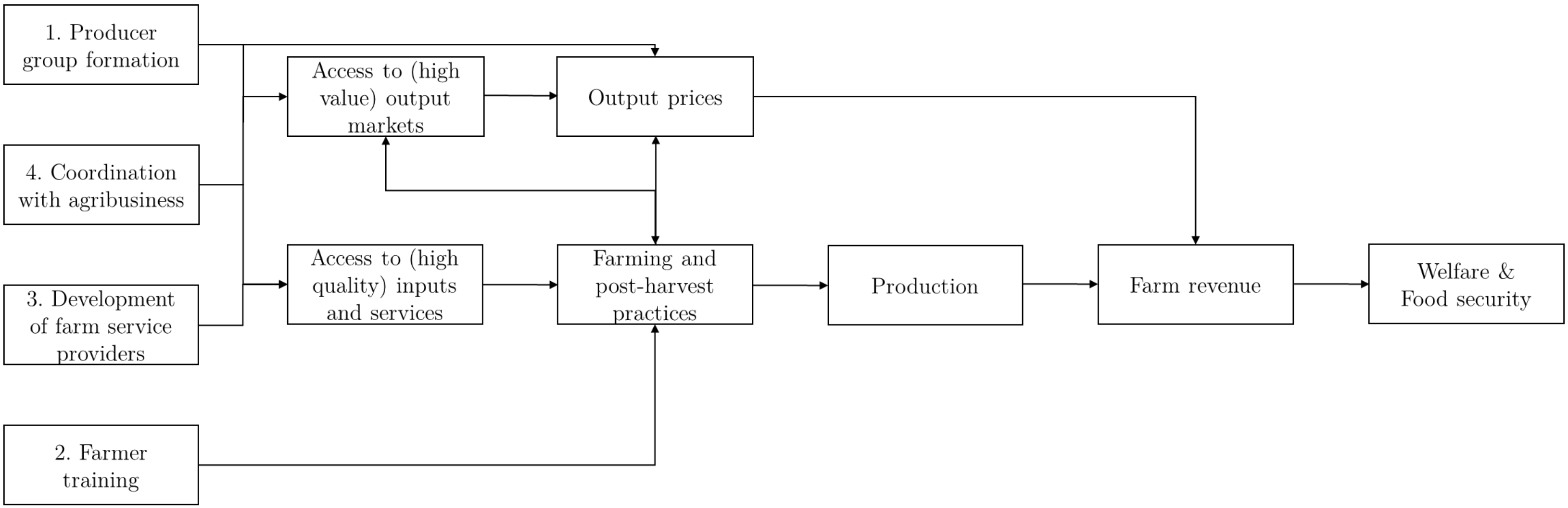


**Figure 3: Map of surveyed project (green) and control (red) unions**

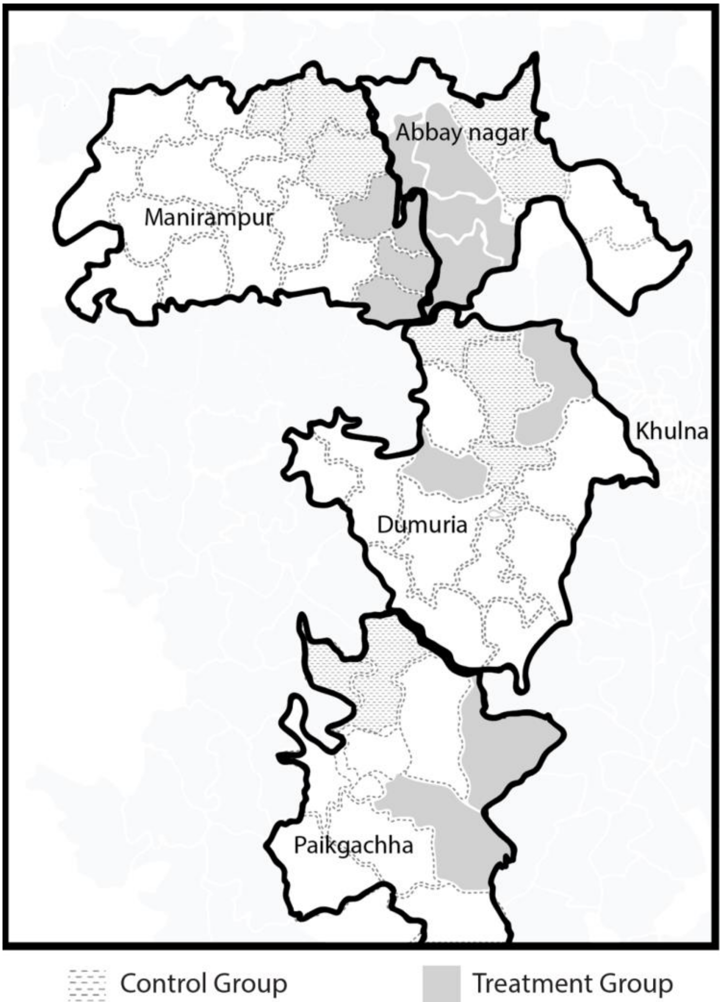
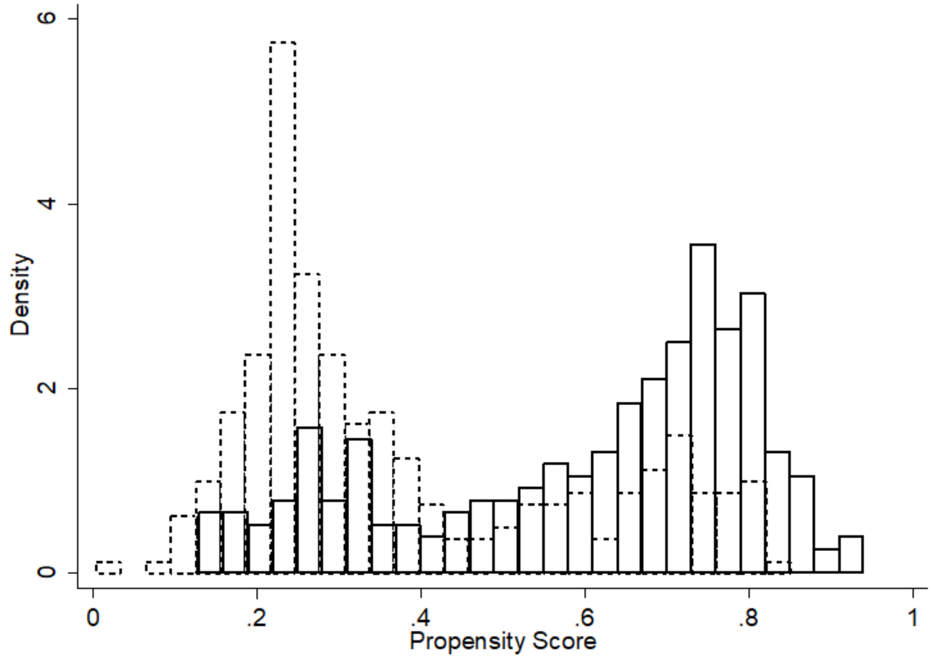


**Figure 4: Distribution of propensity scores of project participants (solid line) and control group (dashed line)**



## 4.11 Tables

**Table 1: Overview of project activities divided by component and sub-sector**

| | Sub-sector | | |
|---|---|---|---|
| **Component** | **Aquaculture** | **Dairy** | **Horticulture** |
| **Farmer Training** | Pond preparation (e.g., regular draining and cleaning of ponds, applying lime and fertilizer, use of synthetic nets).<br>Stocking practices (e.g., nursing before stocking, determining optimal stocking density).<br>Water testing (pH-level, temperature, concentration of phyto and zoo plankton) and use of probiotics.<br>Feeding practices (precise dosage and timing, use of concentrated feeds, production of homemade feed).<br>Promotion and information on the importance of high quality (pathogen free) fingerlings.<br>Harvesting practices (frequent harvesting, selection based on size) .<br>Post-harvest handling (hygienic practices, use of trays). | Hygienic milking and handling (hand washing, cleaning udder, immediate transport to collection center).<br>Feed practices (e.g., use of concentrated feed and green grasses, production of homemade feed)<br>Improved shed management.<br>Promotion of deworming, vaccination, and medical check-ups.<br>Promotion of AI and cross-breeds. | Promotion of organic fertilizer (vermicompost, compost).<br>Promotion of safe and natural pest management technologies such as sex pheromone traps and bio pesticides.<br>Promotion of post-harvest practices (e.g., harvesting at maturity, protected storing, washing, grading, sorting, packaging (using paper), protected transport (using crates)). |
| **Support to farm service providers** | Lead farmers (selling inputs, technical support)<br>Collection centers<br>Cooled transport services<br>Fish food producers | Lead farmer (selling inputs, technical support)<br>Collection centers<br>Local input shops (feed, medicine)<br>Community livestock Service providers (deworming, vaccination, medical check-ups, medicines)<br>Fodder and silage production<br>Milk transportation | Lead farmer(selling inputs, technical support)<br>Collection centers<br>Nurseries<br>Local input shops<br>Vegetable Collectors and sellers<br>Organic compost producers |
| **Coordination activities with agribusiness** | With hatcheries 'R. Rahman' and 'Anik Hatchery' to supply farmers with high quality pathogen free post larvae (incl. discounts and credit facilities)<br>With processor/exporter M.U. Seafood (incl. establishment and support to collection center) | With dairy processor BRAC (establishment of five dairy collection centers, payment based on fat content, feed discount)<br>With Winning Agro, a company providing calf management solutions (financing pilots)<br>With DLS for artificial insemination services | With supermarket AGORA and other retailers and domestic traders (incl. transport support, provision of crates)<br>Several providers of seeds, chemicals, and equipment (discounts, cost-sharing of demo-plots, training support) |

