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China's Agricultural Water Scarcity: Effects on International Markets*

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China's Agricultural Water Scarcity: Effects on International Markets

Water shortages in important grain-producing regions of China may significantly affect China's agricultural production potential and international markets. Falling ground-water tables and disruption of surface-water deliveries to important industrial and agricultural regions have provoked concern that a more dramatic crisis is looming unless effective water conservation policies can be put into place rapidly. While China's water use is unsustainable in some areas, there is substantial capacity to adapt and avert a more serious crisis. Recent changes in water management policies may serve to bring about more effective water conservation. Since China is the world's largest producer and consumer of wheat and cotton, and production of both these crops depends heavily on supplemental irrigation in northern China, the success or failure of these reforms could have significant implications for international markets.

This paper provides an overview of how water scarcity could affect China's agricultural production and trade. The paper identifies the areas where available water resources are most overexploited and the crops most vulnerable to reductions in irrigation. Reviewing the limited work on the impact of water scarcity on agricultural production and trade in China, we comment on the results and the shortcomings of these studies. We present preliminary results from modeling a decline in irrigated land in water scarce areas in China and the effect this would have on China's production and trade. Finally, we describe recent conservation policies and how these may affect crop production in China.

Water Scarcity and Irrigated Agriculture in China

China is moderately endowed with water but water in China is unevenly distributed geographically. With annual per-capita water resources of nearly 2200 m^3, China has roughly one quarter the world average, but well above water scarce endowment levels which tend to range between 1,500-1,700 m^3 per capita for moderate water scarcity (Liu, 1998). China's water, however, is disproportionately distributed in areas south of and including the Chang (Yangtze) River Basin. The productive agricultural areas in northern China have roughly one quarter of the water that the south has. Water shortages are particularly severe in the Hai, Huang (Yellow), and Huai River Basins (World Bank, 2002). Water shortages in the lower reaches of the Huai River Basin can be partly alleviated by a south-north water diversion project in Jiangsu Province that brings water from the Chang (Yangtze) River up into northern Jiangsu.

The Hai River Basin is an area where water shortages are known to be severe. The Hai River Basin roughly adheres to the boundaries of Hebei Province and refers to a number of tributaries that flow into a short sea channel in Tianjin known as the Hai River. Underlying this surface water structure is a complex set of overlapping aquifers, with varying recharge rates. A major reason why water resources in the Hai River Basin are in decline is because it is the site of two metropolises, Beijing and Tianjin, and several smaller cities.[1] These urban areas are drawing down the groundwater table at alarming rates and many have experienced land subsidence as a result. In addition, irrigated area has increased over the last 40 years due to widespread establishment of tubewells powered by electric or diesel pumps. The expansion of irrigation not

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[1] In addition to Beijing (population 13 million) and Tianjin (population 9 million), there are three other cities with populations over 1 million and five with populations between 500,000 and 1 million in the basin.

only has allowed for higher yields, but also allows farmers to double crop, generally winter wheat followed by corn. The area became a major wheat-producing region as irrigated area increased. Extensive irrigation, coupled with urban and industrial demand for water, have drawn down the water tables throughout the basin at increasing rates, exceeding three meters per year in some rural regions in the 1990s (Wang and Huang, 2002). Surface water is also overexploited. Cangzhou, a downstream prefecture in Hebei Province, receives less than 10 percent of the surface water deliveries than it did in the 1970s (Lohmar and Crook, 2002).

Water resources in the Yellow River Basin are also showing signs of overexploitation. The Yellow River meanders from its headwaters on the edge of the Tibeten Plateau in Qinghai Province, turns north through the steppe and desert provinces of Gansu, Ningxia and Inner Mongolia, turns south along the Shaanxi and Shanxi border, then turns east again and towards the ocean through northern Henan and Shandong provinces. Since the early 1970s, water in the Yellow River is often drawn off to such an extent that the river does not flow into the ocean for part of the year. In 1997 and 1998, overexploitation was particularly acute, the river did not reach the ocean for over 220 days in both years, and the dry stretch reached as far as 700 kilometers inland (Liu, 1998; Liu, 1999). When this happens, farmers in the productive downstream provinces of Shandong and Henan, are denied surface water for part of the irrigation season.

