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McKinsey Climate Change

From bread basket to dust bowl?

Assessing the economic impact of tackling drought in North and Northeast China

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Preface

Climate change will create new risks and challenges for China – in both public and private sectors – requiring significant adaptation to manage the impact on lives, livelihoods, and assets.

Despite China's significant efforts to estimate investment needs for adaptation and progress toward the Bali Action Plan, decision-makers do not have access to a practical fact base and effective decision-support tools.

Hence, the objective of this report is to provide decision-makers in China with the facts and frameworks needed to design an adaptation strategy and deliver financial resources. The analysis in this report was conducted by **McKinsey & Company** in close collaboration with the **International Cooperation Center of The National Development and Reform Commission (NDRC)** and **Professor Lin Erda's** group from **The China Academy of Agricultural Sciences (CAAS)**.

While this report studies climate change adaptation in China, it forms part of a McKinsey & Company global initiative. Our global perspective towards this topic is available in our recently published "Shaping Climate-resilient Development Report".

The China study is part of the global initiative of The Economics of Climate Adaptation Working Group, which was formed in September 2008 under the initiating sponsorship of the Global Environment Facility. The Working Group is comprised of members drawn from multiple disciplines across the private, public and social sectors, who provided the institutional collaboration needed to tackle the challenge of building a quantitative framework to assess the economics of adaptation:

- The initiating sponsorship for the effort came from the Global Environment Facility (GEF), a global partnership between 178 countries and many international institutions, private sector institutions, and NGOs

- Swiss Re, a leading global reinsurer, was a lead contributor to the research, and brought its natural catastrophe risk assessment knowledge to bear on the challenge of quantifying climate risk

- McKinsey & Company, a global management consulting firm with extensive experience working on issues related to climate change, drove the analytical execution and contributed to the fact base of this report

- Sponsorship and key guidance were provided by ClimateWorks, an international network of foundations focused on achieving low-carbon development; the Directorate General Development of the European Commission, which focused on developing a practical methodology to assist adaptation in the most climate- vulnerable developing countries; the Rockefeller Foundation, which brought its deep experience of building climate resilience in developing countries; and Standard Chartered Bank, a global bank with a focus on the emerging markets of Africa, Asia and the Middle East, many of which are among the most exposed to climate risk

We would like to thank **Mr. Xiaochong Zhang** from **International Cooperation Center, NDRC**, for his support and guidance on our analysis report, and **Mr. Sijia Zhang** from **The Division of Information and Consulting, International Cooperation Center, NDRC**, and his colleagues for their support of our work.

We would like to acknowledge the **Institute of Environment and Sustainable Development in Agriculture, CAAS** for their support in data, research methodology development and experience sharing, especially for the guidance from **Prof. Erda Lin, Prof. Yinlong Xu** and **Prof. Changrong Yan**, and the work support from **Prof. Wei Xiong, Ms. Sanai Li, Mr. Ji Gao** and **Ms. Jie Pan**.

Executive summary

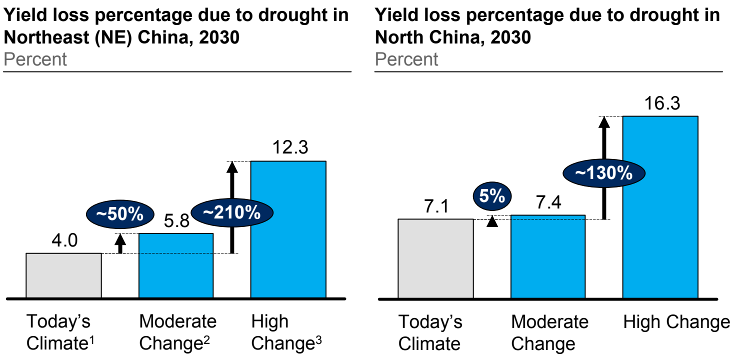
Climate change has become a rising concern globally. How countries adapt to, or cope with, potential climate change related hazards is therefore a necessity. However, there is little quantitative analysis at the regional level upon which to base an adaptation strategy.

McKinsey & Company has conducted research to understand the future extent of drought loss in North and Northeast China under the climate change context. The purpose of the study is to provide a fact base and the frameworks needed for decision-makers to design a drought adaptation strategy, and for private players to develop relevant agriculture strategies. We have closely cooperated with the leading research group, Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences.

Our analysis suggests that the impact of climate change on drought loss could be very region-specific. For instance, under our "Moderate" Climate Change scenario in 2030 climate change could drive up drought losses by 50% in Northeast China, though would not have significant impact in North China. Specifically, in Northeast China, climate change is expected to increase drought loss from ~4% yield loss to ~6% (~11.5 bn RMB) in 2030; while in North China, drought loss will remain around ~7% yield loss (~6.5 bn RMB). [Exhibit 1]

One reason for this region-specific impact is that climate change leads to different precipitation patterns within each region. Specifically, in Northeast China the impact of climate change creates a decrease in precipitation during the critical Spring months, thus increasing the probability of drought in the region. Meanwhile in North China, climate change has limited impact upon precipitation patterns during the critical Summer months. Furthermore, Northeast China is far more vulnerable to extreme drought due to its relatively under-developed drought-resistance system.

Exhibit 1: The impact of climate change is likely to be region specific: It is likely to have a higher impact in Northeast China than in North China


Yield loss percentage due to drought in Northeast (NE) China, 2030
Percent

Yield loss percentage due to drought in North China, 2030
Percent

Yield loss Million tons	4.5	6.5	13.8	3.1	3.3	7.2
Value loss RMB billions	7.8	11.5	23.3	6.1	6.5	13.9

1 Today's climate: PRECIS model output based on 1961-90 historic data
2 Moderate Change: Avg. output of PRECIS model based on A2 scenario by IPCC; 50% increase of severity and freq. of extreme drought
3 High Change: Avg. of 90th percentile output of PRECIS based on A2, 100% increase of severity and freq. of extreme drought

SOURCE: PRECIS model; CEIC; Research Of The Social And Economic Impact Of Drought, Yingqiu Liu; Team analysis

Extreme drought presents a greater threat, as it is difficult to forecast and has the potential to cause larger-scale damage to agriculture and farmers' incomes. Our "High" Climate Change scenario, under which extreme drought occurs, indicates ~80% of farmers could be impacted by 2030, meaning 35 million farmers could suffer >50% of agricultural income loss[1], resulting in an economic loss of ~60bn RMB in Northeast China alone.

While the Chinese government has implemented various drought mitigation measures in recent years building on these efforts from a solid fact base will be important to enhance China's resilience against the increased probability of drought due to climate change.

In evaluating drought-adaptation measures, we screened >30 measures and selected 4 groups of measures based on their impact and feasibility. These are water-saving irrigation, planting, seed, and engineering measures.

It is estimated that ~50% of the 18 bn RMB losses in North China and Northeast China in 2030 could be averted by fully adopting all 4 groups of measures. Further development of some of the measures could reduce another ~10% of the total drought loss, though there are barriers to this. For instance, improving seed technology to create higher drought resistance is dependent on a technology breakthrough. Measures other than the 4 groups identified could avert further loss, though these were not included in our analysis due to the challenge of quantifying them, e.g. optimizing crop structuring, and genetically-modified seeds.

Regardless of the adaptation measures put in place to mitigate risk, unpredictable extreme drought can cause severe yield and income loss to farmers. We therefore see agriculture insurance as a viable risk-transfer measure to protect farmers against this risk, particularly in regions where extreme drought is more severe and frequent, such as Northeast China.

The region-specific impact identified means there is no "one-size-fits-all" approach to adaptation. Hence, in North China, we suggest greater use of water-saving irrigation techniques, while in Northeast China we suggest expanding the irrigation area and promoting agriculture insurance.

Economically, all the captioned measures, except engineering measures, have life-time positive economic returns. However, farmers could be averse to investing in technologies with relatively long payback periods (~3 years for drip/sprinkle irrigation). We estimate a total investment of ~100 bn RMB during 2010-2030 in North and Northeast China[2]. If extrapolated to the whole country based on agriculture GDP proportion, these measures would require an accumulative upfront investment of RMB ~500bn in 2010-2030, resulting in ~25 bn RMB per year on average. Currently, China invests ~10 billion RMB on water-saving irrigation annually, which accounts for only 40% of the investment required. [Exhibit 2]

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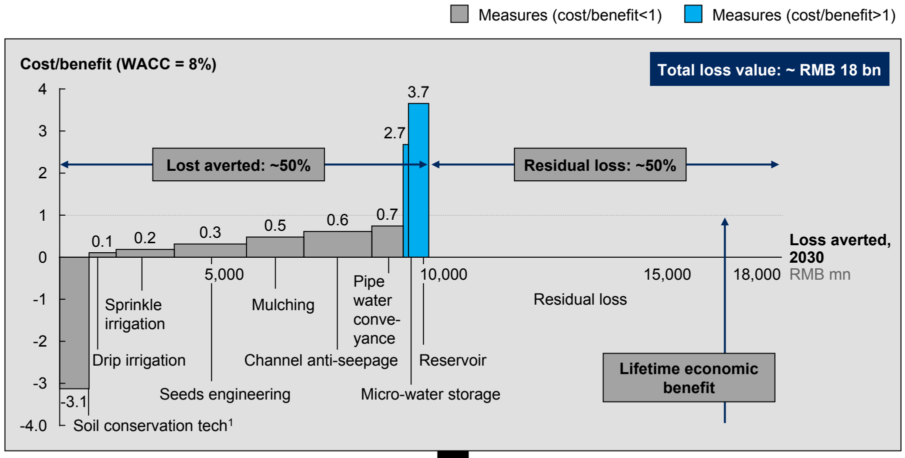
[1] Assume no further technology adaptation in 2030 compared to 2008.

[2] Total investment may be de-evaluated, e.g. upfront investment of seed companies is not included in the calculation.

Exhibit 2: ~50% of the "expected" annual loss can be reduced by 9 measures in 2030



- Around ~50% of the expected loss can be averted by measures
- Most of these measures have lifetime economic benefits that are greater than costs (NPV>0)

[1] Negative cost/benefit ratio means there is cost-saving in long-term. E.g. Soil conservation technique can have large cost-saving from less tillage operation and fertilizer usage. Its benefit is limited as it can only avert small loss during drought and has no yield improvement in normal condition.

SOURCE: Expert interview; Team analysis

To realize the full benefit of the measures, we see potential for closer collaboration between the public and private sectors in overcoming implementation challenges, particularly in the areas of financial support, capability building, and regulatory environment.

Different categories of measures would require specific implementation approaches. For instance, the key challenges to implementing irrigation measures are a reluctance of farmers to invest due to risk, purchasing power and low awareness. Here we see an opportunity for private players to resolve these issues by taking the lead in providing financial assistance, and building maintenance and extension systems. For seed measures, IPR is the key barrier for both private and public players to invest and develop their R&D capabilities. Therefore, clear regulation and implementation from the government would be a prerequisite to fully capturing the opportunity in this category.