**Table 2: Descriptive Statistics for Control and Project group**

| Variables | Control | Project | Difference, p-value |
|---|---|---|---|
| Household head age | 49.211 | 48.783 | 0.670 |
| (years) | (0.673) | (0.818) | |
| Household head female | 0.034 | 0.024 | 0.289 |
| (dummy) | (0.008) | (0.006) | |
| Household head education: | | | |
| - Some primary | 0.196 | 0.138 | 0.189 |
| (dummy) | (0.033) | (0.027) | |
| - Finished primary | 0.121 | 0.083 | 0.092 |
| (dummy) | (0.018) | (0.014) | |
| - More than primary | 0.370/ | 0.549 | 0.002 |
| (dummy) | (0.028) | (0.046) | |
| Land size owned | 0.414 | 0.685 | 0.015 |
| (hectare) | (0.086) | (0.058) | |
| Household size | 4.581 | 4.933 | 0.014 |
| (# of household members) | (0.074) | (0.117) | |
| Wage income | 372.405 | 293.726 | 0.227 |
| (USD/year) | (44.399) | (46.440) | |
| Income from land rent | 59.969 | 76.409 | 0.629 |
| (USD/year) | (26.541) | (21.715) | |
| Milk Producer | 0.117 | 0.190 | 0.170 |
| (dummy) | (0.034) | (0.040) | |
| Aquaculture producer | 0.302 | 0.723 | 0.000 |
| (dummy) | (0.068) | (0.043) | |
| Horticulture producer | 0.170 | 0.154 | 0.751 |
| (dummy) | (0.028) | (0.042) | |
| Distance to main road | 0.128 | 0.072 | 0.123 |
| (kilometer) | (0.031) | (0.016) | |
| Output market participation | 0.308 | 0.516 | 0.001 |
| (sold/produced) | (0.036) | (0.039) | |
| Production value | 614.454 | 1476.137 | 0.003 |
| (USD) | (107.705) | (230.100) | |
| Farm Revenue | 252.475 | 780.925 | 0.006 |
| (USD) | (59.216) | (156.906) | |
| Farm expenditures | 259.424 | 511.150 | 0.018 |
| (USD) | (48.150) | (84.282) | |
| Farm profit | -6.949 | 269.775 | 0.005 |
| (USD) | (27.472) | (79.130) | |
| Net farm income | 355.030 | 964.986 | 0.002 |
| (USD) | (65.542) | (152.484) | |
| Length hungry season | 1.026 | 0.708 | 0.109 |
| (Months) | (0.143) | (0.125) | |
| N | 265 | 253 | |

**Table 3: Probit regression for propensity score weighting**

| Variables | Project participation |
|---|---|
| Household head age | -0.002 |
| | (0.005) |
| Household head female | 0.024 |
| | (0.369) |
| Household head education: | |
| - Some primary | 0.038 |
| | (0.192) |
| - Finished primary | -0.115 |
| | (0.230) |
| - More than primary | 0.207 |
| | (0.167) |
| Land size owned | 0.253** |
| | (0.117) |
| Household size | 0.049 |
| | (0.039) |
| Wage income | 0.000 |
| | (0.000) |
| Income from land rent | -0.000 |
| | (0.000) |
| Milk Producer | 0.104 |
| | (0.176) |
| Aquaculture producer | 0.878*** |
| | (0.149) |
| Horticulture producer | -0.374** |
| | (0.170) |
| Distance to main road | -0.340 |
| | (0.354) |
| Output market participation | 0.223 |
| | (0.236) |
| Production value | 0.000* |
| | (0.000) |
| Farm expenditures | -0.000 |
| | (0.000) |
| Length hungry season | 0.057 |
| | (0.039) |
| Constant | -1.006*** |
| | (0.337) |
| N | 518 |

Only the pre-project data captured in the 2014 survey is used.

**Table 4: Two sample means, differences, and t-statistic after kernel weighting**

| Weighted Variable(s) | Mean Control | Mean Participants | Difference | t-statistic |
|---|---|---|---|---|
| Household head age | 47.812 | 48.838 | 1.026 | 0.81 |
| Household head female | 0.020 | 0.026 | 0.006 | 0.45 |
| Household head education: | | | | |
| - Some primary | 0.163 | 0.145 | -0.018 | 0.54 |
| - Finished primary | 0.085 | 0.081 | -0.004 | 0.15 |
| - More than primary | 0.544 | 0.543 | -0.002 | 0.04 |
| Land size owned | 0.700 | 0.641 | -0.060 | 0.85 |
| Household size | 4.741 | 4.850 | 0.109 | 0.77 |
| Wage income | 293.906 | 292.100 | -1.807 | 0.04 |
| Income from land rent | 87.642 | 69.963 | -17.679 | 0.73 |
| Milk Producer | 0.168 | 0.179 | 0.011 | 0.33 |
| Aquaculture producer | 0.701 | 0.705 | 0.004 | 0.11 |
| Horticulture producer | 0.192 | 0.167 | -0.025 | 0.73 |
| Distance to main road | 0.081 | 0.076 | -0.005 | 0.41 |
| Output market participation | 0.504 | 0.495 | -0.008 | 0.27 |
| Production value | 1244.403 | 1184.508 | -59.895 | 0.54 |
| Farm expenditures | 499.319 | 468.940 | -30.379 | 0.66 |
| Length hungry season | 0.628 | 0.645 | 0.017 | 0.13 |

**Table 5: Double difference estimation (after kernel matching)**

| Outcome | Mean 2014 Control | Mean 2014 Project | Difference 2014 | Mean 2016 Control | Mean 2016 Project | Difference 2016 | Double Difference |
|---|---|---|---|---|---|---|---|
| (1) Output market participation | 0.504 | 0.495 | -0.009<br>(0.037) | 0.437 | 0.560 | 0.123***<br>(0.037) | 0.131**<br>(0.051) |
| (2) Production value | 1244 | 1185 | -59.90<br>(161.2) | 1232 | 1876 | 643.9***<br>(209.6) | 703.8***<br>(261.2) |
| (3) Farm revenue | 558.7 | 597.6 | 38.93<br>(103.4) | 845.5 | 1356 | 510.7***<br>(166.6) | 471.7**<br>(198.0) |
| (4) Farm expenditures | 499.3 | 468.9 | -30.38<br>(62.1) | 720.9 | 990.4 | 269.5**<br>(106.9) | 299.9**<br>(121.4) |
| (5) Farm profit (3-4) | 59.38 | 128.7 | 69.31<br>(82.6) | 124.7 | 365.8 | 241.1**<br>(107.7) | 171.8<br>(132.3) |
| (6) Net farm Income (2-4) | 745.1 | 715.6 | -29.52<br>(130.9) | 511.5 | 885.9 | 374.4**<br>(159.5) | 403.9*<br>(213.2) |
| (7) Length hungry season | 0.628 | 0.645 | 0.0170<br>(0.126) | 0.690 | 0.303 | -0.386***<br>(0.131) | -0.403**<br>(0.180) |
| N (on common support) | 255 | 234 | | 255 | 234 | | |

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

**Table 6: Summary of robustness checks: reporting the matched difference-in-difference estimates using different specifications**

| Model | Output market participation (1) | Production value (2) | Farm revenue (3) | Farm Expenditures (4) | Farm Profit (5) | Net farm Income (6) | Length hungry season (7) |
|---|---|---|---|---|---|---|---|
| Kernel bandwidth of 0.1 | 0.132** | 701.7*** | 491.6*** | 304.1*** | 187.6 | 397.6** | -0.399** |
| | (0.051) | (239.3) | (176.9) | (112.6) | (130.7) | (189.7) | (0.180) |
| Kernel bandwidth of 0.02 | 0.135** | 729.6** | 476.4** | 314.0** | 162.4 | 415.6* | -0.455** |
| | (0.057) | (285.5) | (201.9) | (126.8) | (133.4) | (221.4) | (0.196) |
| One-to-three nearest neighbors matching | 0.120** | 664.4*** | 465.8*** | 277.4*** | 188.4* | 387.0** | -0.421** |
| | (0.0458) | (230.3) | (157.3) | (103.7) | (111.9) | (176.5) | (0.185) |
| Hirano and Imbens (2001) matching | 0.153*** | 632.2*** | 460.3*** | 318.8*** | 141.4 | 490.2** | -0.416** |
| | (0.0422) | (168.79) | (146.2) | (95.86) | (104.8) | (165.7) | (0.166) |
| Matching variables excl. all pre-project outcomes | 0.099** | 479.4** | 423.9*** | 346.9*** | 77.0 | 132.5 | -0.539** |
| | (0.047) | (239.4) | (159.0) | (103.5) | (117.6) | (190.2) | (0.172) |
| Matching variables excl. all time variant variables | 0.073 | 501.8** | 362.2** | 318.7*** | 43.5 | 183.1 | -0.507*** |
| | (0.051) | (229.7) | (167.0) | (114.2) | (124.0) | (193.4) | (0.172) |
| Using IHS transformation | 0.142*** | 0.692** | 0.701* | 0.559** | 0.915 | 1.766** | -0.433** |
| | (0.052) | (0.284) | (0.425) | (0.272) | (0.958) | (0.714) | (0.187) |
| Keep observations with outliers farm revenue | 0.128*** | 1095.0** | 763.5* | 288.0* | 475.5 | 807.05* | -0.367** |
| | (0.050) | (514.8) | (434.7) | (136.8) | (351.4) | (459.8) | (0.180) |

# Chapter 5. Agricultural Commercialization and Farm Household Diets: Evidence from Rwanda and Bangladesh*

## 5.1 Introduction

Agricultural commercialization—a process by which farmers increasingly participate in markets—is widely acknowledged as a central aspect of economic development. By allowing farmers to specialize, to learn from trade-based interactions, and to use manufactured farm inputs, commercialization can increase agricultural productivity (Barrett 2008; Govereh et al. 1999; Strasberg et al. 1999), rural incomes (e.g., Haggblade et al. 1989; Muriithi and Matz 2015; Von Braun 1995; Zeller et al. 1998), and stimulate structural transformation (e.g., Barrett et al. 2017; Timmer 1988).[41]

There is, however, less consensus on how agricultural commercialization affects nutrition. At the macro-level, it is debated to what extent higher agricultural productivity and food availability contributes to better access to nutritious and diverse diets for the poor (Ruel and Alderman 2013). At the micro-level, the discussion focuses on the agriculture-nutrition linkages within the farm household (e.g., Carletto et al. 2015). This is an important topic in the larger debate because many households in developing countries still depend on farming for their livelihood and a large share of these households suffers from undernutrition.[42]

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41 The causality from commercialization to agricultural productivity likely also runs in the other direction. See Barrett (2008) for a discussion on the close relationship between farmer market participation and technology adoption.