It is important to note that losing irrigation does not affect all crops equally. Precipitation on the North China Plain is unevenly distributed throughout the year, with 70 percent of the rainfall arriving in the three-month period from July-September. Single season corn can be grown in this period without supplemental irrigation. Irrigation, however, allows farmers to double crop, usually winter wheat followed by corn, and still realize satisfactory yields. Winter wheat is irrigated roughly 4-5 times, once in the fall after planting, then 3-4 times in the spring when rainfall is low, and is harvested in June. If rainfall is still low after planting corn in late June, and water is available, farmers may irrigate corn to get the seedlings started, but the bulk of corn production occurs during the period with adequate rainfall. Cotton in the North China Plain is usually a single season crop that also relies on supplemental irrigation in the spring, but can withstand a dry spell before the rainy season, when the important flowering period begins. Surface water deliveries are most unreliable during the high irrigation season of May-June.

Implications for Agricultural Production

There are a few published estimates of how water shortages will affect agricultural production in China (Table 1). Modeling approaches vary in these estimates and include a hydro-climatic approach (Heilig et. al., 2000), a hydrological-economic approach with varying water prices (Rosegrant and Cai, 2002), and extrapolation of water use and water efficiency trends (Yang and Zehlner, 2000). In addition, the results vary widely, even within the same study. For example, Heilig et. al. predict that at current level of water use efficiency, China’s grain production will fall short of projected demand in 2025 by 156 mmt, but that with increased efficiency, grain production can exceed projected demand by 22 mmt in that year. Rosegrant and Cai’s results show a more moderate effect. They predict that China will import 47.2 mmt of grain in 2025 as a baseline and this figure rises to 56.7 mmt under a scenario where water prices are tripled.

Under a scenario where water use efficiency increases in addition to the higher water prices, imports fall back to below the baseline, to 46.3 mmt.

While these studies provide insight into how China's agricultural sector may respond to water shortages, there are a number of shortcomings with the analysis. One is they all provide long-term projections of China's agricultural supply and demand. Such long-term projections are difficult to rely upon, indeed, in 1977, no one would have predicted that China would be a net corn exporter in 2002. In addition, these studies generally take China as a whole, but water scarcity is very much a regional phenomenon. Water scarcity affects northern China's wheat, corn and cotton growing regions. In southern China, where nearly all of China's rice is produced, flood control and drainage are the major water related problems, not water scarcity. Indeed, projects to transfer water from the south to the north are one means China is pursuing ot relieve water shortages in the north.

An additional shortcoming in some of these studies is that they aggregate grains together which conceals an important underlying dynamic driven by income growth and urbanization. Rising incomes and urbanization are generating more diversified diets in China, increasing the consumption of livestock products, fruits and vegetables, while decreasing per capita consumption of staple grains such as wheat. Thus, demand for feed grains such as corn is expected to rise dramatically over the next few decades as China's per capita consumption of livestock products approaches that of Taiwan or other wealthier Asian countries. Conversely, consumers in China are eating less staple food grains, such as wheat, as they diversify their diets. Corn, however, is less threatened by unreliable irrigation because it is grown in the rainy season, while wheat relies heavily on supplemental irrigation. In addition, demand for cotton in China is expected to increase as the Multi-Fiber Agreement ends in 2005, but cotton is rarely considered in estimates of water scarcity and agricultural trade.

To address some of these concerns, we estimated the effects of a decrease in irrigated area using the China model that is incorporated in to the USDA Country-Commodity Linker System (CCLS). The CCLS is a partial equilibrium model used to provide the annual USDA Baseline projections. The model solves for international supply and demand for 24 commodities in 42 countries and regions (see appendix 1). This allows us to determine how different crops, and international markets for each crop, are affected by water shortage scenarios. The China model is disaggregated into six regions, and we focus on the northern region which include five agricultural provinces (Hebei, Henan, Shandong, Shanxi) as well as two metropolitan centers (Beijing and Tianjin). This region is where agricultural production is most threatened by water scarcity and is the site of 57 percent, 38 percent and 38 percent of China's wheat, corn and cotton production respectively (NBS, 2002).

