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**Value Chains and Technology Transfer to Agriculture
in Developing and Emerging Economies**

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Abstract

Value chains in the agrifood sector are undergoing a rapid process of modernization, characterized by the emergence of private standards and different systems of vertical value chain governance. In this article we investigate the technological implications of these developments at the farm-level. We explicitly modelled the conditions under which technology transfer and adoption will occur in a value chain setting and reviewed the corresponding evidence on these issues. We find that technology transfer within a value chain can occur in an environment with imperfect credit and technology markets, but depends on the surplus generated by the technology, the holdup opportunities of the supplier and the type of technology. Finally, using these findings we discuss the implications of public investment and the role of private standards as a potential catalyst for technology adoption and transfer.

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; Sheahan and Barrett 2014)¹.

The existing literature has tried to find explanations for this phenomenon by looking at farmer characteristics (e.g. Duflo et al. 2011)), the learning process (e.g. Lambrecht et al. 2014), the quality of technological inputs (Bold et al. 2015) and profitability (e.g. Suri 2011). In this paper we study how value chains may affect technology adoption.

In the past decades, agrifood value chains have transformed drastically (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). In the more successful cases, 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). Within the same time-

¹ Foster and Rosenzweig (2010) define technology as the relationship between inputs and outputs and the adoption of new technologies as the use of new mappings between inputs and outputs. In the empirical literature technology adoption is often measured by the use of intermediate inputs (e.g. fertilizer, improved seeds, cooling equipment for dairy), the application of certain practices (e.g. integrated soil fertility management) or by land or labor productivity, which are in fact outcomes rather than indicators of technology adoption. Technology transfer is then the act of actively passing a technology from one actor to the other. In line with Smeets (2008) we distinguish technology transfer from indirect “non-intentional” spillovers or externalities. Although the focus in this article is on the former, the empirical literature has generally not made this distinction.

span, urbanization and a global increase in average consumer purchasing power resulted in an increased demand for high value and differentiated food products. Food safety and other quality aspects, such as convenience, diversity, branding and the sustainability of the production process have become increasingly important.

This had an important impact on modern technology adoption downstream from the farm. There is widespread evidence that food processors, marketing 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).

However, our focus in this article is on the farm-level adoption of new technology. Value chains had a major impact on this. 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 their suppliers' products often required investments in new technologies, be it to get higher yields for minimum output or to obtain higher quality or to satisfy other types of standards². With imperfect (or non-existing) technology markets, a key mechanism to allow suppliers (farms) to access and adopt these new

² Most standards, codified or not, either directly or indirectly prohibit the use of less costly technology (Swinnen et al. 2015). In fact many of the most visible standards for consumers directly prohibit or require the use of certain inputs. Examples of commonly prohibited inputs are child labor, chemical inputs (in accordance with organic farming standards), or battery cages in the production of poultry. Examples of commonly required inputs are milk cooling equipment for dairy farmers and traceability systems for farmers supplying supermarket channels. Additionally, standards often require certain practices. For example GlobalGap certification requires Lychee farmers in Madagascar to use clean water for pre-harvest hand washing and to implement good picking and packaging practices for the transportation from the farm to the processing unit (Subervie and Vagneron 2013).

technologies was through vertical coordination. Vertical coordination takes many forms, including smallholder contracting with interlinked technology transfer, triangular structures with technology suppliers or financial institutions or vertically integrated production (World Bank 2005; Swinnen 2007).

This article 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) and Swinnen et al. (2015), we then develop a model 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 suppliers can occur in an environment with imperfect credit and technology markets and depends on the surplus generated by the technology, the holdup opportunities of the supplier and the type of technology. We also discuss the implications of different types of public investment on technology adoption and the role of private standards.

The contribution of this paper to the literature is twofold. 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. Bellemare 2012; Maertens and Swinnen 2009; Michelson 2013; Andersson et al. 2015) 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, Noev et al. 2009). This article 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 et al. 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 local 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 supplier is operating is key for understanding these effects.

Empirical studies indicate that particular value chain characteristics in the agricultural sector – such as the type of marketing channel (traditional, export, supermarket), the role of private standards (e.g. HCCP, GlobalGap, Organic or Fair Trade) and the type of governance structure (spot markets, contract farming, vertical integration) - indeed impact the production technology of farmers. As discussed before, this literature is thin. Few studies give explicit attention to technology transfer, although

they do provide information in the form of descriptive statistics and qualitative findings. Exceptions include Asfaw et al. (2009), Rao et al. (2012), Farole and Winkler (2014) and González-Flores et al. (2014). Moreover, some studies focusing on the welfare impact of farmer participation in modern value chains have included the effects on the use of technological inputs and on productivity as an explanatory step towards income (e.g. Minten et al. 2009)³.

The existing *theoretical* literature on vertical spillovers through backward linkages (i.e. from buyers to suppliers) is scarce and focused on manufacturing. Most notable references include Rodriguez-Clare (1996) and Markusen and Venables (1999). However, these and other studies tend to focus on vertical spillovers in the form externalities (i.e. non-intentional); through economies of scale, increased competition, demonstration effects or worker mobility for instance, while we model *intentional* technology transfer. Pack and Saggi (2001) model intentional technology transfer in manufacturing, taking into account the potential for leakage of the new technology to similar companies supplying to the buyer's competitors. We focus on the question whether it is profitable for the buyer to transfer technology to suppliers, regardless of economy-wide effects⁴, in a value chain setting by considering the type of technologies relevant for agriculture.

The remainder of this article is structured as follows. In section 2 and 3 we develop a simple model of technology adoption and transfer in a value chain setting in an

³ A major challenge for value chain studies, which are typically based on surveys, is to attribute causality. The "selection" within a value chain is likely to depend on supplier characteristics, such as location, land size, entrepreneurial ability and the type of production technology. While most studies control for observable variables (e.g. location and land size) by using methods such as propensity score matching, it is much less common to see studies that can convincingly deal with reverse causality, or with unobservable supplier variables correlated with both value chain participation and production technology (e.g. entrepreneurship).