42 Carletto et al. (2017), for example, report that the prevalence of stunting (an indicator for severe micronutrient deficiencies) among children of farm households is 42% in Tanzania, 36% in Uganda, and 31% in Malawi.

Many agricultural development programs by governments, international organizations, and donors stimulate market participation by farmers for the economic reasons mentioned earlier but do not consider the implications for farm household nutrition.[43] In some cases, policies (implicitly) assume that the diet and nutritional status of farm household members will improve as a result of the income gains associated with market participation (see e.g., IOB 2018).

In this chapter we estimate whether commercialization in Bangladesh and Rwanda is indeed associated with better diets. This should increase our understanding of the short-term nutritional implications—whether unintentional or assumed—of a wide range of policies and programs that stimulate market participation by farmers, including infrastructural development (e.g., Omiti et al. 2009), support to farmer cooperatives (e.g., Chagwiza et al. 2016), and public value chain development (see Chapter 4 of this dissertation).

Our contribution to the literature is fourfold. First, we exploit the panel component of our dataset to estimate a fixed effects model that allows us to control for potential unobserved time-invariant confounders. To our knowledge, all rigorous studies that found evidence in support of a positive relationship between commercialization and nutrition are based on cross-sectional data and could therefore not control for unobserved time-invariant heterogeneity (Ogutu et al. 2017; Radchenko and Corral 2018; Shively and Sununtnasuk 2015; Von Braun and Kennedy 1994).[44] Carletto et al. (2017), using country-representative panel data from Malawi, Uganda, and Tanzania, is the only study we are aware of that uses a fixed effects model, but they find no evidence for a relationship between commercialization and nutritional status.

Second, we explore whether the relationship between commercialization and the quality of farm household diets is non-linear. The marginal effect of commercialization on nutrition might be different for households closer to self-subsistence than for households that already sell a large part of what they produce. We account for this possibility by also estimating a second order polynomial regression model.

Third, we look at the effect of commercialization on the quality of dietary intake, operationalized by a novel indicator called *nutrient adequacy*. This indicator uses household consumption data to compare actual intake of fifteen

[43] Stimulating market participation by farmers is, for example, an important objective in the agricultural development strategies by the government of Ethiopia (Federal Democratic Republic of Ethiopia 2015), the government of Uganda (The Republic of Uganda 2016), the International Fund for Agricultural Development (IFAD 2016), and the World Bank Group (see e.g., Horst and Polo 2016).

[44] Although there is a large body of literature from the 1970s and 1980s that emphasized the potentially adverse effect of commercialization on nutrition, it is mostly based on anecdotal evidence. For this reason, we do not discuss these studies here. For an extensive review of this literature see Von Braun and Kennedy (1986).

macro- and micro-nutrients with the recommended intake by WHO. Most of the literature instead looks at the effect on child nutritional status or on household food expenditure (e.g., Carletto et al. 2017; Shively and Sununtnasuk 2015; Von Braun 1995; Wood et al. 2013). We argue that actual dietary intake is a better indicator for dietary quality than food expenditure, because it also captures food consumed from own production and because higher food spending might not contribute to a better diet in terms of nutritional value. In addition we argue that it is a more sensitive indicator than child nutritional status, which is influenced by many other factors than diet (e.g., the disease environment, water and sanitation facilities, and access to health care). Others that have investigated the effect of commercialization on the quality of dietary intake used more crude measures, such as the food consumption score (Radchenko and Corral 2018), or only took into account the intake of a small number of nutrients (Ogutu et al. 2017).

Fourth, based on our conceptual model, we explore the underlying mechanisms. The literature that has found a positive effect of commercialization on the quality of diets invariably points at the effect on income as to why commercialization leads to better diets. We will test this mechanism, but we will also investigate whether there are other factors at play that can reduce or counteract this effect.

Our estimation results suggest that the average effect of agricultural commercialization on the quality of diets is limited. We find a modest positive effect of commercialization on both dietary diversity and nutrient adequacy in Rwanda, but we do not find evidence for a positive effect in Bangladesh. In fact, we find that commercialization in Bangladesh has had no effect on nutrient adequacy of diets and that it is associated with *less* dietary diversity. Moreover, in both Bangladesh and Rwanda, we find evidence that the relationship between commercialization and dietary quality is best characterized as concave. This suggests that commercialization does contribute to better diets for farm households that sell yet a small share of their production but that the effect diminishes with higher rates of commercialization and can become negative for households that are already sell a large share of the food they produce.

The remainder of this chapter is organized as follows. In the next section (5.2), we describe the conceptual model. Section 5.3 presents the data and discusses how we operationalize our main concepts. Section 5.4 discusses the identification strategy. Section 5.5 present the estimation results and some robustness test. Section 5.6. concludes this chapter by summarizing the findings and discussing some limitations and implications for policy makers.

## 5.2 Conceptual Model

The main hypothesis tested in this chapter ($H_1$) is that commercialization has a positive effect on farm household diets. This hypothesis relies on two underlying economic assumptions that are tested in this chapter as well.

The first assumption is that commercialization increases farm household income ($H_2$). Barrett (2008) explains why, since Adam Smith and David Ricardo, economists consider market participation as key for higher farm incomes. The classic reasoning is that market participation allows farm households to specialize in the products for which they are relatively skilled or well-endowed (e.g., owning land that is particularly suitable for the production of a specific crop). Instead of undertaking food production to satisfy the household's full range of food consumption needs, the farmer can specialize in the product for which it holds a comparative advantage, sell the surplus, and buy the food products for which it holds a comparative disadvantage. In addition, market participation can lead to further efficiency improvements and higher incomes by increasing the farmer's access to technologies (e.g., improved seeds, fertilizer, or equipment ) by relieving the farmer's liquidity constraints or through value chain technology transfer (see Chapter 2 and 3).

The second assumption is that higher incomes lead to more diverse and nutritionally adequate diets ($H_3$). This assumption is closely related to what is now commonly referred to as Bennett's Law (1941). This "law" is a well-established empirical regularity that income is negatively associated with the share of "starchy foodstuff" (e.g., wheat, potatoes, corn, or rice) in peoples diets. In other words, an increase in incomes is expected to lead to a more diversified diet in which non-starchy foodstuffs (e.g., vegetables, fruits, nuts, meats, fish, and dairy) are consumed more.

The main hypothesis that is being tested in this chapter logically follows from these two assumptions. If indeed market participation increases farm income and if this additional farm income is indeed used to diversify food consumption away from staple crops, it must be that market participation leads to more diverse (and better) diets for the farmer's household.

It remains a question, however, whether these two assumptions add up to a positive net-effect of commercialization on farm household diets or whether there are other factors at play that can reduce or counteract this effect. For our main hypothesis to be true we thus also need the assumption that commercialization has no negative effect on dietary diversity and nutrient adequacy through any other mechanism once the effect via household income is accounted for ($H_4$).

Recently, the literature has identified several potential alternative pathways through which agricultural commercialization can affect farm household diets (see e.g., Carletto et al. 2015). Two in particular have received much attention. First, if commercialization leads to specialization it might also lead to a reduction in the diversity of food produced and, as such, a reduction in the diversity of food the household can access from own production. This might lead to less diverse diets, particularly for households that have less market access (Hirvonen and Hoddinott 2013).[45]

Second, it is suggested that commercialization can shift production responsibilities and control over income from the women to the men in the household and increase the weight of the men's preferences in household (food) consumption decision making (see e.g., Chege et al. 2015; Fischer and Qaim 2012; Ogutu et al. 2017). In many rural contexts there exist a traditional division in male and female crops (Doss 2001; McPeak and Doss 2006). Commercial crops are typically the male's responsibility. Commercialization (selling a larger share of what is produced) can result in more decision making power for the men in the household if it leads to a shift from non-commercial to commercial crops. Various studies present evidence that income earned by female household members contributes more to household-level food expenditures, dietary quality, and food security than income earned by male household members (e.g. Chege et al. 2015; Duflo and Udry 2004; Van den Broeck et al. 2018).

## 5.3 Data and Descriptive Statistics

### *5.3.1 Survey data*

The analysis is conducted using household-level data collected in South-West Bangladesh and South-East Rwanda. All households were administered a country-specific questionnaire in the first half of 2014 and again in the first half of 2016 on topics such as agricultural production, marketing, and food consumption. The data were collected for the purpose of evaluating the effectiveness of three agricultural development projects in these regions (one in Rwanda and two in Bangladesh). These evaluations were commissioned by the International Research and Policy Evaluation Department of the Ministry of Foreign Affairs of the Netherlands (IOB 2018). Each survey has a strong regional focus

[45] Market participation might, however, also result in increased availability of nutrients if the household adopts the commercial crop next to its existing production for home consumption (e.g., in the form of a home garden) or if the household specializes in crops rich in nutrients (as observed, for example, by Chege et al. 2015).

and includes a random sample of project participants and control households.[46] This means the sample is not representative for the broad group of farm households in these countries. It is, however, illustrative for the type of farmers and regions targeted by agricultural development programs.

### *5.3.2 Operationalization of main concepts*

We follow Strasberg et al. (1999) and Govereh et al. (1999) by defining commercialization as the gross value of crop sales divided by the production value (i.e. the gross value of all crops produced). Sales and production values are calculated based on sample- and product-specific median prices. In addition to agricultural crops, we include the production and marketing of aquaculture (e.g., black tiger shrimp, tilapia, and carp) in the case of Bangladesh, where aquaculture is a key source of livelihood among farmers in the sample.

