Chapter 4

Confronting future water risks

This chapter discusses policy responses that seek to reduce water risks in hotspots. An economic model is used to assess the role of farmers, private companies, and governments in mitigating water risks. A policy action plan is proposed to address water risks for agriculture production in hotspot locations, mitigate the market impacts that may result, and alleviate broader socio-economic impacts.

The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Key messages

Farmers, agro-food companies and governments share the burden and responsibility of confronting future water risks in hotspot areas, and will respond differently according to their incentives and capacity to respond. Farmers will respond to future water risks if sufficiently well informed of impacts and solutions, by adopting better practices or by shifting activities. However, they may not be as responsive to water risks to which they contribute. For instance, a farmer is more likely to change practices in response to a drought than reducing his use of fertilisers or pesticides in response to a pollution problem.

Agro-food companies in hotspot regions face different constraints and are more likely to respond when they heavily rely on products vulnerable to water risks. Companies may resort to purchasing products from farms outside hotspot regions, they may change their agricultural inputs or ingredients, or may partner with farmers to address risks under stewardship programmes. Large companies, in particular, may have more incentive to respond to agriculture water risks when they face reputational damage.

Governments should complement efforts by private stakeholders to mitigate water risks and co-ordinate reponses in hotspot regions. Governments should incentivise farmers to engage in risk reducing behaviours by increasing the benefits of acting or the cost of inaction and encouraging supply chain actors to also play their part.

This chapter proposes a three-tier action plan for governments that incorporates the hotspots approach.

1. At the hotspot level, governments should adapt existing national policy instruments, such as a cap and trade water systems, to conditions in hotspot regions, and introduce targeted instruments directly addressing water risks, such as locally-tailored information provision and extension efforts.

2. At the national and international level, governments should ensure that markets are well integrated and functioning so that when a problem arises it does not have a ripple effect. Well-functioning food markets play a key role in diluting price effects and ensuring that regional effects are contained. International trade partners should ensure that markets remain open to avoid having market reactions worsening the problem.

3. At a broader level, international collaboration aimed at increasing the resilience of vulnerable hotspot regions can mitigate risks, including through information and technology sharing and financial assistance. For example, China and the western states of the United States have collaborated with the Australian government to learn about the functioning of water markets in the Murray Darling Basin. Countries not facing water risks themselves should anticipate how water shocks in other countries can affect them through food insecurity, social unrest or migration.

The medium-term outlook suggests that the required policy actions will be different in each of the three hotspots studied. The Southwest United States should continue to vigourously apply policies already in place, but agriculture will need to adapt to drier conditions. Northeast China would need to reinforce and scale-up current policy initiatives, such as the use of water pricing to curb water demand, and decouple agricultural support from input use. Northwest India would need to overhaul existing policies such as energy subsidies and the promotion of solar pumps that may accelerate groundwater depletion. Steps already taken, including the introduction of a groundwater model bill, suggest a willingness to move in the right direction.

4.1. From project impacts to effective responses: Who, what and how to confront future water risks?

In the previous chapters, the hotspot approach has been proposed and used to identify countries and regions subject to future agriculture water risks, the possible impacts they may have on the agro-food system and beyond have then been assessed. This chapter analyses and identifies solutions to respond to such risks. The proposed responses will be assessed generally and are applied differentially in the three identified hotspot regions and in others projected to face high agriculture water risks.

Three questions are addressed. First, who can and should respond to acute water risks? Given that high water risks generate private and public damages, governments should share the responsibilities with farmers and companies. What should they do? A simple economic model will be used to assess the incentives farmers and companies in hotspot locations face to respond to water risks, to understand what actions they are likely to undertake, and consequently, to identify what governments should do and in which circumstances. A policy plan is then proposed to respond to the three layers of impacts defined in Chapter 3: production impacts in hotspot regions, direct market impacts in other regions and countries and indirect food security impacts.

The chapter is organised in four subsections. Section 4.2 discusses what the role of farmers and food companies may be in addressing water risks in hotspot regions. Section 4.3 presents the proposed action plan for governments. The plan is then detailed in two parts; Section 4.4 outlines policy options to mitigate agriculture production risks at the hotspot location, and Section 4.5 describes measures to reduce broader sector risks, and to limit chain reaction that would affect non-hotspot countries. Section 4.6 closes the chapter with a discussion of implications for three pre-identified hotspot regions.

4.2. Sharing the burden and responsibilities of responding to acute water risks: The role of farmers, food companies and governments

Just as water risk impacts can differently affect producers and other agro-food market participants in hotspot regions (Chapters 1 to 3), they each have different motives to respond to water risks. This section analyses the incentives for reaction and possible responses of farmers and agro-purchasing food companies in hotspot regions. It addresses ongoing and future water risks and identifies what complementary role governments may play in that setting.

As a preamble, an important distinction should be made between: exogenous and endogenous risks. Water risks that farmers face exogenously—which will be denoted as exogenous risks—including those related to climate change and competing water demand on which an individual farmer (and food company) has limited effect. In contrast, endogenous water risks are risks to which an individual farmer (or company) contributes, e.g. nutrient runoffs leading to water pollution or intensive groundwater use leading to aquifer depletion. Even if most situations will involve a mix of both risks, the set of incentives farmers and food companies face may differ accordingly.

A simple economic model can help identify the critical factors affecting the likelihood and types of responses to water risks (the details of the derivations are presented in Annex 4.A1).[1] Assume that an economic agent (farmer or agro-food company) is confronted with two possible scenarios, it may be facing acute future water risks with probability φ, or no water risks with probability $(1-\varphi)$. The expected profits the agent faces can be expressed as $E(\Pi/NR) = \varphi.\Pi_1 + (1-\varphi).\overline{\Pi_1}$, assuming Π_1 is the profit under water risks and $\overline{\Pi_1}$ is the agent's profit under no risk both at time t1 (future) with no reaction (NR).[2] A similar expression can be derived if the agent decides to react to this possibility (noted R): $E(\Pi/R) = \varphi.\Pi_R + (1-\varphi).\overline{\Pi_R}$ with Π_R and $\overline{\Pi_R}$ as the profit derived with this reaction under risks and no risks, respectively. A perfectly informed agent will then respond to future water risks if and only if: $E(\Pi/R) \geq E(\Pi/NR)$ which is equivalent to the following arbitrage equation:

$$\varphi[(\overline{\Pi_1} - \Pi_1) - (\overline{\Pi_R} - \Pi_R)] \geq \overline{\Pi_1} - \overline{\Pi_R} \quad (1)$$

This equation can be interpreted as an incentive compatibility constraint. It means that the agent will only take action if the net benefit from reaction under risks exceeds the costs it involves under no risks. The probability θ that equation (1) is verified, which can be interpreted as the likelihood of reaction, increases with the probability of water risks (φ) and the expected profit losses with inaction if such risk were realised ($\overline{\Pi_1} - \Pi_1$). Conversely, this probability decreases with the remaining water risk impacts with the response ($\overline{\Pi_R} - \Pi_R$) and the relative costs the response may involve in a case of the absence of water risks ($\overline{\Pi_1} - \overline{\Pi_R}$).

Naturally, the profit functions used in (1) will differ according to different actors, and whether agents face exogenous risks or directly affect future water risks (endogenous risks). The next two sub-sections will use this arbitrage equation as a basis to discuss responses by farmers and companies.

Farmers respond more proactively to short- or medium-term exogenous water risks by changing practices and technology or by switching activities

The responses of individual farmers to water risks in the hotspot region are subject to multiple factors. In the immediate or medium term, farmers with information and access to capital will take action to mitigate exogenous water risks on their production and revenue, so long as it is profitable for them to do so (equation 1). Their reactions can be triggered for instance by extreme events (e.g. Mechler et al., 2010), or the deterioration of water quality with agriculture consequences or a gradual reduction in access to usable water (OECD, 2013). This is consistent with the observation that climate change adaptation generates private future benefits for farmers; therefore, they will have an incentive and should have a role to play to reduce the impact they may face in the future (e.g. Ignaciuk, 2015).

Table 4.1. Factors affecting the probability of farmers responding to future water risks

Key factors	Effect on the probability of reaction θ		Effect on the strength of responses
	Short-medium term	Long term	
Probability of risks	Positive effect	Positive effect	Positive effect
Price of products	Positive effect	Positive effect	n/a
Cost of water	Positive effect	Positive effect	n/a
Price of inputs	Ambiguous	Ambiguous	n/a
Information about risks or response	Positive effect	Positive but lower effect	More options possible
Capacity to respond	Minimum threshold to reach		Stepwise progression
Freedom to operate	Positive effect until a maximum		Stepwise progression
Risk aversion	Positive effect		Positive effect
Protection to risks	Possible negative effect		Negative effect
Discount rates	No effect	Negative effect	Negative effect (long term)
Projection uncertainties	No effect	Negative effect	Negative effect (long term)

Source: Authors own work, based in part on derivations from the model.

In detail, however, a range of factors will affect the probability of farmers' response (Table 4.1).

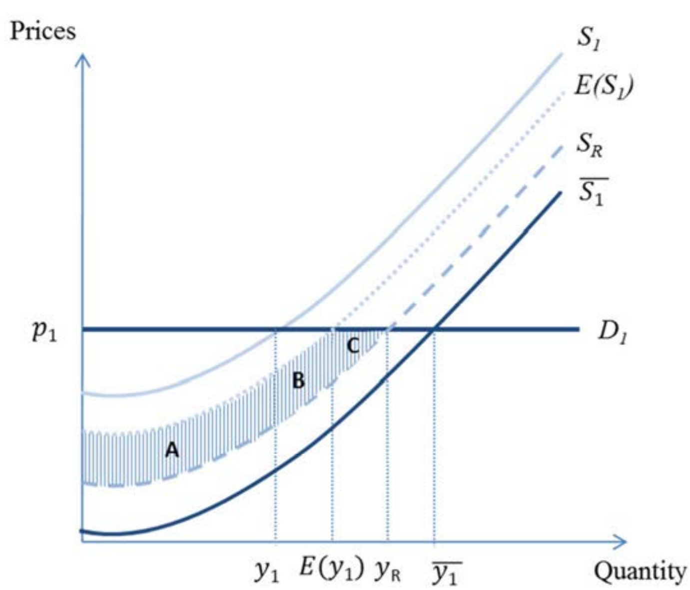
- A number of economic factors affect the probability of responses (Annex 4.A1), such as the effectiveness and possible foregone revenues associated with the reaction, but also how water risks affect the use of other (non-water) inputs, their costs, and the costs of water (i.e. water prices).
- Other constraints, non-accounted but possibly adaptable in the model, can alter the balance between action and inaction. In particular:
  - Insufficient information about the risks (φ unknown or ignored) or the response, especially when considering long-term risks that are not realised yet, can prevent reaction.
  - Farmers' capacity to respond (e.g. $\overline{\Pi_1} - \overline{\Pi_R}$ exceeding the budget of the farmer), and his or her lack of access to credit, can also prevent any response, so does their freedom to operate (policy environment, long-term, non-recoverable investments).

- Farmers' degree of risk-aversion may result in attributing more weight into risky situation (de facto inflating φ), which will increase the likelihood of response but may also result in costly "overreaction" (the choice of non-profitable alternative).
- On the other hand, the possible protection to risks (insurance) farmers have could partially reduce the likelihood of response (by lowering $(\overline{\Pi_1} - \Pi_1)$). This is consistent with findings of the climate change adaptation literature; e.g. Annan and Schlenker (2015) find that American farmers with insurance opt for more heat sensitive crops and do not have the incentive to engage into adaptation.
- In the long run, discount rates (not accounted for in the model) and real uncertainties on future water conditions (for which there is no robust information) and on technical solutions may also alter incentives to react. Even if the combination of the two may in fact reduce the effect on reaction.

Farmers will typically adapt to high water risks by changing practices or technologies, or by switching agriculture activities (Mendelsohn, 2016).[3] The choice of option will depend on the factors listed in Table 4.1, as well as the type of water risks and market conditions (relative profitability and availability of agriculture alternatives).[4] Assuming farmers face an observable reduction of available and usable water supply that will affect their production and revenue; they may increase their water use efficiency to produce at least as much with less water. When considering a water quality risk they may resort to change in practices, including, drainage, dilution or treatment. Alternatively, for both water quantity or quality risks, they may change agriculture activities towards more profitable or less risky sources of income.[5]

Each of the options involve trade-offs for individual farmers, that depend on the transaction costs and/or foregone benefits of the solution if no risk is actually realised (Annex 4.A1.2). In particular, changing practices will only occur if the costs of doing so are inferior to the risk avoidance benefits, and changing agriculture activity will only be profitable if the alternative provides more resilient and still viable revenue.

Figure 4.1. Market effects of water risk responses



Note: S_1 is the supply with risk, $\overline{S_1}$ with no risk, $E(S_1)$ expected supply, and S_R supply with reaction. D_1 is the demand curve. This simplified illustration assumes a perfectly elastic demand and water risks are interpreted as a vertical shift in supply.

Source: Author's own work.