⁴ A number of studies have demonstrated that also in agriculture technology transfers can have significant spillover effects beyond the contracted products (Jayne, Yamano, and Nyoro 2004; Minten, Randrianarison, and Swinnen 2009). For example, Negash and Swinnen (2013) find that the participation by Ethiopian farmers in the castor value chain strongly increased the yield of their non-contracted food crops as a result of increased access to fertilizer and technical assistance.

environment of technology and credit market imperfections. The model subsequently takes into account different types of value chain governance, contract enforcement issues and different types of technologies. In each section the model is complemented with a review of the empirical evidence. Section 4 uses this model to study the implications of different types of public investment. Finally, section 5 discusses the role of private standards as a potential catalyst for technology adoption and transfer.

2. A Basic Model of Technology Adoption in Value Chains

Consider a value chain (see figure 1) in which a farmer (or more general: a supplier) with a fixed allocation of labor and land can produce, using “basic technology”, a quantity q_L of a low quality product that can be sold for a price p_L , to a trader, processor or retailer, who we refer to as the buyer. This buyer can sell the supplier’s product (possibly after processing) to a consumer for a fixed price p_b . To keep the model simple, we assume p_b is net of any costs incurred (e.g. for processing or marketing) and thus represents the value of the supplier’s product to the buyer. Assume there are two potential markets for the buyer to sell: a high value and a low value. In the market for low quality products, the buyer is a price-taker and $p_b = p_L$. If the supplier’s product complies with specific standards, the buyer can sell the product in the high value market at $p_b = p_H > p_L$.

To comply with the standard or to increase his productivity, the supplier needs to apply a more advanced technology. To start we keep the definition of “technology” very general. Later (in section 4) we will look at different types of technologies and how this affects the results. The technology can come from different sources. The most obvious source is for the farmer to buy the technology from a “technology providing company” (e.g. fertilizer company, agro-dealer or extension agency) for a price τ^f .

We assume that this technology is necessary to comply with the buyer's private standard or that it can (also) increase the supplier's productivity, reflected in a higher quantity produced q_H , given fixed land and labor inputs. The total value generated by applying the advanced technology is then defined as $V = p_b q_H$. Defining $l = p_L q_L$ as the farmer's opportunity cost, the gross-surplus created by adopting the technology (θ) is defined as $\theta = p_b q_H - p_L q_L = V - l$ and the net-surplus as $S = V - l - \tau^f$. The farmer will decide to adopt the technology if this net-surplus S is positive, i.e. if:

$$V \geq \tau^f + l \quad (1)$$

Or, if $\theta \geq \tau^f$. This result is illustrated in panel (a) of figure 2.

This general condition captures both the quantity and the 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 and if the quality effect is stronger (captured by p_b , with $p_b = p_H$ or p_L with $p_H > p_L$). Technology adoption decreases with the price of technology τ^f .

Empirical evidence

In "traditional markets", the empirical literature finds that the adoption of technological inputs is positively associated with the prevailing output market prices, while they find a negative association with the prevailing prices of technology. Alene et al. (2008) for example, showed for Kenyan maize farmers that a 1% increase in maize price increases the probability of fertilizer use by 5% and the intensity of use by 1.04%. Similarly, Winter-Nelson and Temu (2005) found for Tanzanian coffee growers that a 1% increase in price, increases the expenditure on chemical inputs (such as fertilizer and pesticides) by 1.25%. Another study by Zerfu and Larson (2010), shows using a countrywide panel household

survey from Ethiopia that adoption of fertilizer is negatively associated with the price of fertilizer relative to output prices.

In “modern value chains” and for products complying with codified standards prices generally tend to be higher, which might positively affect the incentive to adopt yield technology. Wollni and Zeller (2007) for example find that participation in the specialty coffee segment (gourmet coffee, organic, shade-grown or fair trade) by Costa Rican coffee farmers receive an average price that is 0.09US\$/lb higher compared to the price received on conventional markets. Similarly, Asfaw et al. (2009) shows that Kenyan vegetable producers who are both exporting and GlobalGap certified receive a price which is 25% higher than what is received by non-certified exporters and 150% higher than what is received by producers who market their produce domestically. Another example is a study by Subervie and Vagneron (2013) who found the mean maximum price received by lychee farmers in Madagascar to be 15% higher for GlobalGAP certified farmers than for non-certified farmers, after controlling for other farmer characteristics. Finally, Hansen and Trifkovic (2014) show that Vietnamese Pangasius farmers who comply with standards (i.e. GlobalGAP and BAP) and have a written agreement with a trader receive a substantially higher average farm gate price, compared to farmers who do not comply or do not have a contract.

Not all studies find that high value chains pay higher prices. Michelson et al. (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). However, (average) prices may be a misleading indicator. Michelson et al. (2012) suggest that farmers accept a lower price, because Walmart covers the transportation costs and risks of sourcing the crop in the field. Moreover, the price offered by Walmart is less volatile than the price on the traditional market. Handschuch et al. (2013) found similar

results; although ChileGAP or USGap certified raspberry farmers in Chile obtain significantly lower prices for fresh raspberries on average, they also face considerably less price variation. Similarly farmers in Hungary and Slovakia preferred certain value chains and the required technology because the 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.

3. Technology Transfer Through Vertical Coordination in Value Chains

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 (Rozelle and Swinnen 2004; Croppenstedt, Demeke, and Meschi 2003; Morris 2007). That is of course assuming the technology is available at all. If not, $\tau^f = \infty$.

It may well be that the buyer has better access to the modern technology than the supplier. It is likely that the buyer has less credit constraints as it has more collateral or more cash flow for financing the technology, or, because it faces lower transaction costs. The latter can be the case when the buyer provides the technology to multiple suppliers (e.g. as part of an outgrower scheme) and benefits from economies of scale⁵. There is much empirical evidence that suggests that this is a realistic assumption.

