Forman Journal of Economic Studies
Vol. 17(1), 2021 (January–June), pp. 161-174 DOI: 10.32368/FJES.20211708

Measuring Crop Productivity Index of Agro Ecological Zones of Punjab and Its Relationship with Climate Factors

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Abstract

Agriculture is mainstay of Pakistan's economy. In this study we construct a new measure of crop productivity index and test its validity for climate variables in agricultural ecological zones (AEZs) of Punjab province. Our study followed the FAO's definition of AEZs in this regard. Crop productivity index is developed with the application of principal component analysis, including major crops like Maize, Sugarcane, Rice, Jowar, Cotton and Wheat. The data on crops from the year 1981-2018, are used. To develop productivity indices on AEZs with same ecological conditions is one of novel features of the present study. Study reveals diverse empirical results. The zones 2, 4 and 6 are ranked as highest productive areas. These zones include D.G. Khan, Rahimyar Khan, Multan and Muzaffargarh areas. The empirical findings confirm the validity and stability of this new construct. Among the climate factors, average maximum temperature plays a significant role for productivity.

Keywords: Crop Productivity, Agro Ecological Zones, Climate Factors, Average Maximum Temperature

JEL Classification: Q18, Q50, Q54

1. Background and Literature

Being mainstay of Pakistan economy, agriculture sector accounts nearly 20 % GDP and employs 43% of labor force (Government of Pakistan, 2018-19). The country has harvested more than 23 million tons of wheat. Sugarcane, cotton, and rice are most important crops along with wheat, which jointly contribute for more than 75% of the value of total crop yield.

The Punjab plays pivotal role in agricultural production of the country. Having the five most important rivers of Pakistan – Indus, Chenab, Sutlej, Jhelum, and Ravi—Punjab is identified as the 'grain basket' of the country for its rich fertile alluvial soils and irrigated plains. Agricultural sector employs more than 16 million people, 45% of the Punjab's labour force and is the employment cause of almost three-quarter of the female labour force (Pakistan Bureau of

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Statistics, 2019). During 2000-2015, Punjab's Gross State Product (GSP) has grown at an annual rate of 4.1% (Pasha, 2015). However, the province suffered inconsistent economic progress due to political, climatic, and social challenges, leading to unpredictable growth in Punjab and particularly in traditional agricultural sector.

Agricultural productivity is defined differently by various disciplines including agriculturalists, geographers, agronomists, and economists. To economists in general it is "output per unit of an input factor" or "output per unit of land area". Agricultural productivity is 'the ratio of output to input in relation to land, capital and overall assets employed in agriculture' (Safi et al., 2014). It is a dynamic concept, which includes efficient management of existing natural and human resources, technical advancement, and organizational set-up for the agricultural production.

Agricultural productivity is reliant on number physical, socio-economic, and technical factors. Physical factors include climate, altitude, soil, etc. Socio-economic factors are size of landholding, tenancy system, occupational structure, education, etc. Technical factors are the irrigation, mechanical facilities, biological factors, and high yielding variety (HYV) of seeds. All overhead factors are dynamic and highly diverse both in space and time, due to this spatio-temporal variation in agricultural productivity (Mohammad and Majeed, 1992). Liu, et.al. (2018) find that heterogenization of small farmers, the transformation of agricultural inputs from a manual labour to a growth in farm machinery and the expansion of scale of land management increase the crop productivity. Fast growing agriculture total factor productivity is necessary for ensuring food security and increase in productivity of land has been a catalyst of real economic growth for a number of developed and developing countries (Capalbo, and Antle, 2018).

Agricultural productivity is considered as the most significant indicator to demonstrate the spatial pattern of agricultural development. It helps in identifying the least productive areas of a region or zone. It also gives information of actual situation, the real reason of agricultural backwardness of a particular area. It will be of great benefit in suitable regional planning for the maintainable development of each area with respect to its climate and geographical conditions.

The purpose of this study is to construct a new measurement of agricultural productivity by introducing a Crop Productivity Index (CRPI) of all

Agro Ecological Zones of Punjab according to FAO definition.[3] Our study measures land productivity of target area by different methods with the help of major crops. The study also identifies overall most productive zone and investigates empirical impact of climate factor on CRPI.

