Potential Impacts of Drought Tolerant Maize: New Evidence from Farm-trials in Eastern and Southern Africa

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Abstract

We estimate the impact of drought tolerant maize varieties in 13 countries in sub-Saharan Africa using geo referenced farm-trial data from 49 locations in eastern and southern Africa. Planting dates were matched with rainfall data in order to generate better drought risk zones in each country. Maize drought tolerant varieties perform better than popular commercial maize varieties grown in sub-Saharan Africa. Estimates are in the range of $132-$353 million to producers and consumer accruing in the 13 countries during the 2017-2016 period. Analysis of risk based on higher moments of yield distribution points out that there are drought tolerant varieties that have the same level of risk but offer higher overall gains compared to popular commercial varieties.

Keywords Drought Tolerant Maize, Risk benefits, Higher Moments

JEL code Q11, Q16

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Introduction

Drought is one of the most severe problems that farmers face in developing countries as well as more developed countries. Given a more variable climate, increasing temperatures and shifts in weather patterns across continents (Masih et al. 2014; United Nations 2013) there is a need for more drought tolerant crops and other effective strategies to enable farmers to better cope with the negative effects of a changing climate. The adoption of drought tolerant varieties is a way to increase farmer welfare and make them more resilient to drought and climate variability. In addition, yield risk reduction may also increase the wellbeing of smallholder farmers and contribute to improved decision making in the long run. Shiferaw et al. (2011) summarize the importance of maize as food, nutrition and livelihood security and point out that crop breeding to overcome biotic and abiotic stresses will play a key role in meeting future maize demand.

During the last decades there has been a lot of effort to develop drought tolerant maize (DTM) varieties by several Consultative Group for International Agricultural Research (CGIAR) centers such as the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute of Tropical Agriculture (IITA). Farm and experiment station trials of DTM varieties have shown increased mean yields and reduced variability compared to other varieties from the private sector (La Rovere et al. 2010). However, as more research results from drought tolerant maize trials become available there is a need to update results and generate estimates that will aid in a better characterization of the impact of drought tolerant maize varieties across sub-Saharan Africa.

The objective of this study is to provided updated estimates of the impact of the maize varieties developed by the Drought Tolerant Maize for Africa (DTMA) project in Kenya, Uganda, Ethiopia, Angola, Tanzania, Malawi, Mozambique, Nigeria, Mali, Benin, Zimbabwe, Mali, and Ghana. This study offers several important improvements to the work done by La Rovere et al. (2010). First, we use georeferenced farm-level trial data from 49 locations in southern and eastern Africa and compare the performance of the DTM varieties with other private sector varieties planted side by side to gain a better sense of yield and yield stability gains. Second, we use 8-day increments of rainfall data and planting dates of the farm-trials to characterize drought through several drought risk levels for the 49 trial locations which enables us compare performance of DTM across different drought regimes. Third, we provide estimates of the share of risk of the higher moments of the yield distribution of drought tolerant maize compared to other popular commercial varieties in the 13 countries examined in this study.

The rest of the paper is organized as follows. The methodology is provided in section 2, followed by the data description in section three. Results are presented in section four and a conclusion is provided in the last section.

Methods

Benefits from mean yield increases

The methodology in this study is similar to that of La Rover et al. (2010). Changes in producers and consumers income from mean yield increases of DTM varieties under each of the 5 drought risk frequency zones (described below) in each country can be estimated as:

$$Pr.\ Y = KPQ_p - \Delta PQ_p \qquad (1)$$

$$Cs.\ X = \Delta PQ_c \qquad (2)$$

where $Pr.Y$ is the change in producers income, $Cs.\ X$ is the change in consumers expenditure in the market, ΔP is the change in price, Q_p is the quantity produced, Q_c is the quantity consumed, K is the unit cost reduction calculated based on the DTM substituting other commercial improved maize varieties, and from DTM substituting landrace (i.e., traditional, non-improved varieties).[1]

Benefits from yield variance reduction for each drought risk frequency zone

Following La Rovere et al. (2010), the monetary value B for the change in income variation due to changes the variance of yields for a risk-averse producer in each drought risk frequency zone in each country can be expressed as: [2]

[1] For a detailed description see La Rovere et al. (2010).
[2] For more details refer to Newbery and Stiglitz (1983) and Kostandini et al. (2009).

$$\frac{B}{\overline{Y}_0} = \frac{1}{2} R\left\{\sigma_{Y0}^2 - \sigma_{Y1}^2\right\} \qquad (3)$$

where $\overline{Y_0}$ is mean income, σ_{y0} is the coefficient of variation of maize income before the adoption of DTM varieties and σ_{y1} is the coefficient of variation of income after the adoption.