In each case, the solution will allow farmers to move away from maximum damages and improve their expected revenues, but it will not enable them to reach the profit level they would expect under no risk, because of the cost of response, as illustrated in Figure 4.1. Farmers will take action only if it allows them to obtain larger expected net revenue (with equilibrium quantity yR) than expected revenue with no reaction (quantity E(y1)). The gain of reacting is represented by the hatched area A+B+C in Figure 4.1, defined by the difference between the two supply curves E(S1) and SR under the demand curve.[6]

There are many examples of farmers' adaptation to exogenous water risks. The global development of groundwater irrigation in many regions was encouraged by decreasing precipitation and/or surface water variability (OECD, 2015a). In the United Kingdom, potato farmers responded to the 1975-76 drought by installing irrigation systems to better cope with rainwater shortfalls, and have not seen equally high production damages during subsequent droughts (Mechler et al., 2010). In the face of increasing dry conditions, many California growers have gradually shifted their activity towards higher value per water drop, and increased their water efficiency (Cooley et al., 2014). Farmers have also adapted to increased risk of salinity by changing their practice as observed in the Netherlands (van Duinen et al., 2015).

When faced with endogenous constraints, farmers face a slightly different set of incentive compatibility constraints. In this case, farmers' use of water and the impact they may have on water resources in the present affects their own future water risks. In the model, the probability of risks will depend on water uses and/or impact at present (Annex 4.A1). The incentive compatibility constraint (equation 1) remains essentially the same. Voluntary and anticipatory responses to water risks can be expected when the risks of not acting exceed the cost of taking action today. Responses to endogenous water risks also include changing practices, changing inputs and activities. Groundwater salinity in the irrigating region of the Californian Salinas Valley is an example whereby the risk of irreversible costs triggered actions of farmers in co-ordination with cities (OECD, 2015a). In Northern China, farmers have responded to groundwater shortage by taking the control of wells and pump assets, developing markets, adopting water savings and changing cropping patterns (Wang et al., 2007).

Yet the trigger to take action is not automatic, because of the possibility of free riding behaviour; the probability of future risks depends on the water use and/or impact of all farmers in the region at present. An individual farmer reducing water use or water impact in the short term, by switching to different activities or practices, will reduce water risks in the long term, thereby reducing the need (and probability θ) for any farmer to invest in future response. This situation depicts a Nash non-co-operative game; the outcome of a farmer's action depends on that of other farmers. Therefore, unless the farmer represents a significant share of water use in the hotspot region, or that s/he faces a sufficiently strong signals to account for future water risks (policy or investment return), s/he may not have sufficient incentive to act. Collective action by farmers can help overcome this individual incentive constraint, as observed in certain regions with water quality initiatives (OECD, 2013b).

Agro-food companies are more likely to respond when they strongly depend on products vulnerable to water risk or when they risk harm to their reputation

Agro-food companies in hotspot regions face different constraints. They purchase farmers' products, whose prices they may affect, and these products may only represent one input in their production chain. They rely on procured products from multiple farmers that may in some case be also located outside of the hotspot region. Therefore, farmers' water risks may not automatically result in significant costs for companies. Their profit will also depend on prices for finished products which could be unrelated to water risks. Relatively larger companies may also be subject to different types of impacts; beyond future production losses, not responding to endogenous water risks may affect their reputation, reducing their sales and the confidence of their financial investors.

As with farmers, risk probability and the price of output will increase their likelihood of response (higher stakes), but generally the response of food companies (and related organisations) will also vary largely by scope, market factors and dependency with local food supply (Annex 4.A1.3). Larger operating companies that rely on a broader market may not suffer significant losses from production risks in hotspot located farms; therefore, other things being equal, their threshold for response is higher. Smaller companies are more vulnerable to losses and will need to find ways to adapt more rapidly.

Under exogenous water risks, the type of responses will depend on the economic viability of the option and the scope of operations. Three options can be envisaged. First, companies may purchase products from farms outside of the hotspot region, if those alternative regions do not face an equally high risk; second, they may possibly change their agriculture inputs (or ingredients); and third, they may undertake stewardship programmes with farmers to ensure that they respond to risks (change practices or technologies). The choice of responses among these three options depends on transaction costs, such as transport costs for outside of the region engagement, cost of alternative ingredients, or alternative practices (Annex 4.A1.3). The response will also depend on the scope of operations; larger companies may be able to shift their purchases to other production units outside of the hotspot region in a temporary or permanent way, or engage with farmers. Smaller companies' existence may depend on supplies in the hotspot region.

Companies' incentive compatibility constraint will be altered when considering endogenous water risks caused by farmers and by their own operations. In this case, three factors change; first, farmers decision to react may matter, second, farmers contribution to overall risks, which could create uncertainties, and third, relatively large companies not reacting face reputation risks that may affect their sales (losses of revenues) or the confidence of investors on which they rely (e.g. affecting the companies' long term growth and investments). Reputation risks can be factored in as penalties (Annex 4.A1.3). Everything else being equal, because they face such reputation risks, larger companies are more likely to engage into a response than smaller ones.

More specifically, however, the question is whether larger companies will favour one approach or another. Moving away from water risk locations may have some reputation risks, as it avoids solving the problem and may displace the problem to other regions. Changing inputs could be helpful if the substitute effectively reduces the water risk factor and encourage farmers to produce alternative crops. Yet effectively engaging with farmers is probably the preferred option for consumers and investors. This option may evolve from stewardship initiatives to contracting and private standards, moving from voluntary options to mandatory requirements.[7] Market power may play a role in determining whether the approach will work; companies that have the largest agriculture market share can exert more power on their suppliers than smaller ones.

Smaller companies may approach the problem differently, as they are less likely to face reputation issues with investors or consumers. If such issues are not important, the problem they face will be similar to that of an exogenous risk, albeit facing more uncertainties in the future.

Examining the combined responses of farmers and companies: gaps, lack of co-ordination and strategic behaviour

Farmers and companies will respond to water risks differently depending on the type of farm and company and their respective sets of constraints. More resilient farmers will react to exogenous or endogenous risks to which a more vulnerable farmer may not be able. A large company may be more able to respond to different types of risks than a small company. If greater water risk will increase the average probability of response by all actors, it is difficult to predict the share of farms and companies that will effectively be able to tackle the risks proactively without knowing more about regional and market characteristics.

This heterogeneity of responses applies when considering the three regions of Northeast China, Northwest India and Southwest United States. Northeast China is populated by very small farms that may be vulnerable or semi-resilient to water risks. At the same time, the sector includes large agro-food companies, at least partially state-based,[8] who may contribute to risk mitigation especially if they are rated based on government objectives. In Northwest India, farmers can also be considered vulnerable or semi-resilient, while most food companies operate on a small to medium scale and may not be willing or able to respond to risks. In the Southwest United States, a large share of farms operate on a very large scale, with capacity to respond, and may act in conjunction with large co-operatives or companies to minimise the risks. Yet in all three regions, continued groundwater depletion also shows that endogenous water risks have not been satisfactorily addressed by farmers or companies.

In reality, uncertainties about future water risks may also matter, as these risks will be perceived differently among actors, possibly leading to co-ordination problems. In the above section, the behaviour of companies and farmers was analysed separately to understand the type of incentives they may respond to facing a possible but generally known risk. However, the risk is not only uncertain but it may also be perceived differently by different farmers and companies depending on their level of information and degree of risk aversion. For instance, farmers may believe that water risks are higher than companies do. Consequently, there may be asymmetric information and risk perception among farmers and among companies. In general, the actors with higher risk perceptions are more likely to react before other actors, assuming they share the same level of information. Better informed actors about risks will also act faster than others, assuming that they share the same degree of risk aversion.

The lack of information and possible information asymmetries may create co-ordination problems and lead to inefficient autonomous response to risks. If farmers get helped to mitigate risks, why do it on their own? If some companies act to reduce risk, why should others also contribute? Companies could do less than they would according to economic expectations, especially if farmers perceive the risks are higher than they perceive. Farmers may wait for companies to take any action and therefore under-adapt.

In the case of the three hotspot regions, the level of information about water risks does vary significantly (due to education, information access, capacity etc.). The three regions have already suffered long and intense drought spells, so awareness on water risks is high among all types of actors. However, information on the extent of the problem, its future projections, and the contribution of farmers to water challenges likely vary significantly from India to China and the United States. Large companies operating in the United States may also be more proactive than in the two other countries due to their capacity to provide flexible responses. Just like companies harvesting lettuce in California are able to change location three times a year to respond to climatic conditions, they may also be able to adapt to changing water supply and climatic conditions.

Well-defined government actions are needed to encourage and facilitate effective and co-ordinated responses

The role of government should be to incentivise farmers to engage in risk-reducing behaviours by increasing the benefits of acting or the cost of inaction, encouraging supply chain actors to also play a part of the role in risk mitigation activities. In particular, governments should address exogenous risks by increasing the probability of response by farmers (θ). This can be done, for instance, by providing more and better information on the cost of inaction and supporting effective response, but it may also involve regulatory instruments that will ensure that farmers take actions. For endogenous risks, governments have a role to play to redress information asymmetry to avoid co-ordination failures, but also to provide a signal for risk-enhancing farmers to take action, by employing regulatory or economic incentive measures (OECD, 2010b; 2014 and 2016f). For instance, increasing the price of water may encourage the uptake of practices or changes in crops under water risks (Annex 4.A1). Because risk-enhancing actions will generally continue, the government’s engagement should have a long time horizon, with targets and monitoring, to ensure that efforts undertaken during a period are not wasted in a future period.

Still these actions will not be warranted in all contexts. Accounting for autonomous actions by farmers and companies, three main criteria appear necessary to any government intervention to address water risks in hotspot location.

- *Rationale*: Government’s action will be warranted economically if it addresses market failures or market imperfection (OECD, 2014). Ignaciuk (2015) identifies seven criteria whereby public action is warranted for climate change adaptation ranging from knowledge development and dissemination to removing institutional barriers. Governments have a role to mitigate market failures associated with the risk of floods and droughts for agriculture (OECD, 2016f).

- *Additionality*: Government's engagement in hotspot water risks will only be effective if it adds significantly to existing policies towards agriculture risk management; it should drive either new or more intense responses in hotspot locations, and avoid overlap with existing broader government efforts (such as information provision or investment in irrigation efficiency).

- *Targeting the right actors*: For government's action to enhance welfare, it should focus on the most likely impacted actors and account for autonomous reactions. Public action will only be effective if it aims at accounting for the capacity and incentives of farmers and companies to undertake autonomous actions, thereby identifying adaptation gaps.

The level of action is also an important consideration when planning for government's response to water risk hotspots. Adopting a hotspot approach will necessitate increased engagement on water risk mitigation in specific agriculture regions, either directly by national agencies or by devolving responsibilities to regional authorities. Local agriculture and water basin agencies and regional authorities (cities, district, counties, provinces or states) in charge of water and agriculture will need to be accounted for to ensure an effective response. National government agencies will therefore need to define their role in such system, be it as a facilitator or federator of responses, a complementary actor, an investor or funder, or by assuming a regulatory oversight role.

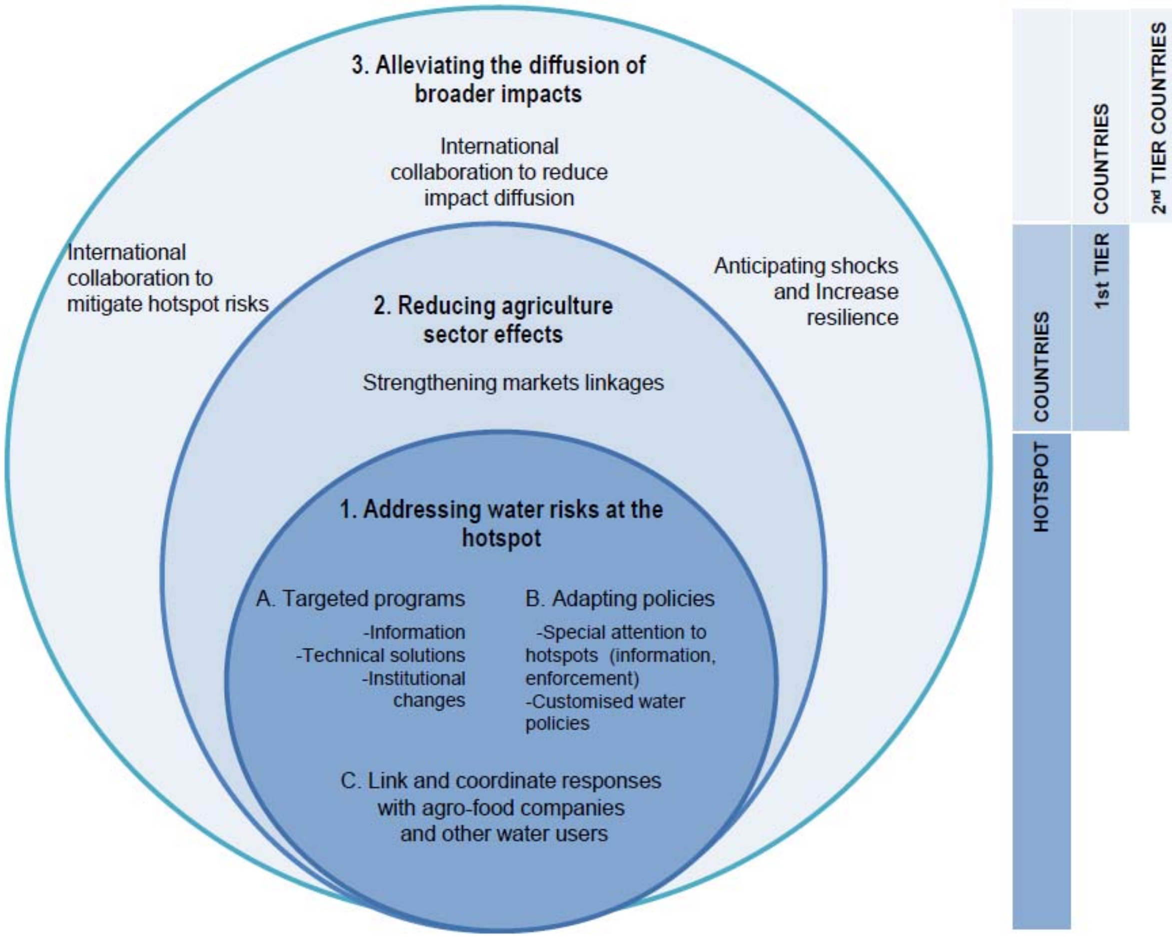
The analysis has shown that agriculture future water risk management is a responsibility that can be shared by farmers, companies and governments The next sections will consider a set of policy actions to mitigate water risks at and beyond hotspot locations.