Multidimensional scaling has been done by many authors with different approaches. The Analytic Hierarchy Process (AHP) is one of the popular approaches that are being used in many areas. The AHP was familiarized in late 1970s which is purely based on expert judgment. The relevant experts present their opinion to numerous alternatives. This methodology is subjective in nature as it is built on expert's judgment. Parker (1991) constructed environmental problem index using public attitude as a weighting technique. The AHP technique has been used by Ercot and Moran (1991) in ranking of municipal landfill potential sites for City of Edmonton, Canada. Narain et al. (1991) proposed a technique for construction of composite index to assess agricultural development. This technique is affected by the problem of multicollinearity. Ahmad et al. (2003) recognized prospective agro-forestry areas by means of Objective Analytic Hierarchy Process (OAHP). Kumar et al. (2012) proposed empirical method for sensitivity analysis of composite index using variance-based technique. The techniques used so far to construct composite index are subjective in nature and are influenced by the problem of multicollinearity.

Kumar et al. (2013) projected and used Principal Component Analysis (PCA) in creation of composite index to overcome the issue of multicollinearity and developed Agriculture Development Index of Bihar State, India. Kumar et al. (2015) also constructed flower production index of the districts of West Bengal and classified the districts on the basis of flower production index. Majumder et al. (2017) constructed cash crop index and ranked the Indian states on the basis of constructed index. Thus, in the present study, Crop Productivity Index (CRPI) has been constructed by using PCA with major crops for 14 ecological zones of Punjab. There are 9 divisions and 36 districts of Punjab, the details are in Table 1.

[3] FAO (2018)

Table 1: Administrative Units of Punjab

Division Name	Districts Included in Division	Area (km²)	Population (2017)	Pop. Density No/SqKM
Bahawalpur	Bahawalpur, Bahawalnagar Rahim Yar Khan	45,588	11,464,031	251.4704
Dera Ghazi Khan	Dera Ghazi Khan, Layyah, Muzaffargarh, Rajanpur	38,778	11,014,398	284.037
Faisalabad	Faisalabad, Chiniot, Toba Tek Singh, Jhang	17,917	14,177,081	791.264
Gujranwala	Gujranwala, Hafizabad,Gujrat, MandiBahauddin, Sialkot, Narowal	17,206	16,123,984	937.114
Lahore	Lahore, Kasur, Nankana Sahib, Sheikhupura	11,727	19,398,081	1,669.76
Multan	Multan, Lodhran, Khanewal, Vehari	17,935	12,265,161	683.867
Rawalpindi	Rawalpindi, Jhelum, Chakwal, Attock	22,255	10,007,821	709.689
Sahiwal	Sahiwal, Pakpattan,Okara	10,302	7,380,386	716.40
Sargodha	Sargodha, Khushab, Mianwali, Bhakkar	26,360	8,181,499	310.38

1.1. Agro Ecological zones of Punjab

Agro-ecological zoning refers to the separation of an area of land into land resource mapping units, each having a unique mixture of landform, soil and climatic characteristics, and the land cover having a specific range of potentials and constraints for agricultural land use (FAO, 1996).

According to FAO (2018), Punjab province can be divided into fourteen Agro Ecological zones depending on climate factors. This study takes these zones for productivity measurement. Selection of districts for respective zones is decided by calculation of district area and its majority share to its zone. Details are given in the following Table 2.

Table 2: Ecological Zones of Punjab

S No	Zone Name	Districts
1	**Cholistan desert**	Bahawalpur
2	**Arid- irrigated**	Rahimyar Khan
3	**Cotton-sugarcane**	Rajanpur
4	**Rod-i-Kohi**	D.G. Khan
5	**Semi-desert irrigated**	Lodhran
6	**Mix cropping**	Multan, Muzaffargarh
7	**Cotton mix cropping**	Khanewal, Vehari, Bahawalnagar
8	**Maize wheat mix cropping**	TobaTekSingh, Jhang, Sahiwal, Pakpattan
9	**Thal-Gram crop**	Bhakkar, Layyah.
10	**Rice and wheat**	M.B. Din, Sheikhupura, Lahore, Sargodha, Faisalabad Hafizabad, Nankana Sahib, Kasur, Okara, Chiniot
11	**Thal zone 2**	Khushab, Mianwali
12	**Rice –zone**	Gujrat, Sialkot, Narowal, Gujranwala
13	**Groundnut Medium Rainfall**	Jhelum, Chakwal
14	**High Rainfall**	Attock, Rawalpindi