The buyer can then offer the supplier a contract, which includes the transfer of technology and conditions for purchasing the supplier's 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

⁵ Another reason may be lower information asymmetries if the buyer is closer to the final consumer (see figure 1) and therefore has better knowledge on consumer preferences and what type of technology used by the supplier is likely to be valued.

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 τ . For simplicity we assume the supplier's "disagreement payoff" is equal to l . The buyer's and supplier's participation constraints are then defined as $\Pi^B \geq k$ and $\Pi^S \geq l$, with Π and Y denoting the buyer's and supplier's contract payoff ⁶. The total value created by the technology transfer can be defined as $V = p_b q_H$, while the (net-) surplus of the contract is defined by $S = V - l - k = \theta - \tau$

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. We denote the share that accrues to the supplier as β , with $0 \leq \beta \leq 1$, and assume this is exogenously determined⁷. Now consider first the case that contracts are always perfectly enforced. In this case, given the disagreement payoffs of both parties, the contract payoffs are

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

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

Under these assumptions, the technology transfer will take place if the net-surplus is positive, i.e. if

$$V \geq \tau + l \quad (4)$$

or, after rewriting, $\theta \geq \tau$. This result is illustrated in panel (b) of figure 2. Similarly as in the case of technology adoption, technology transfer is more likely if the effect of technology transfer on the value of the supplier's product ($p_b - p_L$) or on the production

⁶ This implicitly assumes it is not profitable for the buyer to acquire the technology by himself. The model would however also hold without this assumption (as long as $k^f > k$).

⁷ The determination of β is a question which has received a lot of attention in the literature but, as yet, has not been fully resolved (see e.g. J. F. M. Swinnen et al. 2015; Doyle and Inderst 2007).

efficiency is higher ($q_H - q_L$) and if the buyer's opportunity costs of transferring the technology are lower (τ).

Empirical evidence

The provision of finance and inputs by traders is elaborately discussed in the interlinked contract literature (e.g. Smith, Stockbridge, and Lohano 1999; Hoff and Stiglitz 1990). But also in the context of modern value chains many case studies have documented processors and traders providing finance to suppliers. Dries and Swinnen (2010) for example showed that it was common practice for Polish dairy processors to offer credit programs and bank loan guarantees to their suppliers. They find that both types of financial assistance stimulated dairy specific investments in livestock upgrades and cooling equipment.

Case studies documented traders and processors directly providing pre-financed technological inputs to farmers as part of their procurement schemes (e.g. Dries and Swinnen 2004; Minten et al. 2009; Gow et al. 2000). Bellemare (2012) for example shows the extent to which different processing companies in Madagascar active across a range of different crops (e.g. cotton, vegetables, rice and barley), provide farmers with improved seeds, pesticides and fertilizer. Although there is large variation in the extent of technology transfer across processing companies, the bulk of interviewed farmers under contract were provided some type of technological inputs.

Besides the provision of technological inputs and finance, it has often been observed that buyers assist suppliers in less tangible ways, through training for instance. This is documented in multiple case studies (e.g. Gow et al. 2000; World Bank 2005; Negash and Swinnen 2013). Minten et al. (2009), for example, describe the case of a vegetable exporter in Madagascar that engaged in contracts with 9.000 smallholders and

provided training on subjects such as harvesting methods, the use of chemical inputs and on how to make and use compost, which changed the farming practices applied to both contracted and off-season crops. 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 suppliers (including assistance around quality and health, safety and environmental issues).

Most of the evidence on technology transfer in agriculture comes from high standard markets in developing and emerging countries. This could be due to reporting bias. The emergence of modern value chains and private standards in developing countries is a topic that has recently received a lot of attention. However, Schipmann and Qaim (2011) provide some evidence that technology transfer is more common for high standard value chains by demonstrating 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 who deliver to the traditional market. Many others present a clear association between participation in high value chains and the application of modern technologies. Handschuch et al. (2013), for example, present descriptive statistics which show that certified raspberry producers have more advanced farming skills (i.e. they are applying water, pesticides and fertilizer as recommended) and have better farm management (i.e. they are more likely to document in- and outputs). Moreover they spent more on fertilizer and pesticides, have 28% higher yields, and produce a higher share of high-quality raspberries that are marketed as fresh fruit (32% vs 13%). In the Kenyan vegetable sector, Asfaw et al. (2009) show that although complying with GlobalGap does not affect the quantity of pesticides applied, it does lead to the use of a safer type of pesticide. Rao et al. (2012) show that Kenyan vegetable farmers supplying to the supermarket channel tend to use more fertilizer, seeds and manure per acre and have a

higher sales revenue per acre. Neven et al. (2009) find that the average land and labor productivity are, respectively, 59% and 73% higher for those super-market channel farmers than for traditional channel farmers.

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 possibilities for holdup. First, the supplier could decide to divert the technology provided by the buyer (such as fertilizer, improved seeds or machinery) by selling it. Alternatively, the supplier 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 need to account for the cost of the provided technology. Finally, the buyer could hold up the supplier 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 supplier the value of his best alternative at that point.

In this article we focus on contract enforcement problems because of the possibility of supplier holdup through technology diversion⁸. If the supplier diverts the technology, he or she can get a benefit between τ and τ^f . This depends on the nature of the market imperfections (or cost advantage of the buyer) in the technology market. If the

⁸ Buyer holdup, will generally not affect the occurrence of technology transfer, since buyers have an incentive to stimulate modern technology use by farmers. Side-selling by supplier potentially affects the occurrence of technology transfer in a slightly different way than input diversion, it is conceptually similar and would make the analysis unnecessarily more complex See Swinnen et al. (2015) for a treatment of these alternative hold-ups.

difference 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 τ (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 τ^f (since other farmers in the village can now buy it locally). In this section, we assume the benefits of diverting the input is τ . In addition, the supplier can still realize his opportunity cost of labor l . By violating his contract, the supplier suffers a reputation cost $\phi \geq 0$ ⁹. Hence, with technology diversion, the payoffs are $\Pi_d^S = l + \tau - \phi$ and $\Pi_d^B = 0$ ¹⁰.