Content

Introduction

The China study is part of the global initiative of The Economics of Climate Adaptation Working Group, which was formed in September 2008 under the initiating sponsorship of the Global Environment Facility. We set out to develop a practical framework – grounded in robust analysis – that would allow national and local decision makers to assess the "total climate risk" facing their economies, and to minimize the cost of adapting to that risk through climate-resilient economic development strategies.

We aim to address this important global concern, in a practical way, as reflected in the overall project approach. Our analysis assesses climate hazard risks and adaptation measures at the local level through a series of case studies using a methodology that results in (1) an assessment of climate hazard risks and losses through 2030, (2) a prioritized set of adaptation measures based on bottom-up cost benefit assessment, and (3) a detailed analysis of the implementation challenges of the measures and the proposal on the solutions for the government as well as private players.

Why focus on drought loss?

Climate change is believed to cause severe extreme weather phenomena, such as tropical cyclone, drought, and flooding, which pose significant threats to the environment, people and economies. All these hazards will require further research to identify appropriate adaptation strategies. However, establishing a fact base for all climate-related hazards in a country of China's vast scale presents obvious challenges in terms of time and resources. We therefore narrowed our scope to focus on drought in North and North East China.

The three main climate-change related hazards to affect China in recent years are flooding, with economic losses totaling 68 billion RMB, drought, and tropical cyclone, each accounting for losses of 53 bn RMB. While there is little variation between these hazards in terms of economic loss, drought presents a greater threat to rural stability and national food security.

From a social security perspective, e.g. rural area stability and food security, drought has caused more damage than flooding and tropical cyclone. Between 2004 - 07, 140 million people (primarily rural populations) were affected by drought, compared to 108 million (primarily urban populations) affected by flooding, and 51 million by wind hazards. On average, drought has caused 20% agriculture income loss[3] to 16% of farmers annually in China. The impact of drought upon agriculture could pose a threat to China's food security goal. Drought adversely impacted 21 million hectares of crop fields between 2004 - 07, compared to 9 million hectares impacted by flooding, and 3 million hectares by tropical cyclone.

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[3] Agricultural income accounts for ~50% of total farmers' income in China in 2004-2007

Why focus on North and Northeast[4] China?

Historically, drought has been a nationwide problem in China, and almost every province has experienced drought loss. However, we selected North and Northeast China as our primary focus due to the severity of drought in the two regions, and their vulnerability to manage drought.

The combined drought loss of North and Northeast China is more than double that of other regions[5] and accounts for almost a quarter of national economic losses due to drought. This takes on greater significance considering that the two regions account for 21% of China's total agriculture production. The yield base of the two regions–and hence the crops at risk of drought–will increase as China's population grows.

North and Northeast China are also highly vulnerable to drought. The ratio of drought impacted area (>30% yield loss) to drought covered area (>10% yield loss)[6] is a good indicator of vulnerability, as it reveals the extent and severity of the loss that drought can cause. North and Northeast China recorded among the highest ratios in China between 1951-2000[7].

Hence, our analysis focuses on drought loss in North and Northeast China due to the high potential impact on people and on the agriculture sector, which holds the key to some of China's highest priorities, including rural stability and national food security. This is not to say that other hazards or other regions are lower priority; indeed we hope this report may also function to provide a methodology or reference for analysis of other climate-change related hazards, including, flooding, wind and climate zone shift.

Uncertainty and major assumptions of our analysis

Certain assumptions were necessary in the course of our analysis, for example: the uncertainty in long-term climate forecast, uncertainty of how carbon dioxide concentration could impact climate change, uncertainty of the long-term economic and price forecasts for adaptation measures. While these assumptions were made based on available facts, we list the assumptions here in the interest of full transparency, and with the acknowledgement that the potential for uncertainty exists.

For meteorological estimation, we used the PRECIS Regional Climate Modelling System to simulate meteorological conditions under climate change: 30 samples of output in medium term under the IPCC A2 scenario. Under the "Today's" Climate scenario, we used historical meteorological conditions (1961-90).

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[4] We selected Heilongjiang, Jilin and Liaoning for Northeast China, and Hebei, Shanxi, Beijing and Tianjin for North China

[5] In terms of drought severity, Northeast China and North China accounted for 24% and 23%, respectively, of national economic loss due to drought

[6] Drought impacted area is the sown area with >30% yield loss, this ratio is 10% for drought covered area

[7] With the exception of Northwest China. But Northwest China had a much lower total drought loss (11% of China) and is thus not selected in the scope of our report

To estimate yield vulnerability, we used the FAO CROPWAT model to calculate yield loss percentage under drought. We fixed crop price and sown area based on the historic average of recent years.

Furthermore, in the course of our research many experts emphasized that year 2030 is relatively short-term under the climate change context. More catastrophic changes in climate could occur over a longer time horizon, say to 2050 or 2100, and their impact should not be underestimated. For instance, glacial shrinkage in the Tibetan Plateau is expected to reduce the water of major rivers by 2050 and have a dramatic impact on agriculture. The potentially worsening threat of climate change beyond the 20-year horizon is beyond this particular effort due to data limitation and challenges in forecasting the economics of the adaption measures.

Drought loss analysis

Since the 1950s, China has lost increasingly large amounts of vital food crops to drought. Even more will be at stake as yields keep rising to meet the demand of the growing population. This chapter examines the overall drought loss to China and considers the potential impact of climate change in North and Northeast China.

Magnitude of drought loss

Since the 1950s yield losses due to drought have steadily increased in North and Northeast China, from 7% to 13% for North China and from 2% to 8% for Northeast China. By the 1990s the two regions incurred total losses of 12 million tons, accounting for almost 40% of national losses.

Despite government efforts to stem the losses (e.g., investing RMB 16 billion in drought mitigation in North and Northeast China during the 1990s, with a year-on-year growth of 30%) they will continue to rise as the yield base of these important agricultural regions grows in order to satisfy the demand of China's growing population.

China currently produces ~510 million tons of grain annually. By 2030 this will rise to ~590 million tons[8] to meet projected demand from food consumption (in line with population growth to 1.4 billion), animal feed and industrial use. Twenty eight percent of this–more than the grain production of Brazil[9]–will be produced by North and Northeast China. Hence, there is a heightened risk of increased value loss as the production base grows.

Region-specific impact of drought loss

Our research indicates that the expected impact of climate change upon agricultural drought loss in China is likely to vary greatly between regions, as depicted by the projections for these two biggest grain-producing regions. Our forecasts show that, under the "Moderate" Climate Change scenario, Northeast China could see a ~50% increase in drought loss, while the impact on North China is relatively limited.

We arrive at this conclusion by making drought-loss projections under the following three scenarios:

- "**Today's Climate**" is a scenario assuming the climate of the next 20 years will remain the same as historical climate conditions. We used 1961-90 climate conditions as input and simulated the output by PRECIS model.
- "**Moderate Climate Change**" is a scenario of average value of the forecast assuming a medium-high CO2 concentration scenario. We use the average value of the forecast from the PRECIS model under the Intergovernmental Panel on Climate Change (IPCC) A2 scenario, in which CO2 concentration reaches 560 parts per million in the atmosphere (ppm) in the 2040s. In

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[8] Assuming China will remain 100% self-sufficient on food crops, and that other crops share the same production growth rate as food crops

[9] Assume Brazil enjoys the same growth rate of food crop production. (In 2008, the yield of food crop in Chinas is ~20% higher than that in Brazil)

addition, we assume a 50% increase in of the severity and the frequency of extreme drought[10].

- “**High Climate Change**” is a scenario under the same CO2 scenario of “Moderate Climate Change” scenario but uses the average of 90th percentile forecast of the PRECIS model. In addition, we assume 100% increase in of the severity and the frequency of extreme drought[10].

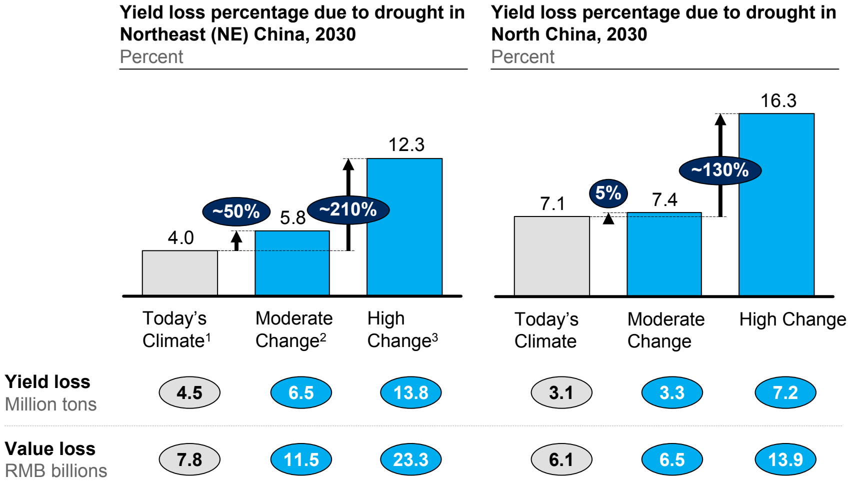
The comparison between all these scenarios indicates that the impact of climate change on drought loss by 2030 will be very region-specific. The projected impact under each scenario is described below [Exhibit 3]:

Under Today’s climate scenario, the expected total loss to both regions by 2030 is 14 bn RMB[11]. Of that, Northeast China accounts for 8 bn RMB (representing a 4.5 million ton yield loss, or 4.0% of total production) and North China for 6 bn RMB (representing 3 million ton yield loss, or 7% of total production).

Under the Moderate Climate Change scenario, the total loss rises to 18 bn RMB, with Northeast China losses rising by ~50% to 11.5 bn RMB (6.5 million ton yield loss, or 6% of production), compared with a 5% rise in the North China losses to 6.5 bn RMB (3 million ton yield loss, or 7% of production).

Under the High Climate Change scenario, the total loss rises to 37 bn RMB, with Northeast China losses tripling to 23 bn RMB (13.8 million ton yield loss, or 12% of production), while North China losses rise to 14 bn RMB (7 million ton yield loss, or 16% of production).