Using the ERS China model and CCLS, we estimated three different scenarios of water scarcity.[2] The scenarios are based on assumptions of decreasing irrigation water available for wheat, corn, and cotton production in the three provinces of Hebei, Shandong and Henan. Hebei province nearly matches the watershed of the overexploited Hai River Basin, while Shandong and Henan are large agricultural provinces on the downstream end of the Yellow River Basin where

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[2] The three scenarios are: 1) Hebei loses 10 percent of its irrigated acreage; 2) Hebei loses 20 percent of its irrigated acreage and Shandong loses 10 percent and; 3) Hebei loses 30 percent of its irrigated acreage, Shandong loses 20 percent and Henan loses 10 percent. See Appendix 2 for more details on how we constructed these scenarios.

disruptions in the flow have led to unreliable water deliveries. These scenarios conform to the severity of water shortages in these three large grain-growing provinces are intended to represent a shock to the model, rather than a real fall in irrigated area over a specified period. The fall in irrigated area in these scenarios, however, is not an entirely unrealistic expectation. Researchers and policymakers inside and outside of China argue for substantially reducing irrigated area in the Hai River Basin in order to reverse the rapid fall in the groundwater tables. Over-expoitation of the Yellow River has caused widespread disruption in irrigation water deliveries in Shandong Province in the recent past, and these disruptions were worsening through the 1990s. The total decrease in irrigated area for wheat, corn and cotton under these scenarios are reported in table 2.

The three scenario shocks are incorporated into the model (appendix 2) and results from the scenario runs are compared to the 2003 Baseline projections to determine how water scarcity may impact agricultural production and trade. The model produces 10-year projections of supply and demand for the included commodities. Because we are interested in how the scenario shocks cause farmers to move out of crops that rely on irrigation and how these changes affect production generally, we average the changes over the 2003-2007 marketing years. This is similar to how other scenario experiments with the CCLS model are reported (Lohmar, Hansen, Seeley and Hsu, 2002).

Our results indicate that water shortages have a significant affect on the production of these important commodities, but that the affect on trade will be significantly influenced by trade liberalization policies. As predicted, wheat is the most affected crop, with production falling 7.75 mmt (7.5 percent) under scenario 3, the most severe water shortage scenario (Table 3). This compares to a decrease of 4 percent and 1.2 percent for cotton and corn respectively under scenario 3.

Imports, however, do not respond to the fall in production as would be expected if there were perfect integration between international markets and China's domestic markets. For example, for wheat, net imports rise by 2.2 mmt under scenario 3, far short of the 7.8 mmt fall in production. Instead, consumers absorb most of the shock, reducing consumption by 5.6 mmt under scenario 3. This pattern is true for corn as well, where consumption falls by 1.1 mmt and net imports rise by only 0.5 mmt to accommodate a 1.6 mmt production shortfall under scenario 3. Cotton, however, is more responsive to international markets, with imports rising by 134 tmt as production falls by 194 tmt under scenario 3. In addition to a fall in consumption, the stocks for these three commodities are also drawn down in response to the higher prices that stem from the production shortfall.

China's poor price transmission can be seen in how domestic prices respond compared to international prices. Focusing again on scenario 3, domestic prices rise dramatically for wheat and cotton (but not so much for corn – table 4). For wheat, domestic farm prices rise by 18 percent and consumer prices rise by over 16 percent. But the international price for wheat only rises by roughly one percent. Thus, under these scenarios, consumers reduce their consumption more and production decreases less than if the price increases were dampened by increasing imports. The story is similar for cotton, where consumer and producer prices increase by almost 7 percent, but international prices rise only 1.3 percent. If China was more integrated into international agricultural markets, then domestic prices would not rise so dramatically, and this could lead to imports larger than the falls in production that result form these scenarios. This is because, under the poor price transmission, farmers outside the water scarce areas increase production of the water sensitive crops as the prices rise, an effect that would be dampened by imports under a more liberal trade regime.

The Role of Water Policy Reform

China has responded to the threat of severe water shortages by promoting water conservation at all levels of water management and the success or failure of these efforts will have significant implications for agricultural production in the future. As part of a national increase in infrastructure investment, China has significantly increased spending on water conservancy infrastructure such as wastewater treatment facilities and maintenance of aging irrigation infrastructure (Lohmar, et. al., 2003). In addition, policymakers are promoting a variety of water policy reforms that are sometimes tied to investment funds. Water policy reforms include reforms of river basin management, reforms of irrigation district management, and reform of water prices and other means to give producers an incentive to adopt water saving practices. The success of these reforms, however, will likely have different effects on China's agricultural production.