In case there is no external contract enforcement (beyond what is captured in the reputation costs), any contract offered by the buyer must offer the supplier at least as much as his payoff when diverting the inputs in order to be “self-enforcing”¹¹. That is, two conditions must now be satisfied for the technology transfer contract to be abided by: the supplier’s participation constraint ($\Pi^S \geq l$) and his incentive compatibility constraint ($\Pi^S \geq l + \tau - \phi$). This results in the following contract payoffs under imperfect enforcement.

$$\Pi^{S\#} = \max(l + \beta S ; l + \tau - \phi ;) \quad (5)$$

$$\Pi^{B\#} = V - Y^\# \quad (6)$$

The contract is not always feasible. For a technology transfer to be feasible under the assumption of imperfect enforcement, enough value has to be created by the transfer

⁹ Reputation cost of contract breach are considered exogenous and can be interpreted in different ways. First, the supplier could suffer a moral cost of breaking his word. Second, he could suffer a loss of social standing. Third, he could lose future trade opportunities, with this particular or other buyers.

¹⁰ Note we model k and l as “sunk” costs, which is why they do not directly show up in the buyer and supplier’s payoffs. These costs will be reflected in the buyer and supplier’s participation constraints.

¹¹ Another solution for these problems is complete vertical integration, whereby the buyer and the supplier merge into one company to align interests (Klein, Crawford, and Alchian 1978; Williamson 1979). It is beyond the scope of this article to discuss under which conditions one solution is preferred to the other.

to cover for the participation constraints and the holdup opportunity. This is the case when:

$$V \geq V^{min} = \max\{l + \tau; l + 2\tau - \phi\} \quad (7)$$

This result is illustrated in panel (c) of figure 2. In words, the feasibility of technology transfer under imperfect enforcement is increasing in the value created by using the technology V and the supplier's reputation cost ϕ , while it is decreasing in the buyer's and supplier's opportunity costs, τ and l .

Empirical evidence

Interviews with value chain agents (company managers and farmers in value chains) yield much anecdotal evidence of failed efforts to establish value chain-driven technology transfer. Sound empirical "evidence" is less available since it is obviously difficult to observe technology transfer *not* taking place because of potential hold up problems. There is however substantial literature on the break-down of interlinked contracting in traditional outgrower schemes in Africa after the liberalization process (Swinnen and Maertens 2007; Swinnen et al. 2010). This break-down resulted from a shift from state controlled exchange to private enforcement, which was too weak or absent many African countries to keep systems of vertical coordination in place. Similarly, studies on the transition processes in the 1990s document extensive value chain breakdown following holdup problems in agrifood chains (Gow and Swinnen 1998; 2001; Swinnen and Rozelle 2006).

Some case studies on high value chains do also provide indications that supplier hold is a serious problem by reporting on the measures taken by buyers to prevent this behavior. Minten et al. (2009) for example report that a processing firm in Madagascar,

who provides its suppliers with technological inputs and technical assistance, invested heavily in systems to intensively monitor their suppliers to counter opportunistic behavior. Another indication of the importance of the issue is given by Schipmann and Qaim (2011), who report that 23% of the farm contracts in the sweet pepper retail and export value chains in Thailand include agreements about side-selling.

3.3 Technology Transfer through Vertical Integration

An alternative for the buyer to contracting with local suppliers is to vertically integrate and control the production process itself. In case contract breach is likely (determined by the conditions in the previous section), the buyer may opt to vertically integrate upstream.

There are several empirical cases documented in the literature of vertically integrated production systems, including in the horticulture sector in Senegal (Maertens et al) and East Africa (Dolan and Humphrey 2000). In this case technology transfer to agriculture occurs within a vertically integrated company. Such vertical integration can also result from (or be induced by) other factors such as the necessity to control the production process. Especially if certain practices by suppliers are difficult to observe, but essential in complying with private or public standards (e.g. restrictions on the use of pesticides and child labor). Another factor that could induce a preference for larger scale production are large fixed transaction costs, which would make it less efficient to source from many individual smallholders. This factor is to some extent offset by risk aversion on the buyers end as depending on a few large scale suppliers might threaten a secure flow of supplies. Given the space constraints of this article and the need to integrate these additional factors, we have not formally modeled this process.

Empirical evidence

There is much literature on how standards in high value chains and the associated requirements for suppliers to invest in modern technology (as well as the need to economize on transaction costs) has (a) induced a shift to larger suppliers; (b) led to a significant amount of vertically integrated production systems, but (c) also a remarkable heterogeneity in supply systems, with smallholder contracting far more common than initially expected (for surveys, see e.g. Beghin et al. 2015; Maertens and Swinnen 2014; Reardon et al. 2009).

4 Different Types of Technologies

So far we have not been very specific in our definition and use of the term “technology”. The concept of technology can be used to capture a variety of different factors which affect the quality or productivity of the production process and the product, including the use of improved seeds, specific types of fertilizer, knowledge transfer (in the form of training and extension), 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 in previous sections, they also differ in important aspects.

One aspect relates to how specific the technology is for the transactions between buyer and supplier. If the technology is 100% specific to the transaction, it has no value outside the contract; if it (or its effects) are also valued by others it is less specific. This aspect is captured by parameter α , which increases with the value of the technology outside the contract. Hence, the less specific the technology, the higher α .

Another aspect is the time dimension of the technology transfer. Some technologies need to be provided every production period. This is the case when the buyer provides the supplier with production technology that is used up in the production

process, such as improved seeds and pesticides. Other technologies affect the production process beyond the current period, such as knowledge transfer (e.g. in the form of training or information) or the transfer of machinery (e.g. cooling equipment in dairy). These differences will affect the time dynamics of value that is created. We represent this dimension by parameter γ .

The time dynamics can be dealt with in several ways. Optimally, the length of the contract will equal the time of the value creation by the transferred technology. However, in many cases long-term contracting may not be feasible because it is very difficult to enforce or because it is not allowed by regulation.