Consumers' risk benefits from yield variance reductions (through changes that the variance of prices has on their expenditures) in each drought risk frequency zone are measured as:

$$\frac{B}{\overline{X}_0} = \frac{1}{2} R\left\{\sigma_{p0}^2 - \sigma_{p1}^2\right\} \qquad (4)$$

Where $\overline{X}_0$ is the mean consumer expenditure, $\sigma_{p_0}^2$ squared coefficient of variation of prices before the introduction of DTM and $\sigma_{p_1}^2$ is the squared coefficient of variation of prices in each drought risk frequency zone after the introduction of DTM.

Cost of risk to the farmer from higher moments of yields distribution

Recently, studies (e.g. Chavas and Di Falco, 2009: Shi et al. 2013) have pointed out the importance of including higher moments of yield into risk analysis. This could be more important for rainfed production system which prevails in almost all sub-Saharan African countries. Following Shi et al. (2013) farmer's risk preferences can be represented by the utility function $U(y) = (y^{1-r})/(1-r)$, where r is the Arrow-Pratt relative risk aversion coefficient. The cost of risk for each moment of yield distribution can be estimated as:

$$R_r(x) \approx \frac{r}{2}\frac{M_2(x)}{M_1(x)} - \frac{r(r+1)}{6}\frac{M_3(x)}{M_1(x)^2} + \frac{r(r+1)(r+2)}{24}\frac{M_4(x)}{M_1(x)^3}$$

Where $R_r(x)$ is the cost of risk (measured in units of y) as a function of managerial and location inputs *x*, associated with a risk aversion parameter of *r*, and $M_1(x)$, $M_2(x)$, $M_3(x)$, and $M_4(x)$ are the mean, variance, skewness and kurtosis of yields for each variety planted in the 49 locations described below. In this study, all varieties were planted side by side, thus, they were subject to the same managerial inputs and any differences are due to genetic diversity across varieties. In this study we use a conservative risk aversion coefficient of 1.2 as in Kostandini et al. (2013) and a moderate risk aversion coefficient of 3 as in Shi et al. (2013).

Data

Drought risk frequencies and baseline production data

We use the drought severity index, a new measure of drought based on drought frequencies for the 2000-2011 period in a 5km x 5km resolution (Mu et al. 2013). The new drought measure is divided in 5 classes: very severe drought, moderate drought, mild drought, incipient drought and no drought. In addition, using the detailed data of the type of drought occurrence on 8-day increments for the year 2011, planting and harvest date was matched with the drought frequencies, thus the drought frequencies represent the actual drought stress that each location experienced from planting to harvest in 2011. Given increased climate variability drought frequencies that match the planting dates for that season may provide a better description of drought conditions.

We updated the baseline production data from IFPRI's Spatial Production Allocation Model (SPAM) with more recent production data for each country to generate maize area and production for each of the 5 drought classes in each country. We also used FAO's maize production data for the 2008-2010 period to update the baseline. This is a more realistic production baseline as maize production in Sub-Saharan Africa has increased from early to mid and late 2000s.

Farm trial data for eastern and southern Africa were compiled by the CIMMYT from regional on farm trial in 2011. In these trials, 20 varieties including 3 popular hybrids from the private sector were planted side by side in all 49 locations in eastern and southern Africa.

Mean yield gains and yield variance reductions used in the analysis for the thirteen DTMA countries and for each drought type zone are presented in Table 1. As mentioned above, drought type zones are based on the drought frequencies for the growing period in each of the 49 locations. We compare mean yield and yield variances between the best 3 drought tolerant (DT) varieties and the best 3 commercial varieties. More specifically, we choose the 3 DT varieties with the highest mean yields for each drought risk area and the best 3 commercial varieties for each drought risk area.