To measure dietary quality we use two proxies: household dietary diversity and nutrient adequacy of the household diet. Household dietary diversity is defined as the number of different food groups consumed by any household member in a given reference period (see Swindale and Bilinsky 2006).47 Dietary diversity measures are a relatively easy, quick, and popular way to measure the quality of the diet. Theory suggests that households will diversify into foods containing more micronutrients only when the basic caloric needs are met (Headey and Ecker 2013). This should make dietary diversity an appropriate indicator for both macro- and micronutrient intake. Empirical research tends to confirm this. Diet diversity scores are found to be positively correlated with macro- and micronutrient adequacy of the diet of non-breast-fed children (e.g., Kennedy et al. 2007; Steyn et al. 2006) and adults (e.g., Arimond et al. 2010). The most important disadvantage of this indicator is that it does not consider the actual quantity of macro- and micro-nutrients consumed. This makes dietary diversity as an indicator for dietary quality less sensitive and precise; i.e. a rise in dietary diversity might not translate in a higher dietary quality and vice versa.

Nutrient adequacy is defined as the nutrient content of the food consumed by the household (as a whole) as a percentage of the WHO recommended intake. The nutritional content of the food consumed by the household was calculated based on a 7-day household consumption and expenditure module that

[46] For project information and for the sampling frames used, see the detailed impact evaluation reports for each country on https://english.iob-evaluatie.nl/publications/policy-review/2017/10/01/419-—iob-—review-of-dutch-food-security-policy-2012-2016-—food-for-thought.

[47] The twelve food groups considered are cereals; roots and tubers; vegetables; fruits; meat and poultry; eggs; fish and seafood; pulses, legumes, and nuts; milk and milk products; oils and fats; sugar and honey, miscellaneous. The reference period is "yesterday", except for Rwanda, for which the reference period is "the last 7 days".

captures the consumption of 40 different food items in Rwanda and 70 food items in Bangladesh. The nutrient content of these food items were calculated using country-specific food composition tables. For Bangladesh, we used the food composition table by Shaheen et al. (2013). For Rwanda a country-specific food composition table did not exists. Instead we used the food composition tables by Lukmanji et al. (2008) for Tanzania and Hotz et al. (2012) for Uganda. The nutrients included were Energy (Kcal), protein, carbohydrates, calcium, iron, magnesium, zinc, Vitamin A, B1, B2, B3, B6, B9, B12, and C. The recommended intake is calculated for each household separately by taking the sum of the age- and gender-specific nutrient requirements of all household members (based on WHO and FAO (2004) and WHO (2007)). Dividing the actual intake of each nutrient by the WHO recommended intake and then taking the average over all nutrients gives us the average nutrient adequacy indicator we use in our estimations.48

Several studies have shown that food consumption measures based on household level consumption data are surprisingly comparable to individual level 24-hour recall data, which is generally regarded by nutritionists as the preferred dietary assessment method (see Sununtnasuk and Fiedler 2017 for a discussion of this literature). Since nutrient adequacy is measured at the household level we cannot, however, take into account any potential effect of commercialization on the intra-household distribution of food. Other weaknesses of the indicator used by us include the fact that it is based on crude food categories, that it cannot account for food eaten outside the home or for the preparation method, and that it is sensitive to recall bias (Fiedler et al. 2012). For these reasons, nutrient adequacy, as it is captured here, should not be interpreted in an absolute sense but merely as a proxy for actual nutrient intake.

### *5.3.3 Descriptive statistics*

After cleaning, the final sample includes 690 households in the Rwandan sample and 1088 households in Bangladesh.[49] Table 1 presents the descriptive statistics. In both countries, the sample consists mostly of small-scale farmers. The average land size cultivated in 2014 was about 0.6 hectare in both Rwanda and Bangladesh. These numbers are skewed upward by the inclusion of a small number of large farmers. Indeed, the share of farmers that cultivated less than one hectare is 78% in Rwanda and 84% in Bangladesh.

[48] If actual intake is equal or higher than the recommended intake the individual nutrient adequacy is set at 100%. This means this indicator only takes into account the effects on undernutrition and does not say anything on the effects of overnutrition or obesity.

[49] Between 2014 and 2016 18 households dropped out in Rwanda and 41 in Bangladesh. We do not correct for potential bias caused by this attrition, because the attrition rate is quite low.

In both countries, households produce a large diversity of crops and in the case of Bangladesh, fish and seafood. In Rwanda, all farmers produce cassava but typically combine this with the production of legumes or pulses (91%), cereals (maize) (54%), vegetables (48%), and fruits (38%). The sample from Bangladesh contains the most diversified farmers. Almost all farmers produce rice or some other cereal (93%), typically in combination with fish products from aquaculture (66%), livestock products such as eggs (62%) and milk (35%), spices (88%), vegetables (37%), fruits (37%), or pulses and legumes (28%).

A large part of what is produced by these farmers is consumed by their own households. The share of farm households that do not sell any of their produce is 25% in the Rwandan sample and 21% in the sample from Bangladesh. Among the farmers that do sell at least some of their produce, the average share of produce being sold is 40% in Rwanda and 57% in Bangladesh. What is sold are predominantly food products (as opposed to non-edible cash crops). Important products that are sold include cassava, maize, sorghum, and potato in Rwanda, and rice and fish in Bangladesh. Low market participation in combination with small land holdings means that average farm revenues are also low: USD 194 in Rwanda, and USD 587 in Bangladesh (for sellers). Across the three samples, net-income is higher among sellers than among non-sellers of produce.

Looking at dietary diversity, we see that the average number of different food groups consumed by the household is 7.6 in Rwanda and 7.5 in Bangladesh (out of a maximum of 12 food groups). It is important to note that the reference period for Rwanda is markedly longer, namely "the past week", than for Bangladesh, where the reference period is "yesterday". Looking at the composition of consumption in terms of food groups (see Figure 1), it is clear that farm household diets in both countries primarily lack animal source foods, such as meat, eggs, milk, and fish. This is true to a lesser extent in Bangladesh where 69% of the households consumed fish the day before the interview.

A more fine-grained indicator of dietary quality is nutrient adequacy. Average nutrient adequacy, as measured by us, is 65% in Rwanda and 52% in Bangladesh. Figure 2 shows the adequacy levels of the individual nutrients. The figure suggests that the average diet among households in the Rwandan sample is particularly inadequate in providing the recommended quantities of Magnesium, Calcium, Vitamin A, and Vitamin B12. In the sample from Bangladesh, household diets particularly seem to lack sufficient amounts of Calcium, Iron, and Vitamins A, B6, and B9.

## 5.4 Identification strategy

Estimating the effect of farmer commercialization on household dietary intake is difficult because of the potential existence of confounding variables that correlate with both commercialization and dietary intake. Failing to control for these variables will result in an endogenous explanatory variable of interest (in this case commercialization) and, consequently, a biased estimation (Wooldridge 2001).

We can identify several potential confounding variables. The location of the household, for example, might affect the transaction costs that are incurred when participating in the market as a seller of produce (e.g. transportation costs and opportunity costs), as well as the costs incurred when participating in the market as a buyer of food. In this way, being nearer to an urban center or having better access to transportation infrastructure likely affects both market participation and food consumption decisions (see also Stifel and Minten 2017; Vandercasteelen et al. 2018). It becomes more problematic, however, if potential confounding variables are unobserved. An example of a set of unobserved potential confounders are household consumption preferences.[50] A higher preference for non-food products (e.g., education, housing material, electronics), for example, affects the decision how much to sell—via a higher preference for income than for consumption of own production—and to what extent the acquired income is spent on food.

To deal with this potential endogeneity in our estimations, we primarily rely on the following model:

$$Y_{it} = \alpha_i + \beta C_{it} + \gamma \boldsymbol{Z_{it}} + u_{it} \qquad (1)$$

where the subscripts denote household $i$ at time $t$, $Y_{it}$ is the indicator for household dietary intake (either nutrient adequacy or dietary diversity), $C_{it}$ is the extent to which a farm household is commercialized, $\boldsymbol{Z_{it}}$ is a vector of time-variant household characteristics, including the age, gender, and education of the household head (to account for a change in household head), the natural logarithm of the available cultivable land in hectares, the inverse hyperbolic sine of off-farm income, and the size of the household, and $u_{it}$ is the error term.[51] We use a fixed effects transformation that allows us to eliminate the time-

[50] Household-level preferences can be seen as an outcome of an intra-household (bargaining) process based on the individual preferences of all household members. Individual preferences for food are, in turn, influenced by factors such as the physical environment, socio-economical background, culture, and nutritional knowledge (Patrick and Nicklas, 2005; Spronk et al., 2014).

[51] In addition, every specification used in this chapter controls for project participation. The coefficients are, however, not reported in the regression results.

invariant unobserved household heterogeneity $(\alpha_i)$ (Wooldridge 2001). Using this model we obtain an unbiased estimate of the effect of commercialization on household dietary intake $(\beta)$ under the assumption that the expected value of the error term $(u_{it})$ is zero, conditional on $C_i$ and $\boldsymbol{Z_i}$.

Essentially, this model uses the variation between years within a farm-household to identify the relationship between commercialization and diets. This requires sufficient intra-household variation in commercialization between 2014 and 2016 in the two samples. To check this, we plot the intra-household differences between the 2016 and 2014 commercialization rates in a histogram (see Figure 3). According to the figure, the intertemporal variation in commercialization has a near to normal distribution around zero ranging from (near to) -1 to +1 for both samples (with the exception of a peak at 0 due to the relatively large number of farmers that did not sell any of their produce in both periods). This implies that although most households in 2016 have sold a similar percentage of what they produced as in 2014, there is also a sufficiently large share of households that have decreased or increased their market participation in between years.

A key issue is whether to control for production value in addition to the variables already included in $\boldsymbol{Z_{it}}$. Various studies have dealt with this issue in different ways. Some control for production value (e.g., Carletto et al. 2017), while others do not (e.g., Ogutu et al. 2017). The argument for inclusion of production value as a control variable is that it can potentially confound the estimation. More production means that a lower share of the production is needed to satisfy own consumption needs and that more can be sold, leading to a higher rate of commercialization. More production also means that the household can access food easier, whether it is by consuming it directly or by selling it and by purchasing food on the market. We therefore would expect that not controlling for the production value would lead to an overestimation of the commercialization-effect.