Consider the case that contracts can only be established for one season (for annual crops) or for one year (for continuous production, such as dairy, or perennial crops, such as coffee). Then define γ as the share of the gross surplus that is obtained in the contract year.

Using these two dimensions, we can classify technology into four “types” – as illustrated in table 1. For each “pure” type we give an example. Examples of $\gamma = 1$ technologies are product packaging and fertilizer. They are recurring every year and their benefits are realized in the contract year. Investment in a traceability system or a training on integrated soil fertility management (ISFM) are in principle nonrecurring and provide long term effects, beyond what is realized in the contract year ($\gamma < 1$). Concerning contract specificity (α), often product packaging and traceability systems are customized to the specific needs of the buyer and therefore do not provide value to the supplier outside the contract ($\alpha = 0$). In contrast, technologies such as fertilizer and ISFM can be considered valuable outside the contract ($\alpha > 0$) if sold or applied to non-contracted crops for instance.

To analyze how these technology characteristics affect technology transfer in value chains, we extend our basic model to incorporate these two dimensions. As before, the potential surplus of contracting with a supplier consists of the value in the contract minus the opportunity costs of the buyer and the supplier. The net surplus of the collaboration is now defined by

$$S = \gamma\theta - \tau + \frac{\mu(1-\gamma)}{1+\delta}\theta = \gamma(V - l) - \tau + \frac{\mu(1-\gamma)}{1+\delta}(V - l) \quad (8)$$

where μ represents the probability that the remaining gross surplus from the technology transfer is realized in the future (with $0 \leq \mu \leq 1$) and δ the discount rate¹². The contract payoff to the supplier under perfect enforcement Π^S in the period when the technology is transferred and used is then equal to $\Pi^S = \gamma l + \beta \left[\gamma(V - l) - \tau + \frac{\mu(1-\gamma)}{1+\delta^S}(V - l) \right]$, with δ^S the supplier's specific discount rate. For illustrative purposes, consider the case that the farmer's discount rate is very high ($\delta^S = \infty$) or that the likelihood of future technology use for the buyer is low ($\mu = 0$). In this case the surplus of the transfer simply becomes:

$$S = \gamma(V - l) - \tau \quad (9)$$

Under perfect enforcement, the transfer is feasible if $S \geq 0$, i.e. if $\gamma V > \gamma l + \tau$. Rewriting gives us:

$$V \geq l + \frac{\tau}{\gamma} \quad (10)$$

However, under imperfect enforcement, the self-enforcing contract will only arise if the value of the technology is large enough to satisfy (next to the participation constraint of both parties) the constraint imposed by the possibility of input diversion. Taking into account the specificity of the technology captured by α , the payoffs in case of input

¹² μ is endogenously determined in a dynamic version of the model, and will depend on a variety of factors such as dynamic reputation costs etc.

diversion become $\Pi_d^S = \gamma l + \alpha \tau - \phi$ and $\Pi_d^B = 0$. Since we assume only a portion γ of V is realized we need $\gamma V \geq \gamma l + (1 + \alpha)\tau - \phi$ such that the total value created in the current period covers for both the incentive compatibility constraint of the supplier and the participation constraint of the buyer. Rewriting gives us

$$V \geq l + \frac{(1+\alpha)\tau - \phi}{\gamma} \quad (11)$$

In combination with (10), this gives us the following condition under which technology transfer will take place:

$$V \geq V^{min} = \max\{l + \frac{\tau}{\gamma}; l + \frac{(1+\alpha)\tau - \phi}{\gamma}\} \quad (11)$$

This condition captures two reasons for potential contract failure. First, if $V < l + \frac{\tau}{\gamma}$, the surplus generated by the technology transfer is negative. Second, if $V \geq l + \frac{\tau}{\gamma}$, but $V < l + \frac{(1+\alpha)\tau - \phi}{\gamma}$, the surplus generated by the transfer is positive, but too small to allow the buyer to offer a price to the supplier which prevents him from diverting the technology.

To learn how the type of technology influences the feasibility of the technology transfer we take the derivative of V^{min} with respect to α and γ and obtain $\frac{\partial V^{min}}{\partial \alpha} \geq 0$ and $\frac{\partial V^{min}}{\partial \gamma} < 0$. This implies that the feasibility of technology transfer decreases in the technology's value outside the contract α , and in the share of the gross surplus that is generated in the current period γ . This is illustrated in figure 3 and 4.

Figure 3 shows that if the mix of technology shifts from a higher specificity (α_0), to lower specificity (α_1), with $\alpha_1 > \alpha_0$, this will lead to a higher payoff for the supplier when diverting the transferred technology. This means that the net-surplus S should be higher for the contract to be self-enforcing and that technology transfer will become less feasible.

However, this is only the case as if $\alpha\tau > \phi$. As long as $\alpha\tau \leq \phi$ it is not interesting to divert the technology and the supplier will obey the contract terms. Therefore, all else equal, it will be more feasible to transfer a very specific technology (e.g. product packaging) than to transfer a more generic technology (e.g. fertilizer).

Figure 4 shows that an increase in the share of the gross surplus that is created by the technology in the current period from γ_0 to γ_1 , shifts the surplus function ($S = \gamma(V - l) - \tau$) to left, while making it more steep (i.e. given V , more surplus S is created in the current period). This means technology transfer becomes more likely, also for technology with a lower effectiveness θ . If the supplier has no incentive to divert the technology (i.e. if $\alpha\tau \leq \phi$) the shift in V^{min} is relatively small. However, for technology with a high value outside the contract (α), such that $\alpha\tau > \phi$, the increase in feasibility from a rise in γ is potentially much bigger. All else equal, the transfer of very specific technology with short term effects (e.g. product packaging) is more likely to occur, than technology transfer that either is less specific (e.g. fertilizer) or can be applied for a longer term (e.g. a traceability system). A transfer of technology that is both non-specific and long-term oriented (e.g. ISFM training) is the least likely to occur.