Exhibit 3: The impact of climate change is likely to be region specific: It is likely to have a higher impact in Northeast China than in North China



1 Today’s climate: PRECIS model output based on 1961-90 historic data
2 Moderate Change: Avg. output of PRECIS model based on A2 scenario by IPCC; 50% increase of severity and freq. of extreme drought
3 High Change: Avg. of 90th percentile output of PRECIS based on A2, 100% increase of severity and freq. of extreme drought

SOURCE: PRECIS model; CEIC; Research Of The Social And Economic Impact Of Drought, Yingqiu Liu; Team analysis

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[10] The increase of severity and frequency only applies to 1-in-50-year drought
[11] The value loss calculated here are all based on 2008 price

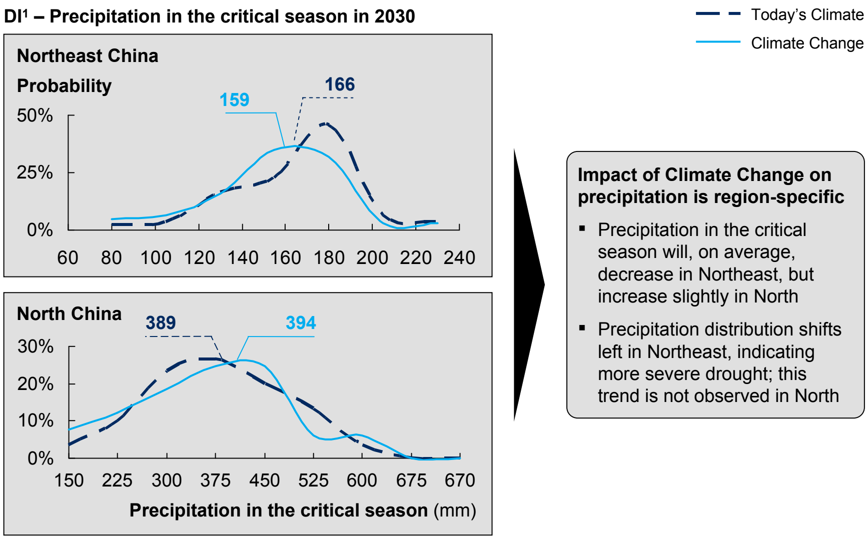
The vastly differing impact of climate change upon drought loss in North and Northeast China can be attributed to regional differences in climate, crop structure, and capability to fight drought.

Specifically, climate change creates changes to the precipitation in North and Northeast China. In Northeast China, it leads to a decrease in the critical springtime precipitation, putting the rainfed crops at greater risk. In North China, however, the critical summer-time precipitation increases slightly. [Exhibit 4]

Though many climate factors, such as temperature and sunshine duration, contribute to drought, the precipitation level during the critical growth period of crops is a predominant factor. In Northeast China, where the climate can only support one harvest per year, crops are sown in spring thus spring-time precipitation is critical. In fact, there is a strong correlation between historical drought-covered area and shortage of Springtime precipitation in Northeast China. In contrast, in North China, there are two harvests per year and the sown periods cover Spring, Summer and Autumn. Summertime precipitation accounts for 80% of the annual precipitation and shows the largest correlation with historical drought-covered area. Therefore, we use Springtime precipitation of Northeast China and Summertime precipitation of North China as indicators of drought.

The suggestion that climate change could increase average annual precipitation in Northeast China ought not to be mistaken for climate change relieving drought in Northeast China. Our analysis indicates that climate change will still lead to

Exhibit 4: Future climate forecast suggests that Climate Change will reduce precipitation of the critical season in Northeast China, but not in North China



Impact of Climate Change on precipitation is region-specific

- Precipitation in the critical season will, on average, decrease in Northeast, but increase slightly in North
- Precipitation distribution shifts left in Northeast, indicating more severe drought; this trend is not observed in North

1 Drought Indicator (DI) is defined as the precipitation of critical seasons, based on correlation between historical seasonal precipitation and drought covered area; North: Summer precipitation; Northeast: Spring precipitation

SOURCE: PRECIS model; Team analysis

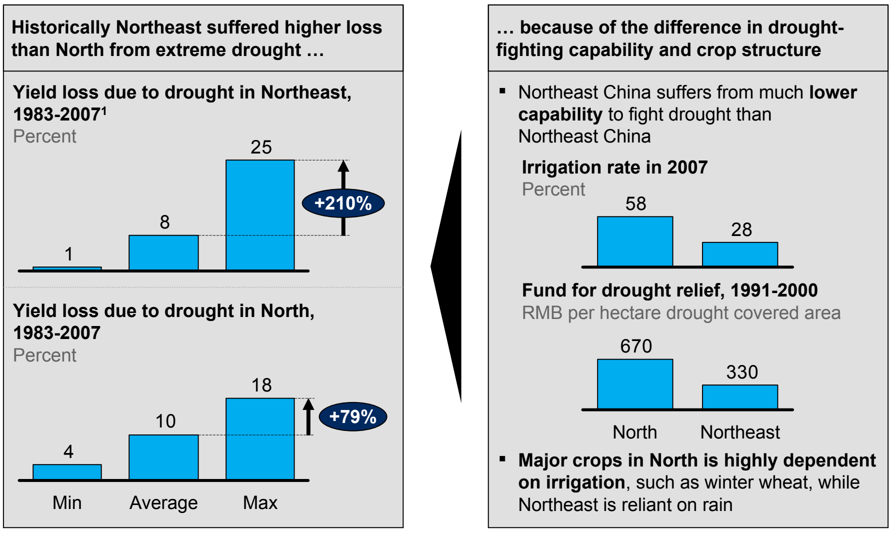
increased drought because it decreases the critical Springtime precipitation, which is the key driver for drought loss, rather than annual precipitation. In addition, current analysis also suggests climate change could lead to the biggest temperature increase in Northeast compared to other regions in China, which would contribute to the severity of drought in Northeast China.

Another major driver of the regional difference is Northeast China's relatively low capability to fight drought, leaving it highly vulnerable to severe drought and extreme events. In the last 25 years, considering the 3 most severe droughts, Northeast China has incurred losses that are 200% higher than that of average drought loss, while the difference in magnitude is only around 80% for North China. [Exhibit 5]

Northeast China's relatively wetter climate (about 18% more annual precipitation compared to North China) has hindered the region's ability to fight drought. Farmers in the region are less equipped and experienced to manage drought due to limited resources. The irrigation rate of 28% in Northeast China is less than half of North China's, and Northeast China also receives less than half the drought assistance of North China (330 RMB per hectare of drought-covered area vs 670 RMB/ha between 1991-2000).

Climate change is widely believed to induce more extreme weather events. For example, The China National Climate Change Program[12] has identified links between the frequency and intensity of extreme climate/weather events throughout China in the last 50 years and environmental changes, such as more severe drought in North and Northeast China. Scientists from the program predict the frequency of extreme climate/weather events to increase further

Exhibit 5: Northeast China is more vulnerable to extreme drought than North China



Historically Northeast suffered higher loss than North from extreme drought …

… because of the difference in drought-fighting capability and crop structure

- Northeast China suffers from much **lower capability** to fight drought than Northeast China
- **Major crops in North is highly dependent on irrigation**, such as winter wheat, while Northeast is reliant on rain

1 Min. is the average of the lowest 3 numbers; Max. is the average of the highest 3 numbers

SOURCE: CEIC; Research Of The Social And Economic Impact Of Drought, Yingqiu Liu; Team analysis

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[12] China National Climate Change Program 2007 document, NDRC

in the next 100 years. There is currently no quantitative data linking climate change to frequency of extreme events, but our scenario analysis provides us with preliminary estimates of the drought loss impact due to climate change in Northeast and North China.

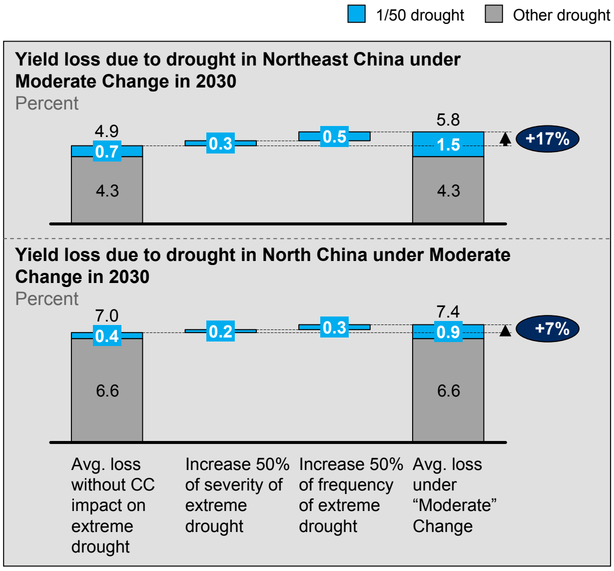
Under the Moderate Climate Change scenario, we assume climate change will increase the severity and frequency of extreme drought by 50% in 2030; Under the High Climate Change scenario, both severity and frequency would be increased by 100%. The estimate of this scenario is based on historical extreme droughts in the area over the past 25 years (1983 – 2007). In terms of frequency, historical comparisons taken from 1983-2007 show the most extreme drought occurred in the last 10 years (1999 in North, and 2000 in Northeast China). In terms of severity, our historical comparisons show that the impacted area of the two most severe droughts during 1997-2007 was 40% greater than that which occurred between 1983-1996 in North China, and 70% in Northeast China.

As a result, under the Moderate Climate Change scenario, extreme events would almost double the contribution to the average expected annual loss, i.e. from 14% to 26% in Northeast China, and from 6% to ~10% in North China. Under the High Climate Change scenario, drought loss due to extreme events will account for 23% and 10% of the overall drought loss in Northeast and North China respectively. [Exhibit 6]

In conclusion, the impact of climate change on drought is very region-specific. This implies that there is no one-size-fits-all solution. When developing an adaptation plan, region-specific investigation and analysis will be required and the adaptation strategy will vary region by region.

Exhibit 6: If climate change leads to more severe and frequent extreme drought, Northeast China will be more severely impacted

- **Use average output of PRECIS forecast for normal drought**
- **Assume the severity and frequency of extreme drought will increase by 50%[1] due to climate change**



[1] The severity and frequency increase of extreme drought are assumptions that apply to 1/50 extreme event only

SOURCE: CEIC; Research Of The Social And Economic Impact Of Drought, Yingqiu Liu; Team analysis

Other impact of drought

Impact to livestock

While short-term measures have been successful in reducing the impact of drought upon livestock, it will present a more serious long-term problem. To understand the impact on livestock, we looked at Inner Mongolia, whose grassland comprises 30% of China's total grassland in use for grazing.

Improved infrastructure, such as wells, cattle houses etc., has resulted in a 73% decrease in cattle loss due to drought between 1960s and 1990s, even though the number of cattle affected by drought increased during this period. However, short-term improvements will not prevent the exacerbation of the problem in the longer term. Drought has accelerated the regression of grassland and significantly deteriorated the ecological condition in Inner Mongolia, doubling the frequency of sandstorms. Such deterioration creates a shortage of good pastures, which affects the meat quality of livestock and hence herdsmen's incomes.

Therefore, longer-term, drought could lead to a greater impact on rural incomes due to the additional investment required for anti-drought facilities, and lower cattle quality.

Impact to farmers life quality and income

Urbanization trends will see the number of famers impacted due to drought loss decrease by 10-20% in 2030 (10 mn in Northeast China and 20 mn in North China). But while the number of farmers will decline, the average loss per farmer will increase as land plots also increase. According to the McKinsey report, "Preparing for China's Urban Billion", China's rural population will decrease by 25%, and arable land per famer will increase by ~30% in 2030 (0.5ha/capita in Northeast and 0.2 ha/capita in North China).

The situation would be more severe under extreme drought. For instance, in Northeast China, extreme drought in 2007 impacted ~25 mn farmers (44% of total farmers) with agricultural income losses of ~50%. This presents a serious threat particularly to farmers without extra income. Under the High Climate Change scenario, in Northeast China ~80% of farmers per year could be impacted by drought by 2030, which means 35 million farmers could lose >50% of their agricultural income[13]. Continued drought on such a scale could pose a significant threat to the stability of rural incomes.