Table 1. Mean yield and variance reduction in Eastern and southern Africa (based on 2011 on-farm trials in 49 locations in Eastern and southern Africa)

	Very Severe Drought	Moderate Drought	Mild Drought	Incipient Drought	No Drought
Observations	2	11	8	9	19
			3 Best DTs		
Mean yield gains	0.96	0.25	0.06	0.32	0.32
Yield CV reduction	-0.05	0.07	0.04	-0.14	-0.03
Skewness	-	-0.05	-0.11	-1.51	-0.35
Kurtosis	-	-0.05	0.10	0.18	-0.20
			3 Best over all sites		
Mean yield gains	2.07	0.60	0.27	0.76	0.42

Results indicate that DT varieties outperform commercial varieties in terms of mean yields across all drought type zones and they have lower variances in 3 of the 5 drought type zones. However, in two of the five drought type zones, the yields of DT varieties have higher coefficients of variation (CVs) compared to commercial varieties. There could be several explanations as to why variances are higher in some of the maize drought type zones. As DT varieties are generally more drought resistant than commercial varieties, the amount and the timing of the rainfall during the growing season may affect them differently. In order to gain more insights one needs to investigate how rainfall timing affects yield during different stages of the plant growth for DT and commercial varieties. This will be investigated in future work.

Adoption rates

Revised adoption rates for each country are reported in Table 2 based on revised current and expected seed production volume in each of the thirteen countries. The second column indicates the overall adoption rate for the 2007-2016 period. This includes replacing commercial varieties as well as traditional landraces. During the four years from the last round of adoption rates, the DTMA project has collaborated more closely with private sector seed companies in each country and they have developed a more realistic seed road map based on their past and current production volumes and the capacity to uptake DTM varieties in the years to come.

Table 2. Revised adoption rates of DT varieties.

Country	DT adoption rate 2007-2016	Share of DT replacing existing improved varieties
Kenya	0.119	0.150
Ethiopia	0.079	0.110
Uganda	0.107	0.300
Tanzania	0.051	0.200
Angola	0.072	0.500
Malawi	0.129	0.450
Mozambique	0.110	0.380
Zambia	0.164	0.400
Zimbabwe	0.260	0.400
Nigeria	0.250	0.200
Ghana	0.250	0.200
Benin	0.150	0.100
Mali	0.150	0.150

Supply and demand elasiticities

Country specific demand elastities used in this study are: 0.49 for Malawi (Ecker and Qaim, 2008); 0.48 for Mozambique (Corzine, 2008); and 0.53 for Kenya, Ethiopia and Uganda (Omamo et al., 2007). Country specific supply elasticies are: 0.45 for Zimbabwe (Cutts and Hassan, 2003); 0.173, 0.2 and 0.157 for Kenya, Ethiopia and Uganda, respectively (Omamo et al., 2007); 0.22 for Mozambique (Corzine, 2008); and 0.24 for Ghana (Kuwornu et al., 2011). For the other countries, the demand elasticity used is 0.73 and the supply elasticity used is 0.36 for all countries in sub-Saharan Africa which are the same as in IFPRI's IMPACT model.

Results

Results from the economic analysis are presented in Table 3. These are the conservative benefits for the 2007-2016 period from the introduction of DTMA varieties in the 13 countries using the adoption rates of Table 2 and comparing the gains from the 3 best DT varieties over all 49 site. The results in the upper panel of Table 3 indicate producer and consumer gains from mean yield increases while the ones in the lower panel indicate producer and consumer gains from yield variance reductions for each drought type zone in each country. The negative results in the lower panel of Table 3 are a result of higher yield variances of DT varieties compared to commercial varieties which lead into increased risk and therefore less risk gains compared to commercial varieties in these environments.

These conservative results suggest that a total of US $132 million dollars of benefits will be generated by 2016 due to DTMA. Nigeria, Zimbabwe and Kenya will gain the majority of benefits with $38 million, $26 million and $15 million, respectively. Zimbabwe also gains the most production gains with an increase of 10% of total production from the baseline during the 2007-2016 period.[3] We find that risk benefits constitute a small share of overall benefits and, as stated above, this is due to increased variability associated with DTMA varieties in the moderate and mild drought zones. However, overall, DTMA varieties are more stable compared to commercial varieties and they generate positive benefits.