Empirical evidence

There exists yet very little empirical evidence on the conditions under which it is more or less likely for technology transfer to occur, let alone on the type of technology. However, there is evidence that for longer term technologies, many buyers try to set up contractual systems (or vertical coordination mechanisms more general) where the technology suppliers or financial institutions are integrated in order to spread the risk and costs of contract breach and to enhance enforcement capacity (lower information asymmetries and higher reputation costs). For example World Bank (2005) and Swinnen (2006)

document a variety of institutional systems for farm-level technology investments in dairy and brewery-grain chains in Eastern Europe. This includes the provision of bank loan guarantees and joint contracts between processing companies (buyers), banks and technology providers.

5 Interaction between Public Investment and Technology Transfers through Value Chains.

Using this model we can now investigate the effect of public investments on technology adoption by farmers. Relevant public investments would include fertilizer subsidies, infrastructure projects or rural credit programs. The first order effect on technology adoption of these type of investments is straightforward: the price for which a farmer can directly purchase the technology τ^f is expected to drop. This leads to a shift to the left of the net-surplus function in figure 2(a). All else equal (i.e. the gross-surplus created by the technology stays constant at θ), it becomes more interesting to purchase the technology directly.

However, whether this public investment will lead to a shift from technology transfer through value chains to direct purchase of technology depends on the nature and extend of the public investment and the type of market imperfection that caused the gap between the cost for the farmer τ^f and the transfer costs of the buyer τ . If the difference between τ and τ^f is due to transport costs, an infrastructural program (or a fertilizer subsidy) is indeed expected to reduce τ^f , but will simultaneously reduce the supplier's holdup payoff when diverting the technology (in this case $V^{min} = l + \tau + \tau^f - \phi$). This is can be illustrated by a shift of V^{min} to the left in figure 2(c); i.e. we expect technology adoption via transfer to increase, while there is no reason to expect farmers to switch

from technology transfer through value chains to direct purchase (since this has not become more attractive in relative terms).

If on the other hand, the difference between τ and τ^f is due to credit market imperfections, a rural credit market program (that leads to lower interest rates for farmers) is indeed expected to reduce τ^f , but will have no effect on the pay-off from technology-diversion (in this case $V^{min} = l + 2k - \phi$) and will therefore not make technology transfer more likely. A reduction in τ^f is therefore expected to have no effect on technology transfer, up to the point where it becomes more interesting to purchase the technology directly (i.e. if $k^f < 2\tau - \phi$). We can then expect technology transfer to disappear in favor of direct purchases.

6 Discussion: Standards as a Catalyst for Technology Transfer and Adoption

The model can also be used to study how the emergence of private standards affects the occurrence of technology adoption and transfers. The introduction of private standards can theoretically affect many of the variables in our model. First, private standards directly affect supplier technology; by requiring or prohibiting the use of certain technological inputs or practices private standards are expected to improve the quality and value of the produce. Secondly, private standards are often used as a marketing tool for the buyer that can generate value for consumers through enhancing product differentiation. Thirdly, well communicated private standards reduce information asymmetries and transaction costs, which will reduce the cost of sourcing differentiated (high quality) raw material. In terms of our model, these three effects will result in an increase of the price the buyer can receive for his product p_b (which we assumed is net of transaction, processing or marketing costs), like explained in section 2. Fourth, the

introduction of private standards might reduce the costs of technology adoption through direct purchase k^f and through technology transfer k by standardizing the technology necessary for compliance. Indeed, compliance costs are expected to go down (e.g. via economies of scale and lower information asymmetries) if the requirements to comply become common knowledge. Finally, private standards may affect the specificity of the transferred technology. Effectively, the transferred technology necessary to comply with standards is less likely to have value outside the contract, making it less interesting to divert the technology.

Using this we can expect that the introduction of standards leads to enhanced technology adoption and transfer through the positive effect of p_b on V , the negative effects on τ and τ^f and the negative effect on the specificity of the technology transferred α . This is in line with the previously discussed evidence on the effects of private standards and high value chains on technology adoption and transfers (i.e. Neven et al. 2009; Schipmann and Qaim 2011; Rao et al. 2012; Handschuch et al. 2013).

7 Conclusion

In this article we reviewed the literature on the implications of value chain developments for farm-level technological change and developed a model that identified the different conditions under which we can expect upstream technology transfer to occur.

We find that technology transfer might be a profitable way for buyers to source (high quality) produce in an environment characterized by imperfect credit and technology markets. However, this will only be feasible when the buyer has superior access to technology compared to the supplier. Moreover, we find that the profitability (and occurrence) of the transfer depends on a range of other factors. First, the technology should be sufficiently effective to overcome the buyer's and supplier's opportunity costs.

Second, imperfect contract enforcement and the opportunity of supplier holdup negatively affects the feasibility of the transfer. Finally, whether the transfer will occur depends on the type of technology. In this respect, our model demonstrated that technology which is very specific for the relationship with the buyer, and which only affects the production process for one period, is more likely to be transferred than technology that either is more generic or has longer term effects. We also discussed how public investment affects the occurrence of technology transfer and adoption, will depend on the nature of the market imperfections and the extent and type of public investment.

Although empirical studies that aim to precisely verify these mechanisms are absent, we show ample evidence that these results are generally in line with the emerging literature on value chains and technology adoption.