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[13] Assume no further technology adaptation in 2030 compared to 2008

The important “grain giants” of North and Northeast China are key to feeding China’s growing population, though they are highly vulnerable to drought, already accounting for almost 40% of national yield losses, these two regions will produce 25% of China’s food crops by 2030. Drought loss due to climate change will take its toll on the increasing yield base, though with greater impact on Northeast China, where drought loss will increase ~50%, compared with a very limited impact on North China. It is not only crops that are at stake; if climate change leads to continued extreme drought, rural incomes and living standards will also be affected. A region-specific adaptation strategy will be required to minimize the losses.

Evaluation of counter measures

Introduction

Along with global temperature rises, China has seen an increase of extreme events, such as earthquakes, drought, and flooding. The Central Government has implemented various measures in response. In its 11th Five-Year Plan, for example, the government set strategic goals for disaster response and reduction. Key tasks under the plan include building a database of natural-disaster risks, setting up a natural-disaster forecasting and early-warning system, implementing a comprehensive coordinated disaster-response management system, led by government authorities and leveraging private players, NGOs and civil organizations.

Drought-specific measures implemented by the government in recent years have seen positive results. A multi-billion RMB investment ensured safe drinking water for over 109 million people in rural areas. The government increased investment in farmland irrigation and drainage facilities, focusing on construction of support facilities and water-saving facilities in major irrigation areas. As a result, farmland irrigation and drainage, as well as flood and drought resistance abilities, have significantly improved: Around 4,000 seepage prevention projects have been undertaken for unsafe reservoirs since 2008.

But as climate change threatens to increase the probability and severity of drought (such as the extreme drought experienced by Northeast China since 2007) how can China build on its efforts to minimize the negative effects of climate change and enhance its resilience?

Risk-mitigation measures

Summary

Drought mitigation measures are wide-ranging. To define the most effective measures requires answering a series of questions. For example, what is the scope of application and disaster-mitigation potential of each measure? What is the cost and economic impact? And what are the requirements for successful implementation?

In order to answer these questions we analyzed more than 30 drought-mitigation measures and selected 9 based on their importance and feasibility[14] to reduce drought loss in North and Northeast China. The 9 measures are categorized into 4 groups, which work together to optimize water-resource management along the agriculture value chain. The 4 groups of measures are:

- **Irrigation measures:** anti-seepage channel, pipe-water conveyance, drip irrigation and sprinkle irrigation
- **Seed-engineering measures:** to make plants more drought-tolerant through conventional breeding (not considering genetic modification)

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[14] Selection criteria include: the measures must be suitable for the crop type and landscape in North and Northeast China and their potential to avert drought loss needs to be significant and quantifiable

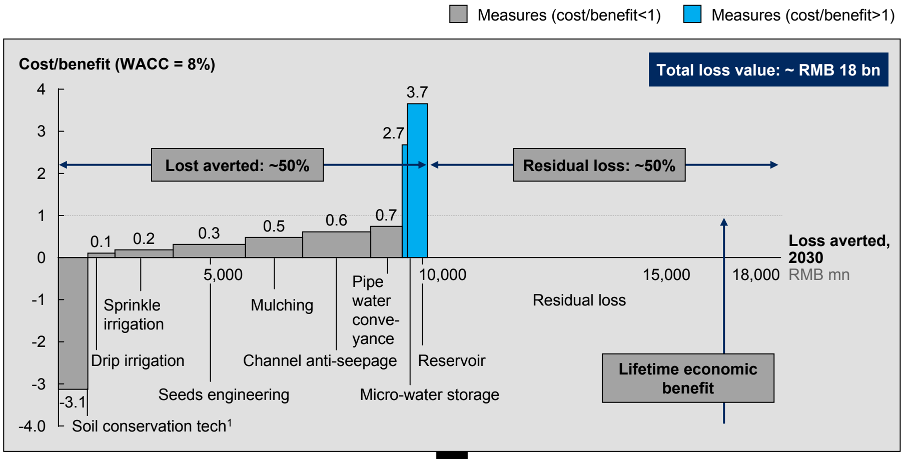
- **Planting measures:** protective cover and soil conservation
- **Engineering measures:** reservoir and micro-water storage facilities

After identifying the specific drought-loss mitigation measures, we analyzed the maximum application scope of each measure and its drought prevention effectiveness. We further analyzed the investment required, operating cost and economic benefits of each measure, based on which we developed the "cost curve of drought prevention measures for North and Northeast China" in order to review the measures in a quantitative and systematic manner.

The x axis of the cost curve represents "drought loss reduction," meaning the drought loss reduced annually by each measure by 2030, considering technical constraints only. The y axis represents "cost benefit ratio," meaning the potential economic benefits of each measure. When the cost benefit ratio of a measure is below 1, the measure's net economic benefits are positive. All costs and benefits are present value estimates, calculated at current prices up to 2030.

It should be acknowledged that in defining the potential to avert loss we considered the maximum technology potential for each measure and only took into consideration the hard technology constraints–not the economic constraints. That is to say cost is not a limiting factor in the cost curve; the rationale being that technologies that are currently too costly to adopt may become more affordable in the future due to technology breakthroughs. Also governments/donors may consider financing those options for the end-users if the technologies are important to averting loss. [Exhibit 7]

Exhibit 7: ~50% of the "expected" annual loss can be reduced by 9 measures in 2030



- Around ~50% of the expected loss can be averted by measures
- Most of these measures have lifetime economic benefits that are greater than costs (NPV>0)

1 Negative cost/benefit ratio means there is cost-saving in long-term. E.g. Soil conservation technique can have large cost-saving from less tillage operation and fertilizer usage. Its benefit is limited as it can only avert small loss during drought and has no yield improvement in normal condition.

SOURCE: Expert interview; Team analysis

Analysis of cost curve

Based on our forecast of drought loss for 2030, the annual drought loss of North and Northeast China is ~RMB 18 billion under the Moderate Climate Change scenario. By analyzing the cost curve of the mitigation measures, we identified ~RMB 9 billion drought loss reduction–half of the expected loss. It is important to note that while these 9 measures are relatively similar in terms of impact, no single measure is significantly superior to another. Therefore, parallel implementation of the mitigation measures would be required.

With the exception of the two engineering measures, all measures have positive net present value, i.e. they are all profitable long-term, driven by the yield improvement and cost-saving efforts. As these measures guarantee investment returns, investment from the agriculture and business sector should be drawn to them. However, implementation challenges exist, such as lengthy payback periods. More details of the challenges are provided in the chapter “Implementation challenges and actions to overcome them” (p35-42).

It is noteworthy that the impact of these mitigation measures is region-specific. While the average impact on drought loss reduction in North and Northeast China is 50%, it is 65% specifically in North China and 45% in the Northeast. This is mainly because the irrigation area in North China is twice that of the Northeast, and this is not expected to change greatly in the future.

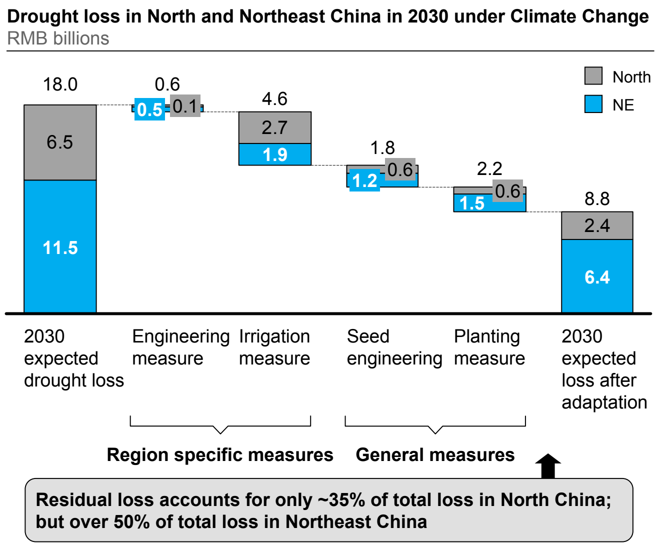
Given the regional differences in crop structure and infrastructure between North and Northeast China, region-specific adaptation strategies are necessary. We would suggest more aggressive use of water-saving irrigation techniques in North China, while expanding the irrigation area and use of agriculture insurance in Northeast China to reduce its vulnerability to drought and extreme events. Seed engineering measures can be applied to both regions. [Exhibit 8]

The potential for the mitigation measures to avert loss is driven by two factors: the application scope of the measures, and the drought-resistant effectiveness when drought actually occurs. In evaluating the measures we have sought to ensure there is no overlap between them on the cost curve. For example, we assumed different irrigation measures were applied to different crop types; sprinkle irrigation only applies to grains, while drip irrigation only applies to cash crops. Details of each measure are provided below:

Irrigation measures

The irrigation measures described in this report consist of 4 technologies: pipe-water conveyance, channel anti-seepage (pipeline technology), sprinkle irrigation and drip irrigation (field irrigation technology). Together, these 4 measures can avert one quarter of the expected drought loss in North and Northeast China by 2030, equivalent to RMB 5 billion.

Exhibit 8: Seed engineering and planting measures are applicable to both regions, while irrigation and engineering measures are region-specific



Drought loss in North and Northeast China in 2030 under Climate Change
RMB billions

Residual loss accounts for only ~35% of total loss in North China; but over 50% of total loss in Northeast China

SOURCE: Expert interview; Team analysis

Specifically, the loss reduction and cost benefit ratio is RMB 800 million and 0.7, respectively for pipe-water conveyance; RMB 1.7 billion and 0.6 for anti-seepage channel, RMB 700 million and 0.1 for drip irrigation and RMB 1.5 billion and 0.2 for sprinkle irrigation.

Pipe-water conveyance refers to the delivery of water from the source to the field through plastic or concrete pipelines. This measure can improve the water utilization rate from 45% in traditional soil pipelines to ~95%. Anti-seepage channel refers to optimal design of the water channel using sealing materials, such as polyurethane or concrete, and improves the water utilization rate from 45% to 55-65%. Pipe-water conveyance is usually applied to well irrigated areas where water costs are higher and less water is carried. Anti-seepage channels are usually applied to non-well irrigated areas (or channel-irrigation areas) due to larger water flow and the relatively lower cost. Therefore in our analysis, we assumed that by 2030 pipe-water conveyance is 100% penetrated in well irrigated areas and anti-seepage channel is 100% penetrated in non-well irrigation areas.

Drip irrigation is the network, composed of gate, pipeline, piping and drip head, that transmits water directly to the crop roots. This technology can achieve water savings of 35-50% over conventional irrigation. In sprinkle irrigation, water is distributed through pipes, then sprayed into the air, where the water breaks down into smaller droplets before falling to the ground, similar to natural rainfall. It can achieve water savings of 30-50% over conventional irrigation. Drip irrigation is usually applied to cash crops, mainly because it is more costly and its application to field crops (such as wheat and corn) is complicated, involving the installation of dripping equipment in fields. Sprinkle irrigation is applicable to grain crops in irrigation areas. Our analysis assumes that the penetration of drip irrigation and sprinkle irrigation for cash crops and grain crops in irrigation areas will reach 80% by 2030.