In terms of drought type zones, most benefits accrue to producers and consumers that reside in zones that experienced moderate and incipient drought. Generally, most benefits from mean yield gains accrue to producers which receive more than twice of the benefits compared to consumers, while most benefits from increased yield stability accrue to consumers due to lower price variability.

Based on the last estimates of UD$76 million for the research and deployment costs for the 2007-2016 (not including research costs that have gone into drought tolerant research prior to 2007) the benefits cost ratio for this project is 1.8. However, when considering that drought tolerant maize will reach smallholder farmers who use a significant share of their maize production for home consumption, part of the benefits will also include reduced food insecurity.

Table 4 summarizes the results presented in Table 3 for each country, drought type zone in each country, risk benefits as well as producer benefits for each country. More specifically, column 2 illustrates the total benefits in each country and column 3 illustrates the benefits of each country on the total benefits from all thirteen countries. Columns 4-8 present the share of benefits for each drought type zone in each country. The share of benefits from yield variance reductions in each country are presented in column 9 and the share of the benefits that goes to producers in each country are illustrated in column 10. Columns, 11, 12, and 13 indicate total production gains (in Metric Tons (MT)), the percentage production increase and the share of the

[3] Monetary gains in Zimbabwe should be interpreted with caution as the country has experienced hyperinflation during the last decade, especially in 2008 and 2009.

total production gains in each country on the total production gains in all 13 countries, respectively.

Upper bound estimates from choosing the best 3 DT varieties for each site are reported in Table 5. The gains under this scenario are larger and they amount to $353 million. Thus, the overall benefits from DTMA range between $132 and $353 million.

Finally, Table 6 illustrates the cost of risk to the farmers in terms of tons per hectare due to variance, skewness and kurtosis for a risk aversion equal to 3 (moderate risk aversion) and equal to 1.2 (conservative risk aversion). The results should be interpreted as the amount of maize in tons per hectare that the farmer is willing to give up to replace a risky yield with mean yield. Results suggest that the amount of yield that the farmer is willing to give up to replace risky yields with the mean is considerable for the risk related to the variance of yields and substantially less for the risk due to kurtosis. Skewness of yields for all the varieties that we examine actually reduces risk and it partially offsets the risk added by the kurtosis. As expected, the cost of risk is higher for a risk aversion coefficient of 3 and lower for a risk aversion coefficient of 1.2. New drought tolerant varieties (DTNs) have a higher total cost of risk when compared to old drought tolerant varieties (ODTs) and commercial maize varieties (CMs). However, mean yield gains more than offset the additional risk brought by the DTNs. In fact, there can be instances where a DTN can have very similar cost of risk to the best CM and a substantially higher mean yield as in the case of DTN6 versus CM3.

Conclusions

Using recent geo referenced farm-trial data, and updated adoption rates, geo referenced spatial maize production data, and elasticities we estimate the benefits of DTMA for the 2007-2016. Results suggest gains in the range of $132-$353 million of benefits in the 13 countries and an encouraging benefit-cost ratio in the range of 1.8-4.6. However, these benefits do not include spillover effects in neighboring countries or increased human capital generated from this investment. DT maize stands to provide significant benefits, especially when considering climate change and increasing temperatures in Sub-Saharan Africa.

The analysis on the higher moments of risk suggests that new drought tolerant varieties have, on average, a higher total risk compared to commercial maize varieties widely used by farmers but when considering the costs and the benefits, new drought tolerant varieties are significantly better. In addition, there are new drought tolerant varieties that have the same level of overall risk compared to commercial varieties but they have higher mean yields leading to more benefits.

Finally, the use of geo referenced farm-trial data provides opportunities to select varieties which perform better under certain conditions and reduce the downside risk in each location leading to more efficient technology adoption recommendations.

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Table 3. Potential impacts of DTMA during 2007-2016 from 3 best DTNs over all sites (in US$ 2016 dollars).