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

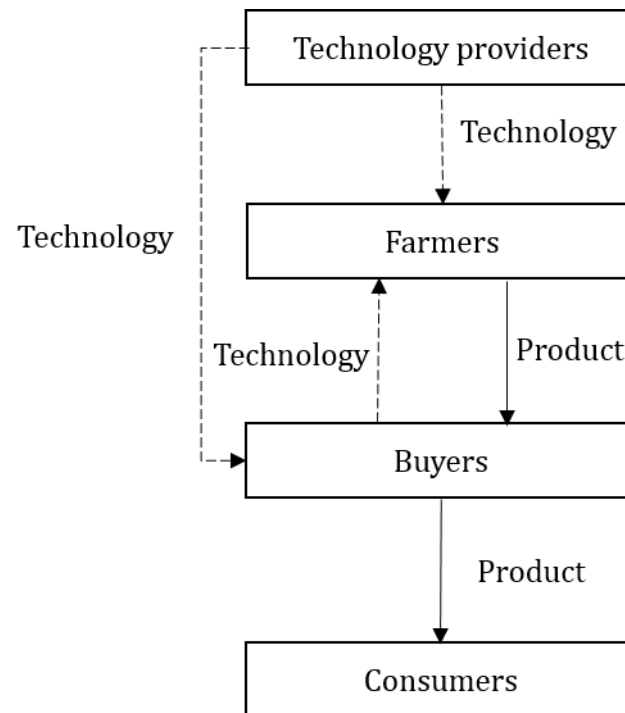


Figure 2. Supplier use of advanced technology under three scenarios: (a) direct purchase of technology, (b) technology transfer through value chain contracting under perfect enforcement and (c) technology transfer through value chain contracting under imperfect enforcement.

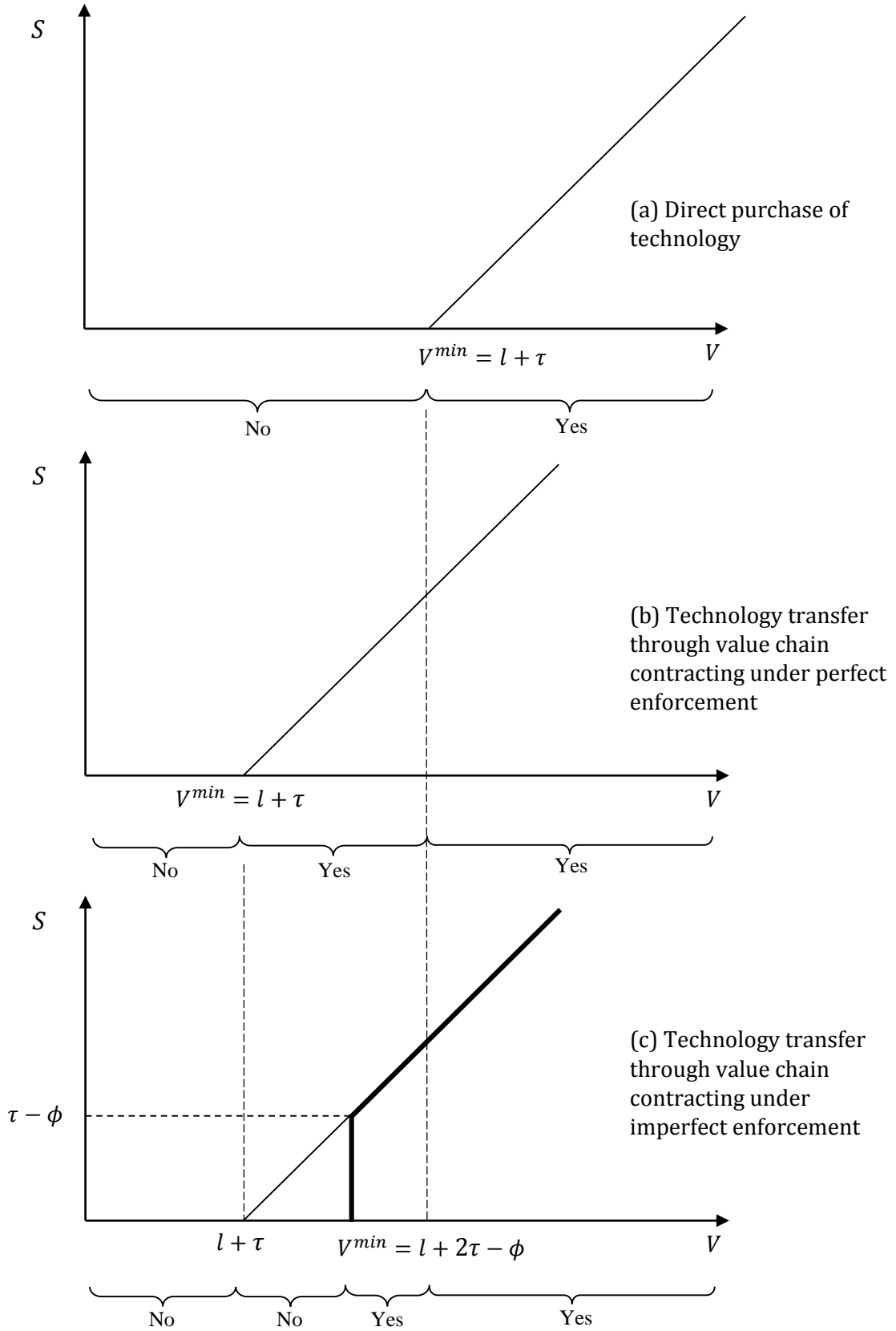


Table 1. Different types of technology

	Value outside of the contract (α)		
		$\alpha = 0$	$\alpha > 0$
Share of gross-surplus obtained in contract period (γ)	$\gamma = 1$	e.g. product packaging	e.g. fertilizer
	$\gamma < 1$	e.g. traceability system	e.g. ISFM training

Figure 3. Impact of a shift from α_0 to α_1 (with $\gamma_1 > \gamma_0$)