For example, the successful reform of water management at the river basin level will improve irrigation reliability in productive grain growing regions. This, in turn, will increase China's capacity to produce crops such as wheat and cotton that rely on supplemental irrigation in water stressed regions. Current policy reforms to improve river basin management include increasing the regulatory authority of the National River Basin Commissions (there are 7 NRBCs in China, one for each of China's major river basins) so that they have more power to enforce provincial withdrawal limits. The Yellow River flowed to the ocean every day in year 2000, an event largely credited to this policy. China is currently considering a system of water withdrawal rights along river basins, so that provinces can trade these rights among themselves and result in a more economically efficient allocation of water. However, determining how these rights are initially allocated and the mechanism of exchanging and enforcing them are, understandably, contentious issues and have yet to be established.

Another set of reforms being established are irrigation management reforms. These include establishing water user associations and contracting the management of lateral canals to individual entrepreneurs, along with a variety of other types of management reform. The reforms have been adopted in some areas more than other and their effectiveness varies as well (Wang, Xu, Huang and Rozelle, 2003). While these efforts generally increase the reliability of water deliveries and ensure the users at the downstream end of the irrigation system receive their share of the water, the main focus is usually to reduce water consumption while maintaining yields. Thus, by themselves, these reforms will not likely result in an increase in aggregate agricultural production. Coupled with river basin transfers, however, they could play an important role by maintaining agricultural production in areas that will lose access to water in such transfers, which will free up water for delivery to more productive regions.

Finally, water prices are being reformed in an effort to increase farmers' incentive to use water more conservatively. This reform effort, however, will likely take place over a longer term for two reasons. One is that the reform is politically controversial because increasing water prices goes against another important and sensitive policy goal: increasing farm incomes. Another reason, and perhaps the more important of the two, is the high costs involved in establishing and managing a system where farmers pay for water according to the volume of water they use. With over 200 million farm households each farming several small plots of land, it will be very costly to measure and monitor volumetric deliveries to each plot. Thus, a variety of second-best solutions will likely be established prior to volumetric pricing.

While the reform of water prices will likely take a long time to work through, the success of these efforts may have a more profound impact on China's agricultural production than the other types of reforms. As farmers become more sensitive to the costs of their water consumption, they will seek ways to increase the value of the water they use. This likely will involve moving into high-value cash crops as the case in other water stressed agricultural regions such as California's Central Valley. High-value fruits and vegetables often are water intensive, but they are also well- suited to production using sophisticated water-saving irrigation technologies, more so than field crops such as wheat. In addition, such crops are usually labor intensive, and China is a relatively labor abundant agricultural economy vis-à-vis the rest of the world. Thus, stronger incentives to use water more economically at the farm level, coupled with increasing integration into international markets, may play a significant role in China's overall agricultural transformation. With a more liberalized trade regime, China may well become an exporter of labor intensive crops and an importer of land intensive crop that can be grown in areas where water resources are less stressed. Under this scenario, water shortages will be part of the process that transforms China's rural economy.

Conclusion

Over-exploitation of water resources and the changes brought about to adapt to limited water resources will almost certainly induce changes in China's agricultural production patterns. In creasing urban demand for water as well as demand for environmental flows will limit the amount agriculture can continue to draw off the water system in important grain producing areas of northern China. But many of these areas have seen dramatic increases in grain production due to the establishment of irrigation systems over the last 50 years. With irrigation now threatened and policy no longer focused on providing cheap irrigation to maintain grain self-sufficiency, changes in agricultural production are likely to occur. Given China's size and importance in the world food system, these changes will likely affect international markets.