4.3. A three-tier action plan for governments: From reducing hotspot risks to alleviating broader indirect impacts

A three tier action plan is presented in Figure 4.2. The scope of action is differentiated for the hotspot region, the market directly impacted (1st tier), and the indirectly impacted (2nd tier) countries—reflecting the three layers of impacts discussed in Chapter 3. Priority should be given to mitigating agriculture water risks in identified hotspot locations (1), not only for effectiveness and efficiency reasons, but because the more risk mitigation is conducted at this level, the lower impact there will be outside of the hotspot location. Recommended actions in sphere (2) and then (3) are conditional on the efforts undertaken at the hotspot location and may become secondary if hotspot level risks are well managed.

Figure 4.2. Proposed action plan for governments to address future water risk hotspots

Left hand side: Response by impact layer, Right hand side: scope for action for each type of country



Note: 1st tier country: market partner, 2nd tier country: other countries potentially affected.

Source: Author's own work.

The following sections describe these proposed actions, it first focuses on priority actions in the hotspot country and then moves to market and broader effects.

4.4. Reducing the risk at the source: Targeted programmes, adapted policies, and co-ordination with key stakeholders

The proposed action plan (Figure 4.2) incorporates three types of action for governments in hotspot locations. As for most regions, water risk hotspots require well-functioning generic water policies (OECD, 2016a). Beyond these, **two main policy approaches** can play a role in mitigating future agriculture water risk in hotspot regions. First governments can introduce additional targeted programmes or investments that add to pre-existing policies to better adjust to future risk; second, they can adapt existing national policies at the regional level to better respond to projected critical risks. Both approaches have merits, and may gain from being combined. As a complement to these approaches, **governments should co-ordinate their efforts** with relevant stakeholders. In particular, they should interact with and/or facilitate water stewardship efforts by agro-food sector companies. In addition, they should account for interaction of agriculture with other water users and the policies to which they are subject. The rest of this section will look at these three aspects (additional programmes, adapting policies, co-ordination with other actors) successively, encompassing different types of approaches based on the existing literature and illustration from existing programmes.

Targeted approaches to mitigate agriculture water risk in hotspot areas

Having identified future water risk locations, governments can decide to introduce additional programmes in hotspot locations to both increase effectiveness and reduce the cost of intervention. The level of action can vary by region, state or province, to a county or district, or even farms most at risk or most responsible for water risks, and could expand if successful in the hotspot area if funding allows.

Governments should engage into a combination of technical and institutional approaches to tackle water shortage risks. For agriculture water shortage risks, targeted initiatives should aim at reducing water consumption (demand side) or storing more water (supply side), and may include approaches geared toward technical or institutional solutions (solutions that require changes in the conditions under which farmers are operating) as shown in Table 4.2. These approaches may address both exogenous and endogenous water risks, and include investments, incentive programs, or new regulations.

Table 4.2. Targeted initiatives to tackle agriculture water shortage risks

	Demand side	Supply side
Technical solutions	-Establish water resource and water use monitoring systems -Targeted information programme to encourage context-specific water efficient farm practices -Cost-share programmes for efficient pressurised irrigation systems, precision agriculture sensors, or water conservation practices in the region -Support breeding for less water savvy and drought tolerant crops and livestock	-Conduct water supply vulnerability assessment -Targeted investment the development or maintenance of local dams, canals, and irrigation systems -Cost-share programmes into rainwater harvesting or infiltration ponds -Target investment in aquifer storage mechanisms (managed aquifer recharge, aquifer storage and recovery). -Invest in water reuse systems
Institutional solutions	-Regulating agriculture water use in the region or watershed -Setting up a charges for water used that varies with risks -Setting up water transfer or water market mechanisms -Measures favouring a shift away from water intensive crops	-Establishing regional groundwater banks

Source: OECD (2010, 2015a, 2016f); Cooley et al. (2016); Nam et al. (2015); and Ward (2016).

Governments should consider promoting technical solutions, via incentive, cost-share, R&D investment, or information instruments, as these have the advantage of enabling direct targeted actions on the source of the problem. On the demand side, they could invest in water monitoring and information systems, as these are constraints for farmers to act. They could also encourage farm management practices directed towards irrigation efficiency, which, if coupled with consumption reduction objectives, have a significant potential in addressing risks of water shortages in agriculture. For instance, Jägermeyr et al. (2016) use a projection model to simulate irrigation water productivity increases associated with different farm management practices globally under climate change scenarios. They find that irrigation efficiency improvements could lead to savings accounting up to 48% of non-productive water consumption. Governments could also promote precision agriculture and water conservation management practices as these have a potential to decrease water use (OECD, 2016d). In the Indian state of Haryana, Ambast et al. (2006) estimated that improvements in irrigation and fallowing practices for rainwater conservation and groundwater recharge would increase wheat productivity by 23% while potentially stabilising groundwater levels. Investing in regionally-focused applied breeding programmes towards less requiring or more drought resilient crop varieties and animal breeds may also contribute significantly to reduced water use, by favouring the switch of farmers to other relatively profitable opportunities why stabilising or lowering water consumption.

On the supply side, governments should focus their attention on addressing gaps, and facilitate or support investments in promising options for agriculture and water (Hanjra and Qureshi, 2010; Cooley et al., 2016). Investments in storage, if properly designed, can help sustain agriculture production under increasingly unstable precipitations (OECD, 2016d). Water reuse (or recycling) is increasingly seen as a necessity for operations to become less water thirsty in drought-prone regions (Hasler-Lewis, 2014). Irrigation development is also an effective means to reduce water shortage risks in drought-prone rainfed agriculture regions, particularly in developing countries (HLPE, 2015). In addition, in humid agriculture regions that expect to face future shortages, such as part of the United Kingdom, there may be some benefit to design supplemental irrigation schemes (Rey et al., 2014).

In recent years, targeted information efforts have been used to strengthen the resilience of farmers to climate change, including those related to future water shortage risks. The US Department of Agriculture has developed "climate hubs" (Box 4.1), or regional agencies covering specific agro-climatic regions, with the goal of assessing and responding to locally-specific agriculture or forest production vulnerability (USDA, 2016). A similar approach, focusing on irrigation vulnerability on the water supply side, has been conducted in Korea (Nam et al., 2015).

Box 4.1. Informing farmers of adaptation options: The USDA Climate Hubs

The US Department in Agriculture launched the Climate Hub regional programme in 2014, with the objective of "delivering science-based knowledge, practical information and programme support to farmers, ranchers, forest landowners, and resource managers to support climate-informed decision-making in light of the increased risks and vulnerabilities associated with a changing climate". Seven regional hubs were launched to cover the wide range of agro-climatic conditions spanning the United States. Within the Southwest Regional Climate Hub, California has been separated into a Sub Hub, to reflect the specificities of California's agriculture and climate challenges. Hubs rely on agents from regional or state offices of the USDA Agriculture Research Service or the USDA Forest Service, in collaboration with the USDA Natural Resources Conservation Service.

The Climate Hubs offer tools, management options and technical support to farmers, ranchers and landowners to help them adapt to climate change. The first activity undertaken in each hub or sub-hub is to use projected climate change impacts to map the vulnerability of different types of farms to climate change within the region. Hub or sub-hub agents then work with agronomic, livestock and forestry researchers and extension specialist to develop customised brochures and/or other information tools that recommend possible agronomic or technical responses to specific future climatic risks to different types of activity. The third step consists in disseminating these information brochures, and providing support to their application in local farm service agencies, with the support of land grand university extension specialists. In California, much of the vulnerability is related to the risk of water shortages; farmers have been proposed a menu of technical options to preserve water, store groundwater or become more efficient.

Source: USDA (2016) and personal conversation with USFS officer at the California Sub-hub.

Policies that provide financial support to technical approaches, even in a targeted manner, can have limitations if done in isolation of signals aiming at controlling total water use. In particular, support for irrigation efficiency has been found in a number of instances to be ineffective (OECD, 2015a; Ward, 2016). Shifting to more efficient irrigation in the absence of institutional controls on expansion of consumptive use can lead farmers to switch to crops that require more irrigation, reduce deficit irrigation or expand acreage, leading to an actual increase in water consumption.[9] This has been observed in northeastern Spain for instance, where irrigation modernisation has led to increased consumptive use (Lecina et al. 2009; Jimenez and Isidoro, 2012). Furthermore, increasing water efficiency can lead to reduce recharge of aquifers, reducing groundwater recharge, which further the problem of groundwater depletion in critical regions, like Northwest India (Ward, 2016) or the High Plains Aquifer (Pfeiffer and Lin, 2014). Dam or infrastructure investments also can result in conflict and lead to environment problems, and generally do not result in long term changes in the use of water.

Hotspottargeted institutional solutions may provide more lasting options for government to address water shortage (bottom row of Table 4.2). In particular, well-designed water transfers have the potential to help alleviate agriculture water risks in the United States Southwest (Cooley et al., 2016). In Australia, the multi-state water market around the Murray Darling Basin, regulated under an independent agency, provides incentive for farmers to be efficient and change agriculture activities based on the price signal they receive.

Since its introduction, farmers have been able to cope with largely fluctuating climatic conditions (Young, 2016). The system, however, required significant changes in resource allocation, involved prolonged efforts for years, and significant public investment. Encouraging nimble water transfers, adapted to local need and conditions, temporary and may also help in allowing conditional flexibility either for users in hotspot areas (nimble water transfers), or during severe weather events, potentially involving different set of actors (Colby, 2016). Measures that also discourage the use of relatively more water intensive agriculture activities may also have a role to play-reducing support for these crops or promoting the use of other activities may help in shifting the water consumption pattern in a hotspot region.

Targeted institutional solutions are especially relevant in the case of groundwater; successful groundwater management schemes generally involve collective action based management schemes that could effectively be used in water risk hotspot regions. The Nebraska Natural Resource District system is a successful example of management, whereby local actors decide of targeted approaches to sustainably manage groundwater use, to limit overdraft and its economic environmental consequences (Kassman, 2016). Groundwater banking and groundwater market initiatives often rely on local initiatives.

Naturally, addressing water shortage risks will be more effective with a combination of technical and institutional solutions. For instance, Saleth et al. (2016) analyse pathways to effective agriculture water demand management and show that institutions, infrastructures and technologies are necessary elements to an impact pathway to reduce agriculture's impact on water resources. Table 4.3 shows a suggested approach to address the problem of long-standing rapid depletion of groundwater in irrigated fields of Northwest India proposed in the literature.

Table 4.3. Proposed policy instruments to manage agriculture groundwater use in Northwest India

	Local	State and national	Regional / global
Information	-Generalisation of energy and/ or water metering systems	-Development of water databases (quantity, quality) -Aquifer mapping	
Technical Investment	-Water-saving technologies (e.g. drip irrigation, laser-levelling direct seeding) -Recycling of sewage water for irrigation -Groundwater recharge -Aquifer rehabilitation programmes		-Development of crop varieties resistant to salinity and drought
Economic	-Collective water resource management -Crop diversification -Alternative rural revenue	-Reform of the energy flat-rate system -Decoupling of subsidies with groundwater abstraction	
Regulatory		-New legal framework (Groundwater Bill) -Better application of the regulation in notified areas	
Multi-factor			-Mitigation of climate change

Sources: Badiani et al. (2012); CCAFS and CIMMYT (2014); Dasgupta (2016); Gleeson and Wada (2013); Hanasz (2014); OECD (2015a), Taylor et al. (2013).

Governments should consider multiple instruments to reduce flood risks

Governments can also resort to a combination of targeted technical and institutional solutions to manage flood water risks. There are increasingly sophisticated tools to identify and map flooding areas, incorporating future climate scenarios that can lead to targeted engineered responses at the territorial level (Poff et al., 2015). Governments can respond to floods by employing technical responses, such as by investing in infrastructure (dams, seawalls), emergency information and response systems (OECD, 2016f). At the production level, farmers can be encouraged to develop drainage system; they may also need to adapt their farming practices (Weather and Evans, 2009). Flood tolerant varieties of rice and other crops have been developed and successfully used in flood prone regions. Submergence-tolerant (SUB 1) rice varieties, developed by an international consortium or researchers using marker assisted selection, were commercially released in 2009-11, were rapidly adopted to reach an estimated 3.8 million farmers covering 2.5 million ha in 2012 in flood-prone regions of India, Nepal and Bangladesh (Ismail et al, 2013). Institutional solutions are less frequent. The development of integrated flood management encourages the use of payment for flooding protection (OECD, 2015c), in which farmers would get paid to provide fields for flooding. The United Kingdom is increasingly moving in this direction (OECD, 2015c; Weather and Evans, 2009).