2. Data And Methodology

The data of District-wise crops and area under cultivation are collected from different publications of Punjab development statistics and FBS reports for the period of 1981-82 to 2017-2018. Then per acre crop production has been computed for further calculation of land productivity. PCA is used for the construction of Crop Productivity Index by using major crops for the 14 ecological zones of Punjab province. Rice, cotton, Jowar, maize, sugarcane and wheat are main food crops and were considered for calculating the productivity. Principal components are gained by Eigen vectors of the estimated correlation matrix and standardized values of variables. The principal components are obtained, as given in Equation (1).

$$P_1 = a_{11}X_1 + a_{12}X_2 + \cdots + a_{1j}X_j + \cdots + a_{1q}X_q$$

$$P_2 = a_{21}X_1 + a_{22}X_2 + \cdots + a_{2j}X_j + \cdots + a_{2q}X_q$$

. .

$$P_i = a_{i1}X_1 + a_{i2}X_2 + \cdots + a_{ij}X_j + \cdots + a_{iq}X_q$$

. .

. .

$$P_q = a_{q1}X_1 + a_{q2}X_2 + \cdots + a_{qj}X_j + \cdots + a_{qq}X_q \quad (1)$$

Where,

P_i: ith principal components

X_j: standardized values of jth variable

a_{ij}: Element belongs to ith Eigen vector and for jth variable

i =1, 2, 3, …, q, j =1, 2, 3, …, m

The next step was to construct composite index using the obtained Eigen values of variables and principal components as given below

$$CRPI_i = \phi_1 P_1 + \phi_2 P_2 + \cdots + \phi_n P_q \quad (2)$$

Where,

CRPIi: composite index for ith zone, ϕ_i: loading factors=1,2, …, n;

Pq: qth principal components.

Principal components analysis (PCA) is a statistical technique used to convert a number of correlated variables into a lesser number of uncorrelated variables termed principal components, while retaining maximum of the novel variability in the data (see Feridun and Sezgin, 2008)

3. Index of Agro Ecological Zones of Punjab

Now we do the principal component analysis for different Agro Ecological zones. The outcomes of the component analysis for Crop productivity index of different zones are presented in Tables 3-5. This proportion differs from zone to zone. For example, the lowermost proportion of the primary component is 40 percent in the case of fourteenth

Agro ecological zone and the highest for zone 10, that is, 64 percent. So, we will keep the primary component in all cases.

Table 3: Component Analysis for Crop Productivity Index of AEZs
Eigen values of All Six Components

AEZ	First	Second	Third	Forth	Fifth	Sixth
Zone 1	3.4985	1.4235	0.6399	1.9974	0.1496	0.8875
Zone 2	3.3749	0.9088	0.7572	0.5947	0.2848	0.7947
Zone 3	3.1667	1.08645	0.94835	0.4769	0.2181	0.10345
Zone 4	3.7695	0.8648	0.7068	0.2616	0.2582	0.13921
Zone 5	4.5302	0.9788	0.29712	0.08786	0.074377	0.31623
Zone 6	2.6641	1.5966	0.8348	0.5412	0.2221	0.1412
Zone 7	3.4045	1.7363	0.3771	0.3094	0.1145	0.0582
Zone 8	3.4958	1.1247	0.61178	0.579	0.1191	0.06956
Zone 9	3.22619	0.99455	0.7696	0.4697	0.3545	0.1855
Zone 10	3.8822	0.90532	0.7479	0.2808	0.119	0.0647
Zone 11	3.1661	1.0986	0.7637	0.5777	0.2795	0.1145
Zone 12	3.8107	0.9859	0.6885	0.2843	0.1396	0.091
Zone 13	2.9943	1.215	0.6741	0.5361	0.4928	0.0877
Zone 14	2.4036	1.3494	1.1364	0.8352	0.2754	2.4036

Table 4: Component Analysis for Crop Productivity Index of AEZs
Proportions of Each Component