The argument against including production value as a control is that commercialization is expected to affect income and in turn dietary intake *via* its impact on production. Because commercialization is expected to increase productivity (as discussed in the Section 5.2) it is also expected to lead to higher total production and, hence, a higher production value and higher income. In this way, production value is a potential mechanism. As a control it might therefore capture some of the potential positive effects of commercialization on dietary intake and this might result in underestimation of the commercialization-effect.

The arguments for inclusion of production value in the model are, in our opinion, not a-priori better than the arguments against inclusion. Our main model and hypothesis relies, however, on the effect commercialization on diets through its effect on income. If we keep production value constant, we would essentially obtain an estimate of the effect of commercialization on diets through other mechanisms than enhanced productivity and higher income. We therefore decide not to include production value as a control variable in our main specification. We will, however, later on check whether commercialization has an effect on diets if income is kept constant.

## 5.5 Results

### *5.5.1 Unconditional correlation between commercialization and diets*

Before proceeding with the results of the main estimation model outlined in Section 5.3, we graphically assess how farmer commercialization is associated with dietary diversity and nutrient adequacy. In Figure 4, we plot the predictions of a simple and a quadratic linear regression of commercialization on dietary diversity and of commercialization on nutrient adequacy together with the 95% confidence intervals for the pooled 2014 and 2016 samples.

The figure suggests that commercialization is positively associated with both dietary diversity and nutrient adequacy. The coefficients for the simple linear model are all positive and statistically significant at the 5%-level, except for the regression on the sample from Bangladesh (for which the p-value is still smaller than 0.1).[52] The quadratic regression results, however, suggest that the relationship is better characterized by the quadratic function. Indeed, Figure 4 shows that for both indicators and for all country samples the relationship is concave-shaped: all quadratic terms are negative and have p-values smaller than 0.05.

### *5.5.2 Main estimation results*

We now turn to the results of the estimation strategy as outlined in Section 5.3, which controls for household fixed effects and time-varying household characteristics. Informed by the visual evidence for a concave relationship in the previous section, we also run a specification with a quadratic commercialization term. The main estimation results are given by Table 2 for Rwanda and Table 3 for Bangladesh. These results are illustrated by Figure 5. This figure shows the predicted dietary diversity and nutrient adequacy at different rates of commercialization (keeping other covariates at their average value). We discuss these results in turn.

[52] See Table A1 and A2 in the supplementary appendix.

First, we estimate that there exists a positive relationship between commercialization and dietary diversity and between commercialization and nutrient adequacy in Rwanda (see Table 2). This confirms our main hypothesis that farmer commercialization increases the diversity and adequacy of farm household diets. The effect is, however, modest in size. Indeed, we estimate that an increase in commercialization by 10 percentage points is associated with an increase in the number of food groups consumed by 0.05 and an increase in nutrient adequacy by 0.7%.

Second, in Bangladesh we do not find evidence for our main hypothesis (see Table 3). The results suggest that commercialization has no effect on nutrient adequacy of diets and that commercialization is associated with *less* dietary diversity. In fact, an increase in commercialization by 10 percentage points is estimated to be associated with a reduction in the number of food groups consumed by 0.05. This negative effect in Bangladesh, albeit also modest in size, is remarkable considering the positive (unconditional) correlation between commercialization and dietary diversity (see Figure 4). These results also demonstrate that a reduction in dietary diversity does not automatically translate in a reduction in nutrient adequacy.

Third, also after controlling for household fixed effects and time-varying characteristics, the relationship between commercialization and diets is, in general, better characterized as concave.[53] This is best observed by looking at Figure 5. Commercialization contributes to better diets for farm households that sell yet a small share of their production but the positive effect is diminishing with higher rates of commercialization and at a certain point can even become negative for households that are already selling a large share of the food they produce. The turning points depend on the country sample and the dietary indicator. For nutrient adequacy, the turning point for both countries is at a commercialization rate of about 50%. This would indicate that any further commercialization beyond this point does not further contribute to improved diets.

### *5.5.3 Robustness*

We test the robustness of our findings using a number of alternative specifications, indicators, and sub-samples. Robustness tests include (a) clustering standard errors at the household-level instead of at the community-level; (b) excluding households that were autarkic (those who did not sell produce in 2014 and 2016); (c) excluding households that were fully commercialized (those

[53] Note that the concavity of the relationship between commercialization and dietary diversity in Rwanda is a bit more uncertain: the quadratic term is negative but not statistically significant.

who sold all their produce in both 2014 and 2016); (e) excluding households that participated in an agricultural development project; (f) using the number of different foods *items* consumed instead of different food *groups* consumed as a measure for dietary diversity; and (g) excluding macro-nutrients (energy, protein, and carbohydrates) in the calculation of nutrient adequacy of the diet. These estimation results are presented in the appendix (see Supplementary Appendix). None of the alternative specifications yield estimations that deviate meaningfully from our main results in Table 2 and 3.

Finally, we estimate a model naïve of time-constant household heterogeneity (see Table 4). We do this by pooling the 2014 and 2016 data, treating the data as cross-sectional, and by including community fixed effects to control for locational factors, such as nearness to markets, roads, and other facilities, and for natural conditions that are the same for households in one location. A model without household fixed effects is used by most other studies in the literature but it cannot control for unobserved time-invariant household characteristics that are potentially correlated with both commercialization and dietary intake, such as (time-constant) household preferences.

The pooled OLS model yields qualitatively similar results as our main specification for Rwanda but the results deviate for Bangladesh. Not controlling for household fixed effects in this case yields higher estimates for the effect of commercialization on dietary diversity and nutrient adequacy. Instead of concluding that commercialization reduced dietary diversity and did not affect nutrient adequacy, these results would have suggested no effect on dietary diversity and a positive effect on nutrient adequacy.

### *5.5.4 Mechanisms*

To enhance our understanding of the underlying mechanisms, we conduct a simple mediation analysis. In particular, we estimate the following two models:

$$Y_{it} = a_{1i} + b_1 M_{it} + c_1 C_{it} + \gamma \boldsymbol{W_{it}} + e_{1it} \quad (2)$$

$$M_{it} = a_{2i} + b_3 C_{it} + \gamma \boldsymbol{W_{it}} + e_{2it} \quad (3)$$

where $M_{it}$ represents the inverse hyperbolic sine (IHS) transformation of household net-income and $\boldsymbol{W_{it}}$ is a vector of household characteristics similar to $\boldsymbol{Z_{it}}$ but excluding off-farm income. Household net-income is calculated by taking the farm revenue (production sold times the actual average price received), subtracting the farm input expenditures, and adding the income from off-farm activities, such as wage labor, non-farm entrepreneurial activities, and income from renting out land.

By estimating these two equations we gather evidence on the validity of the three underlying assumptions in our conceptual framework:

$H_2$: Commercialization has a positive effect on household net-income;
$H_3$: Household net-income has a positive effect on dietary diversity and nutrient adequacy;
$H_4$: Commercialization has no effect on dietary diversity and nutrient adequacy if income is kept constant.

The results are presented in Table 5. To interpret the effect sizes we use the product of coefficients method (Sobel 1982)—multiplying $b_1$with $b_3$—to obtain the indirect association of $C_{it}$ with $Y_{it}$ via $M_{it}$. These are reported in Table 5, alongside the estimates of $c_1$—the direct association between $C_{it}$ and $Y_{it}$ while controlling for $M_{it}$—and the earlier obtained estimate $\beta$—the total association between $C_{it}$ and $Y_{it}$ (see Equation 1).[54] These estimates are summarized in Table 6.

For both Rwanda and Bangladesh we find that commercialization is associated with an increase in net-income and that an increase in net-income is associated with an increase in dietary diversity and nutrient adequacy (see Table 4). In other words, based on these estimation results we cannot reject hypothesis 2 and 3. In Rwanda this indirect association via income explains a large share of the total association between commercialization and diets (see Table 6). Moreover, the estimated direct association between commercialization and diets (after controlling for income) is not statistically significant (see Table 5). This means that for Rwanda we cannot reject hypothesis 4.

The estimates from Bangladesh tell us a different story. Although the indirect association is also statistically significant in Bangladesh, in size it is much less important. The coefficients $b_1$with $b_3$ are lower in absolute terms but their product is also low relative to the estimate for the direct association. This might explain why we did not find a positive and statistically significant effect of commercialization on dietary diversity and nutrient adequacy in Bangladesh. In addition, the negative effect of commercialization on dietary diversity seems to be primarily explained by a negative direct association once we control for income. This would suggest that mechanisms other than the income channel are important in explaining the effect on dietary diversity. We therefore cannot reject hypothesis 4 based on the data from Bangladesh.

[54] The indirect and direct association do not precisely add up to the total association because of the small difference in the control vectors $\boldsymbol{W}_{it}$ and $\boldsymbol{Z}_{it}$.

## 5.6 Summary and discussion

We investigated the relationship between commercialization and farm household diets using household level panel data from Rwanda and Bangladesh. Controlling for household fixed effects and observed time-variant household characteristics, we estimate that agricultural commercialization has had a positive effect on the diversity and nutrient adequacy of the diet of farm households in Rwanda but not in Bangladesh.

Commercialization in Rwanda is associated with higher income, which, in turn, is associated with a more diverse and nutritionally adequate diet for the farm household. This positive income effect explains a large share of the total positive effect of commercialization on diets. Moreover, there is no evidence that alternative causal pathways between commercialization and diets are important.

The evidence from Bangladesh presents us, however, with a different story. Here, we find that agricultural commercialization does not contribute to better diets. In fact, we find that commercialization has no effect on nutrient adequacy and, on average, *reduces* the diversity of the diet. While we do find evidence for a positive income effect, the estimated effect size is very small. Moreover, mechanisms other than income seem to be more important and can explain why commercialization negatively affected the diversity of the diet.

Another important finding from this study is that the relationship between commercialization and the diversity and adequacy of farm household diets is best characterized as concave. In other words, commercialization contributes to better diets for farm households that sell yet a small share of their production but the positive effect is diminishing with higher rates of commercialization and at a certain point can even become negative for households that are already selling a large share of the food they produce.