Targeted efforts are well suited to mitigate water quality risks

Water quality risks are especially appropriate to the use of targeted initiatives around a hotspot region, because they tend to be locally heterogeneous and accumulating locally over time. The management of point source pollution is generally easier as it focuses on reducing pollution at the source. Diffuse pollution typically on the contrary spans over much more extensive areas, and will also differ significantly from one place to another, impacting water resources in a heterogeneous manner, leading to opportunities of acting on prioritised areas.

Governments can resort to a range of technical options to address endogenous or exogenous water quality risks in hotspot locations. Water quality measurements, investment in monitoring equipment, information programmes to support drainage and/or improved used of agriculture inputs, promoting precision farming, conservation agriculture and water treatment systems could be undertaken in areas most at risks. Given the complexity of water quality issues, the success of public efforts is not guaranteed and will rely on a careful design and monitoring system (Box 4.2). Governments can encourage and/or fund specialised breeding efforts; for instance the development of salt tolerant varieties of vegetables that can rely largely on seawater or brine aquifers has proven to be effective in the Netherlands and is now being envisaged in other salinity-prone regions (van Risselberghe, 2016). Additional technical solutions for the future may be under development; for instance, applied nanoscience present some potentially interesting solutions to control water quality impacts from agriculture (Dasgupta et al., 2016). Governments can also undertake larger investments in infrastructure to stop seawater level increases, slow salinity or other contamination of waterways to reduce future water risks.

Box 4.2. The challenge of reducing endogenous salinity risks in Australia

Australia is subject to different types of salinity. Primary salinity is naturally based affecting patches of land. Secondary salinity, results from water leaking to saline aquifers. The leaked water raise water tables, with saline water reaching the surface and then evaporating. Such phenomenon can result from the planting of shallow-rooted plants, that leave water leaking, or by excess water from irrigation.

Several programmes have been designed to address this challenge over the years. In 2000-07, the National Action Plan for Salinity and Water Quality spent a substantial amount (AUD 1.4 billion) on programmes spread into river catchment areas, to provide means to monitor, information, extension programmes, or grants to land manager to change their practices. Despite these substantial efforts, and acknowledging the complexity of the problem, several evaluations have found that the programme had not been able to effectively mitigate salinity notably because it failed to prioritise investments, set realistic targets, and support programmes towards long term goals (Pannell et al. 2014).

More recent programmes have focused on information and targeted investments. The National Water Quality Management Strategy proposes guidance on salinity trigger values and outlines ways to reduce salinity and adapt irrigation practices. The Australian Government's Water for the Future programme is promoting more efficient use of water on farms. The initiative "Caring for our Country" also will fund specific targeted programmes to address the risks in different contexts.

Source: Australian Government (2010); Pannell et al. (2010).

Targeted approaches have been employed to address diffuse nutrient pollution from farming zones in certain countries (OECD, 2017). These approaches typically include both technical and institutional components, coupling scientific assessment with policy response going almost to the farm level. In Scotland, for example, a targeted extension programme to reduce effluents prioritised pollution catchments, then launched data gathering exercises, awareness programmes for farmers, and one to one engagement with farmers to identify solutions and was ultimately able to significantly increase the uptake of best management practices by farmers (Aitken and Field, 2015). The Southland region of New Zealand developed a physiographic approach to water quality risks; incorporating results from different modelling exercises to target responses to farms that can generate the most groundwater nitrate contamination (see Annex 2.A1.3).

Water quality trading can be effective to tackle water risks locally and could potentially be extended to a wider number of areas facing endogenous water risk problems (Shortle, 2012; Rockefeller Foundation, 2015; OECD, 2017). While they require relatively elaborate institutional settings, such markets can prove effective in reducing diffuse pollution (OECD, 2012). Several schemes have been developed especially in North America, but also in New Zealand (e.g. OECD, 2015b).

Responding to multiple water risks in hotspot areas

Targeted water risk mitigation measures can also respond to multiple types of risks at once, albeit sometimes prioritising actions on one risk while addressing other. On the technical side, precision agriculture and irrigation efficient practices can for instance help reduce the use of inputs, e.g. via the use of fertigation (i.e. combining pressured irrigation system with the application of fertilisers). The Delta Programme in the Netherlands, while focusing on protection to seawater flooding, also works against intrusion of saline water into freshwater used in part for irrigation. Investments in multi-purpose dams, if well-designed and strategically placed, can provide protection from flooding; ensure a steady water supply, while also responding to a demand for energy and recreation (Naughton et al., 2017). More research may be needed in targeted solutions that can respond to multiple risks at once.

Given the range of options available and limited funding availability, governments should set up a prioritisation mechanism to identify which are the most cost-effective options. The design of the plan could be that used in other agro-environmental programmes (OECD, 2010a) or customised to water issues. For instance, Beher et al. (2016) propose a mechanism to prioritise programmes aiming at reducing marine run offs and apply it to sub-catchments adjacent to the Great Barrier Reef in Australia.

Enhancing existing agriculture risk management and water policies to address critical risks in hotspot regions

In parallel, governments should try to tailor broader policy levers in hotspot locations to respond to critical water risks. Water management often combines national and subnational (watershed) level policies to ensure that localised issues are treated in a differential manner in different hydrologic zones. For instance, watershed decentralised management is at the core of the EU Water Framework Directive. A hotspot approach would reinforce this approach by enabling even more flexibility to address localised critical water risks particularly for agriculture. This may comprise not only customised regional water policy responses but prioritisation of national agriculture or water policy programmes.

Table 4.4 reviews how past OECD policy recommendation to mitigate water risks in agriculture could be relevant and adapted to a hotspot management approach. Covered work includes analysis of agriculture risk management (OECD, 2011), as well as recommendations to address the challenges of adapting to climate change (OECD, 2014; Ignaciuk, 2015), to control groundwater intensive use (OECD, 2015a), and to mitigate the risk of floods and drought mitigation (OECD, 2016f).

Table 4.4. Adapting policy recommendations to address future agriculture water risk hotspots

Recommendation	Area*	Relevance and application to a hotspot management approach
Information support		
Build and maintain sufficient knowledge of groundwater resource and use;	GW	Special attention to hotspot areas
Establish information systems to support farmers, water managers and policy makers	WQ	Special attention to hotspot areas
Risk management		
Information, regulation and training to support market-based instruments for risk management	ARM	General-applies to hotspot areas
Managing catastrophic risks	ARM	General- applies to hotspot areas
Providing a clear framework for the allocation of risk-sharing and responsibilities, and facilitating the development of insurance products.	FD	Special attention to hotspot areas
Holistic approach to risk management	ARM	Special attention to hotspot areas
Water policy changes		
Manage surface and groundwater conjunctively where relevant; Favour instruments that directly target groundwater use; Prioritise demand–side approaches	GW	General- applies to hotspot areas
Take a holistic approach to agriculture pollution policies; Use a mix of policy instruments to address water pollution; Set realistic agriculture water quality targets and standards	WQ	General- applies to hotspot areas
Apply a "tripod" combination of regulatory, economic and collective management instruments to address intensive use of groundwater	GW	Special attention to hotspot areas
Take into account the Polluter-Pays-Principle to reduce agriculture water pollution.	WQ	Adaptable in hotspot areas by modulating instruments
Design policies to ensure long term sustainable water management; Improve crisis management of droughts and floods in agriculture by developing flexible instruments for water allocation, with economic instruments	CCWA FD	Adaptable in hotspot areas- with more flexible allocation systems and/or economic instruments
Enforcement		
Enhance the enforcement of regulatory measures	GW	Special attention to hotspot areas
Enforce compliance with existing water quality regulations and standards	WQ	Special attention to hotspot areas
Removing policy distortions		
Remove farm support that artificially increase risk exposure	CCWA	General- applies to hotspot areas
Remove disincentives for farmers' adaptive actions	AACC	General- applies to hotspot areas
Avoid non-water related price distorting policy measures, such as subsidies towards water intensive crops and energy	GW	General- applies to hotspot areas
Remove perverse support in agriculture to lower pressure on water systems.	WQ	General- applies to hotspot areas
Other recommendations		
Assess the cost effectiveness of different policy options to address water quality in agriculture.	WQ	General- applies to hotspot areas
Agronomic and supply-side measures as complement under high groundwater stress.	GW	Special attention to hotspot areas
Enable the development of private innovation and encourage public-private partnerships in agriculture technology R&D	AACC	Special attention to hotspot areas
Ensure infrastructure are climate-proof	AACC	Special attention to hotspot areas
Monitoring and evaluation of adaptation policies	AACC	Special attention to hotspot areas
Foster agriculture land as provider of floodplains and soil water retention services	FD	Special attention to hotspot areas

Note: * AACC: Adapting agriculture to climate change (Ignaciuk, 2015); ARM: agriculture risk management (OECD, 2011); CCWA: climate change water and agriculture (OECD, 2014); FD: mitigating floods and droughts (OECD, 2016f); GW: managing agricultural groundwater use (OECD, 2015a); WQ: controlling water quality (OECD, 2012).

Source: Author's own work, based on cited references.

Three categories of recommendations emerge, distinguishing actions based on their level of application and relevance for a hotspot approach.

- A first category regroups general policy recommendations that will need to be applied at the national level, with no differentiation in hotspot areas. This includes the removal of agriculture policies encouraging water misuse or the exposure of farmers to water risks, such as support for polluting inputs, or electricity subsidies for groundwater irrigation.
- Second, a large share of measures can be applied more forcefully or in priority in hotspot areas. This includes improving information systems, enforcing regulations in or strengthening groundwater policies. Each of these measures involves additional efforts by the national or local governments to mitigate water risks for farmers, without changing the direction of political actions.
- The third category of recommendations—pertaining to water allocation regimes and the use of economic instruments—could be specifically adapted to hotspot conditions.

Economic instruments could be adapted to tackle agriculture water risks in a hotspot area or even specifically targeted and designed for these areas. As discussed in Section 4.1, increasing the cost of water can encourage farmers to respond to shortage risks. Demand elasticities of irrigation largely vary across contexts, so water charges do not always result in any change in water consumption (OECD, 2010; 2015a). The question would then be how to introduce gradually stronger signals and how to ensure that economic instruments respond to future water risks. Water markets have the advantage of setting the price without requiring information about water conditions; they can respond to medium-term fluctuation and evolve over time (e.g. OECD, 2015d; Mendelsohn, 2016). The use of cap and trade, with a reduced cap over time, could help incentivise market actors to become water efficient faster. Charging water would require assessment and monitoring of the situation by an agency, but if politically feasible could drive efforts forward. Non-market quantitative restrictions can also be gradual based on the evolution of water risks. In all these cases, a clear target and transparent plan of action should be set over a long-term horizon.

Several national or state policies have been designed to enable locally differentiated responses. In California, the Sustainable Groundwater Management Act relies on semi-autonomous management in groundwater bodies. All groundwater bodies have to reach sustainability objectives by 2042, but they have the liberty to decide how to get there (see Box 4.3). In the case of water quality risks, Denmark has been introducing a targeted regulation for nitrate pollution into groundwater, imposing more strict oversight on farming zones that are more likely to lead to increased groundwater pollution (Højberg, 2016). The reform includes increased emphasis on zones that are more likely to impact aquifers (Ibid.).

Box 4.3. Adapting efforts to address groundwater overdraft in California

Groundwater depletion for agriculture irrigation is a major challenge in California. Groundwater is an important water source for California farmers, accounting for nearly 40% of irrigation withdrawals in average years (Maupin et al., 2014) and up to 60% in dry years. UCCHM (2014) estimates that over 60 km3 of groundwater have been lost in the Central Valley over the last half century. There are strong indications that groundwater overdraft is worsening: recent data show that the Sacramento and San Joaquin River Basins collectively lost nearly 31 km3 of groundwater between October 2003 and March 2010, or about 4.8 km^3 per year (Famiglietti et al., 2011). Overdraft is especially severe in the southern parts of the Central Valley, where groundwater levels have reached more than 33 meters below previous historic lows (CDWR, 2014). Overdraft has resulted in saltwater intrusion and other water quality impacts, significant land subsidence, lost water storage, and increased energy costs, among other adverse impacts.

Groundwater use has been unregulated in much of California. In response to worsening groundwater conditions, the state recently passed the Sustainable Groundwater Management Act of 2014 (SGMA). The act provides a framework for local authorities to manage groundwater supplies but allows for state intervention if necessary to protect groundwater resources. Specifically, it requires the formation of local agencies by mid-2017 and requires those agencies to adopt and implement local basin management plans by 2022. Additionally, it requires basins to achieve groundwater sustainability goals by 2040 in medium- and high-priority basins in critical overdraft and by 2042 in all other medium- and high-priority basins. While it remains to be seen the extent to which sustainability goals will actually be achieved, SGMA is an important step toward more rational and sustainable use of California's groundwater resources. In the long term, the intention of SGMA is that its implementation should increase the reliability of groundwater for agriculture and other users, leading in particular to a new long term –sustainable- equilibrium for irrigated agriculture.

Source: Cooley et al. (2016), citing CDWR (2014); Famiglietti et al. (2011); Maupin et al. (2014) and UCCHM (2014).