Despite their drought-prevention effectiveness, the irrigation measures have some negative impact on the environment. For example, lack of a proper drainage system may result in soil salinization. On the other hand, conventional irrigation has its own merits to eco-system conservation as the water it “wastes” partially enters the groundwater system or is absorbed by the vegetation.

Seed engineering measures

The seed engineering measures described in this report refer to the drought-resistant breeds in traditional cultivation; genetic modification technology is not considered. Currently, drought resistant breeds can reduce drought-loss by around 30%. By 2030, seed engineering measures are expected to avert 10% of total drought loss, equivalent to RMB 1.8 billion with a cost benefit ratio of 0.3.

Drought-resistant breeds are currently applied to all crops in rainfed areas and are gradually being applied to irrigated areas. However, drought-resistant breeds are not necessarily preferred by farmers as they do not guarantee the best output, even with sufficient water supply. Therefore, it is assumed in this report that by 2030, the penetration of seed engineering measures will be 80% for rainfed areas in North China, and in Northeast China 90% penetration in rainfed areas and 20% in irrigated areas.

Planting measures

Planting measures described in this report consist of mulching covers and conservation tillage. We estimate that these two measures can avert 12% of total drought loss by 2030, of which mulching covers account for RMB 1.4 billion and conservation tillage for RMB 700 million.

Mulching covers involve mulching plastic film over soil to prevent vaporization and maintain a constant temperature. This can achieve water savings of ~25% over conventional irrigation. Conservation tillage includes no-till, reduced tillage and stubble mulching, and involves establishing crops in the previous crop’s residues, which helps soil and water conservation, maintaining soil humidity and increasing soil fertility. This measure can achieve water savings of 15-25% over conventional irrigation.

Mulching covers and conservation tillage can be applied to both grain crops and cash crops. This report assumes the two measures are mutually exclusive, with respective penetration of 40%. It should be noted that mulching covers may cause pollution issues as incomplete films could pollute the soil. Therefore, there could be a long-term affect on agriculture output and the ecological environment. Furthermore, mulching covers are not appropriate for dry sand lands, barren lands, and heavy clay soils due to high temperature, inconvenient fertilizing and difficulty to apply mulching. Similarly, conservation tillage is affected by weeds and pests, which affect output.

Engineering measures

The engineering measures described in this report include reservoirs/dam ponds and micro-water storage systems. The measures are estimated to avert 4% of total drought loss by 2030. The loss aversion and cost benefit ratio is RMB 500 million and 3.7 for reservoirs/dam ponds and RMB 100 million and 2.7 for micro-water storage.

Reservoirs/dam ponds refer to reserving water with reservoirs and use of dam ponds for irrigation during the drought season. Micro-water storage, mainly applied to mountainous and hilly areas, involves reserving water with small rain collection facilities. Reservoirs and dam ponds are only applicable to Northeast China, as the reservoir density in North China has almost reached saturation. By 2030, the measure will expand irrigated areas in Northeast China by 15% and increase the irrigation rate from the current 28% to 32%. Micro-water storage is only applicable in the hilly and mountainous rainfed areas in North China. We assume that by 2030, the measure will reach 10% penetration in rainfed areas in North China[15].

In addition to averting drought loss, these measures would also have positive environmental and social benefits for the regions. The high irrigation ratio of North China is achieved at the expense of over-usage of underground water. It is estimated that Hebei province alone has over-extracted 50 bn tons of water since 1975. This could lead to short- and long-term environmental issues, including deteriorating quality of under-ground water, ground vegetation degradation, and accelerating desertification. The use of these adaptation measures could help to ease this ecological pressure.

Loss reduction potential beyond cost curve

The 9 measures have the potential to avert ~50% of drought loss per year by 2030; the remaining 50% is residual loss. We see three opportunities beyond what is covered in the cost-curve analysis to avert further residual loss. Firstly, we could expand or deepen selective cost-curve actions or improve their expected effectiveness to fight drought, such as irrigation and seed measures, though the feasibility is uncertain. Secondly, some adaptation efforts such as crop restructuring could contribute to loss reduction, although these are excluded from the cost-curve measures due to uncertainty and challenges in quantification. Thirdly, agricultural insurance intervention could be an effective lever to transfer losses from extreme drought events. (Further details on insurance are provided in section “Risk-transfer measure: Insurance”, p32.)

First, seed engineering and irrigation measures hold further potential for loss reduction. Under our assumption, the two measures together have the potential to reduce residual drought loss from 50% to 40% in 2030. However, high uncertainty

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[15] Hilly areas account for 70% of total rain-fed areas of North China, where only a small portion is suitable for rain collection with the right topography

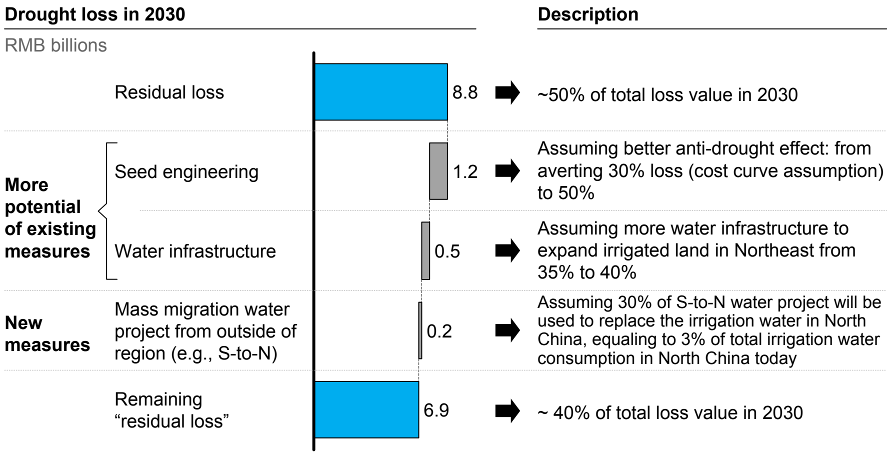
exists in terms of feasibility. Specifically, if a technology breakthrough in seed engineering is made which enables seeds to double their drought-tolerance characteristics, a further ~7% of total drought loss could be averted. If we assume expanding the irrigation rate in Northeast China by 5% of the sown area, it could further avert an additional 2-3% of overall drought loss. And if we could use 30% of the water transferred from the South-North water transfer project for agriculture and irrigation in North China, we can avert yet another ~1% of total drought loss. [Exhibit 9]

In addition to these, other measures could also be important to avert further loss but are highly uncertain or very difficult to quantify, therefore we did not plot them on the cost-curve. This, however, does not mean their loss aversion potential should be neglected. For example, genetically modified (GM) seeds capable of increasing drought tolerance are a viable option technologically. Recent research advances suggest great potential for GM seeds. But there is a large degree of uncertainty around whether or when GM seeds will be commercialized in China.

Crop structure change is another example. This measure helps achieve an optimal match between water resources and the water demands of crops by planting crops more fitting to the natural environment. It has proved highly effective in Beijing, where phasing out rice production has significantly reduced water usage. In 2000, the Beijing government introduced crop restructuring in response to high water consumption due to the low water price and wasteful water practices, such as flood irrigation. As a result, water usage in agriculture which historically accounted for 50% of the overall water usage shrank to only 25-30%. Our cost-curve analysis did not include such measures due to difficulties in accurately quantifying the effects.

Other measures include artificial precipitation, ecosystem improvement, and the establishment of drought prediction and analysis systems.

Exhibit 9: Other measures could further reduce the "residual loss" within a limited range and high uncertainty



	Drought loss in 2030 RMB billions		Description
	Residual loss	8.8	~50% of total loss value in 2030
More potential of existing measures	Seed engineering	1.2	Assuming better anti-drought effect: from averting 30% loss (cost curve assumption) to 50%
	Water infrastructure	0.5	Assuming more water infrastructure to expand irrigated land in Northeast from 35% to 40%
New measures	Mass migration water project from outside of region (e.g., S-to-N)	0.2	Assuming 30% of S-to-N water project will be used to replace the irrigation water in North China, equaling to 3% of total irrigation water consumption in North China today
	Remaining "residual loss"	6.9	~ 40% of total loss value in 2030

Other measures, such as GMO seeds, crop structure optimization, eco-system optimization, and cloud seeding, could further avert the remaining residual loss to certain extent. However, it is very challenging to quantify their impact due to uncertainty of the impact of the measures and low data availability

SOURCE: Team analysis

Risk-transfer measure: Insurance

The main methods for dealing with risk are mitigation and risk transfer. The measures analyzed above are means to mitigate the risks of drought. But when faced with extreme drought conditions, simply relying on mitigation measures is not enough. Risk transfer levers, such as agriculture insurance, can play a pivotal role here.

Insurance could benefit farmers from the protection afforded against loss of income, and the ability to quickly rebuild their livelihoods in the event of a disaster wiping out crops and livestock. It also helps reduce the financial burden on society and prevents overstretching the government budget in disaster relief. Furthermore, while WTO provisions do not allow government to subsidise farmers, they do allow for government to subsidise agriculture insurance, and many countries consider it an effective tool to support and protect local agriculture development.

Our results suggest that under the Moderate Climate Change scenario, at a starting compensation rate of 30%, by 2030, agriculture insurance could cover losses of ~700 mn in North China and ~1 bn in Northeast China per annum[16], which accounts for ~10% of total annual losses on average. Insurance is even more important during extreme cases – drought loss could reach 64 bn RMB in Northeast China and 13 bn RMB in North China and over 70% of the land will suffer from over 30% yield loss.

The Chinese government has strongly promoted agriculture insurance in recent years. In 2007-08, following the introduction of government subsidies, China's agriculture insurance market grew exponentially to reach ~11 bn RMB. China is now the world's second-largest market, after the U.S., and with a current penetration rate of 25% vs 75% in the U.S., there is still room to grow – both geographically and in value per policyholder. The next chapter provides more details on this.

Both risk mitigation and transfer methods are needed to best address the threat of drought, and the two measures are complementary and mutually reinforcing. On the one hand, mitigation efforts can reduce expected drought loss (e.g., by using water-saving irrigation), and therefore lower insurance premiums, meaning insurance could be more broadly adopted. On the other hand, risk transfer can diversify the severe loss in the event of extreme drought, and allow decision makers to adopt more efficient measures without having to worry about extreme situations, thereby reducing the cost. For instance, it is rarely financially viable to construct an irrigation system that would suffice in extreme drought. The more efficient solution is to design for regular drought, and transfer the risk of more extreme drought to an insurer. As decision makers look across the breadth of adaptation measures to address a potential natural disaster, it is vital to find the right balance between risk mitigation and risk transfer measures, in order to create a comprehensive program that has maximum effectiveness and efficiency.