When weighing these conclusions one should take into account that our methodology has some limitations. First, although providing an improvement on models that are naïve of unobserved household heterogeneity, a fixed effects model, as applied here, cannot completely exogenize the commercialization decision. There might be important unobserved time-variant factors for which we do not control that are still confounding the estimation. Secondly, our estimation method might have yielded biased estimates because we did not offer a solution for the fact that production value is both a potential mechanism and confounding variable. As discussed in the chapter, the choice for not controlling for production value might mean we overestimated the effect of commercialization on nutrition. Thirdly, a two year panel might be too short to capture the long-term and more dynamic effects of commercialization. Fourth, additional income resulting from commercialization might be spent on food eaten outside the home. This is not captured by our household questionnaires and therefore not taken into account. Finally, we did not take into account the nutritional effects of agricultural commercialization for consumers (non-farmers).

That being said, three policy implications emerge from our findings. First, agricultural commercialization, in itself, seems to be insufficient to improve diets among farm households in any transformational sense. Even in Rwanda where the average effect of commercialization on dietary quality was found to be positive, the size of the effect was modest. Secondly, policy makers should be aware that promoting agricultural commercialization can actually lead to a reduction in dietary diversity for farm households, as suggested by the results from Bangladesh. Further research is required to uncover the factors that can explain this negative effect. Lastly, the concave relationship between commercialization and dietary quality suggests that it can be useful to enable commercialization for farm households that yet sell a small share of their production. Further stimulation of commercialization of farmers that already sell a large share of what they produce is, however, unlikely to contribute to better farm household diets or can even be counterproductive.

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## 5.8 Figures

**Figure 1: Consumption of different food groups (2014)**

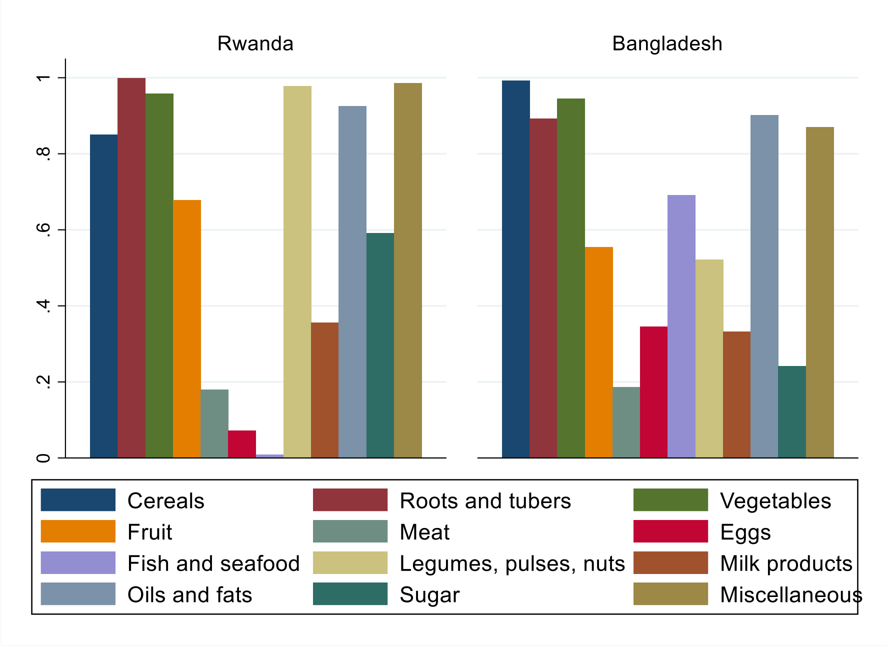



**Figure 2: Nutrient adequacy (2014) in Rwanda and Bangladesh**

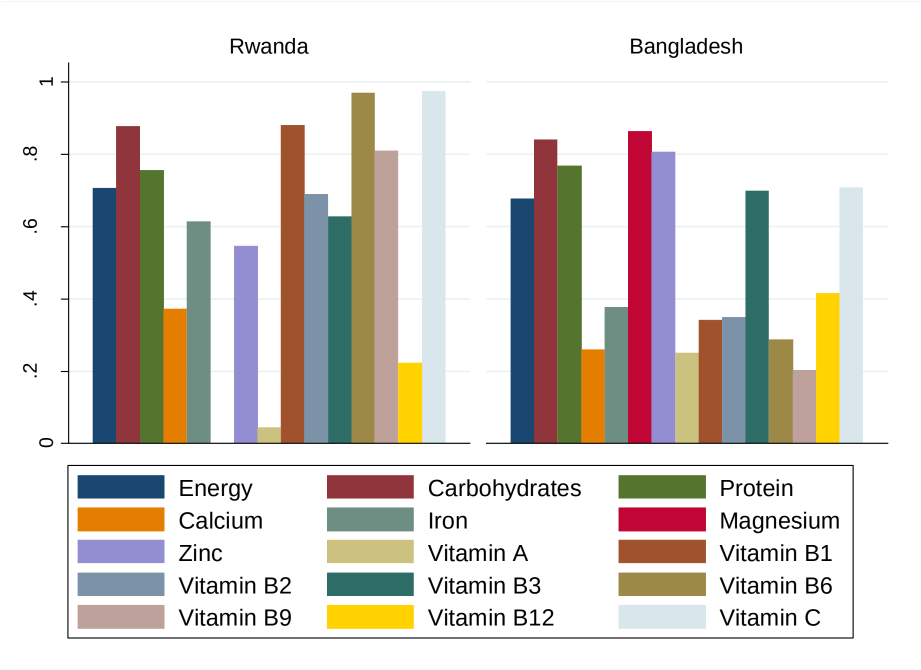


**Figure 3: Intertemporal variation in market participation (2014 to 2016)**

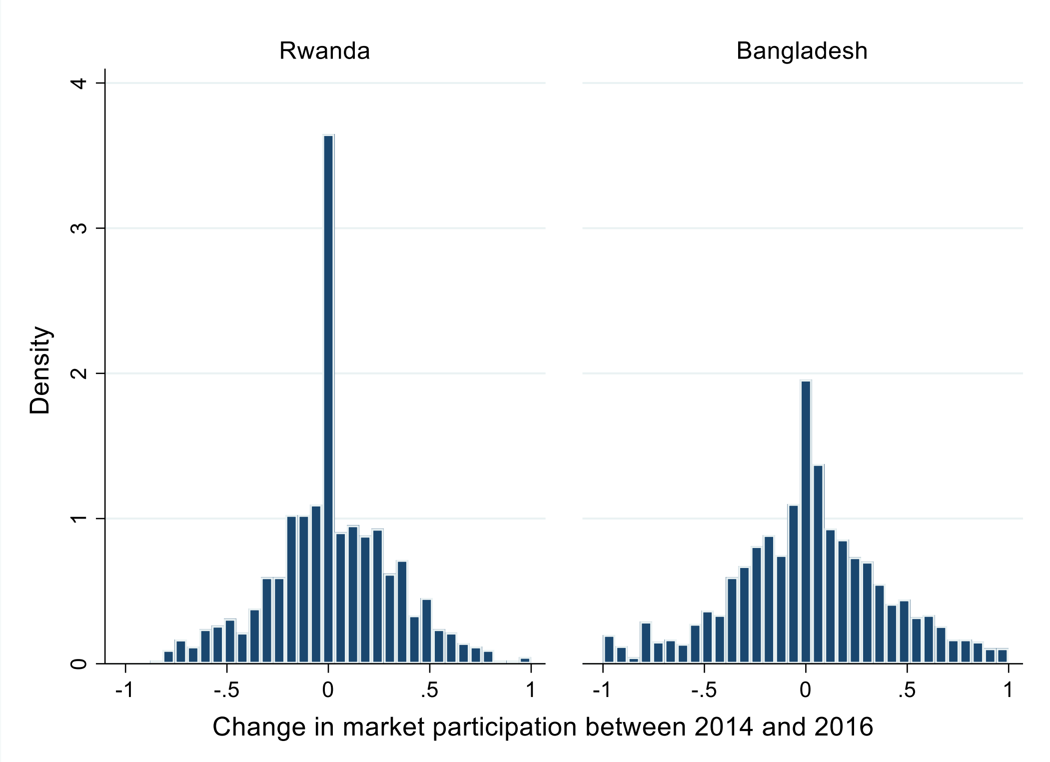


**Figure 4: The linear and quadratic relationship between commercialization and the diversity and adequacy of farm household diets**