The magnitude of the changes on international markets depends on a variety of factors. The success and effectiveness of water policy changes to currently being promoted will make a difference. If effective policies to promote water conservation cannot be put into place rapidly, then a significant decline in irrigated acreage may occur in the Hai and downstream portion of the Huang river basins. This would result in shortfall in production and higher levels of imports, particularly for wheat and also for cotton. The extent to which imports will rise in response to production shortfalls will also depend on China's agricultural trade regime, which is expected to liberalize as it adapts to its membership in WTO. If water policy reforms are successful, however, then there is substantial capacity for China to adapt and avert a dramatic decrease in irrigated acreage. Some policies, however, may not only allow China to maintain irrigated acreage, but also induce movement into high-value horticultural products.

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Table 1. Previous Studies into the Effects of Water Scarcity on China's Agricultural Trade

Reference	Modeling Approach	Conclusions
Brown and Heilwell (1998)	Cites modeling sponsored by the US National Intelligence Council	China imports 175 mmt grain by 2025, and over 200 mmt by 2030
Heilig, Fischer and Van Velthuizen (2000)	Use hydro-climatic model to show that agricultural production is sustainable at current levels and with current technology, but will not keep up with increases in demand.	Find China will produce roughly 156 mmt less than estimated demand in 2025 with current irrigation levels, but has a maximum production potential of 22 mmt above the estimated demand in 2025 if irrigation is expanded.
Yang and Zender (2001)	Extrapolate from current trends of water use and increases in water use efficiency.	Recommends China import 10 mmt of wheat to relieve over-exploitation of water
Rosegrant and Cai (2002)	Use hydrological-economic model linked to IFPRI's IMPACT model to estimate how changes in water prices and water use efficiency in China affect international trade.	Find that China will import 56.7 mmt of grain in 2025 if water prices are tripled, 9.5 mmt higher than the baseline of 47.2 mmt (without raising water prices). Imports fall to 46.3 mmt if water use efficiency increases and water prices rise.

Table 2. Decrease in Irrigated Area in North China Under 3 Scenarios*

Commodities	**Scenario 1**	**Scenario 2**	**Scenario 3**
		(10000 hectares)	
Wheat	268	911	2040
Corn	248	737	1418
Cotton	31	118	282

* The three scenarios are 1) Hebei loses 10 percent of irrigated area; 2) Hebei loses 20 percent of irrigated area and Shandong loses 10 percent; 3) Hebei Province loses 30 percent, Shandong uses 20 percent and Henan loses 10 percent. Sown area is in 1,000 hectares, production and net imports are in million metric tons.

Table 3. Changes in China's Production, Consumption and Trade Under 3 Water Shortage Scenarios

	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
		(quantity change from base)			*(percent change from base)*		
Wheat							
Area (1000 ha)	26288	-204	-695	-1565	-0.8	-2.6	-6.0
Production (mmt)	102.8	-1.0	-3.4	-7.8	-1.0	-3.3	-7.5
Consumption (mmt)	105.7	-0.7	-2.4	-5.6	-0.7	-2.3	-5.3
Net Imports (mmt)	1.89	0.3	1.0	2.2	15.4	52.8	114.7
Stocks (mmt)	60.1	-0.2	-0.7	-1.6	-0.3	-1.2	-2.7
Corn							
Area (1000 ha)	24987	-16	-49	-93	-0.1	-0.2	-0.4
Production (mmt)	134.7	-0.3	-0.8	-1.6	-0.2	-0.6	-1.2
Consumption (mmt)	129.1	-0.2	-0.6	-1.1	-0.2	-0.5	-0.9
Net Imports (mmt)	-3.9	0.09	0.3	0.5	2.2	6.7	12.3
Stocks (mmt)	60.0	-0.05	-0.1	-0.3	-0.1	-0.2	-0.5
Cotton							
Area (1000 ha)	4418	-25	-93	-220	-0.6	-2.1	-5.0
Production (tmt)	4744	-21	-82	-192	-0.4	-1.7	-4.0
Consumption (tmt)	5373	-7	-25	-58	-0.1	-0.5	-1.1
Net Imports (tmt)	653	15	56	134	2.2	8.6	20.5
Stocks (tmt)	2579	-1	-5	-11	-0.04	-0.2	-0.4

*Estimates were generated by the authors using the China model that is used in annual USDA Baseline estimates. The three scenarios are 1) Hebei loses 10 percent of irrigated area; 2) Hebei loses 20 percent of irrigated area and Shandong loses 10 percent; 3) Hebei Province loses 30 percent, Shandong uses 20 percent and Henan loses 10 percent. Sown area is in 1,000 hectares, production and net imports are in million metric tons.