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[16] We assume only >30% loss could be claimed and averted loss = claim amount = amount insured x loss ratio x (1- deductable rate) with a deductable rate of 30%

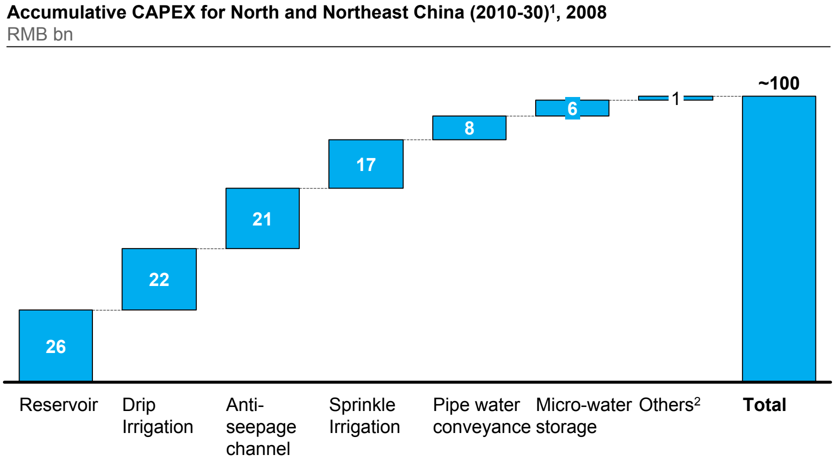
Investment required

China currently has invested an equivalent of 3% of its agriculture GDP in irrigation, which is within the range of investment levels for developed and developing countries (e.g. 2.5% for Australia and 3.7% for India). However, as the risk posed by water shortage and drought is likely to increase in the future, more aggressive actions will be required, along with the allocation of more resources for adaptation.

The 9 adaptation measures require a total capital investment of 100 bn RMB between 2010-2030 in North and Northeast China. If extrapolated to the whole of China using agricultural GDP, the measures would require an accumulative CAPEX of 500 bn RMB in 2010-2030; that is ~25 bn RMB per year on average. Of the four sets of risk-mitigation measures, water-saving irrigation requires the greatest investment, at a total of 16 bn RMB. Given that China has invested ~10 bn RMB per year on water-saving irrigation over the past 10 years, this means an additional investment of 60%. Although this is a sizable investment, it is not unattainable, especially considering the positive returns on most of these adaptation measures.

If we assume farmers and enterprises pay for irrigation systems in the field and the planting measures, while the government supports the infrastructure of water supply, the government would be responsible for ~60% CAPEX, with the remaining 40% shared by farmers and enterprises. This also aligns with the historical investment proportion. [Exhibit 10]

Exhibit 10: A total of ~RMB 100 bn capital investment will be required to avert drought loss during 2010-30 in North and Northeast China



1 Upfront investment of seed companies is not included in the calculation
2 Includes seed engineering, mulching and soil conservation techniques

SOURCE: Team analysis

* * *

In summary, the four sets of risk-mitigation measures are mostly cost-effective and hold the potential to avert ~9 bn RMB expected drought losses in North and Northeast China in 2030 at a total annual investment of ~5 bn RMB. The potential to avert further residual loss would be dependent upon certain conditions, such as technology breakthroughs. Meanwhile, regardless of the mitigation measures put in place, extreme weather events are both destructive and unpredictable, we therefore see agricultural insurance as an important risk-transfer measure.

Whether the full benefit of these adaptation measures can be realized is highly dependent upon the efforts of government, private sector, and individual farmers. Since all the measures are technologically ready and most of them are economically viable in the long-term, why are they not fully embraced currently? What are the factors inhibiting their adoption? And how can they be overcome? We will discuss these implementation issues in the next chapter.

Implementation challenges and actions to overcome them

Introduction

The Government has invested vast resources in response to the recent occurrence of drought, however the potential impact of climate change could make the long-term plan more challenging. While the potential of the 9 countermeasures to avert drought loss is clear, unlocking that potential will require concerted actions by the public and private sector in order to overcome implementation in the areas of financial support, capability gap, and regulatory environment.

Firstly, in terms of financial support, while return on investment is positive and overall investment is only ~25bn RMB per year, the initial investment required is beyond the reach of individual farmers, whose per capita net income is only ~4,000 RMB. Furthermore, due to their low incomes and uncertain yields/ crop prices, farmers are unlikely to risk entering into purchase agreements with extended payback times. (The average payback time of the measures is 3-5 years.)

Secondly, there is a capability gap to overcome which has emerged due to the small scale, highly fragmented structure of farming in China. Unlike farms in the U.S., which are business oriented and span hundreds of hectares, farms in China are mostly smallholdings worked by peasants using traditional farming methods. This creates challenges in educating farmers in current methods and providing a support system (e.g. training and on-time solutions).

Thirdly, while the government has launched a series of actions to protect farmers' interests, such as launching an agriculture insurance pilot program at the provincial level, there is room for a more systematic approach, such as incentive systems and regulatory support for local government and private players to form a coordinated action to improve productivity and capability along the value chain.

In the following section we describe how these overarching challenges specifically impact water-saving irrigation, seed engineering and insurance. We highlight these measures due to their potential to avert significant loss, the wide scope they offer for closer public-private collaboration, and the importance of risk transfer.

Water-saving irrigation implementation challenges

The adoption of drip and sprinkle irrigation has grown at only 4% annually in recent years to reach a current penetration of 5% of the total irrigated area, compared to 55% in the U.S., and ~100% in Israel. However, the Chinese government plans to almost quadruple the penetration of drip and sprinkle irrigation, resulting in 8.4 million hectares in 2020.

Given the currently low penetration rate, a significant opportunity exists for the private sector to shape the market, and with government support, overcome three key challenges to implementation:

Limited knowledge of water conservancy: Due to a generally low level of knowledge on the importance of conserving water, and a pricing system that does not reflect the economic benefits of conserving water, there is a tendency to treat water as a limitless commodity.

Low willingness of farmers to invest: The upfront investment for both drip and sprinkle irrigation is high and the payback period is often longer than 3 years. Chinese farmers tend to be risk-averse and are unlikely to invest up to 60% of their annual agriculture income for sprinkle irrigation equipment. Furthermore, few financial institutions provide effective financial support to farmers for investment, and the small farm size may also fail to meet the optimal scale for the technology to achieve the desired results, thus making the investment even less attractive.

Lack of comprehensive service systems, such as after-sales maintenance service, irrigation products designed according to specific farmland conditions, and extension programs (such as training provided for farmers and local officials). This also increases the investment risk to famers if timely and economical maintenance of equipment cannot be provided.

Potential options to overcome implementation challenges

Since 1995, the government has launched numerous water-saving demonstration projects, completing the construction of 300 water-saving key counties and 18 key cities; however, the current low penetration rate indicates the tremendous scope for more efforts in this area. While the transportation technologies, anti-seepage furrow and pipe, are mostly supported by the government close collaboration between the public and private sector will be key to achieving wider penetration of drip and sprinkle irrigation. Private players (both local and MNCs) could take the lead in developing investment and service solutions, with appropriate government policy and infrastructure support.

We see a number of potential options, mainly around financial support and education, which could be considered as part of an effort to encourage greater adoption of irrigation measures. These options are laid out below in terms of those for government and those for private players, though with the emphasis on collaboration to jointly overcome the challenges.

Potential options for government

The importance of education cannot be over-emphasized to achieve a water-saving mindset. A national level campaign to raise awareness of the importance of water-conservancy is one option for the government to prioritize, which could cascade into strengthening education on the importance of water saving through a concerted effort involving government, schools, research institutions, private sector and NGOs.

In addition to education, financial support is a major factor. Already, government has listed certain types of spray irrigation machineries in its subsidized agricultural machinery list. Some local governments, such as Xinjiang, also provide subsidies for the use of drip irrigation (RMB 100/Mu). This has proven to be effective in encouraging adoption. Besides subsidies, government could also leverage financial institutions to develop more effective lending systems in rural areas to support farmer's investment.

To further promote the technologies, China could leverage available channels, including the national system of agriculture technology promotion, as well as consider setting up more demonstration centers for farmers. This would require devoting more resources to the promotion system, as China currently spends 0.42% of agricultural GDP on agriculture technology promotion, compared to 0.6%-1.0% of developed countries and 0.5% of developing countries.

Potential options for private sector

Since cost is a huge restricting factor for farmers in China, we see two possible opportunities for the private sector to enhance the affordability of irrigation technology. The first concerns reducing costs through innovating in product design and sourcing to meet specific local needs (e.g. farm structure, land and crop type). For example, Xinjiang Tianye, China's leading drip irrigation manufacturer set up a national level research center to localize products and production, achieving over 50% cost advantage against other drip-irrigation players.

Secondly, there could be an opportunity to reduce the burden of the initial investment for farmers by cooperating with financial institutions to help farmers finance the equipment. For example, in December 2008 People's Bank of China encouraged financial institutions to promote microcredit loans and joint guarantee loans in rural areas, with water-saving irrigation explicitly listed. This opens the door for closer partnership between equipment players and financial institutions and a more developed cooperation mechanism could be an important solution space to further promote the penetration of water-saving irrigation.

Besides cost, developing comprehensive service programs would be essential to secure and optimize the utilization of equipment by farmers. The service system would include both maintenance service, as well as tailored local extension programs and demonstration centers. Some private players have already started to develop their service network as their competitive edge. For example, Huayu, a leading Chinese sprinkle irrigation manufacturer, became known for its high quality after-sales service and entered the large-scale sprinkle irrigation market previously dominated by MNCs. For extension programs, private players could consider leveraging existing extension channels established by local government.

Seed engineering implementation challenges

Both the seed market and market share of drought-tolerant seeds have grown significantly in recent years and the trend looks set to continue. The 50 bn RMB seed market has grown at around 9% to become the world's second-largest, after the U.S. Experts expect the market to ultimately reach RMB 80-100 billion. The major driver is the increasing portion of commercially traded seeds (currently

40% in China, compared to the word average of 70% indicating the potential for growth).

Drought tolerance is just one of several characteristics of engineered seeds, making it difficult to measure quantitatively as a specific segment. Nevertheless, the market share is expected to expand more rapidly due to 1) adoption of anti-drought seeds beyond rainfed areas and into irrigated areas due to water-shortages; and 2) the potential for technology breakthroughs to create new breeds capable of significantly reducing loss. For example, a recently developed rice hybrid has shown a 60% higher yield than traditional rice during drought. This kind of technology breakthrough reflects China's role as the world leader in seed engineering of its important staple foods, including rice and wheat, through strong public-sector led work.

The Chinese seed industry is undergoing major changes following the dismantling of the state monopoly of seed production following the enactment of the Seed Law of 2000, which was modified in 2004. Historically, the seed companies are segmented both functionally along the value chain and geographically. Functionally, only publically funded research institutes, rather than seed companies, have R&D capability. Seed companies only play a marketing and distribution role. Moreover, each county has its own seed companies. The Seed Law aims to break the geographic and functional segregation and nurture a more market-driven seed industry in China. In addition, under Chinese government market entry requirements, international players need to form joint ventures with local players.

The changing nature of the market is compounded by its highly fragmented state–the biggest players each hold only ~5% market share–creating several challenges along the value chain, including:

Intellectual property right (IPR) protection: IPR has long been an issue in China and piracy is common. Currently, when a research institute releases a successful seed they can charge a high premium, but without IPR there is the risk of infringement from competitors. This leads to a failure of effective transition of R&D results from government-funded research institutes to the private sector; it also hinders private players from investing in R&D since they doubt they will see a return on the investment.