Governments should collaborate with and facilitate effective actions of the agro-food sector to reduce water risks[10]

As a complement to their responses targeted at farmers, governments will benefit from working with other supply chain actors (e.g. UNEP, 2016). A small number of medium to large agro-food companies have engaged in stewardship programmes focused on water risk mitigation, aiming at reducing the use of water in their production chain (water footprint) and the impact it may have on the local environment.[11]

These water stewardship initiatives widely vary in their scope, scale and design, and have known an evolution from technical fixes to multi-stakeholder partnerships (van der Heide et al., 2016). Involved companies start by conducting water risk assessment to select regions where water risks are most critical. Efforts to reduce the water risk and impacts tend to address risks occurring at the processing stage before those at the farm level. Stewardship programmes at the farm level employ a range of strategies; in the case of shortage risks, this includes reducing water demand and/or increasing water supply. Investments in technical solutions are often associated with incentives design to encourage farmers to change practices (e.g. via farm contracts or cost-share investments). If some programmes are still conducted only on suppliers' farms, leading companies have been progressively shifting their focus towards actions at the watershed level, realising the need to operate at that scale to avoid unwanted results (e.g. reduced consumption being compensated by additional consumption in other areas). Still, the issue of scale remains problematic in many contexts (WWF and IUCN, 2015).

This evolution has implied the need to engage into watershed-level partnerships with a range of local partners beyond primary suppliers (farmers), further implying a growing and multi-faceted involvement of local and national governments (Box 4.4). Governments have been asked to provide technical support and information sharing at a watershed scale, enable and facilitate discussions and partnerships with stakeholders, ensure equitable and sustainable outcomes, and warrant a good governance and regulation of water on which to base actions. Some of the leading agro-food companies on the agriculture-water front even consider that more government involvement is necessary to move forward on the reduction of water risks (Box 4.4).

Box 4.4. Managing water risks for agriculture in collaboration with the private sector: Key lessons from a workshop

The OECD, in partnership with the Dutch Ministry of Economic Affairs, organised a workshop to discuss and advance solutions to improve the management of agriculture water risks in the private sector on 9 November 2016. Participants included representatives of agro-food companies, associated non-profit organisations and OECD delegates. The following takeaway lessons were drawn from the discussion.

- There is a crucial need to **improve information on water risks**. Better data is needed particularly groundwater resources and water quality risks. Shared risk assessment indicators and solution methods are missing.
- **The success of managing agriculture water risks lies in public-private partnership at the local (catchment) level, involving multi-stakeholder engagement**. The local nature of water risk should be addressed with localised solutions, and the public good aspect of water demands collaboration. Because of these two specificities, responses to water risk ought to be holistic and contextualised.
- At the same time, **successful partnerships and collaborations are not simple to implement**. They require leaders who take initiative, convene relevant stakeholders, and facilitate the project. The public sector, in addition to setting regulation, has an important role in bringing the stakeholders together; however, leadership in projects does not have to be limited to the local public authorities. The public sector is also implicated in the scaling up of projects, as it can be helpful in shoring up the necessary financial support.
- **More general public-private partnerships are essential for successfully managing water risks**, acknowledging that the 'distance' between the private and public sector is not the only gap that needs to be bridged. Co-operation is also needed between: scientists and local stakeholders, different government bodies and levels, water experts, agriculture experts, financial experts, or within the private sector.
- **Moving beyond current efforts by the private sector will require government involvement**. Active agro-food companies are ever more energised to address water risk mitigation, but would need governments to help co-ordinate and complement their efforts to advance on sustainable water risk management. At the same time, government policies, including economic instruments could help incentivise response to water risks for the large share of companies that have yet to assess their water risks.

Source: OECD (2016c); the agenda, participants and presentations are available at: http://www.oecd.org/tad/events/workshop-managing-water-risks-for-agriculture.htm.

Governments should therefore find means to take advantage of developing water stewardship opportunities for effective water risk mitigation action. The specific role they may have will depend on the situation. Simply entering the conversation, sharing information on agriculture water risks, policy leverages, and scope for action, and providing input on the design of effective actions could already be valuable. Stronger engagement may lead to cost-effective solutions, that if sustained could lead to effective changes in farmers' practices. Sharing the burden of moving forward especially on the reduction of endogenous risks, if well designed, could help increase the cost-effectiveness of public action.

An example of effective model for partnership was developed by the 2030 Water Resource Group. This group, serving as an enabling entity supported by a consortium of companies, national and international funding agencies, and hosted by the International Finance Centre, convenes stakeholders from the public sector, private sector, and civil society to engage into action towards lowering identified supply-demand water gaps in regions facing critical water shortages. Its objective is to create partnerships at the country level by bringing in key stakeholders towards a common objective, identify acceptable solutions, funding sources and active partners to implement the proposed plan. The initiatives has known a few successes and been asked to engage into more regions in the future.

If local governments are typically called in first, national governments can also support the development and success of such partnerships. For instance, the US government has partnered with relevant stakeholders to share resources and efforts to respond to local resource challenges. Introduced as part of the U.S Agricultural Act of 2014, the USDA Regional Conservation Partnership Program (RCPP) supports the local implementation of USDA land and water resource conservation programmes at the watershed and/or regional landscape scale. Under this programme, the USDA selects projects of partnerships with farmers and a wide range of other land or water related stakeholders—Indian tribes, non-profit organisations, state and local governments, private industry, conservation districts, water districts, universities—to respond to identified resource challenge (USDA NRCS, 2017). USDA and its partners then leverage different sources of public and private funding to "assist producers with a broader set of land and water conservation activities designed to increase the restoration and sustainable use of soil, water, and wildlife and related natural resources across the landscape" (Schaible and Aillery, 2016). As of 2014-15, the RCPP funded USD 66 million of projects towards improving irrigated agriculture (Ibid.).

Governments should also co-ordinate agriculture policy responses with policies targeted at other types of water users

Water risks in hotspot areas will affect a large number of water users beyond actors in the agro-food sector. Policies aiming at reducing impact in the agriculture sector will benefit from co-ordinated efforts to tackle water risks for all sectors (Dinar, 2016; Hanjra and Qureshi, 2010). This may involve local and watershed and national co-ordination efforts around hotspot regional risks.

Governments drawing plans to address water risks especially in hotspot areas would benefit from accounting for the interactions among the key users of water (HLPE, 2015). Analysis of connections on the water-energy-food nexus, or the water-energy-environment nexus, have shown that some tangible interactions exist and can be relatively significant in certain regions (Grafton et al., 2016).

For instance, in Northwest India, the agriculture challenge posed by water risks cannot be separated from that of energy subsidies. The development of low price solar-powered pumps that would reduce electricity requirements and greenhouse gas emissions could also potentially increase depletion, raising the question of how government should adapt to these new technologies (Box 4.5). Undertaking assessment of current and projected water risks in each sector within the hotspot region will be necessary to reduce the likelihood of counteracting or overlapping projects and initiatives.

Box. 4.5. Solar pumps in Punjab: Opportunity or challenge?

Solar powering provides a green alternative energy for tubewells equipped with diesel or electric pumps, and could represent an important development lever in villages that are not connected to the grid. Nevertheless this new source of energy, providing free power with little time restriction, could encourage farmers to pump groundwater with excess, and accelerate withdrawal of aquifers (Shah, 2016; Closas and Rap, 2017). Until now, the installation of a drip-irrigation system was a prerequisite to receive subsidies for solar pumps (DSWC b; Pearson and Nagarajan, 2014). However, this condition might not be sufficient to change the irrigation practice of farmers, especially for rice and wheat, for which drip-irrigation systems are not yet used (Singh, 2015).

In 2000, Punjab began its first State programme for solar pump development. Since then, only 2 000 solar pumps were installed by farmers in the State, since subsidies were often not substantive enough to motivate the investment (Roy, 2015). Nevertheless, the State and Central Governments are pursuing their support programmes, and the cost of solar panels is falling, which suggests further development of solar pumps, threatening to increase the depletion of critical aquifers.

In order to solve this trilemma between clean energy, rural development and groundwater management, the International Water Management Institute (IWMI) initiated a pilot study in Gujarat named “Solar Power as a Remunerative Crop”. The principle of SPaRC is to allow farmers to sell back the surplus of energy left after irrigation. Thus, the additional revenue creates an economic incentive to conserve water (CCAFS and CIMMYT, 2015). It should be underlined that the implementation of this system requires the connection of each solar installation to the grid, which can be an obstacle in poorly connected areas that need an alternative energy source the most.

Sources: CCAFS and CIMMYT (2015); Closas and Rap (2017); Pearson and Nagarajan (2014); Roy (2015); Shah (2016); Singh (2015).

Governments could also promote or facilitate rural-urban water co-operation to respond to a number of water risks (Civitelli and Gruère, 2016). A growing number of rural-urban co-operation mechanisms have linked farmers with cities to tackle water shortage, floods and water quality (OECD, 2015c). This includes successful examples of water transfers to address groundwater depletion in Japan, prominent programmes of payment for ecosystem services ensuring lower water pollution in catchment in France, Germany or the United States, and some emerging examples of flood plain policies in the United Kingdom (Ibid.).

4.5. Addressing the indirect effects of water risk hotspots

Addressing water risks at the production level, as discussed above, should limit sector concerns. Still, because these risks can take unexpected proportions and rely on other user actors, governments should also consider that supporting efforts at a higher economic level could help ensure that the remaining impacts of agriculture water risks are well contained and do not expand or intensify over time.

Strengthening agriculture and food markets for better resiliency

Well-functioning food markets play a fundamental role in diluting the damages, reducing price effects for consumers, and ensuring that regional effects remain limited. As shown in Chapter 3, a water shock in a limited number of regions can result in significant changes in trade flows, compensating gaps on the world market. In a non-functioning market, whereby products would not be able to flow easily from region to region with the associated price adjustments, agriculture production decrease would lead to higher price increases than in an open market, and depending on the price elasticity of demand, either increased cost for buyers or waiting lines.

Integrated markets allow products from other parts of a country or from the international market to compensate for production losses, depress local prices and alleviate shortages. Mechler et al. (2010) simulated the economic impact for agriculture of a drought (-12% of yields) first in the Guadiana Basin and second in broader Southern Spain. The first shock induced large production losses, but a limited reduction in added-value for local farmers, because the price of goods did not change much due to the presence of agriculture supplies in neighbouring regions. Neither did the shock affect local consumers significantly. In contrast, a simulated drought over all Southern Spain created larger damages and market effects. Farmers in Guadiana did not lose as much because of an increase of price, but the overall loss for consumers was much larger.

Similarly, international trade is a recognised key climate change and water risk adaptation mechanism especially in agriculture (HLPE, 2015; OECD, 2014). It allows populations suffering a decrease in production to access substitute products from other countries not facing the same climate and water risks, with reduced price increase consequences. It also allows water savings; for instance, de Fraiture et al. (2007) showed that irrigation consumption would have increased by 11%, had there not been any international trade in cereals in 1995. Jouanjean et al. (2016)'s global empirical analysis further shows that rainfall variation affects prices of agriculture commodities, and that trade flows are reallocated following extreme climatic and water-related events, acting as a compensation mechanism.

Certain types of markets can help mitigate the effect of water risks (OECD, 2014). Future markets have a particular role in risk management, in that they enable market players to lower the impact of climatic shocks over a season or more. Storage may also have a role so long as it does not affect markets. Well-developed markets for insurance that cover multiple heterogeneous regions, mutualising risk to better cover farmers and companies facing higher risks prepare for production shocks and ensure that they can recover from shocks.

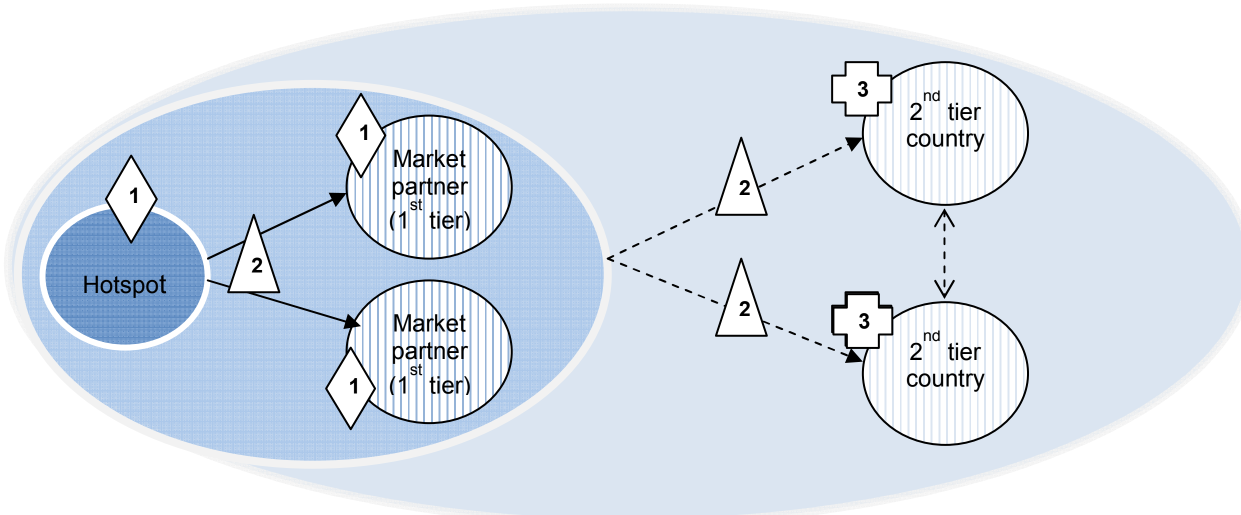
Concerned governments should therefore strengthen and facilitate market linkages, which could involve three types of actions. Governments should enable markets, support transparency, and ensure that market transactions are effective and efficient. Impediments to well-functioning markets, such as high transaction costs or information asymmetries, will delay and or reduce market response, which could become problematic when facing water-related food security threats. Many countries may lack effective road, electricity and information infrastructure and the capacity to store and market goods. Second, Governments should also promote information exchange on markets to increase global preparedness to international food market shocks. The AMIS project aims to provide a monitoring tool for policy and market actors to prepare for price shocks and could be strengthened and expanded (HLPE, 2015). While these shocks may be due to change of market conditions, and/or policies, they may also be the result of climatic shocks in key production areas. Lastly, they should continue to encourage the removal of agriculture tariffs and non-tariff barriers on a multilateral basis. In particular, governments could aim at strengthening discipline on agriculture export restrictions to ensure that low-income water stressed countries can access food on the international market (HLPE, 2015).