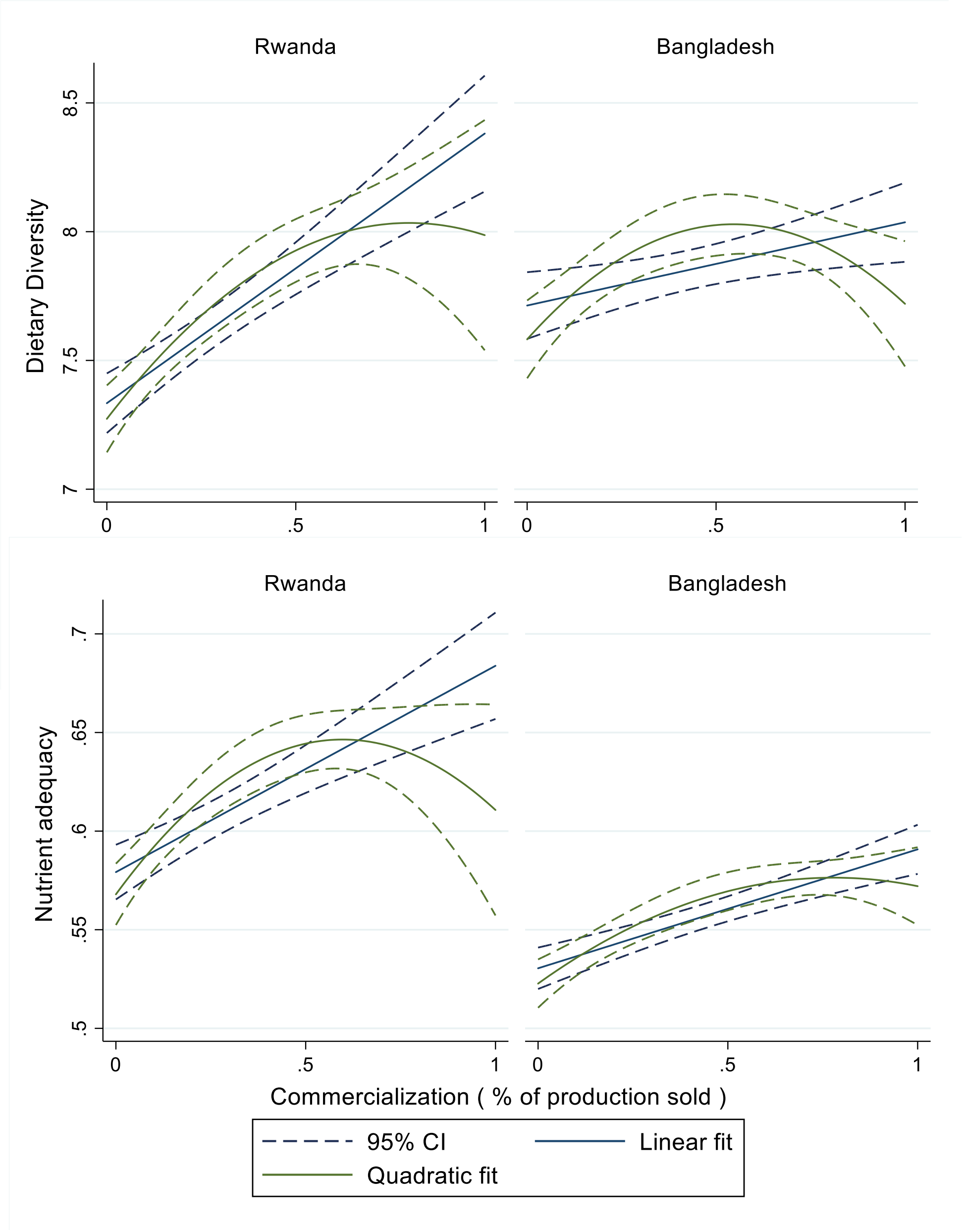
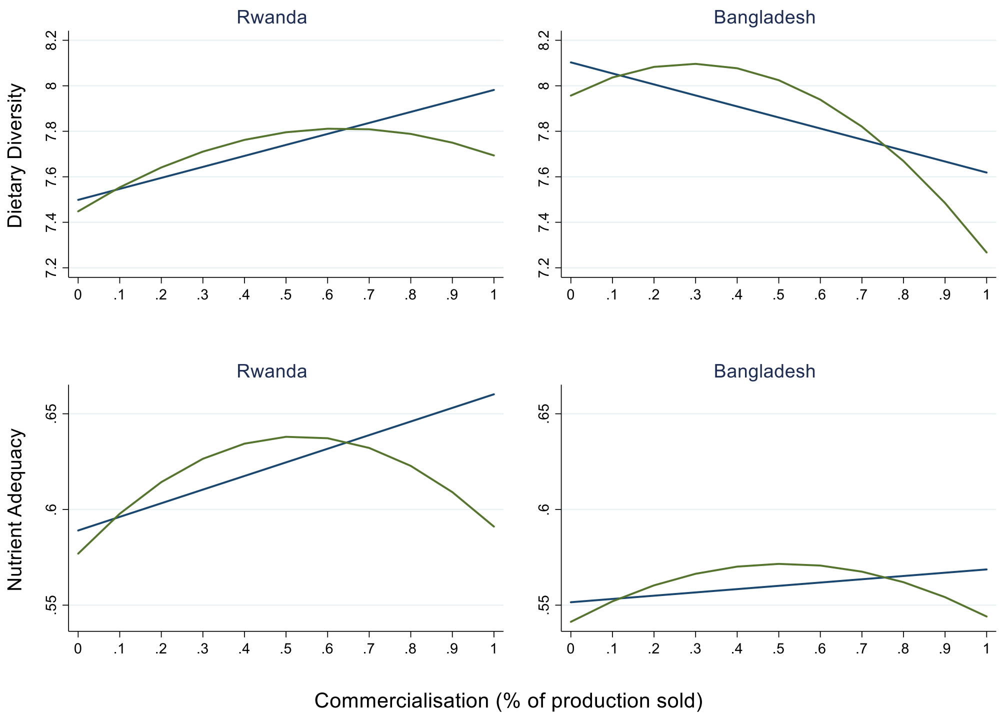


**Figure 5: Predicted dietary diversity and nutrient adequacy from the fixed effects regression at varying rates of commercialization (keeping other covariates at their average value)**



## 5.9 Tables

**Table 1: Descriptive Statistics for Rwanda and Bangladesh (2014): sample means and standard deviations**

| | Rwanda | | | Bangladesh | | |
|---|---|---|---|---|---|---|
| VARIABLES | All | Non-sellers | Sellers | All | Non-sellers | Sellers |
| Commercialization rate | 0.30 | 0.00 | 0.40 | 0.45 | 0.00 | 0.57 |
| | (0.270) | (0.000) | (0.238) | (0.332) | (0.000) | (0.265) |
| Dietary diversity[55] | 7.59 | 7.10 | 7.75 | 7.46 | 7.29 | 7.51 |
| | (1.571) | (1.847) | (1.434) | (2.045) | (1.863) | (2.090) |
| Nutrient adequacy | 0.65 | 0.60 | 0.67 | 0.52 | 0.49 | 0.53 |
| | (0.167) | (0.169) | (0.163) | (0.168) | (0.153) | (0.171) |
| Off-farm income (USD) | 105.83 | 84.48 | 112.92 | 560.98 | 595.51 | 551.77 |
| | (262.250) | (213.790) | (276.290) | (705.115) | (543.632) | (742.260) |
| Net HH income (USD) | 237.03 | 78.87 | 289.55 | 827.43 | 549.10 | 901.63 |
| | (663.373) | (212.291) | (748.650) | (1,417.917) | (554.346) | (1,561.806) |
| Farm revenue (USD) | 146.25 | 0.00 | 194.81 | 463.76 | 0.00 | 587.39 |
| | (600.699) | (0.000) | (686.592) | (1,361.509) | (0.000) | (1,508.560) |
| Farm expenditures (USD | 15.05 | 5.61 | 18.18 | 197.30 | 46.41 | 237.53 |
| | (33.428) | (19.024) | (36.469) | (322.063) | (79.265) | (349.345) |
| Land size cultivated (ha) | 0.60 | 0.38 | 0.67 | 0.58 | 0.27 | 0.67 |
| | (0.571) | (0.477) | (0.582) | (0.909) | (0.395) | (0.986) |
| HH head is female (dum) | 0.27 | 0.30 | 0.25 | 0.03 | 0.03 | 0.03 |
| | (0.443) | (0.461) | (0.436) | (0.166) | (0.184) | (0.162) |
| HH size | 5.06 | 4.81 | 5.14 | 4.91 | 4.72 | 4.97 |
| | (2.004) | (1.998) | (2.001) | (1.804) | (1.623) | (1.847) |
| Age HH head | 46.62 | 46.94 | 46.52 | 50.00 | 49.00 | 50.26 |
| | (13.255) | (14.041) | (12.996) | (14.197) | (14.469) | (14.120) |
| Education HH head: | | | | | | |
| Some primary | 0.32 | 0.33 | 0.32 | 0.19 | 0.18 | 0.20 |
| | (0.469) | (0.472) | (0.468) | (0.395) | (0.388) | (0.397) |
| Finished primary | 0.35 | 0.26 | 0.39 | 0.12 | 0.11 | 0.13 |
| | (0.478) | (0.438) | (0.487) | (0.329) | (0.313) | (0.333) |
| More than primary | 0.09 | 0.07 | 0.10 | 0.43 | 0.37 | 0.45 |
| | (0.286) | (0.255) | (0.296) | (0.496) | (0.483) | (0.498) |
| Number of households | 690 | 172 | 518 | 1,088 | 229 | 859 |

Standard deviations in parentheses; HH= household.

[55] Note that the reference period is "yesterday" for Bangladesh, while it is "last week" for Rwanda.

**Table 2: Main estimation results for Rwanda**

| VARIABLES | (1) Dietary diversity | (2) Dietary diversity | (3) Nutrient adequacy | (4) Nutrient adequacy |
|---|---|---|---|---|
| Commercialization rate | 0.483** | 1.145* | 0.071** | 0.230*** |
| | (0.236) | (0.603) | (0.030) | (0.080) |
| (Commercialization rate)$^2$ | | -0.900 | | -0.216** |
| | | (0.727) | | (0.103) |
| IHS (Off-farm income) | 0.067*** | 0.067*** | 0.009*** | 0.009*** |
| | (0.017) | (0.017) | (0.003) | (0.003) |
| Land size cultivated | 0.088* | 0.084 | 0.019*** | 0.018*** |
| | (0.052) | (0.052) | (0.006) | (0.006) |
| HH head is female | -0.419 | -0.442 | 0.103 | 0.098 |
| | (0.340) | (0.334) | (0.066) | (0.065) |
| HH size | 0.086 | 0.083 | -0.057*** | -0.058*** |
| | (0.061) | (0.061) | (0.009) | (0.010) |
| Age HH head | -0.015 | -0.012 | -0.005* | -0.005* |
| | (0.017) | (0.017) | (0.003) | (0.003) |
| Education HH head: | | | | |
| Some primary education | -0.046 | -0.035 | -0.009 | -0.007 |
| | (0.180) | (0.183) | (0.023) | (0.023) |
| Finished primary | 0.117 | 0.134 | 0.003 | 0.007 |
| | (0.254) | (0.261) | (0.030) | (0.030) |
| More than primary | 0.309 | 0.331 | 0.013 | 0.019 |
| | (0.334) | (0.341) | (0.040) | (0.040) |
| Project participation | 0.125 | 0.122 | -0.033** | -0.033** |
| | (0.111) | (0.111) | (0.014) | (0.014) |
| Constant | 7.680*** | 7.531*** | 1.119*** | 1.084*** |
| | (0.790) | (0.811) | (0.131) | (0.132) |
| R-squared | 0.045 | 0.047 | 0.159 | 0.166 |
| Number of hhid | 692 | 692 | 692 | 692 |
| Cluster FE | NO | NO | NO | NO |
| Household FE | YES | YES | YES | YES |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