Lack of strong R&D capability among local players: Prior to the enactment of the Seed Law of 2000, Chinese seed companies did not have R&D capability. Furthermore, initial R&D investment is huge and can take more than 5 years with uncertain results, thus local companies may be hesitant to invest, resulting in low R&D capability which affects the long-term performance of companies. Even aggressive leading players only invest ~5% of revenue to R&D, compared to 10% invested by international players. The situation is compounded by the lack of adequate IPR protection to secure the return on investment in R&D, as described above.

Low capability in branding and management, specifically among local companies.

Lengthy approval process of 3-5 years for national level commercialization is excessive compared to the lifetime of the technology. The approval or registration process is around half this in countries such as the U.S.

Potential options to overcome implementation challenges

Given that China's seed market is still transitioning from government-owned to market-driven, there is an inevitable learning curve for both public and private players. Developing a stringent IPR protection system and strengthening the R&D capability of private players would be the key success factors for this field. Since the nature of the seed industry involves heavy investment in R&D a robust IPR protection system to secure the return on the investment is a precondition.

Potential options for government

Potential options for government to consider to drive the uptake of drought-resistant seeds lie in enhancing the regulatory environment for IPR, and in encouraging collaboration between public and private sector to enhance the R&D capability of the whole industry.

International companies hesitate to enter China primarily due to intellectual property concerns. Meanwhile, lack of IPR protection undermines the margins of local seed companies and thus their R&D capability. One step to demonstrate that China is serious about protecting IPR would be to develop a strict IPR protection system with clear penalties for seed companies and distributors breaching the regulation.

To enhance R&D capabilities, we see the potential to encourage collaboration between public research institutes and seed companies, local companies and global companies, to achieve synergies in R&D. Though China has invested ~450 mn RMB per year in recent years[17], this investment could be more effective if private players could build on the research achievements and market them to farmers.

Furthermore, the current approval process for new seeds is ~5 years, which is at least double that of other countries such as the U.S. While realizing the importance of a thorough approval process to ensure the safety of its citizens, streamlining the approval process for new seeds would shorten the time to market, and the payback period for investment of seed companies.

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[17] Investment from "Seed Project" 11th 5-year plan by the Ministry of Agriculture and NDRC

Potential options for private sector

China's seed market presents opportunities for both local players and MNCs in terms of R&D, and alliance building. Both local and global players could take a longer view of investing in R&D to enhance their capabilities by working closely with research institutions or through backwards integration.

There is a tremendous opportunity for local and global players to benefit from each other's mutual strengths through strategic alliances to improve local knowledge, and strengthen capability in marketing and management. For example, Denghai, a local leading player in corn seed, formed a joint venture with Pioneer in 2002 to produce a highly successful breed, which became one of the best-selling seeds in the market. The success was not only due to high product quality, but also understanding of farmers' needs, and an excellent marketing strategy.

Furthermore, leading companies could continue their efforts in market consolidation to increase the economies of scale in terms of R&D, production and distribution.

Genetically modified (GM) seed technology could further improve the performance of drought-tolerant seeds, however public acceptance remains uncertain.

Preliminary results indicate GM seeds hold greater potential to increase yields, compared to other seeds in drought conditions. The early generation of drought-tolerant corn is estimated to prevent ~50% yield loss under water-restricted conditions. There is currently no GM seed in food crops on the market, but seed giants are working towards introduction. Monsanto, for example, hopes to have its first transgenic drought-tolerant corn seed on the market by 2012.

Previously, research institutes in China were focused on the first generation of GM crops, whose major feature is resistance to disease, insects and herbicides. However, China has started to work on developing a second-generation of GM crops with anti-drought capability in wheat and corn.

While there is debate concerning the longer-term consequences of introducing GM crops, there are indications that China is gradually moving in that direction. The Chinese Premier, Wen Jiabao, gave a resounding indication that GM crops could play a key role in achieving food security in 2008, saying: "To solve the food problem, we have to rely on key science and technology measures, including biotechnology and GM technology."

Furthermore, in July 2008, The State Council approved a RMB 24 billion budget for research of GM crops with the goal of developing high-quality, high-yield and high-resistance new species for rice, wheat, corn, cotton and soybean. This would further boost the R&D activities in agricultural biotechnology, which 2000 scientists in 200 government-sponsored labs have already been working on.

Agriculture insurance implementation challenges

As mentioned in the previous chapter, regardless of the risk mitigation measures put in place, unpredictable extreme events bring the risk of severe income loss. We therefore see agriculture insurance as an important risk-transfer mechanism to reduce the impact on both government and individuals.

The agriculture insurance market has grown rapidly in the past 2 years, reaching ~11bn RMB in 2008, thanks to a strong government push in the form of subsidies and pilot programs. To build on this success and extend the protection afforded by agriculture insurance to those who most need it would require attention to the following areas:

Limited availability of reliable data in China to assess the risks and set price in a scientific way.

Shortage of clear regulations on agriculture insurance: though under discussion for some time, an agriculture insurance law has yet to be enacted. In addition, coordination between various government departments, central and local. government could be enhanced.

Low demand from farmers due to low awareness and purchasing power.

Lack of a risk diverse mechanism for insurance companies to properly transfer their own risks, resulting in a high premium they charge for farmers.

High operating costs for insurance companies in underwriting or loss evaluation and distributing the products, given the fragmented farm structure in China.

Potential options to overcome implementation challenges

More than half of the agriculture insurance premiums are from government subsidies in China, underscoring the important role of government. Globally, agriculture insurance is heavily dependent on government support. However, to develop a sustainable business model, the government will in the long term need to leverage more private players. Below are some potential options for the government to continue driving the growth of agriculture insurance together with industry players.

Potential options for government

As well as continuing and possibly extending its subsidies to farmers, potential next steps for government lie in the area of data collection and developing the required infrastructure and system. The industry would benefit from a data collecting system which ensures data quality and quantity, as well as a means to share the data with research institutes and the private sector to better price risk and innovate product design. A scientific risk-assessment system is essential to provide confidence to private players in this field.

As agriculture insurance is a new field involving a high degree of complexity, the clear answer is not yet obvious. Therefore, innovating and experimenting with various products that adapt to different regional conditions before aggressive penetration could help toward developing an optimal solution. Government could consider providing financial incentives or policy support for insurance companies to innovate product design, e.g. climate index based insurance, crop specific insurance. In addition, government could set up a disaster reserve or national risk diversification mechanism to strengthen the resilience of the insurance system under extreme events.

Finally, government could consider ways to accelerate the legislation process by creating a sound regulatory framework to define the roles of government and private sector in agriculture insurance and set the game rules.

Potential options for private sector

The agriculture market could present a tremendous opportunity for insurance companies, given the potential future growth: current penetration rate of agricultural insurance is only 25% of sown area, versus 75% in the U.S. Securing rural incomes is high on the government's agenda and could further drive growth, especially in vulnerable regions, such as Northeast China. To capture this opportunity, insurance companies could develop innovative products to expand insurance coverage, such as innovating product design to meet the local needs and save operating costs. For example, India developed weather index insurance and successfully promoted it to the whole country. The weather index can save the costs of loss measurement and accelerate the claim payment process.

In addition, companies could expand their reach by leveraging rural financial institutions and the national system of agriculture technology promotion to help distribute products. Companies could also initiate working together with the government to build the much-needed risk-diversification mechanism together.

Land reform

Major policies relating to rural areas could influence the pace of adoption of the measures. In October 2008, China enacted a landmark rural land-use reform policy under which farmers will be granted official land-use right certificates and the right to lease their contracted farmland to other parties for the first time. This will likely encourage the consolidation of farms into bigger plots. The land transfer rate could be between 40% and 60% by 2025[18], resulting in average plot size doubling from 0.63 hectare to ~1.2 assuming a 50% land transfer rate. Increased plot sizes would increase the effectiveness of investing in machinery and irrigation and thus provide farmers with incentives to invest. It may also make farmers more willing to buy insurance to cover their larger and higher-valued land to transfer their investment risk. Equipment providers and insurance companies could therefore focus on a smaller number of customers (owning larger plots) and thus improve their service support and lower per-unit operation costs.

* * *

As is typical for any feat worth achieving, considerable collaboration will be required between major players and the government. The key action for government would be establishing an all-encompassing regulatory framework with clear policies and incentives in place to ease implementation. Companies must also play a role, not only in developing their goods and services, but also in contributing their know-how and expertise to ensure strong foundations are built along the entire value chain, and then the whole industry will benefit.

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[18] Assuming that average transfer rates could range from as high as 60 percent, such as in the pilot village of Xiaogang in Anhui province, to as low as 40 percent, such as the Wenjiang area of Chengdu city

Appendix: Methodology

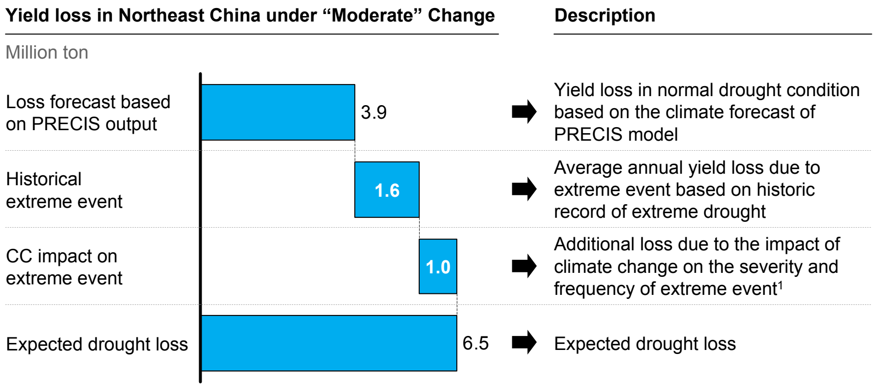
Overview of the methodology on drought loss

Our analysis aims to estimate the drought loss of agriculture in Northeast and North China in 2030 and how climate change would impact the drought loss. In order to achieve this, we have analyzed 3 different scenarios: Today's Climate, Moderate Climate Change, and High Climate Change

- **"Today's Climate"** is a scenario assuming the climate in 2030 would remain the same as historical climate conditions. We used 1961-90 climate conditions as inputs.
- **"Moderate Climate Change"** is a scenario of average value of the forecast assuming a medium-high CO2 concentration scenario. We use the average value of the forecast from PRECIS model under the IPCC A2 scenario, in which CO2 concentration reaches 560 ppm in 2040s. In addition, we assume a 50% increase of the severity and frequency of extreme drought[19].
- **"High Climate Change"** is a scenario under the same CO2 scenario as "Moderate Climate Change" but uses the average of 90th percentile forecast of the PRECIS model. In addition, we assume 100% increase of the severity and frequency of extreme drought.