AEZ	First	Second	Third	Forth	Fifth	Sixth
Zone 1	0.5831	0.2373	0.1067	0.0333	0.0249	0.0148
Zone 2	0.5625	0.1515	0.1262	0.0991	0.0475	0.0132
Zone 3	0.5278	0.1811	0.1581	0.0795	0.0364	0.0172
Zone 4	0.6282	0.1441	0.1178	0.0436	0.043	0.0232
Zone 5	0.755	0.1631	0.0495	0.0146	0.0124	0.0053
Zone 6	0.444	0.2661	0.1391	0.0902	0.037	0.0235
Zone 7	0.5674	0.2894	0.0628	0.0516	0.0191	0.0097
Zone 8	0.5826	0.1875	0.102	0.0965	0.0198	0.0116
Zone 9	0.5377	0.1658	0.1283	0.0783	0.0591	0.0309
Zone 10	0.647	0.1509	0.1247	0.0468	0.0198	0.0108
Zone 11	0.5277	0.1831	0.1273	0.0963	0.0466	0.0191
Zone 12	0.6351	0.1643	0.1147	0.0474	0.0233	0.0152
Zone 13	0.499	0.2025	0.1124	0.0893	0.0821	0.0146
Zone 14	0.4006	0.2249	0.1894	0.1392	0.0459	0.4006

Table 5: Loading factor for Crop Productivity Index

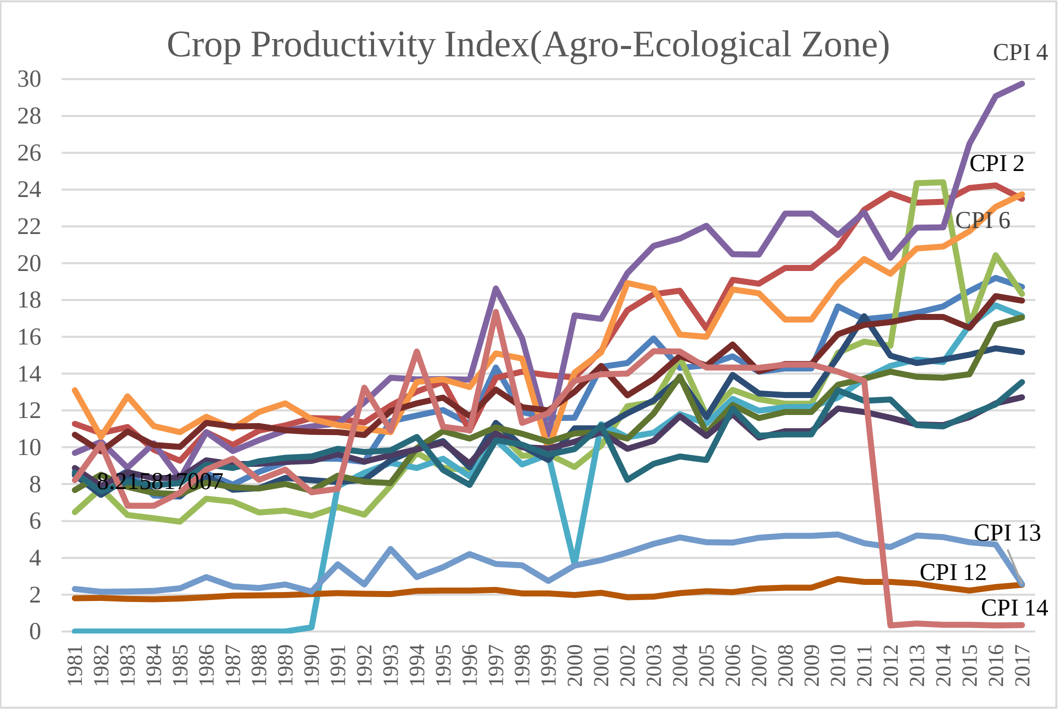
			Loading Factors			
AEZ	**Rice**	**Cotton**	**Jowar**	**Maize**	**Sugarcane**	**Wheat**
Zone 1	0.1244	0.2444	0.1119	0.0154	0.2440	0.2599
Zone 2	0.13498	0.12243	0.1444	0.10778	0.23902	0.25140
Zone 3	0.241572	0.255732	0.00062	0.032436	0.195541	0.274157
Zone 4	0.141376	0.199452	0.052075	0.19972	0.20196	0.20539
Zone 5	0.169415	0.116281	0.16	0.14055	0.200883	0.21289
Zone 6	0.022141	0.029687	0.31866	0.029412	0.319338	0.280794
Zone 7	0.138087	0.203762	0.22629	0.175142	0.215574	0.041168
Zone 8	0.061703	0.075515	0.226671	0.146919	0.251201	0.237949
Zone 9	0.149305	0.132787	0.011946	0.216783	0.241474	0.247705
Zone 10	0.143565	0.196515	0.041575	0.206752	0.198916	0.212798
Zone 11	0.132642	0.025154	0.091204	0.280688	0.227911	0.085381
Zone 12	0.206298	0.16008	0.1404	0.224202	0.033416	0.235613
Zone 13	0.499	0.2025	0.1124	0.0893	0.0821	0.0146
Zone 14	0.11717	0.28281	0.21077	0.35534	0.03382	0.11717