Table 4. Changes in Domestic and International Prices that Result from Scenario 3

Commodities	Farm Price	Consumer Price	International Price
	(percentage change from Base under scenario 3)		
Wheat	18.0	16.7	1.0
Corn	1.5	1.5	0.4
Cotton	6.8	6.8	1.3

Appendix 1. The China Model and CCLS

This study uses the Country-Commodity Linked System of models developed at USDA's Economic Research Service. The system contains 42 foreign countries and regional models, and the Food and Agricultural Policy Simulator (Fapsim) model of U.S. agriculture. The country models account for policies and institutional behavior such as tariffs, subsidies, and trade restrictions. A rest-of-world model handles any missing country-commodity coverage. In general, production, consumption, imports, and exports in the models depend on world prices (determined by the system), on macroeconomic projections (determined outside the system) and on domestic and trade policies (determined inside and outside the models). The CCLS is large, containing about 18,000 equations per year of projection, and incorporates an extensive amount of USDA country and commodity analysts' expertise.

The China model used in this analysis incorporates behavior of state trading enterprises (STE's) and WTO commitments (such as tariff-rate quotas) into import and export equations for each commodity. The model consists of six different regions, which are aggregated by provinces with similar agriculture production. The six regions include northeast, north, northwest, east, central, south. World price signals enter the domestic market only to the extent that these STE influenced trade equations respond. China's domestic prices adjust until suppliers make available just as much as users will want to buy.

Fapsim is an annual econometric model of U.S. agriculture whose structure reflects economic theory and institutional knowledge of the sector. The model contains over 700 equations that describe supply, use, prices, and policies, such as commodity loan rates and marketing loans.

The system reaches simultaneous equilibrium in prices and quantities for 24 world commodities markets for each of the 10 projected years in the Baseline analysis. The 24 commodity markets include coarse grains (corn, sorghum, barley, and other coarse grains); food grains (wheat and rice); soybeans, rapeseed, sunseed, and other oilseeds (and their corresponding meals and oils); other crops (cotton and sugar); and animal products (beef and veal, pork, poultry and eggs).

Appendix 2 Water Scarcity Scenarios

To model the water scarcity scenarios in northern China, we divided cultivated area into irrigated and non-irrigated area for wheat, cotton, and corn in the northern region using statistics for effectively irrigated area reported by China's National Bureau of Statistics. We then assumed yields for both irrigated and non-irrigated land for each crop based on a variety of sources, and modified these yields so that the average, weighted by the irrigated-non-irrigated area matched the yields used in the 2003 Baseline projections. The assumed irrigated and non-irrigated yields for the three commodities are reported in table 1a.

With the model modified as outlined above, we run three separate scenarios: Scenerio 1) Hebei loses 10 percent of its irrigated acreage; Scenario 2) Hebei loses 20 percent of its irrigated acreage and Shandong loses 10 percent and; 3) Hebei loses 30 percent of its irrigated acreage, Shandong loses 20 percent and Henan loses 10 percent. A decrease in irrigated area planted to wheat, corn, and cotton is applied in the model for each year of the projection for the three scenarios. The available irrigated area reduced in scenario one is 268, 248, and 31 thousand hectares for wheat, corn, and cotton respectively. In scenario two irrigated area is decreased by 911, 737, and 118 thousand hectares for wheat, corn, and cotton respectively. In scenario three irrigated area is decreased by 2046, 1446, and 284 thousand hectares for wheat, corn and cotton. The decrease in irrigated area is maintained each year for these crops in the northern region throughout the scenario. Wheat and cotton has only marginal subsitiution to non-irrigated area, but we constrian corn so that 95 percent of decreases in irrigated corn area will become non-irrigated, since corn was traditionally grown in this area even before irrigation and can do well with just rainfall. This accounts for small decrease in corn area in the results.

Table 1a. Yield by average 5 years is base

	Wheat	Corn	Cotton
North	4.75	5.22	0.92
Non-Irrigated	3.59	4.65	0.61
Irrigated	5.48	5.58	1.07