Policy approaches to mitigate the risk of international chain reaction

As discussed in Chapter 3, critical water risks in one or more agriculture regions can diffuse indirectly to other countries. Acute water risks can lead to imbalanced land investments that can deprive a country of future water and food security. Agriculture water risks may contribute to food insecurity, social unrest, possible conflicts and/or migration outside of hotspot regions. These impacts can vary in scope and duration- ranging from a few countries to global consequences, and from a rapid shock to a sustained trend that last for years or more.

Three proposed government responses can be envisaged, following Chapter 3's characterisation of impact ripples. Governments in first or second tier countries can respond to risk spreading in three ways (Figure 4.3), first, they can try to help reduce the risk in the hotspot or first tier countries, second, they can aim at mitigate the impact from the two waves, or third they can focus on increasing the resilience of 2nd tier countries to these possible impacts. The first two ways will require international co-operation, the third will focus on national policies.

Figure 4.3. Three options can help respond to ripples of impact



Notes: 1. Supporting risk reduction in the hotspot country and its market partners; 2. Mitigating impact diffusion; 3: increasing the resilience of 2nd tier countries.
Source: Author's own work.

International collaboration efforts to reduce agriculture water risks

Governments in the first and second tier countries can contribute to increasing resilience and lowering impact in hotspot locations bilaterally or via engaging more forcefully in international collaboration. They can participate in regional or international efforts by sharing information, expertise, co-operating on research and development, technology and services trade, or even contribute to the actual management of risks. Examples of these different linkages have emerged in the last few years.

Bilateral co-operation can take several forms depending on the characteristics of the involved countries. Government can support research and development exchanges on water risk monitoring, agriculture water efficiency improvements, lowering or treating water quality risks. There are multiple examples of such co-operation involving regions or countries facing high agriculture water risks. In 2015, the Californian Department of Food and Agriculture has exchanged with the Government of the Netherlands to facilitate exchange of expertise on climate-smart agriculture, including adaptation practices to water risks. The State of California has also exchanged with Israel on effective means to reduce agriculture water risks (Siegel, 2015). Water-depressed countries, such as China and the states in the West of the United States, have been exchanging with Australia's government and university experts to learn about the setting and functioning of the Murray Darling Basin's water markets. Within a development co-operation framework, the Technical Centre for Agricultural and Rural Cooperation (CTA), the joint co-operation institution of the EU and the African Caribbean and Pacific Group of States, includes a number of national programmes to reduce less water to produce more.[12] From 2007-16, the Japanese International Cooperation Agency (JICA) supported a project to increase water use efficiency in Tunisia (JICA, 2007).

Governments may also facilitate exchanges by concluding agreements between institutions, or by supporting international trade of technology and services. Israel's company expertise in highly efficient irrigation technologies has been promoted overseas as of 2011; Israel held 30% of the global market for advanced irrigation solutions (Ministry of Industry, Trade and Labor, 2011). Korea Rural Community Corporation, a state-based company affiliated with the Korean Ministry of Agriculture, Food and Rural Affairs, has been promoting new technology to better manage irrigation infrastructure and equipment (Ji-hye, 2014).

Governments may also engage in agriculture and water risk policy discussions at the international level. Several recent developments have shown an acceleration of interests of the international agriculture policy community on the challenges raised by high water risks. In 2015, the Committee on Food Security's High Level Panel of Experts on Food Security and Nutrition published a report on water for food security and nutrition, to respond to the fundamental question "How can the world ensure food and nutrition security given increasingly scarce water resources, especially in some regions, and the increasing competition for water uses?" (HLPE, 2015: 9). In 2016, under the Dutch EU presidency, the EU formed a taskforce dedicated to agriculture and water issues. In January 2017, under Germany's G20 presidency, agriculture ministers of the G20 countries signed a declaration and action plan entitled "Towards food and water security: Fostering sustainability, advancing innovation" which encompass commitments to address water scarcity, water quality and to reduce water risks (G20, 2017a and 2017b). In parallel to this event, 83 agriculture ministers the January 2017 participating to the Global Forum on Food and Agriculture (GFFA) adopted a Communiqué entitled "Agriculture and Water- Key to Feeding the World" outlining their intention to enhance farmers' water access, improve water quality, reduce water scarcity risks, and manage surplus water (GFFA, 2017).

International co-operation can also operate through support to global financing initiatives for climate change adaptation. Recent efforts facilitated by negotiations at the UN Framework Convention on Climate Change, including the development of the Green Fund, aim to support adaptation in developing countries, in which agriculture is often a key sector and one that is the most likely to be affected by climate change.

Multilateral trade negotiations on reducing barriers to environmental goods and services—as part of the Environmental Goods Agreement in particular, but also in regional trade agreements—may also have positive implications on risk mitigation. Eliminating barriers to trade of water monitoring devices, pressurised irrigation systems, and other related devices should facilitate their uptake in countries that can benefit most from those.

International collaborative efforts to mitigate the diffusion of primary and secondary impacts

International collaboration can also contribute to reduce the diffusion of impacts from water risks. As discussed in Chapter 3, agriculture water risks can increase investments in land markets that can create tensions and augment inequalities, and it can generate threats to food security with significant consequences on nearby countries, especially manifested via social and broader conflicts, political instability, and resulting migration.

Foreign land investments, while presenting risk mitigation potential, should be monitored on a case-by-case basis to ensure that land transactions do not result in detrimental water and food security outcomes for local populations. Land rich countries can benefit from such investments, and producing on land in a water abundant context can help reduce pressure on water resources in a highly water stressed country. But multiple examples have shown that it also can bear costs for non-represented stakeholders in the recipient countries.

Governments of contracted parties should ensure that the outcome of land investments remain positive in the long run. A number of conditions should be fulfilled to avoid unwanted outcomes from foreign land investments (as defined in a voluntary guideline, see FAO, 2012). In particular, there should be transparency in negotiations, deals should respect existing land and water rights, the benefits of the transaction should be shared with local communities, and the deals should be subject to a careful impact assessment to ensure their environmental sustainability (von Braun and Meinzen-Dick, 2009). Third party organisations, governments or international organisations could help support this goal by providing an external view.

Responding to food security and associated risks will solicit complex responses that overpass agriculture, and generally delve into development co-operation strategies. These include the role of emergency food aid, but also broader development co-operation programmes that support social safety nets, open and functioning markets, more stable political systems and good governance (Breisinger et al., 2015; OECD, 2013a). Effective co-operation is also needed to anticipate and manage migration flows (OECD, 2016e).

Anticipating and preparing for secondary impacts from agriculture water risks at the national level

The broad range of indirect consequences of agriculture water risks implies that proactive management of those risks in advance by governments of third-tier countries will be challenging. Just like hotspot regions, other countries should try and anticipate possible issues, be prepared to develop solutions, and/or to adjust policies accordingly.

Governments should monitor climate change projections and the evolution of agriculture risks in other countries. The hotspot identification exercise conducted in Chapter 2 shows that there is a growing body of evidence around a number future water risks globally. Uncertainties in assessment remain significant, but it is likely that more and better studies will be released in years to come.

Anticipating possible secondary impacts may also call upon the use of foresight exercises, building hypothetical scenarios and envisaging evolution of water crises, and possibly supporting these efforts with simulations. Prospective exercises can help anticipate complex scenarios for agriculture and explore options to strengthen resilience (OECD, 2016b).

Using methods that can adapt to changes of course—or follow adaptive pathways—could also help anticipate the risks. Haasnoot et al. (2013) propose a planning process that allows for changing situations. They consider likely scenarios and potential actions to mitigate the different water risks. Each of the action is then attributed a "sell-by-date", which indicate when a change in the course of action may be needed under each option. They then propose an efficient dynamic pathways to address the risks and work towards preferred pathways, each with initial action, threshold for change of course, and next step action. Haasnoot et al. (2013) apply the approach to salinity, water shortages and floods in the Rhine Delta, but similar approach could be used to tackle hypothetical indirect impacts from foreign water risks.

Countries anticipating migrating flows should try and anticipate and take action early to avoid future crises (OECD, 2016e). This encompasses anticipating future migratory flows and the needs for infrastructure and capacity; making pre-commitments to act if these flows are realised, and adapting existing policies to respond to crisis (Scarpetta, 2016, citing OECD, 2016e).

Governments in developing economies should also be encouraged to promote policies and investments to enhance food security, to increase the resilience of their farming populations (Hanjra and Qureshi, 2010). This includes increased investment in rural areas, policies to improve nutritional outcomes and to enhance agriculture productivity sustainably (OECD, 2013a). More broadly, these governments should pursue broad agriculture development agendas to strengthen the resilience of farmers, and reduce poverty (World Bank, 2008). The use of a territorial approach could help address food security while respecting the diversity of geographic, economic and governance systems (OECD/FAO/UNCDF, 2016).

4.6. Implications for the three hotspot regions

The capacity of farmers and companies to take action and the degree to which governments engage in water risk management, in particular regions, can provide an indicator of expected impacts in hotspot countries, market partners (1st tier) and potentially other countries (2nd tier) in the future. In particular, the impacts of the three agriculture production hotspot regions analysed in this report will likely vary significantly.

United States Southwest farmers are relatively resilient to water risks; many farmers have taken significant steps to adapt to drier conditions in recent years. Recent policy developments also suggest that California is taking proactive steps to manage water shortages (groundwater management and investments), even if their implementation will take time (full implementation is for 2040) and could therefore set the state in a low equilibrium.[13] Beyond drought emergencies, federal agencies recognised the importance of water issues in the region. The March 2016 Presidential Memorandum on building national capabilities for long-term drought resilience aimed to address drought impacts in the Western United States

(US White House, 2016). Other states in the Southwest are also increasing their efforts to reduce pressure on water. These efforts could reduce the impacts of water risks from this hotspot to other regions and countries through agriculture markets. State authorities could consider additional options, such as encouraging agriculture and urban water efficiency improvements, investing in water banks and recycled wastewater systems, and facilitate well-defined water transfers (Cooley et al., 2016). Still, under the current course, agriculture production will likely be altered, but continue to be a highly productive and large income generating sector in the region.

Farmers in Northeast China operate on very small land plots and remain relatively vulnerable to shocks. The Chinese government has launched important policy reforms to respond to water challenges, moving from a water supply augmentation policy to more demand control and quality emphasis. In 2011, it launched the three red line policies aiming at controlling water use, increasing water use efficiency, and reducing water pollution (Tan, 2014). A number of initiatives have been taken that focus specifically on agriculture water use, including the modernisation of irrigation systems (van Steenbergen et al., 2016) and the use of economic instruments (pricing and markets) (Liu and Speed, 2009; Wang, 2017). Agriculture policies are now moving towards the decoupling of agriculture support from inputs, which could improve water quality impacts from agriculture. These and other reforms demonstrate the Chinese government's demonstrated willingness to address water risks. The challenge will be to effectively implement these policies, especially in rural areas, and particularly in the Northeast region, to reinforce and upscale current efforts and promising initiatives to manage water imbalances and water quality problems. Therefore, whether water risks from this hotspot may impact other regions or countries will depend largely on the effective implementation of policies in the next decade.

Farmers in Northwest India also have limited capacity to adapt to water risks. India's federal government has launched large initiatives on water (River Ganga rejuvenation), including groundwater management proposed a groundwater model bill, and there are some signs of possible interest to move towards decoupling farmers' payments to become an income support (Gulati, 2016). At the same time, state policies in the Northwest supporting energy subsidies appear to remain in place, and the government promoted shift to solar pumps could accelerate groundwater depletion (Closas and Rap, 2017). Federal and state governments should aim at redirecting farmers' incentives, ensure that existing regulations are enforced, and consider engaging into new policy initiatives, possibly in partnership with the private sector to tackle the multi-faced challenges of the region. Under the current course, the region may take longer to come towards a lasting reduction of water risks for agriculture and in the meantime its water risks may still impact other regions and countries.

Similar qualitative assessment could be run for other agriculture regions and countries subject to high water risks, in particular those around the Mediterranean Sea, in Latin America, Sub-Saharan Africa or Southern Africa (Figure 2.2 in Chapter 2). Combining water and agriculture risks with an assessment of farm and companies' capacity to respond and a review of water and agriculture policy plans shall provide a first indication of whether the country could be facing agriculture damage, and potentially create further market and broader impacts in other countries. It will not be sufficient to ascertain expected impacts, but can be used to at least eliminate countries unlikely to face significant agriculture water risk-related damages, and to compare countries' potential damages with a reasonable confidence.