The expected drought loss includes two parts, normal drought and extreme drought event. To estimate the loss of normal drought, we built a model with the input of climate data from the PRECIS model; to estimate the loss of extreme drought, we use historic records of extreme events as the baseline, and make different assumptions on the impact of climate change under different scenarios. [Exhibit 11]

Exhibit 11: Overall methodology to calculate expected drought losse the "residual loss" within a limited range and high uncertainty



Yield loss in normal drought condition based on the climate forecast of PRECIS model

Average annual yield loss due to extreme event based on historic record of extreme drought

Additional loss due to the impact of climate change on the severity and frequency of extreme event[1]

Expected drought loss

1 Applies only to 1-in-50-year event

SOURCE: PRECIS model; CEIC; Team analysis

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[19] Extreme drought is defined as 1-out-of-50-year event

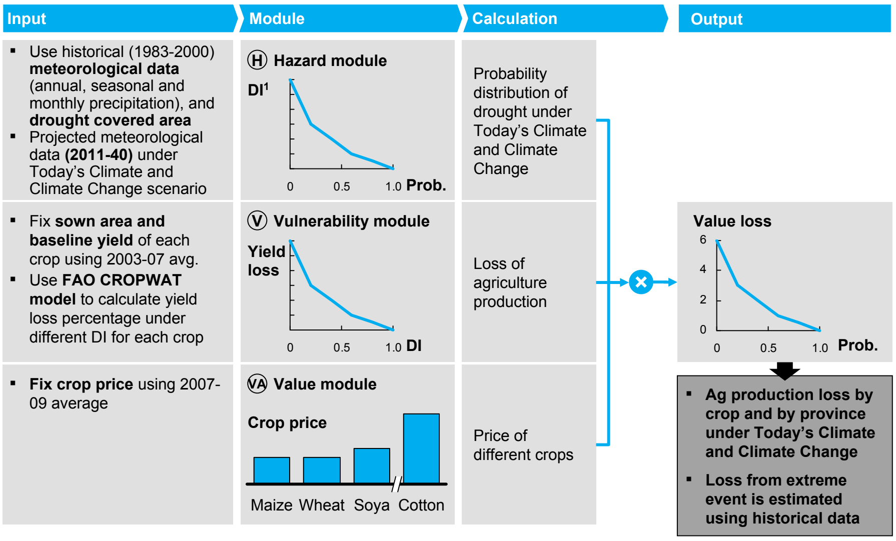
Methodology to estimate the loss of normal drought

To estimate the normal drought loss, we have built a model that is composed of 3 modules:

- **Hazard module** examines the probability and severity of drought based on historical and future meteorological data
- **Vulnerability module** examines the relationship between crop yield loss and drought severity
- **Value module** includes the crop price

By multiplying the three modules, we derive the total value loss. All modules and calculations are by crop, by province and by scenario. Calculating the loss from all provinces and crops generates total drought loss of North and Northeast China. [Exhibit 12]

Exhibit 12: Methodology of calculating agriculture drought loss under Today's Climate and Climate Change scenarios



Input

- Use historical (1983-2000) **meteorological data** (annual, seasonal and monthly precipitation), and **drought covered area**
- Projected meteorological data **(2011-40)** under Today's Climate and Climate Change scenario

- Fix **sown area and baseline yield** of each crop using 2003-07 avg.
- Use **FAO CROPWAT model** to calculate yield loss percentage under different DI for each crop

- **Fix crop price** using 2007-09 average

Module

Ⓗ **Hazard module**

Ⓥ **Vulnerability module**

VA **Value module**

Calculation

Probability distribution of drought under Today's Climate and Climate Change

Loss of agriculture production

Price of different crops

Output

Value loss

- **Ag production loss by crop and by province under Today's Climate and Climate Change**
- **Loss from extreme event is estimated using historical data**

1 Drought indicator, which could be a function of annual/seasonal precipitation, or other meteorological parameters

SOURCE: Team analysis

Hazard Module

The purpose of hazard module is to establish a relationship between the severity of drought and certain meteorological parameter.

To achieve this, we have conducted linear regression to correlate meteorological data (including yearly, seasonal and monthly precipitation) with drought covered area based on historical data (1983-2007). As a result, we find that precipitation of critical season is best correlated to drought covered area, and thus could be a good drought indicator (DI). Although the correlation analysis was conducted at provincial level, it shows a regional pattern. [Exhibit 13]

Exhibit 13: Regression analysis of historical drought area shows that spring or summer precipitation could be defined as drought indicator

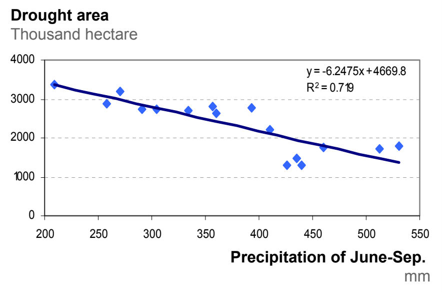
Methodology – Regression analysis using historical data

- Conduct **regression analysis** on drought covered area over monthly, seasonal, and annual precipitation at provincial level (1983-2000 data)
- Select precipitation that demonstrates significant correlation with drought area as **Drought Indicator (DI)**

Spring or Summer precipitation could be the indicator of drought

- **North China** could use Summer precipitation (June to September) as DI
- **Northeast China** could use Spring precipitation (April to June) as DI

Hebei[1] example



1 Including Tianjin and Beijing

SOURCE: CEIC; Team analysis

- **DI in North China** is defined as **Summer precipitation** (June to September)
- **DI in Northeast China** is defined as **Spring precipitation** (April to June)

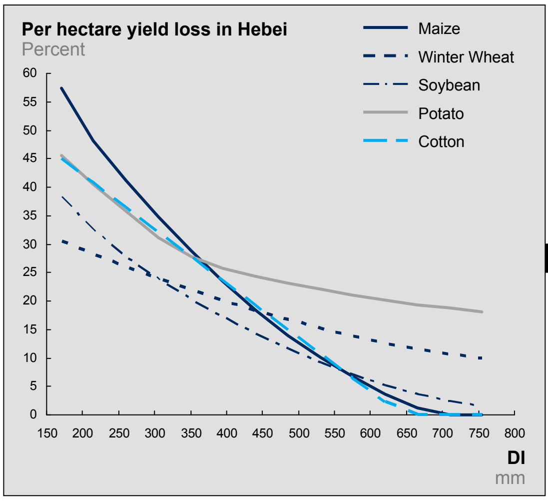
With the input of the emission scenarios (Today's Climate and Moderate Climate Change), the PRECIS model simulates meteorological conditions from 2010 to 2040. We use these data to calculate DI for each province from 2010 to 2040. We also assume that the 2010-40 data reflects the climate condition of 2030, and thus get 30 data points to generate a probability curve of DI in 2030.

Meanwhile, previous correlation analysis has generated a linear relationship between drought covered area and DI. Therefore, the probability curve of drought covered area can be generated at provincial level as well. In order to breakdown the drought covered area by crop, we assumed that drought covered area will be distributed proportionally to the distribution of sown area for all the crops that suffer loss.

Vulnerability Module

Now that we have recognized precipitation in critical season as the drought indicator, we use FAO CROPWAT model to generate the yield loss percentage under different precipitation conditions. By fixing other factors (including soil type, precipitation of other months and evapotranspiration) and inputting a series of DI, a curve of yield loss % over DI is generated to estimate the vulnerability of each crop. [Exhibit 14]

Exhibit 14: Yield loss is generated from FAO's CROPWAT model by establishing the relationship between yield loss percentage and DI



Input of CROPWAT model

- **Soil**: using soil type "medium" in CROPWAT
- **Crops**: using CROPWAT model
- **Rainfall**: testing a group of DIs to cover the range where 2011-40 data stands; Fix the precipitation of other months using 2011-40 avg.
- **ET0**[1]: using average meteorological data from PRECIS model, and calculate using the formula[2]

$$ETp = \left[6.1/10^6 \times Rs \times \left((1.8 \times Ta) + 1.0\right)\right]$$

The yield loss curve is generated by inputting a series of DI value

[1] Potential evapotranspiration
[2] The formula is based on the empirical equation of the solar thermal unit concept (Caprio, 1974)

SOURCE: CROPWAT model; Swiss Federal Research Institute; Expert interview; Team analysis

Since the pattern and amount of irrigation is highly specific to quite small areas and varies by crop type, we have not considered any irrigation in the CROPWAT model. We assume that yield loss percentage per hectare is the same for irrigated areas and rainfed areas when affected by drought. Consequently, no loss from rice will be observed in this model, as most rice is irrigated in China.

The baseline yield for each crop is generated from 2003~07 historic data and the yield growth until 2030. The yield growth is estimated based on the National Mid-to-long-term Plan on Food Security.

Total yield loss for each crop is calculated as the product of yield loss percentage, the baseline yield, and drought covered area from the hazard module. Same as the data of drought covered area, total yield loss will also be a probability curve generated from 30 data points.

As Today's Climate scenario is the model output for 1961-90 meteorological condition, we use the historic yield loss percentage during the same period to adjust the model output under Today's Climate scenario, and apply this adjustment to Moderate Climate Change scenarios.

Value Module

Value module provides the price of each crop. The major assumption in this module is that crop price will remain constant until 2030, and we use 2007~09 average price for all crops.

Date Analysis

To estimate normal drought, we use the 30 data points generated from the above 3 modules. We eliminate the outlier points (1 for North and 0 for Northeast) that exceeds historic 1-in-30-year drought.

- For Today's Climate and Moderate Climate Change scenarios, we use all the data points available to generate a probability curve for production loss and value loss. The average of the data points is recognized as the annual drought loss without extreme event.
- For High Climate Change scenario, however, we use the average of the 3 data points with the largest loss (which represent the 10% worst conditions in the forecast) as the annual drought loss without extreme event.

Geographical consolidation

The above process is identical for all the provinces we have covered, incl. Heilongjiang, Jilin, Liaoning in Northeast China, Hebei and Shanxi in North China. Beijing and Tianjin are included in Hebei when collecting raw data, because 1) they are geographically inside Hebei 2) their agriculture output is minor compared to Hebei. To get the consolidated production loss and value loss, we simply sum up the provinces in Northeast China and North China, respectively.

Methodology to estimate the loss of extreme drought

Extreme drought loss is estimated based on historic 1-in-30-year and 1-in-50-year drought, which can be recognized from historic records. We take the largest drought loss in 50 years as 1-in-50-year event, and the 2nd largest as 1-in-30 year event.

As there is no quantitative analysis available to link climate change and the frequency or severity of extreme drought event, we have introduced adjustment for the extreme event.

- For Today's Climate scenario, we use historic yield loss percentage of historic 1-in-30-year and 1-in-50-year drought for 2030.
- For Moderate Climate change scenario, we assume there is 50% increase of both severity and frequency of 1-in-50-year drought. As a result, the yield loss percentage will increase by 125%.
- For High Climate change scenario, we assume there is 100% increase of both severity and frequency of 1-in-50-year drought. As a result, the yield loss percentage will increase by 300%.

Consolidation of normal and extreme drought

Now that the loss under normal and extreme drought is ready, we add up their contribution to the expected annual drought loss based on their probability, respectively. This process is done separately in North China and Northeast China.

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