The Table 5 displays the loading score of the individual contributions of Rice, Cotton, Jowar, Maize, Sugarcane, and Wheat per acre to the standardized variance of the primary principal component in case of all Agro Ecological Zones of Punjab.

In the case of Primary agro ecological zone, the standardized proportion of the primary principal carries 12.44%, 24.44%, 11.19%, 0.15%, 24.40% and 25.99% from rice, cotton, jowar, maize, sugarcane, and wheat, respectively. Therefore, the crop productivity index in the case of Zone 1 is;

$$CPI = 0.1244 * Rice + 0.2444 * Cotton + 0.1119 * Jowar + 0.0015 * Maize$$
$$+0.244 * Sugercane + 0.2599 * Wheat \quad (3)$$

We develop the index for all zones through same process.



4. Empirical Evidence

The key objective of this study is to size the productivity of each ecological zone of Punjab. However, to further test a quick validity of our measured CRPI series, Table 2A provides the correlation matrix of the series with environmental factors including average of maximum and minimum temperatures, average of SARD and average precipitation. We model this in Equation (4).

$$crpi = f(AveTmmx, AveTmmn, AvePr, AveSard)$$

$$crpi_{it} = \alpha_1 AveTmmx_{it} + \alpha_2 AveTmmx_{it-1} + \alpha_3 AveTmmx_{t-2} + \alpha_4 AveTmmn_{it} + \alpha_5 AveTmmn_{it-1} + \alpha_6 AveTmmn_{it-2} + \alpha_7 AvePr_{it} + \alpha_8 AveSard_{it} + U_{it} \quad (4)$$

Where, CRPI is crop productivity index, Avetmmx and Avetmmn are average maximum and minimum temperatures of an ecological zone respectively. AvePR is average precipitation rate and AveSARD is average of SARD. The lags of both temperatures are used after performing and iterative procedures to identify the lag in order to find the impact of recent (short run) climate changes.[4]

Before doing formal estimation, pair wise Granger Causality and Correlation matrix of the series are given in Tables A1 and A2 in the Appendix.

The causality suggests that CRPI has one way causality with other ecological variables in all cases. The maximum temperature causes crop productivity whereas minimum temperature, SARD and Precipitation do not cause crop productivity in a particular zone. But since causality is not relationship, but it helps in defining the direction, we estimate our model with OLS, setting the series in the model to be stationary.

The estimated coefficients in Table 6 show that the average maximum temperature has positive affect on the crop productivity. Both lags of maximum temperature have also statistically significant role to play, thus it is confirmed that the lag is present in the productivity-temperature nexus. A high temperature in two seasons back plays much stronger role in predicting the productivity. However, current level of minimum temperature reduces the yield per acre by a slight proportion (about 5%) but both lags increase the productivity by 6% and 4 % (though statistically significant), respectively.

Average precipitation reduces the productivity by 13% whereas average of SARD lowers the productivity by 1 percent only. This model is overall significant with F-stat to be high.

To further confirm about the validity of our measured CRPI, Wald test and Chow's structural stability tests are applied. The results are reported in Tables A3 and A4. These tests confirm that the calculation of index is stable for the climate variables used in this model. So, the model is stable at a breakpoint of 2010's flood (a mammoth shock that hit the agriculture sector in Pakistan).

[4]This lag distribution also minimizes the chance of possible autocorrelation.