	Very Severe Drought		**Moderate Drought**		**Mild Drought**		**Incipient Drought**		**No Drought**			**Total Production**	**Total Production**
Benefits from mean yield increases in 2016 (Thousand US $)													
	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS	**Total**	Gains (MT)	Gains (%)
Kenya	553	180	6,194	2,022	1,075	351	2,801	914	0	0	14,091	66,048	2.5
Ethiopia	119	45	2,545	961	490	185	1,586	598	4	2	6,534	47,335	1.2
Uganda	343	102	1,891	560	444	132	769	228	0	0	4,468	29,752	2.3
Tanzania	592	292	3,414	1,684	810	400	2,757	1,360	19	9	11,336	46,018	1.2
Angola	21	10	669	330	175	86	585	288	7	3	2,174	21,690	2.4
Malawi	1,105	812	0	0	796	585	1,337	982	0	0	5,615	27,815	0.9
Mozambique	145	66	1,718	787	340	156	861	395	259	98	4,824	48,087	2.8
Zambia	2,434	1,200	0	0	474	234	991	489	1	0	5,823	28,335	1.4
Zimbabwe	150	92	10,058	6,200	1,989	1,226	4,190	2,583	0	0	26,490	75,687	9.5
Nigeria	8,001	2,411	0	0	6,300	1,899	15,965	4,811	0	0	39,387	58,539	1.7
Ghana	1,548	509	0	0	0	0	2,877	946	6	2	5,887	22,990	1.4
Benin	235	116	0	0	0	0	656	323	0	0	1,330	7,927	0.7
Mali	748	369	0	0	0	0	2,223	1,096	0	0	4,435	6,591	0.6
Subtotal	15,993	6,205	26,490	12,544	12,893	5,252	37,595	15,013	296	115	132,395	486,814	
Benefits from yield variance reductions in 2016 (Thousand US $)													
	PR	CS	PR	CS	PR	CS	PR	CS	PR	CS			
Kenya	(8)	(11)	553	760	230	315	(460)	(622)	-	-	756		
Ethiopia	(2)	(3)	258	387	114	171	(257)	(381)	(0)	(0)	287		
Uganda	(6)	(7)	184	239	96	125	(118)	(151)	-	-	362		
Tanzania	(1)	(3)	35	113	18	60	(42)	(135)	-	-	44		
Angola	(0)	(0)	4	15	3	8	(6)	(19)	-	-	5		
Malawi	(7)	(15)	-	-	69	146	(80)	(166)	-	-	(53)		
Mozambique	(2)	(2)	115	172	51	76	(87)	(130)	(0)	(0)	192		
Zambia	(6)	(20)	-	-	15	49	(22)	(70)	-	-	(53)		
Zimbabwe	(0)	(0)	-	-	0	0	(0)	(0)	-	-	(0)		
Nigeria	(65)	(124)	-	-	584	1,135	(1,015)	(1,900)	-	-	(1,386)		
Ghana	(8)	(17)	-	-	-	-	(145)	(293)	(0)	(0)	(464)		
Benin	(0)	(1)	-	-	-	-	(11)	(36)	(0)	(0)	(49)		
Mali	(0)	(0)	-	-	-	-	(0)	(0)	-	-	(0)		
Sub-total	(106)	(205)	1,149	1,686	1,180	2,085	(2,243)	(3,905)	(0)	(1)	(360)		
Total	15,887	6,000	27,638	14,230	14,074	7,337	35,353	11,108	296	114	132,035		

Table 4. Summary of benefits during 2007-2016 (3 Best DTNs overall sites).

	Total benefits ('000 US$)	Share benefits	Very Severe Drought	Moderate Drought	Mild Drought	Incipient Drought	No Drought	Variance share in total benefits	Producer surplus share in total benefits	Total production gains (MT)	Production increase	Share in total production gains
Kenya	14,847	11%	5%	64%	13%	18%	0%	5%	74%	66,048	2%	14%
Ethiopia	6,822	5%	2%	61%	14%	23%	0%	4%	71%	47,335	1%	10%
Uganda	4,830	4%	9%	60%	17%	15%	0%	8%	75%	29,752	2%	6%
Tanzania	11,380	9%	8%	46%	11%	35%	0%	0%	67%	46,018	1%	9%
Angola	2,178	2%	1%	47%	12%	39%	0%	0%	67%	21,690	2%	4.5%
Malawi	5,562	4%	34%	0%	29%	37%	0%	-1%	58%	27,815	1%	6%
Mozambique	5,016	4%	4%	56%	12%	21%	7%	4%	68%	48,087	3%	10%
Zambia	5,770	4%	63%	0%	13%	24%	0%	-1%	67%	28,335	1%	6%
Zimbabwe	26,489	20%	1%	61%	12%	26%	0%	0%	62%	75,687	10%	16%
Nigeria	38,001	29%	27%	0%	26%	47%	0%	-4%	78%	58,539	2%	12%
Ghana	5,423	4%	37%	0%	0%	62%	0%	-9%	79%	22,990	1%	5%
Benin	1,280	1%	27%	0%	0%	73%	0%	-4%	69%	7,927	1%	2%
Mali	4,435	3%	25%	0%	0%	75%	0%	0%	67%	6,591	1%	1.4%
Total	132,035		17%	32%	16%	35%	0%	0%	71%	486,814		