**Table 3: Main estimation results for Bangladesh**

| VARIABLES | (1)<br>Dietary diversity | (2)<br>Dietary diversity | (3)<br>Nutrient adequacy | (4)<br>Nutrient adequacy |
|---|---|---|---|---|
| Commercialization rate | -0.484* | 0.960 | 0.017 | 0.118*** |
| | (0.258) | (0.678) | (0.011) | (0.039) |
| (Commercialization rate)$^2$ | | -1.649** | | -0.116** |
| | | (0.660) | | (0.044) |
| IHS (Off-farm income) | 0.029 | 0.031 | 0.003 | 0.003 |
| | (0.023) | (0.023) | (0.002) | (0.002) |
| Land size cultivated | 0.157** | 0.145** | 0.013** | 0.012** |
| | (0.071) | (0.069) | (0.006) | (0.006) |
| HH head is female | 0.464 | 0.432 | 0.098*** | 0.096*** |
| | (0.377) | (0.372) | (0.028) | (0.029) |
| HH size | 0.085 | 0.079 | -0.029*** | -0.029*** |
| | (0.054) | (0.053) | (0.004) | (0.004) |
| Age HH head | 0.003 | 0.003 | 0.000 | 0.000 |
| | (0.007) | (0.007) | (0.000) | (0.000) |
| Education HH head: | | | | |
| Some primary education | 0.129 | 0.094 | 0.021 | 0.019 |
| | (0.195) | (0.196) | (0.018) | (0.018) |
| Finished primary | 0.465* | 0.433* | 0.054*** | 0.052*** |
| | (0.232) | (0.229) | (0.016) | (0.016) |
| More than primary | 0.355 | 0.331 | 0.037** | 0.035** |
| | (0.258) | (0.260) | (0.014) | (0.014) |
| Project participation | 1.169*** | 1.167*** | 0.095*** | 0.095*** |
| | (0.215) | (0.217) | (0.013) | (0.013) |
| Constant | 6.912*** | 6.827*** | 0.627*** | 0.621*** |
| | (0.598) | (0.585) | (0.037) | (0.036) |
| R-squared | 0.150 | 0.155 | 0.209 | 0.213 |
| Number of hhid | 1,088 | 1,088 | 1,088 | 1,088 |
| Cluster FE | NO | NO | NO | NO |
| Household FE | YES | YES | YES | YES |

Robust standard errors in parentheses
*** p<0.01, **p<0.05, *p<0.1

**Table 4: Estimation results using pooled OLS**

| | Rwanda | | | | Bangladesh | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| VARIABLES | Dietary Diversity | Dietary Diversity | Nutrient Adequacy | Nutrient Adequacy | Dietary Diversity | Dietary Diversity | Nutrient Adequacy | Nutrient Adequacy |
| Commercialization rate | 0.681*** | 1.400*** | 0.064*** | 0.228*** | -0.045 | 1.120** | 0.030** | 0.113*** |
| | (0.169) | (0.449) | (0.019) | (0.057) | (0.155) | (0.543) | (0.013) | (0.038) |
| (Commercialization rate)$^2$ | | -0.987* | | -0.226*** | | -1.320** | | -0.094** |
| | | (0.544) | | (0.076) | | (0.572) | | (0.036) |
| IHS (Off-farm income) | 0.062*** | 0.063*** | 0.007*** | 0.008*** | 0.034** | 0.034** | 0.001 | 0.001 |
| | (0.014) | (0.014) | (0.002) | (0.002) | (0.015) | (0.015) | (0.001) | (0.001) |
| Land size cultivated | 0.206*** | 0.200*** | 0.027*** | 0.025*** | 0.188*** | 0.176*** | 0.020*** | 0.019*** |
| | (0.044) | (0.045) | (0.005) | (0.005) | (0.044) | (0.045) | (0.004) | (0.004) |
| HH head is female | -0.333*** | -0.338*** | -0.039*** | -0.041*** | 0.075 | 0.078 | 0.047* | 0.047* |
| | (0.120) | (0.119) | (0.014) | (0.013) | (0.213) | (0.205) | (0.025) | (0.025) |
| HH size | 0.015 | 0.014 | -0.026*** | -0.026*** | 0.092*** | 0.089*** | -0.024*** | -0.024*** |
| | (0.018) | (0.018) | (0.003) | (0.003) | (0.021) | (0.022) | (0.002) | (0.002) |
| Age HH head | -0.010*** | -0.010** | -0.001* | -0.001* | 0.002 | 0.001 | -0.000 | -0.000 |
| | (0.004) | (0.004) | (0.000) | (0.000) | (0.003) | (0.003) | (0.000) | (0.000) |
| Some primary education | 0.319*** | 0.307*** | 0.006 | 0.003 | 0.225** | 0.210* | 0.018* | 0.017 |
| | (0.097) | (0.098) | (0.014) | (0.014) | (0.108) | (0.112) | (0.010) | (0.010) |
| Finished primary | 0.615*** | 0.604*** | 0.037** | 0.034** | 0.316** | 0.300** | 0.029*** | 0.027*** |
| | (0.133) | (0.133) | (0.015) | (0.015) | (0.137) | (0.137) | (0.009) | (0.009) |
| More than primary | 0.860*** | 0.858*** | 0.028 | 0.028 | 0.534*** | 0.525*** | 0.029*** | 0.028*** |
| | (0.171) | (0.172) | (0.018) | (0.018) | (0.078) | (0.081) | (0.008) | (0.008) |
| Project participation | 0.269*** | 0.265*** | -0.019 | -0.020* | 1.090*** | 1.088*** | 0.087*** | 0.087*** |
| | (0.096) | (0.097) | (0.012) | (0.012) | (0.226) | (0.228) | (0.014) | (0.014) |
| Observations | 1,382 | 1,382 | 1,382 | 1,382 | 2,038 | 2,038 | 2,038 | 2,038 |
| R-squared | 0.253 | 0.255 | 0.226 | 0.232 | 0.154 | 0.157 | 0.233 | 0.236 |
| Cluster FE | YES | YES | YES | YES | YES | YES | YES | YES |
| Household FE | NO | NO | NO | NO | NO | NO | NO | NO |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

**Table 5: Results mediation analysis**

| | Rwanda | | | Bangladesh | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| VARIABLES | IHS(net-income) | Dietary Diver-sity | Nutrient Ade-quacy | IHS(net-income) | Dietary Diver-sity | Nutrient Ade-quacy |
| IHS (net-income) | | 0.062*** | 0.007*** | | 0.030** | 0.002** |
| | | (0.018) | (0.002) | | (0.013) | (0.001) |
| Commercialization rate | 5.141*** | 0.186 | 0.037 | 1.875*** | -0.561* | 0.012 |
| | (0.383) | (0.244) | (0.030) | (0.568) | (0.276) | (0.012) |
| Land size cultivated (ha) | 0.038 | 0.085 | 0.019*** | -0.030 | 0.157** | 0.013** |
| | (0.099) | (0.052) | (0.006) | (0.164) | (0.070) | (0.006) |
| HH head is female | 0.649 | -0.449 | 0.100 | -0.008 | 0.478 | 0.100*** |
| | (0.605) | (0.337) | (0.064) | (0.813) | (0.367) | (0.028) |
| HH size | 0.199 | 0.081 | - 0.057*** | -0.060 | 0.087 | - 0.029*** |
| | (0.148) | (0.061) | (0.009) | (0.118) | (0.053) | (0.004) |
| Age HH head | 0.025 | -0.015 | -0.005** | 0.021* | 0.003 | 0.000 |
| | (0.040) | (0.017) | (0.003) | (0.012) | (0.007) | (0.001) |
| Some primary education | 0.001 | -0.045 | -0.009 | -0.355 | 0.147 | 0.023 |
| | (0.400) | (0.180) | (0.023) | (0.530) | (0.186) | (0.018) |
| Finished primary | 0.179 | 0.122 | 0.004 | 0.409 | 0.467** | 0.054*** |
| | (0.493) | (0.257) | (0.030) | (0.456) | (0.225) | (0.016) |
| More than primary | 0.875 | 0.326 | 0.017 | 0.515 | 0.363 | 0.038** |
| | (0.604) | (0.328) | (0.040) | (0.551) | (0.251) | (0.014) |
| Project participation | -0.171 | 0.154 | -0.029** | 1.629*** | 1.148*** | 0.094*** |
| | (0.193) | (0.108) | (0.014) | (0.233) | (0.212) | (0.013) |
| onstant | 0.152 | 7.755*** | 1.130*** | 3.395*** | 6.919*** | 0.631*** |
| | (1.956) | (0.778) | (0.131) | (0.802) | (0.611) | (0.036) |
| Observations | 1,382 | 1,382 | 1,382 | 2,038 | 2,038 | 2,038 |
| R-squared | 0.189 | 0.042 | 0.152 | 0.060 | 0.152 | 0.209 |
| Number of hhid | 692 | 692 | 692 | 1,088 | 1,088 | 1,088 |
| Household FE | YES | YES | YES | YES | YES | YES |

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

**Table 6: Overview of estimates for the indirect, direct, and total association**

| | Rwanda | | Bangladesh | |
|---|---|---|---|---|
| | Dietary Diversity | Nutrient Adequacy | Dietary Diversity | Nutrient Adequacy |
| Indirect association ($b_1 b_3$) | 0.319 | 0.036 | 0.056 | 0.004 |
| Direct association ($c_1$) | 0.186 | 0.037 | -0.561 | 0.012 |
| Total association ($\beta$) | 0.483 | 0.071 | -0.484 | 0.017 |