Table 6: Results of Productivity Model
Dependent Variable: Crop Productivity Index

Variable	Coefficient	t-Statistic	Prob.
α_1	0.377	1.884931	0.064
α_2	0.187	3.55799	0.0007
α_3	0.351	2.040998	0.0454
α_4	-0.052	-2.42904	0.018
α_5	0.068	3.243406	0.0019
α_6	0.047	1.981747	0.0518
α_7	-0.1385	-2.74616	0.0078
α_8	-0.01169	-4.59902	0.0001
R-squared	0.8628	Durbin-Watson stat	2.2458
Adjusted R-squared	0.8478	Akaike info criterion	3.02329
F-Stat	49.558	Schwarz criterion	3.2762
Log likelihood	-100.839	Hannan-Quinn criter.	3.1240

5. Conclusions and Discussion

Crop productivity index indicates that performance of Rod-i-Kohi zone 4, Arid irrigated zone 2, and Mix cropping zone 6 shows comparatively better with increasing trend in the agriculture production with similar climate condition in their respective zone.The Agro ecological zones like zone 12, Rice zone, and zone 13, Groundnut Medium Rainfall, are placed in a group with low productivity under study. Production indices are constructed on the basis of administrative boundaries and same ecological conditions. Study reveals diverse empirical results. If we rely on district base analysis then Bhakkar, Sheikhupura, T.T Singh and Vehari are most productive districts. If we analyze on the bases of ecology then zone 2, 4 and zone 6 are ranked as the highest productive areas. These zones include D.G. Khan, Rahimyar Khan, Multan and Muzaffargarh districts.

The calculated indices were tested on climate factors to help gauge their validity and stability. We find these factors have statistically significant relationships with productivity index. Maximum temperature and its two lags play a pivotal role in the agricultural production of ecological zones, as compared to minimum temperature and rainfall. However, the rainfall is much effective in zone 13 and 14, with already low productivity.

Our results imply that the measurement of the index is statistically valid and can be used for the analytical purposes for future research. However, in future research more detailed analysis can be applied.

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Appendix

Table A1: Pairwise Granger Causality Tests
Lags: 2

Null Hypothesis:	F-Statistic	Prob.
AVEPR does not Granger Cause CRPI	0.7185	0.491
CRPIdoesn't Granger Cause AVEPR	1.9152	0.155
AVESARD does not Granger Cause CRPI	0.7792	0.462
CRPIdoesn't Granger Cause AVESARD	13.865	0.0001
AVETMMN does not Granger Cause CRPI	0.0639	0.938
CRPIdoesn't Granger Cause AVETMMN	10.352	0.0001
AVETMMX does not Granger Cause CRPI	3.3513	0.041
CRPIdoesn't Granger Cause AVETMMX	1.2204	0.3016
AVESARD does not Granger Cause AVEPR	6.643	0.002
AVEPR does not Granger Cause AVESARD	9.126	0.0003
AVETMMN does not Granger Cause AVEPR	3.924	0.0245
AVEPR does not Granger Cause AVETMMN	5.038	0.0092
AVETMMX does not Granger Cause AVEPR	9.583	0.0002
AVEPR does not Granger Cause AVETMMX	3.847	0.0262
AVETMMN does not Granger Cause AVESARD	9.391	0.0003
AVESARD does not Granger Cause AVETMMN	5.908	0.0043
AVETMMX does not Granger Cause AVESARD	9.187	0.0003
AVESARD does not Granger Cause AVETMMX	0.521	0.5963
AVETMMX does not Granger Cause AVETMMN	6.935	0.0018
AVETMMN does not Granger Cause AVETMMX	1.951	0.1502

Table A2: Correlations

	CRPI	AVEPR	AVESARD	AVETMMN	AVETMMX
CRPI					
	1				
AVEPR	-0.885				
	0.000	1			
AVESARD	-0.889	0.921			
	0.000	0.000	1		
AVETMMN	-0.697	0.769	0.701		
	0.000	0.000	0.000	1	
AVETMMX	-0.869	0.942	0.974	0.774	
	0.000	0.000	0.000	0.000	1

Table A3: Wald Test:

Test Statistic	Value	df	Probability
F-statistic	141.7907	(8, 896)	0.0000
Chi-square	1134.325	8	0.0000
Null Hypothesis: C(1)=C(2)=C(3)=C(4)=C(5)=C(6)=C(7)= C(8)=0			
Restrictions are linear in coefficients.			

Table A4: Chow Breakpoint Test: 2010S1

Null Hypothesis: No breaks at specified breakpoints
Varying regressors: AVETMMX AVETMMX(-1) AVETMMX(-2) AVETMMN AVETMMN(-1) AVETMMN(-2) AVEPR AVESARD

F-statistic	9.066919	Prob. F	0.0000
Log likelihood ratio	59.82137	Prob. Chi-Square	0.0000
Wald Statistic	72.53536	Prob. Chi-Square	0.0000