Table 5. Summary of benefits during 2007-2016 (3 best DTN at each of the 49 sites)

	Total benefits ('000 US$)	Share benefits	Very Severe Drought	Moderate Drought	Mild Drought	Incipient Drought	No Drought	Variance share in total benefits	Producer surplus share in total benefits	Total production gains (MT)	Production increase	Share in total production gains
Kenya	37,337	11%	4%	55%	20%	20%	0%	2%	75%	171,131	6%	13%
Ethiopia	17,292	5%	2%	52%	21%	26%	0%	2%	72%	123,052	3%	10%
Uganda	12,221	3%	8%	51%	25%	17%	0%	3%	76%	78,855	6%	6%
Tanzania	29,511	8%	6%	41%	20%	32%	0%	0%	67%	119,418	3%	9%
Angola	5,754	2%	1%	41%	22%	35%	0%	0%	67%	57,225	6%	4.5%
Malawi	16,216	5%	25%	0%	43%	32%	0%	0%	58%	80,376	3%	6%
Mozambique	12,256	3%	4%	51%	21%	22%	3%	2%	68%	125,782	7%	10%
Zambia	14,725	4%	53%	0%	24%	23%	0%	0%	67%	71,525	4%	6%
Zimbabwe	71,261	20%	1%	55%	22%	23%	0%	0%	62%	200,773	25%	16%
Nigeria	109,717	31%	20%	0%	38%	42%	0%	-1%	77%	164,394	5%	13%
Ghana	13,004	4%	34%	0%	0%	66%	0%	-4%	77%	52,194	3%	4%
Benin	3,020	1%	25%	0%	0%	75%	0%	-2%	68%	18,138	2%	1%
Mali	10,188	3%	24%	0%	0%	76%	0%	0%	67%	15,096	1%	1.2%
Total	352,502		14%	26%	25%	35%	0%	0%	70%	1,277,959		

Table 6. Estimated cost of risk (tons per hectare of maize) due to variance, skewness and kurtosis

		Risk aversion (r) = 3				Risk aversion (r) = 1.2			
Variety	Mean yield	Cost of risk due to variance	Cost of risk due to skewness	Cost of risk due to kurtosis	Total cost of risk	Cost of risk due to variance	Cost of risk due to skewness	Cost of risk due to kurtosis	Total cost of risk
CM1	3.53	1.67	-0.01	0.12	1.77	0.67	-0.003	0.03	0.69
CM2	3.61	1.48	-0.04	0.12	1.57	0.59	-0.008	0.03	0.61
CM3	3.75	1.83	-0.18	0.30	1.95	0.73	-0.039	0.07	0.76
ODT1	3.29	1.46	-0.11	0.27	1.62	0.58	-0.024	0.06	0.62
ODT2	3.84	2.58	-0.19	0.31	2.70	1.03	-0.042	0.07	1.06
DTN1	3.64	1.34	-0.06	0.17	1.44	0.53	-0.013	0.04	0.56
DTN2	3.80	2.07	-0.14	0.20	2.13	0.83	-0.031	0.05	0.84
DTN3	3.80	2.18	-0.09	0.04	2.14	0.87	-0.019	0.01	0.86
DTN4	3.95	2.21	-0.09	0.15	2.27	0.88	-0.020	0.04	0.90
DTN5	3.96	2.16	-0.11	0.18	2.23	0.87	-0.025	0.04	0.88
DTN6	4.24	1.92	-0.08	0.13	1.97	0.77	-0.017	0.03	0.78
DTN7	4.56	2.26	-0.06	0.09	2.28	0.90	-0.013	0.02	0.91