Notes

1. In particular, in the initial model agents a) have access to information and b) there is no market failure.

2. It is assumed that the expected losses are significant, as farmers are located in hotspot regions.

3. In the long run, farmers may also attempt to increase water storage (rainwater harvesting, infiltration ponds), or attempt to secure other water sources (via reuse, etc.) to reduce risks.

4. The discussion focuses on water scarcity and water quality risks, but the risks of flooding could also be considered, again via a change of practices or activities.

5. If these different options are not economically feasible, they may just use less water, produce less, fallow some or all of their land, or even sell their land and abandon farming in extreme cases.

6. This difference is positive and relatively significant. If however the probability of risks was lower, the difference would decline and could even become negative.

7. As such, their engagement can be assimilated to that of a "private regulator", to address the problem of non-co-operation across farmers.

8. Some of these companies may be subject to reputation risks when such risk is communicated to the public.

9. For any crop mix, efficient technologies increase the share of applied water to consumed water which reduces the costs of consumption, leading to the expansion of water consumption and irrigated acreage.

10. This subsection is largely based on the outcome of a workshop held by the OECD in November 2016. Information on the workshop is available at: http://oecd.org/tad/events/workshop-managing-water-risks-for-agriculture.htm.

11. Still, many other companies still have to consider even assessing their exposure to water risks. For instance Ceres (2015) reported that two third of the 37 large food sector companies they surveyed in the United States had not taken any action on water risks.

12. See http://spore.cta.int/en/dossiers/article/water-for-agriculture-a-focal-point-for-development.html.

13. For instance, as of September 2016, many farmers in the San Joaquin valley were continuing to dig deep wells and intensively withdraw groundwater noting that they would continue until SGMA regulations are put in place in 2020 (Sabalow, 2016).

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Annex 4.A1. Model derivation

4.A1.1. Derivation of equation (1)

$$E(\Pi/R) \geq E(\Pi/NR) \Leftrightarrow \varphi.\Pi_R + (1-\varphi).\overline{\Pi_R} \geq \varphi.\Pi_1 + (1-\varphi).\overline{\Pi_1}$$
$$\Leftrightarrow \varphi.(\Pi_R - \overline{\Pi_R} + \overline{\Pi_1} - \Pi_1) \geq \overline{\Pi_1} - \overline{\Pi_R}$$
$$\Leftrightarrow \varphi.[(\Pi_R - \overline{\Pi_R}) - (\Pi_1 - \overline{\Pi_1})] \geq \overline{\Pi_1} - \overline{\Pi_R}$$

4.A1.2. Modelling the farmer's behaviour

Assume that an individual price taking farmer's profit can be expressed as $\Pi = py - p_w w - p_x.\boldsymbol{X}$, where p is the farm gate price, y farm's output, p_w the expected cost of water (price or otherwise) [1] and w water used, and $p_x.\boldsymbol{X}$ representing other input costs (price times a vector of quantity). Further assume the following log linear production function: $y = \alpha w^{k_w}.\boldsymbol{X}^{k_x}$ with α a positive coefficient for any activity and $k_w$and k_x are production coefficients.

The profit function of the farmer without reaction under risks and no risks at t_1 are, respectively:

$$\Pi_1 = p_1\alpha_1 w^{k_w}.\boldsymbol{X}^{k_x} - p_w w - p_x.\boldsymbol{X} \quad (3)$$
$$\overline{\Pi_1} = p_1\alpha_1 \overline{w}^{k_w}.\overline{\boldsymbol{X}}^{k_x} - p_w\overline{w} - p_x.\overline{\boldsymbol{X}}$$

With $\overline{w}$ and $\overline{\boldsymbol{X}}$ are input quantities without risks, and w and $\boldsymbol{X}$ are the same variables under risks with $w < \overline{w}$.

Assuming they face an exogenous risk of *water shortage*, farmers have two basic alternative options to respond to exogenous risks; to improve their water use efficiency, or to change towards alternative activities. If farmers face exogenous *water quality risks*, such as salinity or other exogenous pollution that threaten their production, they may engage into treatment, drainage or dilution, or other water pollution mitigation practices or opt to change their activities. We will therefore present the three cases separately (efficiency, alternative activity and water quality response).

When considering the first option of changing practices or technology towards efficiency (noted *e*), the profit functions expressed as follows.

$$\Pi_e = p_1\alpha_1 {w_e}^{k_{we}}.\boldsymbol{X}^{k_x} - p_w w_e - p_x.\boldsymbol{X} - C_e \quad (4)$$
$$\overline{\Pi_e} = p_1\alpha_1 \overline{w_e}^{k_{we}}.\overline{\boldsymbol{X}}^{k_x} - p_w\overline{w}_e - p_x.\overline{\boldsymbol{X}} - C_e$$

Where C_e is the fixed cost associated with the more efficient irrigation technology, assuming variable costs are not significant.

In the case of alternative activities (option noted *a*), all agronomic and cost factors change.

$$\Pi_a = p_a\alpha_a {w_a}^{k_{wa}}.{\boldsymbol{X}_a}^{k_{xa}} - p_w w_a - p_{xa}.\boldsymbol{X_a} \quad (5)$$
$$\overline{\Pi_a} = p_a\alpha_a \overline{w_a}^{k_{wa}}.{\overline{\boldsymbol{X}}_a}^{k_{xa}} - p_w\overline{w}_a - p_{xa}.\overline{\boldsymbol{X}}_{\boldsymbol{a}}$$

In the case of water quality risk mitigation (noted *q*), assuming the same amount of water is available either way, the profit functions expressed as follows.

$$\Pi_q = p_1\alpha_1 {w_q}^{k_w}.\boldsymbol{X}^{k_x} - (p_w + c_q)w_q - p_x.\boldsymbol{X} \quad (6)$$
$$\overline{\Pi_q} = \Pi_q$$

In this case the cost c_q is assumed to be mostly variable, to represent the importance of volumes for treatment or change of practices.

Farmers will switch to more efficient practices under the following condition:

$$E(\Pi/e) \geq E(\Pi/NR) \Leftrightarrow \varphi[(\Pi_e - \overline{\Pi_e}) - (\Pi_1 - \overline{\Pi_1})] \geq \overline{\Pi_1} - \overline{\Pi_e} \qquad (7)$$

$$\Leftrightarrow C_e \leq \varphi p_1 \alpha_1 \boldsymbol{X}^{k_x}(w_e{}^{k_{we}} - w^{k_w}) + (1-\varphi) p_1 \alpha_1 \overline{\boldsymbol{X}}^{k_x}\left(\overline{w_e}^{k_{we}} - \overline{w}^{k_w}\right) + p_w[\varphi(w - w_e) + (1-\varphi)(\overline{w} - \overline{w}_e)] \qquad (6)$$

Thus the expected cost of switching to higher efficiency technology has to be smaller than the expected net revenues it will generate. Given that the efficiency condition implies an increase of productivity under risks, i.e., $w_e{}^{k_{we}} > w^{k_w}$, but not necessarily in the absence of risks, so $\overline{w_e}^{k_{we}} \leq \overline{w}^{k_w}$, the probability that inequality (6) stands (noted θ_e) increases with the probability of water risks and the cost of water, but not necessarily with other variables (as these factors increase the right hand side expression of the inequality, assuming all other terms remain constant).

With simplification assumptions of water is de facto free for farmers, no change in water use under risks or no risks, and the same input uses, (7) simplifies to:

$$E(\Pi/e) \geq E(\Pi/NR) \Leftrightarrow K_e \leq p_1 \alpha_1 \boldsymbol{X}^{k_x}\left[\varphi(w_e{}^{k_{we}} - w^{k_w}) + (1-\varphi)\left(\overline{w_e}^{k_{we}} - \overline{w}^{k_w}\right)\right] \qquad (8)$$

In this case, the probability θ_e will also increase with prices and input quantities, given that they increase the right hand side expression of (8).

Farmers will switch to alternative crops under the following condition:

$$E(\Pi/a) \geq E(\Pi/NR) \Leftrightarrow \varphi[(\Pi_a - \overline{\Pi_a}) - (\Pi_1 - \overline{\Pi_1})] \geq \overline{\Pi_1} - \overline{\Pi_a}$$

$$\Leftrightarrow \varphi\left[\left(p_a \alpha_a \left(w_a{}^{k_{wa}}.\boldsymbol{X}_a{}^{k_{xa}} - \overline{w_a}^{k_{wa}}.\overline{\boldsymbol{X}}_a{}^{k_{xa}}\right) - p_w(w_a - \overline{w}_a) - p_{xa.}(\boldsymbol{X_a} - \overline{\boldsymbol{X}}_{\boldsymbol{a}})\right) - (p_1 \alpha_1 (w^{k_w}.\boldsymbol{X}^{k_x} - \overline{w}^{k_w}.\overline{\boldsymbol{X}}^{k_x}) - p_w(w - \overline{w}) - p_{x\cdot}(\boldsymbol{X} - \overline{\boldsymbol{X}}))\right] \geq p_1 \alpha_1 \overline{w}^{k_w}.\overline{\boldsymbol{X}}^{k_x} - p_a \alpha_a \overline{w_a}^{k_{wa}}.\overline{\boldsymbol{X}}_a{}^{k_{xa}} - p_w(\overline{w} - \overline{w}_a) - p_x.\overline{\boldsymbol{X}} + p_{xa}.\overline{\boldsymbol{X}}_{\boldsymbol{a}}$$

$$\Leftrightarrow p_a \alpha_a \left(\varphi w_a{}^{k_{wa}}.\boldsymbol{X}_a{}^{k_{xa}} + (1-\varphi)\overline{w_a}^{k_{wa}}.\overline{\boldsymbol{X}}_a{}^{k_{xa}}\right) - p_1 \alpha_1 (\varphi w^{k_w}.\boldsymbol{X}^{k_x} + (1-\varphi)\overline{w}^{k_w}.\overline{\boldsymbol{X}}^{k_x}) - p_w\left(\varphi(w_a - w) + (1-\varphi)(\overline{w}_a - \overline{w})\right) - p_{xa.}(\varphi \boldsymbol{X_a} + (1-\varphi)\overline{\boldsymbol{X}}_{\boldsymbol{a}}) + p_{x\cdot}(\varphi \boldsymbol{X} + (\boldsymbol{1}-\varphi)\overline{\boldsymbol{X}}) \geq 0 \qquad (9)$$

The expression is hardly tractable, unless simplified. The probability that inequality (9) is verified will increase with the probability of risks and with the cost of water (as long as the use of water with the alternative is effectively lower than that of the original activity, and other variables constant).

Assuming the cost of water is negligible, and that the price of inputs is the same for the two alternative activities, condition (9) becomes:

$$E(\Pi/a) \geq E(\Pi/NR) \Leftrightarrow \varphi\left(p_a \alpha_a w_a{}^{k_{wa}}.\boldsymbol{X}_a{}^{k_{xa}} - p_1 \alpha_1 w^{k_w}.\boldsymbol{X}^{k_x} - p_{x.}(\boldsymbol{X_a} - \boldsymbol{X})\right) + (1-\varphi)\left(p_a \alpha_a \overline{w_a}^{k_{wa}}.\overline{\boldsymbol{X}}_a{}^{k_{xa}} - p_1 \alpha_1 \overline{w}^{k_w}.\overline{\boldsymbol{X}}^{k_x} - p_{x\cdot}(\overline{\boldsymbol{X}}_{\boldsymbol{a}} - \overline{\boldsymbol{X}})\right) \geq 0 \qquad (10)$$

Condition (10) is consistent with a net revenue constraint; the probability that it is realised will increase with the relative market price of the alternative activity and decline with the possible increment in input costs it may be associated with (all other variables remaining constant).

Farmers will adopt water quality mitigation approaches under the following condition:

$$E(\Pi/q) \geq E(\Pi/NR) \Leftrightarrow -\varphi(\Pi_1 - \overline{\Pi_1}) \geq \overline{\Pi_1} - \overline{\Pi_q}$$
$$\Leftrightarrow c_q w_q \leq p_1 \alpha_1 \big(({w_q}^{k_w} - \varphi w^{k_w}).\boldsymbol{X}^{k_x} - (\overline{w}^{k_w} - \varphi \overline{w}^{k_w}).\overline{\boldsymbol{X}}^{k_x} - p_w\big((w_q - \overline{w}) - \varphi(w - \overline{w})\big) - p_x.(1-\varphi)(\boldsymbol{X} - \overline{\boldsymbol{X}}) \quad (11)$$

The total cost of treatment has to be lower than the mitigation of such risks for this condition to be satisfied.

Endogenous risks changes the problem, but not necessarily its incentives

With endogenous risks, the action of water using farmers at time t_0 affects whether there will be a risks in the future, i.e. $\varphi = f(\sum_{k=1}^{n} w_0^i)$ with w_0^i representing the use of water (or water pollution in the case of water quality) of farmer i at time t_0. Typically farmers' use—or misuse—of water will not explain all the risks, but contribute to it. One could assume for instance a linear expression of water risks:

$$\varphi = \varphi_0 + (1 - \varphi_0)\left(\frac{\mu}{W_0}\sum_{i=1}^{I} w_0^k\right) \quad (12)$$

Where φ_0 represents exogenous water risks, $0 \leq \mu \leq 1$ is a parameter capturing the future impact of water use on available resources for the sector and W_0 is the maximum water usable by agriculture at t_0. This formulation implies that $0 \leq \varphi_0 \leq \varphi \leq \mu + (1-\mu)\varphi_0 \leq 1$.