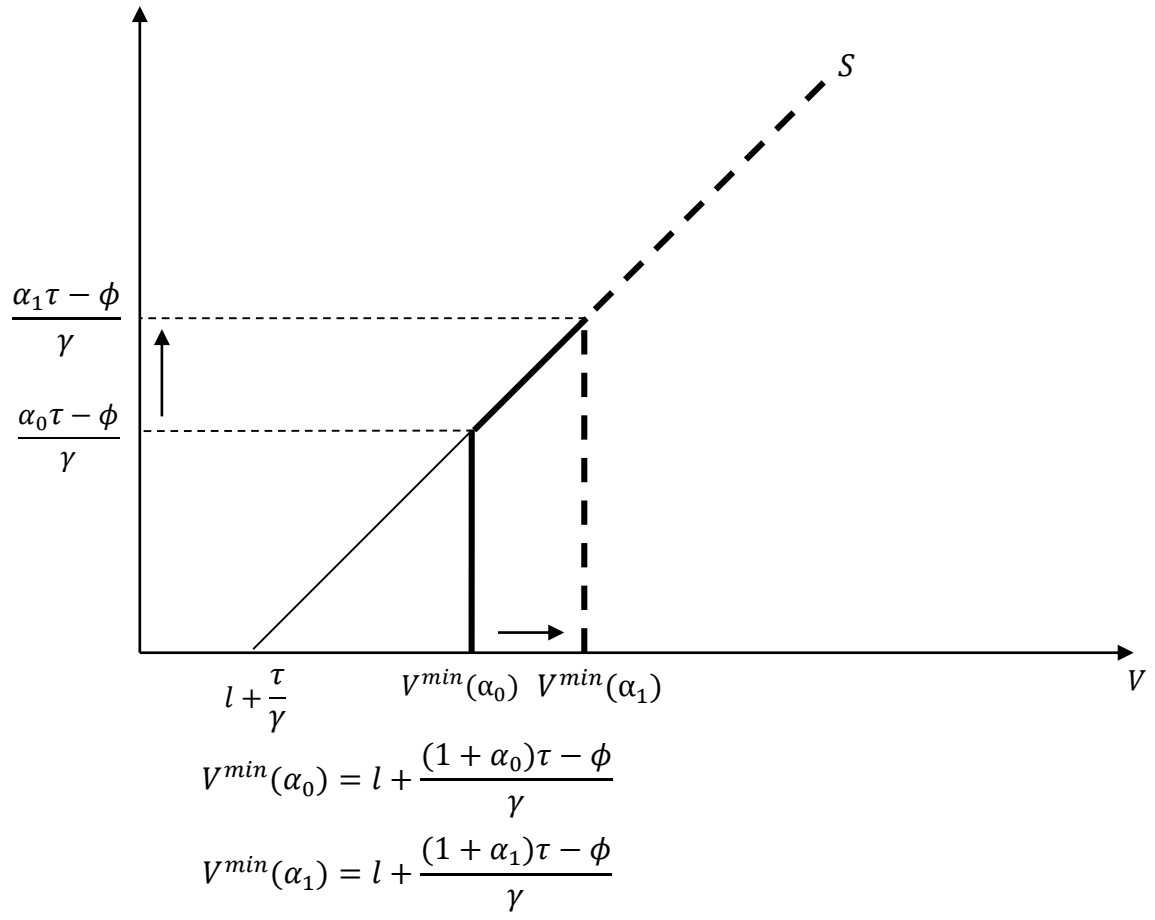
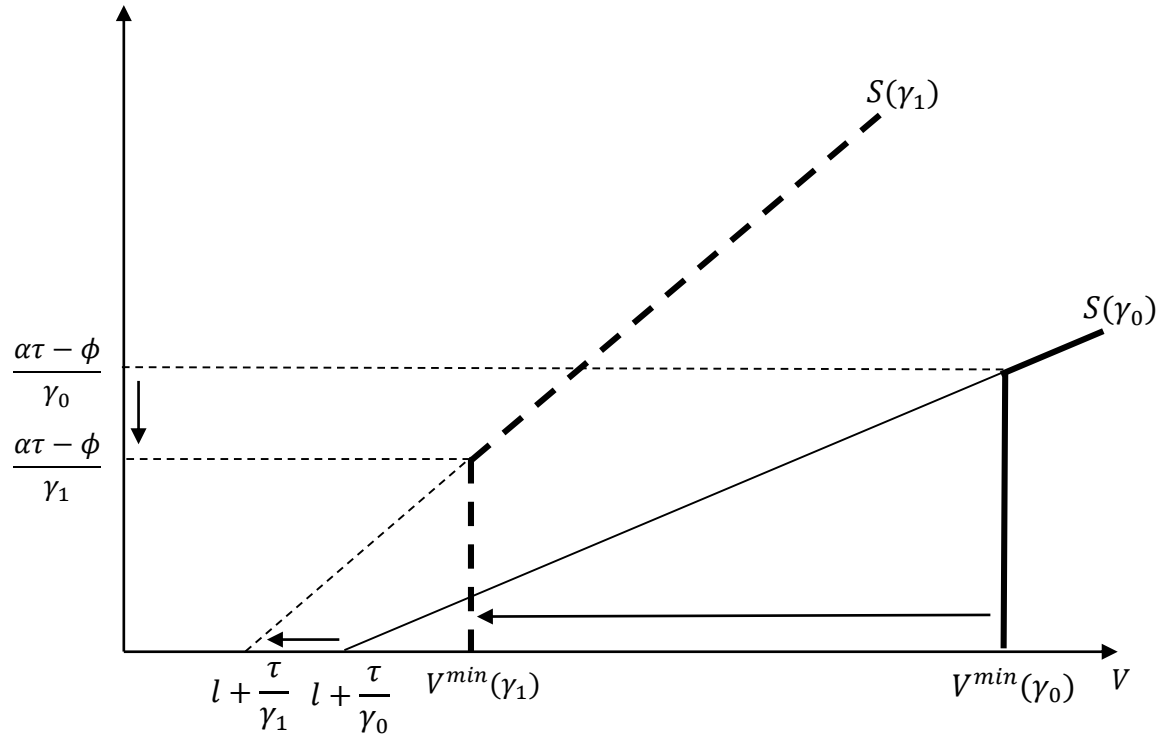


Figure 4. Impact of a shift from γ_0 to γ_1 (with $\gamma_1 > \gamma_0$)



$$V^{\min}(\gamma_0) = l + \frac{(1 + \alpha)\tau - \phi}{\gamma_0} \quad S(\gamma_0) = \gamma_0(V - l)$$

$$V^{\min}(\gamma_1) = l + \frac{(1 + \alpha)\tau - \phi}{\gamma_1} \quad S(\gamma_1) = \gamma_1(V - l)$$