Such specification will change (1) to become:

$$E(\Pi/R) \geq E(\Pi/NR) \Leftrightarrow \left[\varphi_0 + (1-\varphi_0)\left(\frac{\mu}{W_0}\sum_{i=1}^{I} w_0^i\right)\right]\left[(\Pi_R - \overline{\Pi_R}) - (\Pi_1 - \overline{\Pi_1})\right] \geq \overline{\Pi_1} - \overline{\Pi_R} \quad (13)$$

Thus farmers' water use (or pollution) at time t_0 will increase the probability of their reaction in the future, *ceteris paribus*.

A farmer's response will not necessarily change from the exogenous risk case, because the probability of future risks depends on the use (or impact) of *all* farmers at t_0. An individual farmer reducing water use or water impact earlier, by switching to activities or practices, will reduce water risks in the long term, thereby reducing the need (and probability θ) for *any* farmer to invest in future response. However, unless the farmer accounts for a significant share of water use in the hotspot region (e.g. as part of a collective of users), or that s/he faces a sufficiently strong signals to account for future water risks (policy or investment return), s/he may not be sufficient incentivised to act.

The dynamics of the problem are extremely simplified in the model; farmers in hotspot regions may already face risks, and therefore invest early, but the aggravation of risks in the future that they may cause is unlikely to trigger a sufficient incentive to react to future water risks. This is even more the case when acknowledging that multiple variables remain uncertain in the future.

4.A1.3. Modelling the company's response

There are several differences with the previous model, because companies are purchasing farmers' products, because they may affect prices of agriculture outputs, and because these products may only represent one input in their production process. The companies also do not face the same type of impact; in the case of exogenous risks, they may face future production losses, whereas for endogenous risks, they may also face reputation risks, which could reduce their sale and the confidence of investors.

Under exogenous water risks, shifting supplies or ingredients will mitigate risks at a cost

Profit functions at time t_1 are defined as follows:

$$\Pi_1^c = P_1(\sum_i y_i)^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1(\sum_i y_i) - P_z.\boldsymbol{Z} \quad (14)$$
$$\overline{\Pi}_1^c = P_1\left(\sum_i \overline{y_i}\right)^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1\left(\sum_i \overline{y_i}\right) - P_z.\boldsymbol{Z}$$

With P_1 as the output price, $\boldsymbol{Z}$ as other inputs, at price P_z, and y_i as the agriculture product quantity of farmer i ($i \in [\![1, N]\!]$). Given the first stage of the model, some farmers may have decided to respond to risks by increasing efficiency or changing to other activities. It is assumed here that we focus on the N farmers that have decided to continue producing the sourcing ingredient for companies (with $N \leq I$). Of these N farmers, a share σ_e has adopted more efficient water management practices, and similarly a share σ_q has taken measures to mitigate water quality risks.[2]

Under exogenous risks, water is not a main input for their production, and water risks can therefore only affect farmers' production in the hotspot region. Three types of responses are likely: (a) a shift in products outside of the hotspot region, (b) a change of agriculture input within the same region that do not face the same risks, and (c) supporting *(1- σ) N* farmers that have not invested into water efficient practices. Naturally the size of the company will likely determine whether it makes sense to use option (a) or (c), and the type of product will also matter in determining the feasibility of (b). Here we take a hypothetical case where the three possibilities exist.

Under the first option —shifting purchases to other farmers (noted *out*)— an individual company's profits can be derived as:

$$\Pi_{out}^c = P_1(\sum_{l=1}^{L} y_l)^{k_y^c}.\boldsymbol{Z}^{k_z^c} - (p_1 + c_t)(\sum_{l=1}^{L} y_l) - P_z.\boldsymbol{Z} \quad (15)$$
$$\overline{\Pi}_{out}^c = \Pi_{out}^c$$

Assuming the same quantity can be purchased outside of the region, the companies' economic impacts of water risks are mitigated but there is a transport cost c_t for any new product.

Under the second option —changing inputs (noted *inp*) — profits are the following:

$$\Pi_{inp}^c = P_1(\sum_{m=1}^{M} v_m)^{k_v^c}.\boldsymbol{Z}^{k_z^c} - p_v(\sum_{m=1}^{M} v_m) - P_z. \quad (16)$$
$$\overline{\Pi}_{inp}^c = P_1(\sum_{m=1}^{M} \overline{v_m})^{k_v^c}.\boldsymbol{Z}^{k_z^c} - p_v(\sum_{m=1}^{M} \overline{v_m}) - P_z.\boldsymbol{Z}$$

With v_m representing the production of farm m.

Lastly, in the third option, companies might decide to engage into efforts to reduce water use with the non-efficient farmers, proposing to bear an acceptable share ρ of the costs of investment (ensuring that the remaining farmers satisfy condition (7)). Profits are then:

$$\Pi_e^c = P_1(\sum_i y_{ei})^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1(\sum_i y_{ei}) - P_z.\boldsymbol{Z} - \rho N(1-\sigma)K_e \quad (17)$$
$$\overline{\Pi}_e^c = P_1\left(\sum_i \overline{y_{ei}}\right)^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1\left(\sum_i \overline{y_{ei}}\right) - P_z.\boldsymbol{Z} - \rho N(1-\sigma)K_e$$

Where y_{ei} is the production of efficient producer i ($i \in [\![1, N]\!]$).

The arbitrage between the three options and the original one will depend on the cost of transportation, trade-off between more costly ingredients and risks of losing production, and on the cost of supporting farmers to become efficient.

- Option 1: Procuring products out of the region

$$E(\Pi^c/out) \geq E(\Pi^c/NR) \Leftrightarrow \varphi.\left[\left(\Pi^c_{out} - \overline{\Pi^c_{out}}\right) - \left(\Pi^c_1 - \overline{\Pi^c_1}\right)\right] \geq \overline{\Pi^c_1} - \overline{\Pi^c_{out}}$$

$$\Leftrightarrow P_1\left((\textstyle\sum_{l=1}^{L} y_l)^{k_y^c} - \varphi(\sum_i y_i)^{k_y^c} - (1-\varphi)(\sum_i \overline{y_i})^{k_y^c}\right).\boldsymbol{Z}^{k_z^c} - p_1(\sum_{l=1}^{L} y_l - \varphi\sum_i y_i - (1-\varphi)\sum_i \overline{y_i}) \geq c_t(\sum_{l=1}^{L} y_l)$$

$$\Leftrightarrow c_t \leq \frac{1}{\sum_{l=1}^{L} y_l}\left[P_1\left((\textstyle\sum_{l=1}^{L} y_l)^{k_y^c} - \varphi(\sum_i y_i)^{k_y^c} - (1-\varphi)(\sum_i \overline{y_i})^{k_y^c}\right).\boldsymbol{Z}^{k_z^c} - p_1(\sum_{l=1}^{L} y_l - \varphi\sum_i y_i - (1-\varphi)\sum_i \overline{y_i})\right] \quad (18)$$

The cost of transportation has to be smaller than the benefits of mitigating the risks, this condition will hold especially with high risks, high damage with risks.

- Option 2: Changing inputs (ingredients)

$$E(\Pi^c/inp) \geq E(\Pi^c/NR) \Leftrightarrow \varphi.\left[\left(\Pi^c_{inp} - \overline{\Pi^c_{inp}}\right) - \left(\Pi^c_1 - \overline{\Pi^c_1}\right)\right] \geq \overline{\Pi^c_1} - \overline{\Pi^c_{inp}}$$

$$\Leftrightarrow P_1\left[\varphi\left((\textstyle\sum_{m=1}^{M} v_m)^{k_v^c} - (\sum_i y_i)^{k_y^c}\right) + (1-\varphi)\left((\sum_{m=1}^{M} \overline{v_m})^{k_v^c} - (\sum_i \overline{y_i})^{k_y^c}\right)\right].\boldsymbol{Z}^{k_z^c} - [p_v(\varphi\sum_{m=1}^{M} v_m + (1-\varphi)\sum_{m=1}^{M}\overline{v_m}) - p_1(\varphi\sum_{l=1}^{L} y_l + (1-\varphi)\sum_i \overline{y_i})] \geq 0 \quad (19)$$

The expression is hard to track, but if one assumes that the production of the alternative input is not affected with water risks it simplifies to:

$$E(\Pi^c/inp) \geq E(\Pi^c/NR) \Leftrightarrow P_1\left[(\textstyle\sum_{m=1}^{M} v_m)^{k_v^c} - \varphi(\sum_i y_i)^{k_y^c} - (1-\varphi)(\sum_i \overline{y_i})^{k_y^c}\right].\boldsymbol{Z}^{k_z^c} - [p_v\sum_{m=1}^{M} v_m - p_1(\varphi\sum_{l=1}^{L} y_l + (1-\varphi)\sum_i \overline{y_i})] \geq 0 \quad (20)$$

In this case, it becomes another risk mitigation strategy which will be cost-effective only if the additional cost of the ingredient is lower than risk avoidance.

- Option 3: Contracting with farmers

$$E(\Pi^c/e) \geq E(\Pi^c/NR) \Leftrightarrow \varphi.\left[\left(\Pi^c_e - \overline{\Pi^c_e}\right) - \left(\Pi^c_1 - \overline{\Pi^c_1}\right)\right] \geq \overline{\Pi^c_1} - \overline{\Pi^c_e}$$

$$\Leftrightarrow \varphi\left[P_1(\textstyle\sum_i y_{ei})^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1(\sum_i y_{ei}) - P_1(\sum_i \overline{y_{ei}})^{k_y^c}.\boldsymbol{Z}^{k_z^c} + p_1(\sum_i \overline{y_{ei}}) - P_1(\sum_i y_i)^{k_y^c}.\boldsymbol{Z}^{k_z^c} + p_1(\sum_i y_i) + P_1(\sum_i \overline{y_i})^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1(\sum_i \overline{y_i})\right] \geq P_1(\sum_i \overline{y_i})^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1(\sum_i \overline{y_i}) - P_z.\boldsymbol{Z} - P_1(\sum_i \overline{y_{ei}})^{k_y^c}.\boldsymbol{Z}^{k_z^c} - p_1(\sum_i \overline{y_{ei}}) - P_z.\boldsymbol{Z} - \rho N(1-\sigma)K_e$$

$$\Leftrightarrow K_e \leq \frac{1}{\rho N(1-\sigma)}\left[P_1\left[\varphi\left((\textstyle\sum_i y_{ei})^{k_y^c} - (\sum_i y_i)^{k_y^c}\right) + (1-\varphi)\left((\sum_i \overline{y_{ei}})^{k_y^c} - (\sum_i \overline{y_i})^{k_y^c}\right)\right].\boldsymbol{Z}^{k_z^c} - \left[p_1\left(\varphi(\sum_i y_{ei} - \sum_i y_i) + (1-\varphi)(\sum_i \overline{y_{ei}} - \sum_i \overline{y_i})\right)\right]\right] \quad (21)$$

This condition will be more favourable if the share of costs and number of farms is smaller, if the risk for production is greater, and if water efficiency really creates effective solutions to water risks.

While this is outside the scope of the exercise, on a small market, and with a limited number of companies, the decision of one company to opt for one of these solutions or to remain in a default will affect the price of the raw commodity. In particular, if a significant share of companies decides to opt for other inputs, the price p_1 may decline, which could result in less incentives for farms to respond, and in turn affect the non-reacting companies.

Companies are further encouraged to engage with farmers under endogenous water risks

In this case, three factors change. First, farmers' decision to react may change (equation 13) and instead they take action earlier; secondly, their action will affect overall risks which could create uncertainties; and third, relatively large companies that do not react could face risks to their reputation that in turn could affect their sales (loss of revenues) and/or confidence of investors (which would affect long term growth and investments). These risks can be factored in as penalties $g(\varphi)$ depending on the risk φ:

$$E(\Pi^c/NR) = \varphi\left(\Pi_1^c - \overline{\Pi_1^c}\right) + (1-\varphi)\left(\Pi_1^c - \overline{\Pi_1^c}\right) - g(\varphi) \quad (22)$$

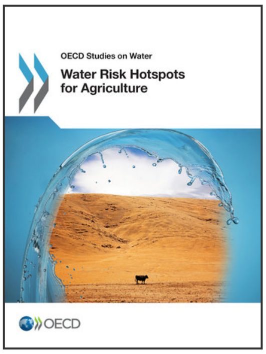
With $\varphi = \varphi_0 + (1-\varphi_0)\left(\frac{\mu}{W_0}\sum_{i=1}^{I} w_0^k\right)$ and $\frac{dg}{d\varphi} \geq 0$

Everything else being equal, larger companies are therefore more likely to engage in a response than smaller companies. In practice, larger companies will also have better access to knowledge and technologies, and may be able to realise economies of scale, increasing the likelihood that they will respond.

Notes

1. The cost of water is set to be exogenous and mostly representing the cost of access. In the case of water markets these prices could evolve with conditions, which would change the outcome.

2. These two shares could be endogenous if prices of agriculture outputs were affected by the choice of companies. To keep things simple, they have been set as exogenous.



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